

Developing a Multi Attribute Decision Making Model for Outsourcing Maintenance Operations Based on Machine's Life Cycle

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Abstract: Outsourcing maintenance operations is one of BPO's (Business Process Outsourcing) expanding businesses. Having a profitable methodology for making this decision is vital. Maintenance operations that are concern about reliability have a unique character of time sensitivity. Based on bathtub curve, machines act differently in different ages. Thus, making a decision about outsourcing these operations regardless to machine's life cycle may ruin the profitability of such decision. The new idea in this article is to include life cycle factor in a decision making model for outsourcing maintenance operations.

Key words: Outsourcing; maintenance operations; Reliability; life cycle; Bathtub curve.

INTRODUCTION

It seems inevitable nowadays not to have any outsourcing operation in a firm. Statistics and most researches show that the rate and volume of outsourcing is increasing around the globe. Due to *Equatera's* data as an international consultant group expert in outsourcing, the volume of outsourcing operations in the last decade has been doubled and is increasing 20% to 30% annually (Takach, 2006). According to *Plunkett Research Ltd*, outsourcing will be an approximately \$500 billion global industry in 2009 and the total turnover of outsourcing operations in 2006 was \$1.2 trillion according to *worldwide business process outsourcing forecast and analysis* and this amount is just 10% of what can be outsourced (IDC, 2006). In a shaky economic time and downfall like nowadays, it has been proven that outsourcing *Non Core Competency activities* has a great roll in being safe and profitable. Industrial organizations are in search of new strategies to increase their competitive advantage and outsourcing is one of the best strategies that can lead to greater competitiveness (Embleton and Wright, 1998).

From outsourcing literature we know that any activity can be outsourced and be put under BPO category. 10 major BPOs are: human resources, logistics, procurement, engineering, marketing, sales, facility operations and management, administration, legal, and finance and accounting (Dong *et al.*, 2007). Outsourcing maintenance operations can be put under facility operations and management category in BPO. There are many researches about BPO for IT or marketing and logistics. But there are very few papers about outsourcing maintenance operations and how should it be done. The object in this article is to create a quantitative decision model for outsourcing maintenance operations based on a machine's life cycle. The new idea here is to involve time factor based on failure rate - which is dependent on a machine's life cycle. The question that we should ask is: "if we outsource maintenance operations of a machine in a specific age of a life cycle, would this decision still be profitable when the age changes?"

Because of considering a machine's life cycle based on failure rate in our model, the decision of picking a maintenance policy may change age by age. Reliability is one of the factors that changes due to *bathtub curve*. Any system behaves differently based on its age. Therefore we can't make a decision for outsourcing maintenance operations independent from a machine's life cycle. Thus, for answering the above question we build a set of decision criteria and some alternatives (different maintenance policies) all based on a machine's life cycle. Thus, outsourcing should not be seen as an automatic ticket to success (John, 1995) and it's not the only strategy for managing maintenance operations. We should make our decision based on determinations that show benefits and losses of each policy in different ages of a life cycle. In terms of maintenance

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outsourcing, a set of potential benefits can be named such as to increase labor productivity, to reduce maintenance costs, to focus in-house personnel on core activities, to obtain specialist skills not available in house, to improve work quality, etc (John, 1995).

Literature Review:

In reviewing most papers arguing about outsourcing decision models, we can find some important concepts and mathematical methodologies for creating our outsourcing decision model:

Developing a Decision Model for Business Process Outsourcing:

- Dong-Hoon Yang, Seongcheol Kim, Changi Nam, Ja-Won Min- *Computers & Operations Research* 34 (2007) 3769 – 3778 (Dong-Hoon Yang, 2007). In this paper Kim develops a decision model for BPO in general. Not specifically maintenance operations. Kim determines the most important determinants and criteria of BPO and uses them in an AHP model. We use Kim's criteria in this article; but eliminating some because of our specific case in maintenance operations. Using the structure of Kim's decision model is not enough for outsourcing maintenance operations. Because Kim's model does not include time factor. Maybe for an operation that is not sensitive to time this model works. Like the decision of producing a material or buying it from an outsider. In this case assuming stable prices, Kim's model produces a perfect decision answer. But in a case that is sensitive to time, like reliability based cases, even if we assume stable prices, there could be major changes in the behavior of our object.

