A LOGISTICS PROV1IDER EVALUATION AND SELECTION METHODOLOGY BASED ON A.H.P. AND LINEAR PROGRAMMING INTEGRATION

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ABSTRACT

In the AHP procedure, experts are asked to provide a numerical quantification in pair-wise comparisons; when dealing with several criteria, inconsistency may rise and Saaty's Consistency Ratio threshold helps in identifying those matrices to be rejected or those interviews to be repeated. However, in certain domains, a faster way to proceed in the determination of the criteria weight is appreciated, along with the opportunity of merging the experts' indications with objective judgments originating from historical data analysis. This is the case of several industrial firms which have to perform a supplier selection. In this paper, we propose an evaluation method that combines AHP, DEA and Linear Programming in order to support multi-criterion decisions of Third Party Logistics providers: a rewarding/penalizing effect, depending on the suppliers past performance, is used to correct the errors resulting from biased quantification of weights in AHP. The proposed model has been validated on the real case of an international Logistics Service Provider.

Keywords: 3PL, supplier selection, AHP.

1. Introduction

Business globalization, customer satisfaction and strong competition force firms to focus on core activities and to outsource the others. In particular, Third Party Logistics (TPL), defined as "a dyadic relationship between shippers (buyers or sellers of the goods) and logistics service providers in a supply chain" (Marasco, 2008), is widespreading. In addition, supply chain integration makes logistics strategic in order to obtain a competitive advantage and this increase the complexity of Third Party Logistics Service Providers (3PLs) activity: industrial firms request strong service customization and the high service level requirements forces 3PLs to adapt to each particular situation, managing simultaneously a large number of different kinds of contract. Hertz and Alfredsson (2003) emphasize the fundamental role of customer adaptation in TPL process development, which leads to long term relationships and risk sharing with partners. To this end, 3PLs selection is one of the most critical aspects of TPL and contracting firms would appreciate an easy and practical multi-criterion evaluation method which avoids limitation in the application field.

Marasco (2008) recently provided a 3PLs literature review identifying a large part of those studies that focus on selection process, providing empirically based insights (McGinnis, Kochunny, & Ackerman, 1995; Menon, McGinnis, & Ackerman, 1998), proposing decision-making models based on the Analitical Network Process (ANP) (Meade & Sarkis, 2002), on the Technique for Order Preference by Similarity to

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Ideal Solution (TOPSIS) and on the fuzzy set theory (Bottani & Rizzi, 2006), and providing conceptual frameworks built around IT (Vaidyanathan, 2005). We can extend the collection of relevant studies generalizing and considering 3PLs selection procedure as a single sourcing supplier selection process. For this purpose, some methods proposed in literature are described by Timmerman (1987) and show problems in terms of subjectivity (categorical method), complexity (cost-ratio method) and converting qualitative judgment to quantitative form (linear averaging or weighted-point method). Recently, Ho, Xu and Dey (2010) reviewed literature about multi-criteria approaches for supplier evaluation and selection, showing that the most popular individual methodologies are Data Envelopment Analysis (DEA) applied by roughly the 18% of the analyzed papers, Mathematical Programming (11,5%) and Analytical Hierarchy Process (AHP) (9%). Hamdan and Rogers (2008) apply Data Envelopment Analysis to 3PLs operations efficiency evaluation process, showing that DEA "*provided significant insights for managers and supported their initial impressions of expected performance of their warehouses. It also provided some opportunity to further benchmark and investigate contributions to efficiency within each of these warehouses*." A critical aspect of DEA is flexibility that, as showed by Chaparro, Jimenez and Smith (1997), can disguise serious inefficiencies. Indeed, analyzing integrated approaches, Ho, Xu and Dey (2010) showed a prevalent used of AHP because of its simplicity and flexibility. However in AHP methodology (Saaty, 1990) we can identify the following practical problems:

- a high number (n (n – 1)/2) of pair wise comparisons are requested for each matrix of n elements;
- an high consistency index is required;
- a variation in the number of alternatives and/or of criteria implies the replication of the procedure (rank reversal) (Dyer, 1990)

The large amount of papers proposing integrated approaches - with mathematical programming and AHP - presents goal programming or multi-objective programming models where coefficients of the objective functions are calculated applying AHP, providing more and useful information to the decision maker, but without addressing the previous described problems. In order to fill this gap, we propose an evaluation method that aims at providing an efficient and effective decision support system to select the suppliers, which is easy to use, which avoids limitation in the application field and which is able to manage effectively multi-criterion complexity. The model is based on the integration of AHP and linear programming and on one of the fundamental principles of DEA.

2. Building the model

The proposed mathematical model aims at being a flexible tool for logistics provider evaluation and selection, getting over the limitation of AHP method related to determining a rigid threshold on Consistency Ratio (CR). In the original version of AHP, indeed, if CR is greater than 0.10 the decision maker traditionally should not tolerate the error and should reject the analyzed matrix; in a business environment, problems connected to this limitation are clearly identifiable: every iterations of the same step implies a cost in terms of time and money.

