OPERATIONAL FRAMEWORK FOR HEALTHCARE SUPPLIER SELECTION UNDER A FUZZY MULTI-CRITERIA ENVIRONMENT

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PURPOSE: This paper studies how a logistics service provider managing the suppliers for several hospitals can innovatively improve the supplier selection process. The paper examines the attribute set for healthcare supplier selection such as response time, reliability, stock quantity, in order to realize optimal cube utilization, cost, and customer satisfaction. This operational framework developed can help a logistics service provider in supplier order management based on the selected criteria set, criteria weight calculation, and supplier ranking under a fuzzy multi-criteria decision making (MCDM) environment.

DESIGN/METHODOLOGY/APPROACH: We adopt a multi-objective decision making approach based on three main criteria of service, cost, and disruption risk. The following modelling approaches are used – (i) the criteria weight are found using fuzzy AHP, and (ii) the ranking of the suppliers are found through fuzzy TOPSIS.

FINDINGS: Sometimes a logistics service provider needs to include multiple suppliers for one product instead of the current single supplier policy, in order to share the risks especially when dealing with public health emergencies and uncertainty in disruptions.

VALUE: This is a practical industrial problem dealing with various facets of MCDM being applied on actual data, so as to bring to bear the actual challenges of using MCDM in dealing with healthcare supplier management.

RESEARCH LIMITATIONS/IMPLICATIONS: Some future extensions and current limitations of this work will include the sole suppliers, namely, suppliers who are exclusive providers of certain unique products mandated by the healthcare regulators, and to include the effects of shelf life and perishability into the products such as the biodegradable sutures.

PRACTICAL IMPLICATIONS: This study can help the healthcare logistics service provider to use data judiciously to select and manage the suppliers optimally, without the unnecessary incurrence of buffer stock at the warehouse, which can lead a high degree of obsolescence.

KEYWORDS: Healthcare, Supplier Selection, MCDM, Fuzzy, AHP, TOPSIS

1. Introduction

The healthcare industry is an important industry especially given the current need for and attention on providing better quality and speedier response to patient care in the hospital. To manage the supply chain of this sector is just as important as the lead time to respond to patient needs at the operating table, and providing quality medical attention depends very much on what happens upstream in the supply chain, invariably beyond the hospital. To ensure quality patient care and service delivery, the choice of suppliers becomes critical in as far as timeliness, quality, reliability, and cost are concerned. Indeed, maintaining a tight control on cost is just as critical given the unwelcome news of price increases on hospital services throughout the world. One common practice used in managing the logistics cost is to practise an outsourcing model whereby the selection, management, and quality assurance of the non-critical medical products is placed under the wings of the logistics service provider as part of the value added service operating regime. In short, the logistics service provider now has to perform over and above the traditional functions of delivery, warehousing, stock control, to include supplier selection, supplier certification, and vendor managed inventory at the hospital on behalf of the suppliers. The reasons for doing so is clearly obvious when viewed through the lenses of the resource based view (Barney 1991) and transaction cost economics (Williamson, 1981). Hospitals simply do not have the expertise to manage and select suppliers for all the products needed for use in a hospital. As highlighted by Prahalad and Hamel (1990), it is simply not their core competence. At the same time, outsourcing to a seasoned hand, the logistics service provider, seems the obvious route to take as the latter would have sufficient economics of scale in warehousing, delivery, operations to lower the cost of transactions at each point of the supply chain. Supplier selection is no exception.

While scholars such as Milgrom and Roberts (1992) have argued that there are many ways to structure an organization innovatively and efficiently through a better coordination of their activities such as that of outsourcing, little is offered by way of prescribing an implementable framework for doing so, especially in Asia where much of the selection is relationship driven.

Therefore, this paper focuses on providing an operational framework for healthcare supplier selection under a multi-criteria decision making (MCDM) setup, operating in a fuzzy environment. In particular, this case study paper looks at the state and practice of healthcare management in Singapore through the lens of a logistics service provider, using the traditional approach of MCDM. For the purpose of this study, we will consider the case of the medical examination gloves, the latex and nitriles.