Vendor Selection in Outsourcing:

- A. Ravi Ravindran - *Computers & Operations Research* 34 (2007) 3725 – 3737 (Vijay Wadhwa, 2007). In this paper we have a Formulation of multi-objective vendor selection model. Ravindran's problem can briefly be described as this: optimizing a process in which a buyer orders multiple products from different vendors in a multiple sourcing network. In our paper we are exactly in the same situation. We have multiple machines in multiple life time situations and we try to maintain them with different policies. One policy can be outsourcing and another one can be insourcing with an existing maintenance group. So we use a similar formulation in our paper as Ravindran's.

Other Studies:

In most outsourcing studies one of the most attractive benefits of outsourcing is increasing the focus on core competence activities. As John D. Campbell mentions in (John, 1995) the definition of BPO is: "concentrating the organization's resources and investments on what it does best – called core competencies; and second, outsourcing all other activities for which the company has neither a strategic need nor a special capability". Generally, non-core competencies are all good candidates for outsourcing (Massimo Bertolini, 2004). But the question is whether maintenance operations are non-core competencies or core competencies. "Not surprisingly, maintenance activities are good candidates for outsourcing. Some of these activities include the maintenance and repair of genetic or common equipment, electronics, environmental equipment, mobile fleets, buildings and grounds, projects and improvements, as well as plant overhauls or turnarounds" (John, 1995). But even assuming maintenance operations as core competency, we can ask:

a- is it not possible for an outsider to provide a better reliability for a firm? Usually maintenance consulting groups have lots of experience and have practiced maintenance operations on many systems. Contractors may have more specialized equipment for performing the service; this may allow the contractor to provide better quality and service at a lower price (Emond, 1994). Because an insider group is not usually up to date and have only experience based on break downs that occur just within their own machines. If these break downs occur in long periods, the insider group may not gain much experience. Besides, when organizations expand and become larger, their maintenance costs rise at the same time, e.g., a case study presented in Massimo Bertolini's case study (Massimo Bertolini, 2004) deals with an Italian company, leader in the field of brick production. The maintenance total annual costs have passed from 3.6 million Euros in 1999 up to 4.3 million Euros in 2002, with an expected similar value for 2003. Thus, implementing a maintenance outsourcing strategy is vital and it has been proven that specialized suppliers available in the market, have lower costs and higher quality rates.

b- We should clearly show what we mean about core competence activities. According to Kim (Dong-Hoon Yang, 2007) core competency "Usually refers to an intellectually based activity or system that the company performs better than any other enterprise in the market". So a core competence activity is an activity that is a firm's competitive advantage and has a big role in making value added. We can know what operation

is core competence only on a case by case basis. Our categorization should be based on a realistic perspective. Maybe for a firm maintenance operations are core competence and for another one may not. But generally as *Stephen C. Welch* says most maintenance operations are not core competence activities in industries (*Stephen, 2007*). It's also obvious that maintenance operations do not make much added value and they are not a competitive advantage for a firm.

In some studies about outsourcing, authors strongly recommend to have a long-term contract with vendors. *Harkins (Harkins, 1997)* emphasizes that outsourcing should be viewed as a long-term measure when deciding what to outsource and making other outsourcing decisions. The main reason for this claim is because having a long term relation has the advantage of having an intensive quality service and organizational adhesion. Like *Christer Idhammer (Christer Idhammer, 2006)* advises to have at least a 5 year contract for outsourcing maintenance operations. In some cases this claim might be correct; but in cases that we face a change in behavior patterns we cannot make a general conclusion for outsourcing timeline, e.g., in cases which we are concern about reliability, the costs of maintenance become lower in the "useful age" and rise in "end of life" based on the bathtub curve. Therefore if we outsource the operation in the early life of a machine in a long-term contract, when it comes to the useful life the outsourcing decision may not be profitable.