We discuss the following. One of the tasks for the operational framework is to establish a criteria set for supplier selection unique to the healthcare sector, namely, with an overall consideration to the response time, reliability and risk of the suppliers, stock quantity to be maintained at each echelon so as to realize the optimal cube utilization, logistics cost, and customer satisfaction. The literature is replete with theoretical models for doing so, for example, Mendoza and Ventura (2012).

This paper is structured as follows. Section 1 provides the necessary introduction and background to our problem at hand. Section 2 highlights the prevailing practice used by the case firm, STL, when evaluating the suppliers of the medical examination gloves. At the same time, we provide a streamlined and improved criteria selection set. Section 3 then develops the operational framework for supplier selection when operating under a multi-criteria, fuzzy environment. Section 4 discusses how the decision results can be obtained using the closeness coefficients and highlights some practical realities or limitations in the framework and concludes with some suggestions for future work.

2. Practice of STL in Supplier Selection

The prevailing practice of the STL is to use the following criteria found in Figure 1 to evaluate their suppliers on determining which supplier to provide the medical examination gloves for both the latex and nitrile types. It can be seen that apart from the four mandatory critical criteria (compliance to tender, supplier recognized by the Health Ministry, appropriately certified, supply to specifications), there are also four non-critical criteria (price, product quality, product shelf life, and track record of the supplier).

TYPE	GLOVES, MEDICAL EXAMINATION	Weightage	Vendor A	Vendor B	Vendor C	Vendor D	Vendor E
Critical Compliance	1. Full compliance with Instructions to Tenderers and Conditions of Contract. The Tenderer shall not change the text of the Invitation to Tender, including but not limited to the Instructions to Tenderers and Conditions of Contract.		Comply / Non Comply/	Comply / Non Comply/	Comply / Non Comply/	Comply / Non Comply/	Comply / Non Comply/
	2. Must not be suspended or debarred by the Standing Committee on Debarment, c/o Ministry of Finance, from partcipating in Government Invitations to Tender.		Comply / Non Comply/	Comply / Non Comply/	Comply / Non Comply/	Comply / Non Comply/	Comply / Non Comply/
	3. Comply with Health Products Act (Cap 122D) Health Products (Medical Devices) Regulations 2010, any licensing conditions and any applicable legislative requirements.		Comply / Non Comply/ Not Applicable	Comply / Non Comply/ Not Applicable	Comply / Non Comply/ Not Applicable	Comply / Non Comply/ Not Applicable	Comply / Non Comply/ Not Applicable
	4. Mandatory requirements of the specifications (1 to 12)		Comply / Non Comply/	Comply / Non Comply/	Comply / Non Comply/	Comply / Non Comply/	Comply / Non Comply/
Non-Critical Compliance	1. Price : Tender Price plus Storage Cost	X %					
	2. Non-Price : (30%)						
	2a. Users' evaluation scores on comfort, fit, product quality.	Y %					
	2b. Product Shelf Life at delivery >= 57 months - 3% >= 54 months - 2% >= 48 months - 1% < 48 months - 0%	Y1 %					
	2c. Track record >= 3 years - 2% >= 2 years - 1% < 2 years - 0%	Y2%					
TOTAL							
Remarks							

Figure 1: Criteria for evaluating suppliers of medical examination gloves

Clearly, some criteria overlap. From the current critical compliance and non-critical compliance of the product list of the medical examination gloves maintained by STL, as well as drawing from the related literature review, we proceed to improve and construct a decision hierarchy structure for STL's supplier selection, in which we establish a criteria set containing 3 main criteria and 11 sub-criteria. Doing so will help the decision maker to better prioritize the weightage based on service attributes rather than mere technical specifications, and draw performance indicators from a logistics angle. Table 1 provides a description of the list of criteria and their sub-criteria.

Table 1: Criteria set for selecting STL's suppliers

Main criteria	Sub-criteria	Description
Service (S)	Compliance with tender (S_1)	Degree of compliance to the specification and requirement in the Invitation To Tender (ITT). It is high when the supplier has less non-compliance on the terms of the tender.
	Product quality (S_2)	Percentage of products which meet STL's expectations on quality. It can be measured by the amount of damaged and deteriorated products, and customer experience of comfort and perceived ease of use of products.
	Product shelf life (S_3)	Length of the product shelf life on delivery.
	Past performance (S_4)	Track record of the supplier, position/reputation in the market either in terms of customer or transaction volume, and the evidence of undamaged deliveries, on time and in full loads in the healthcare industry if possible.
	Response time (S_5)	Lead time taken by supplier to process STL's order request, arrange for production and shipment, and provide after-sales service.
Cost (C)	Price (C_1)	Holding cost + purchase cost. Supplier who can consolidate stock for disposal, help monitor to the cost of the product, or actively choose to streamline cost on behalf of STL has higher priority.
	Investment in R&D (C_2)	Percentage of supplier's investment dedicated to R&D activities such as product design, prototype development and the use of new technologies.
Risk (R)	Output flexibility (R_1)	The manufacture and dispatch flexibility level of products in case of demand surges due to public health emergencies.
	Buffer capacity (R_2)	Percentage/quantity of the buffer inventory of the supplier to cope with emergency orders so as to reduce the risk of stockouts.
	Political & economic stability (R_3)	Political stability of the supplier's country and its attitude to business policies may affect long term relationship between STL and potential supplier.
	Geographical location (R_4)	Supplier location, physical and social status. The origin country of the supplier, the location of plant, the nature of natural calamities and other risk factors should be checked.

Based on the criteria set, we then develop the following decision hierarchy structure in Figure 2 to help STL to select the medical examination gloves suppliers. It can be seen that the first level is the goal/ objective of the tender exercise. The second level is the criteria set encompassing the 11 detailed criteria. The third level is the set of potential suppliers Sp_i who will be assessed by the 11 criteria and the decision-makers can then choose one or several suppliers based on the results obtained from the supplier evaluation process. The template was designed specifically to ensure that all the decision criteria can be readily measured using the transactional data obtained by STL from the tender exercise. However, in reality, some of the data are provided in qualitative response form such as criteria S_2 (product quality) which can stated as excellent, good, average, or okay. This immediately introduces the notion of fuzziness and calls for the need to introduce fuzzy MCDM into the supplier evaluation process.