Developing the Decision Model:

We will answer this major question in this article: Based on a machine's age and considering some decision criteria, what is the best maintenance policy? To make the decision of outsourcing maintenance operations, we use a multi criteria decision making approach. First we will use an AHP model for this problem and then expand it with mathematical variables that we use in a multi attribute decision making approach with operations research tools. For an AHP model we will have a target level, a criteria level and alternatives. In this article first we will build an AHP model for decision of one machine (figure 1). The target is making a decision about outsourcing the maintenance operations. There are 3 ages in a machine's life cycle: infant mortality, useful life, end of life; There are 3 criteria: cost, quality, core competency; and There are 3 alternatives: outsourcing, insourcing, modify & maintain. The full detail of each one will come later in this article. The motive to consider different ages in our decision is that the value of cost, quality and focus on core competency of a maintenance policy changes based on the failure rate. So for each age we'll decide what policy to choose. Building an AHP model for each machine in each age will take lots of time. So we'll use a zero and one programming.

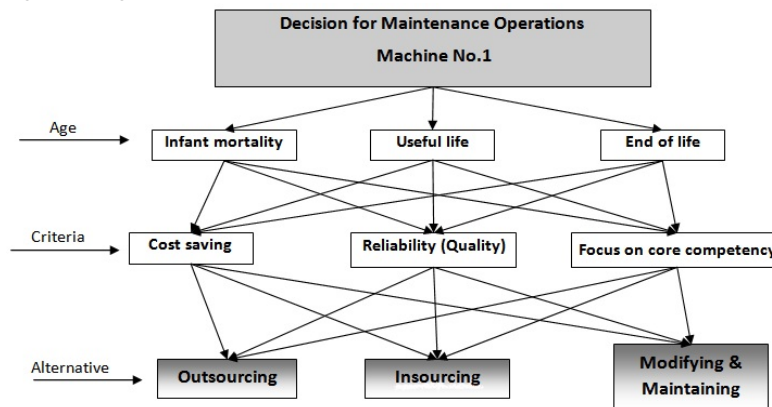


Fig. 1: AHP decision making for machine No.1 based of its three ages, three criteria and three alternatives.

Criteria:

The selections of these criteria are driven by the researches of *Seongcheol Kim et al.* in the article *Developing a decision model for business process outsourcing* (*Dong-Hoon Yang, 2007*) *Seongcheol Kim et al.* have marked out the potential determinations of BPO. Obviously there is a tradeoff between these determinations that we should consider in our model. They are: Cost savings, Focus on core competence, Flexibility, Information security, Loss of management control, Labor union, Morale problem, Vendor's service quality, Market maturity, other firms' outsourcing decisions. *Kim* surveyed 76 biggest Korean industries with collaboration of *Korea Outsourcing Cooperation Association*. He mentions for 10 potential determinants, respondents were asked how important each factor was on a 5-point scale ranging from very unimportant to

very important. From this survey he shows the weight and importance of each criterion for outsourcing. Kim uses a 95% confidence level with a t-distribution. So Potential determinants with rates lower than a 95% confidence interval are eliminated. Thus, these two criteria have been eliminated: Market maturity and other firms' outsourcing decisions. For looking about the effect of other firms' outsourcing decisions see Justus Haucap's article (Stefan Buehlera, 2006).

We will not use all of these 8 criteria for a maintenance operation's policy decision. 3 specific criteria *Cost savings*, *focus on core competence* and *Vendor's service quality* have totally a weight of 0.710. For *Cost savings* 0.110, *focus on core competence* 0.269 and for *Vendor's service quality* we have the weight of 0.331. There are 3 reasons for using just these 3 criteria:

- 1- They have the majority of importance totally equal to 0.710 compare to the rest of criteria.
- 2- About *Information security* and *Loss of management control* that they are two criteria totally weighted as 0.135, we know that maintenance operations don't have a high rank of information security. In other words there is not much valuable information in this section to be worried about. As Kim mentions *if the objectives of an outsourcing company and its vendor's are not aligned, loss of management control over the vendor can occur*. But maintenance operations are not much complicated, so there can't be a critical disagreement between company and its vendor in these operations. So not considering the *Loss of management control* that has only a weight equal to 0.058 would not affect our model.
- 3- The 3 remaining criteria *Flexibility*, *Labor union*, *Morale problem* are most likely non-quantitative criteria with a total weight of 0.155. Because of their non-quantitative nature it's difficult to bring them to our model. But if we wanted to do so, using qualitative numbers would help. But because of the minority importance of these 3 criteria we can eliminate them from our model. Just one issue should be noticed: if we decide to outsource the maintenance operations and not use the inside maintenance operation team or fire them, it's possible to face *Labor union* problems.

Introducing Criteria:

Vendor's Service Quality (Reliability):

the highest weight in Kim's survey is this criterion ($w=0.331$). Here, we are talking about maintenance operations. So as we mention *quality* we mean *reliability* that is the most important aspect of a good maintenance service. If we outsource the operations, based on vendor's technology level, knowledge and human resource, we will have a certain level of reliability (in other word we'll have a certain failure rate) that can be better or worse than the reliability level delivered by inside maintenance team.

Cost Saving:

maintenance operations have certain costs of itself. We'll divide maintenance costs into *fixed costs* and *variable costs*. Maintenance operations' fixed costs include: worker's wage, cost of space, machinery and tools. Variable costs are those that appear in each failure, like repairing machines, replacing broken pieces, cost of lost revenue due to machinery breakdowns, cost of service and transportation. Variable costs of Maintenance operations have an indirectly proportional relation with reliability. If the reliability of a system or machine is high, the variable costs of Maintenance operations have to be low. Thus, for not considering a criterion twice, we will eliminate the variable costs. So if we outsource maintenance operations, the cost will be the vendor's contract price; and if we insource it, the cost will be the fixed costs; and if we modify & maintain the technology and service of inside maintenance team, the cost will be the price of modifying plus the fixed costs of maintaining. In this MADM decision making model we'll compare these costs. The comparing of variable costs is essentially done when we compare the reliabilities (quality). Thus, it will make sense to compare the fixed costs and quality level (reliability level) of alternatives with each other, e.g., one alternative can have a high quality (reliability) service but a high fixed cost due to high technology, knowledge and quantity of staff.

Focusing on Core Competency:

focusing on core competency is now a major concern for CEOs and is an important motive for outsourcing. Focusing on core competency is the strategic benefit of outsourcing. A. Ravi Ravindran has mentioned in his article that by a survey of Accenture, the first motive for outsourcing is not cost saving, but focusing on core competency (Vijay Wadhwa, 2007). Core competence activities are not those that a firm does well, but they are those activities that are the advantage of a firm over competitors and generate the most value (Dong-Hoon Yang, 2007). In this article we assume that if we outsource the maintenance operations in a firm, it would free capacity and capital and time for managing the core competence activities. Thus, we should know

for each firm witch activity is core competence, e.g, marketing, quality, human resource, mass production and etc. in this article for having a general view, we'll use qualitative numbers for measuring the focusing on core competency using a -10 to 10 scale. A negative value means it decreases the focus.

Introducing the Ages in a Life Cycle:

The new idea in this article is to involve time factor in form of *system's age* in the decision model. Managing facilities and machines or in general, managing systems, based on reliability, puts each system in one of the three age periods of bathtub curve: infant mortality, useful life, end of life (figure 2). This idea came from this concerning issue: if we make a decision based on the current behavior of a system, when its age and behavior changes over time, that particular decision may no longer be correct. So if we have to make a decision about maintenance operations of a system, it should consider all ages of a system, i.e., if a system is in its infant mortality period it means there is lots of failures and breakdowns. Then by using any MCDM method we choose the best maintenance policy. But when the system reaches to its *useful life*, failures decrease and reliability increases naturally, then cost of insourcing may become lower than cost of outsourcing. Involving bathtub curve ages has another good advantage: we can schedule a program for what and when to outsource.