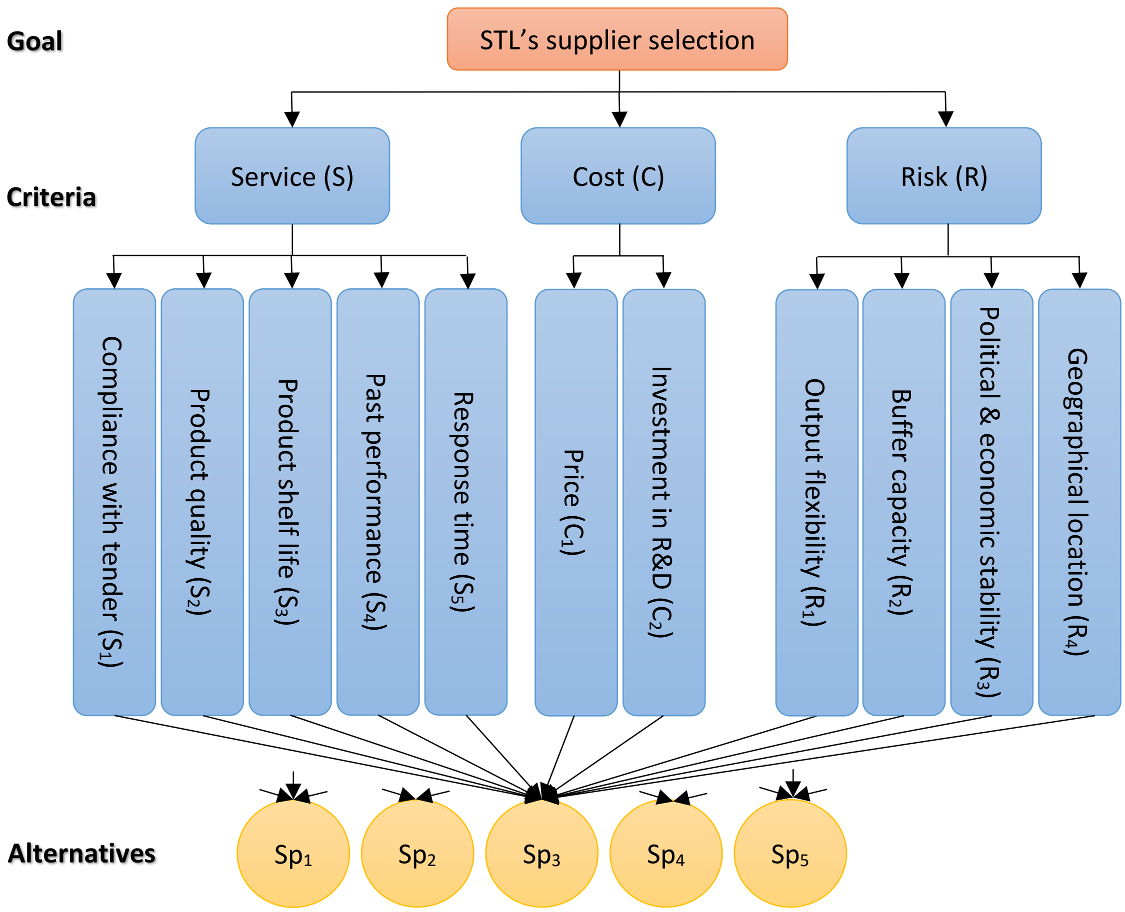

Figure 2: Decision hierarchy structure for STL's supplier evaluation

3. Operational framework for supplier selection and order management

Next, we present the proposed 4-stage operational framework (see Figure 3). There are several phases in this framework, structured as follows. Phase I deals with the criteria set formulation (which was previously presented in Section 2), Phase II concerns computing the weightage of the criteria using fuzzy AHP. Phase III involves the supplier rank determination through fuzzy TOPSIS, so as to help the decision makers to choose the "best" supplier(s). We will briefly mention each of the phases.

Figure 3: Phased operational framework for supplier selection

Phase I. Criteria set formulation

As STL had to choose from 5 potential suppliers, an expert panel of decision makers comprising two senior managers, operations specialist, and hospital user were selected. The criteria set was identified and formulated by the decision group, and the decision hierarchy structure was developed through Figure 2. The decision hierarchy structure is the output of this phase and serves as the input for the next phase.

Phase II. Criteria weight computation using fuzzy AHP

After forming the decision hierarchy, the weights of the criteria are found through the fuzzy AHP method, and they are the output of this phase and the input of the next phase. Analytical hierarchy process (AHP) first introduced by Saaty (1980) is a quantitative technique that structures a multi-criteria, multi-person, multi-period problem hierarchically so that realistic solutions are facilitated. Fuzzy AHP extends Saaty's AHP by combining AHP with fuzzy set theory to solve practical industry relevant hierarchical fuzzy problems. Fuzzy AHP can capture the subjective imprecise judgment of the experts by handling the linguistic variables (see Junior et al. (2014), and Patil and Kant (2014) for more details). The steps for fuzzy AHP in this phase are as follows.

Step 1. The decision group defines the scale of relative importance used in the pairwise comparison matrices.

Step 2. Construct fuzzy comparison matrices.

By using a linguistic scale, the decision group can then make pairwise comparisons for main criteria and sub-criteria. For example, from our interaction with STL, the cost criterion is moderately more important than the risk criterion, and strongly more important than the service criterion, while the risk criterion is equally important with the service criterion. Then the consistency ratio (CR) for each matrix is found. If the value of the CR is no more than 0.2, then consistency of the comparison matrix is considered as acceptable, otherwise the decision group would need to revise the original comparison values in the pairwise comparison matrix until the consistency check is met. While this rule can upset the objectivity of the decision made, it also allows for the decision makers to tweak their judgement until consensus is reached.

Step 3. For each pairwise comparison matrix found in Step 2, the fuzzy synthetic extent is computed using a rigorous mathematical formula.

Step 4. The degree of possibility between two fuzzy synthetic extents is found.

Step 5. The degree of possibility over all other fuzzy synthetic extents is computed.

Step 6. The weight vector of the fuzzy comparison matrices is found.

After normalizing the local weights of the sub-criteria, the global weight can be obtained as shown in Table 2.

Table 2: Weights of criteria for supplier evaluation (criterion importance)

Main criteria	Weight of main criteria	Sub-criteria	Local weight of sub-criteria	Global weight of sub-criteria	Weight rank
Service (S)	0.030956	Compliance with contract (S_1)	0.585155	0.018114	6
		Product quality (S_2)	0.349624	0.010823	7
		Product shelf life (S_3)	0.064051	0.001983	8
		Past performance (S_4)	0.000585	0.000018	10
		Response time (S_5)	0.000585	0.000018	10
Cost (C)	0.691166	Pricing (C_1)	0.999001	0.690475	1
		Investment in R&D (C_2)	0.000999	0.00069	9
Risk (R)	0.277878	Output flexibility (R_1)	0.345761	0.096079	2
		Buffer capacity (R_2)	0.307825	0.085538	3
		Political & economic stability (R_3)	0.196295	0.054546	4
		Geographical location (R_4)	0.150119	0.041715	5

Phase III. Supplier rank determination by fuzzy TOPSIS

After getting the weights of all of the 11 criteria (Table 2, column 5), the fuzzy TOPSIS method is used to rank the potential suppliers. TOPSIS, or the technique for order performance by similarity to ideal solution, is a traditional MCDM method first developed by Hwang and Yoon (1981). In the TOPSIS approach, personal judgments are expressed as deterministic values. In reality, any measurement taken using crisp values is not always possible. A better approach is to utilize the linguistic variables rather than deterministic ones. In this regard, fuzzy set theory can be used to represent the linguistic value. For this reason, the fuzzy TOPSIS method is very suitable for solving real life application problems under a fuzzy environment. The detailed steps for the fuzzy TOPSIS method can be found in Patil and Kant (2014), and Junior et al. (2014). We will leave it to the reader to follow-up on this detail.

4. Discussion and conclusion

To determine the ranking of the potential suppliers to choose from for the medical examination gloves, we compute the closeness coefficient (CC_i) of each alternative, and rank the values in descending order. It can be seen from Table 3 that the different potential suppliers are ranked according to the CC_i in decreasing order. The preference degree of the potential suppliers is also calculated according to the CC_i. The decision group can now determine the number of suppliers to choose for STL based on the obtained supplier ranking. The top three suppliers (Sp_1, Sp_2 and Sp_5) are marked in red.

Table 3: Final ranking of potential suppliers using fuzzy TOPSIS

Supplier	Closeness coefficient	Rank	Preference degree
Sp_1	0.189756	1	1
Sp_2	0.189162	2	0.957790
Sp_3	0.185891	4	0.725322
Sp_4	0.175684	5	0
Sp_5	0.187844	3	0.864158

This operational framework for selecting suppliers can be digitally mounted using software such as Matlab 7.0b, allowing for easy future evaluations. Putting the framework onto a digital platform allows the next available supplier to be readily chosen, and share the risks especially when dealing with public health emergencies and uncertain supplier disruptions.

In conclusion, this paper has helped a logistics service provider to operationalize the selection process of suppliers systematically, using a fuzzy AHP approach to provide suitable values for the weights and applying fuzzy TOPSIS to determine the best ranking of the suppliers under investigation. Finally, we coded the framework on a Matlab platform so that future selection evaluations can be managed expediently. In terms of the limitations, several come to mind. First, the use of the 5-point linguistic scale can be given further granularity as Table 3 suggests that the values of the closeness coefficients for suppliers Sp_1 and Sp_2 lie fairly close to each other, with a very small margin of error. The computational errors or rounding off errors in the earlier steps for instance in the computation of the weights using fuzzy AHP can potentially sway the selection decision. Further, supplier ranking ties have not been properly attributed. There is a need for a better understanding of how to choose between ties. Future work can study the supplier order allocation using a multi-objective program to minimize the total cost and disruption risk (due to the suppliers), and to maximize customer service (for the hospitals).

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