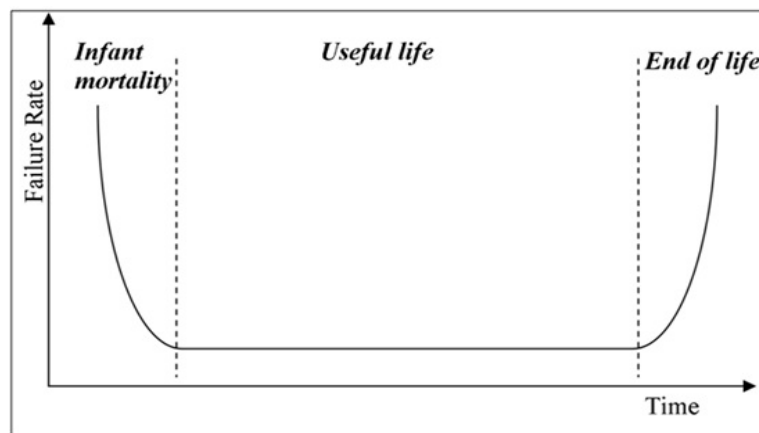


Fig. 2: Bathtub curve. showing the failure rate of a machinery in its lifetime.

The question in this article is how to make a decision for outsourcing maintenance operations for many different systems in their different ages. Each system regarding to its work volume, pace of aging, technology etc, is in a different age. So outsourcing all these systems under one outsourcing contract may not be profitable. With this model, we can have a unique scheduling program for each system. Table 1 shows the main concept of this model for just one machine: machine number "1" is in age "k" that can be one of the three ages of: *infant mortality*, *useful life*, and *end life*; in each age we have 3 alternatives "i": *outsourcing*, *insourcing*, and *modify & maintain*. With choosing each alternative we'll have a unique set of criteria values: *cost saving*, *Focus on core competency*, and *quality (reliability)*. At the end, we are going to decide what to do in each age. The first index presents the number of machine.

Table 1: parametric data of system No.1 in its different ages

End life (k=3)			Useful life (k=2)			Infant (k=1)			
M&M(i=3)	IN. (i=2)	OUT. (i=1)	M&M(i=3)	IN. (i=2)	OUT. (i=1)	M&M (i=3)	IN. (i=2)	OUT. (i=1)	
C ₁₃₃	C ₁₃₂	C ₁₃₁	C ₁₂₃	C ₁₂₂	C ₁₂₁	C ₁₁₃	C ₁₁₂	C ₁₁₁	
R ₁₃₃	R ₁₃₂	R ₁₃₁	R ₁₂₃	R ₁₂₂	R ₁₂₁	R ₁₁₃	R ₁₁₂	R ₁₁₁	S ₁
C.C ₁₃₃	C.C ₁₃₂	C.C ₁₃₁	C.C ₁₂₃	C.C ₁₂₂	C.C ₁₂₁	C.C ₁₁₃	C.C ₁₁₂	C.C ₁₁₁	

Modeling

Data Used in the Model:

1- Following are the indices, which are used in the model formulation:

J: set of systems. For J= 1, 2... n

K: state of age. For K=1, 2, 3 we have *infant mortality*, *useful life*, and *end life*.

I: alternatives. For I= 1, 2, 3 we have *outsourcing*, *insourcing*, and *modify & maintain*.

2- Following are the parameters, which are used in the model formulation:

C_{jki} : the cost of maintenance operations for system “j” in age “k” if we choose alternative “i”.

R_{jki} : the reliability (quality) level obtained for system “j” in age “k” if we choose alternative “i”.

CC_{jki} : the focus on core competency level obtained for system “j” in age “k” if we choose alternative “i”.

Parameters should be normalized before using them in the model

Decision Variable in the Model:

D_{jki} : is a “0” or “1” variable

$D_{jki} = “1”$ if for system “j” in age “k” we choose alternative “i”

$D_{jki} = “0”$ if for system “j” in age “k” we don’t choose alternative “i”

Objective Function:

Based on 3 parameters of “ C_{jki} ”, “ R_{jki} ”, and “ CC_{jki} ” for each system in each age, we want to maximize the utility:

$$\text{Max Utility} = \{W_R \cdot \text{Reliability} + W_{CC} \cdot \text{Focus on Core Competency} - W_C \cdot \text{Cost}\}$$

We use 3 weights as W_R , W_{CC} , and W_C that is the importance of each parameter and have been explained before in this article.

Mathematical formulation of the objective function:

$$1- \text{Cost} = \sum_{i=1}^3 \sum_{j=1}^n \sum_{k=1}^3 C_{jki} \cdot D_{jki}$$

$$2- \text{Reliability (Quality)} = \sum_{i=1}^3 \sum_{j=1}^n \sum_{k=1}^3 R_{jki} \cdot D_{jki}$$

$$3- \text{Focus on core competency} = \sum_{i=1}^3 \sum_{j=1}^n \sum_{k=1}^3 CC_{jki} \cdot D_{jki}$$

Constraints:

$$\sum_{i=1}^3 D_{jki} = 1, \forall k=1,2,3 \ \& \ \forall j=1,2\dots n$$

This means for each system (j) that is in a certain age (k) we should only choose one alternative (i).

Solution Approach: Weighted Objective Method:

Optimization problem:

$$\begin{aligned} \text{MAX} U &= W_R \left(\sum_{i=1}^3 \sum_{j=1}^n \sum_{k=1}^3 R_{jki} \cdot D_{jki} \right) + W_{CC} \left(\sum_{i=1}^3 \sum_{j=1}^n \sum_{k=1}^3 CC_{jki} \cdot D_{jki} \right) - W_C \\ &\left(\sum_{i=1}^3 \sum_{j=1}^n \sum_{k=1}^3 C_{jki} \cdot D_{jki} \right) \end{aligned}$$

Subject to:

$$\sum_{i=1}^3 D_{jki} = 1, \forall k=1,2,3 \ \& \ \forall j=1,2\dots n$$

The answers of this optimization are the values of D_{jki} as “0” or “1”. Thus, we’ll have a set of D_{jki} responding to each age of a system.

Illustrative Example:

Having the data of cost, reliability and core competency of a system in its different ages allows us to use the decision model for choosing the best policy of outsourcing maintenance operations of such system in its life cycle. Table 2 presents the example data. We use Lingo software for making the optimum solution.

Table 2: illustrative data example for system No.1 in its different ages.

M&M	End life		Useful life			Infant			
	IN.	OUT.	M&M	IN.	OUT.	M&M	IN.	OUT.	
75	60	40	40	30	50	70	65	45	Cost(\$)
70	50	65	90	90	80	90	65	80	Reliability (%) S_1
-5	0	8	-1	0	1	-6	0	6	Focus on core competency (Qualitative numbers)

The solution for system No.1 would be:

$$d_{111}=1, d_{112}=d_{113}=0$$

$$d_{122}=1, d_{121}=d_{123}=0$$

$$d_{131}=1, d_{132}=d_{133}=0$$

This means in its “early age” and “end life” we should outsource and in “useful life” we should insource the maintenance operations.

Conclusion:

If we want to make a decision about outsourcing activities that are sensitive to time, we have to include time factor in our decision process. Maintenance operations are such activities and they have a great role in a system’s reliability. So usually we make every effort to have a high reliability level. Outsourcing maintenance operations is increasing throughout industries over the world. The decision to do so or not, has to be based on an optimal approach methodology. There have been lots of talks about what is the correct answer of outsourcing maintenance operations. But one quantitative answer that guaranties the best solution has not yet been found. Outsourcing everything in any time is not the solution; because this decision has to be concern about time, costs and profitability together. The model presented in this article guaranties a decision to be optimum in regard to cost and reliability and focus on core competency together and it looks after the changes over time that occur in every system. Including time factor driven from the concept of bathtub curve is the key answer to this problem.

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