We consider a set of f logistics providers and a 2-levels AHP structure, composed by a set of n criteria, denoted as l_x $(x=1,2,....,n)$ and a set of m_x sub-criteria, denoted as $c_y^{l_x}$ $(y=1,2,....,m_x)$ for each criterion l_x. The comparison between criteria l_i an l_j is denoted as k_{ij}. Analogously, we use $k_{ij}^{l_x}$ for the pair of sub-criteria $c_i^{l_x}$ and $c_j^{l_x}$ of the criteria l_x. The pair-wise comparison allows to calculate the weight of each criterion and of each sub-criterion for each criterion and the overall weight of each criterion, denoted respectively as W_{l_x}, $W_{c_y}^{l_x}$ and $\overline{W}_{c_y}^{l_x}$:

$$W_{l_x} = \frac{\sum_{j=1}^{n} k_{xj}}{\sum_{x=1}^{n}\sum_{j=1}^{n} k_{xj}} \quad \forall\ x = 1,2,\dots,n$$

$$W_{c_y}^{l_x} = \frac{\sum_{j=1}^{m} k_{yj}^{l_x}}{\sum_{y=1}^{m}\sum_{j=1}^{m} k_{yj}^{l_x}} \quad \forall\ x = 1,2,\dots,n \quad y = 1,2,\dots,m_x$$

$$\overline{W}_{c_y}^{l_x} = W_{l_x} * W_{c_y}^{l_x} \quad \forall\ x = 1,2,\dots,n \quad y = 1,2,\dots,m_x$$

From the original version of AHP, we know we should consider only consistent matrices: this is the point where the proposed method allows the decision maker to go on toward an efficient and still significant solution. For this purpose, inspired by Wan Lung Ng (2008), we first introduce an error correction technique based on past supplier performance. Analogously to the cited work, all measures are assumed positively related to the score of a logistics provider (negatively related criteria can be easily converted). The measure of the performance of provider z related to sub-criterion $c_y^{l_x}$ is denoted as $r_{c_y,z}^{l_x}$ and is normalized into a 0-1 scale. Normalized measures are denoted as $P_{c_y\ f}^{l_x}$ and determined as follow:

$$P_{c_y,z}^{l_x} = \frac{r_{c_y,z}^{l_x} - \min_{z=1,2,\dots,f}\left\{r_{c_y,z}^{l_x}\right\}}{\max_{z=1,2,\dots,f}\left\{r_{c_y,z}^{l_x}\right\} - \min_{z=1,2,\dots,f}\left\{r_{c_y,z}^{l_x}\right\}} \quad \forall\ z = 1,2,\dots,f \quad x = 1,2,\dots,n \quad y = 1,2,\dots,m_x.$$

Wan Lung Ng (2008) uses these normalized measures as coefficients in a linear optimization model, where constraints enable the decision maker to incorporate his own ranking of criteria. This brings the process backward to the same problems AHP aims to solve: subjectivity, multiple decision makers, large number of criteria, etc. With the aim of using AHP weights in our model, we denoted as CR_{max} the maximum CR among all matrices and we used it to introduce the concept of variance.

The variances $\sigma_{l_x}^2$ of the weight of each level, ${\sigma_{c_y}^{l_x}}^2$ of the weight of each criterion c_y for each level l_x and ${\overline{\sigma}_{c_y}^{l_x}}^2$ of the overall weight of each criterion c_y are defined as follows:

$$\sigma_{l_x}^2 = C.R._{\max} * W_{l_x}$$

$${\sigma_{c_y}^{l_x}}^2 = C.R._{\max} * W_{c_y}^{l_x}$$

$${\overline{\sigma}_{c_y}^{l_x}}^2 = \left(\frac{\partial \overline{W}_{c_y}^{l_x}}{\partial W_{l_x}}\right)^2 \sigma_{l_x}^2 + \left(\frac{\partial \overline{W}_{c_y}^{l_x}}{\partial W_{c_y}^{l_x}}\right)^2 {\sigma_{c_y}^{l_x}}^2 \quad \forall\ x = 1,2,\dots,n \quad y = 1,2,\dots,m$$

where covariance is assumed equal to zero. After calculating the overall weights (as seen above), all the criteria are sorted from those with the maximum weight to those with the minimum one.

$$\overline{W}_{c_1}^{l_1} \geq \overline{W}_{c_2}^{l_1} \geq \ldots \geq \overline{W}_{c_m}^{l_1} \geq \overline{W}_{c_1}^{l_2} \geq \ldots \geq \overline{W}_{c_m}^{l_2} \geq \overline{W}_{c_1}^{l_3} \geq \ldots \geq \overline{W}_{c_m}^{l_n}$$

In this way, the difference between each couple of subsequent overall weights and relative standard deviation can be calculated as follows:

$$W_{c_y - c_{y+1}}^{l_x} = \overline{W}_{c_y}^{l_x} - \overline{W}_{c_{y+1}}^{l_x} \quad \forall\ y = 1,2,\ldots,m-1 \quad x = 1,2,\ldots,n$$

$$W_{c_m - c_1}^{l_x - l_{x+1}} = \overline{W}_{c_m}^{l_x} - \overline{W}_{c_1}^{l_{x+1}} \quad \forall\ x = 1,2,\ldots,n-1$$

$$\sigma_{c_y - c_{y+1}}^{l_x} = +\sqrt{{\overline{\sigma}_{c_y}^{l_x}}^2 + {\overline{\sigma}_{c_{y+1}}^{l_x}}^2} \quad \forall\ y = 1,2,\ldots,m-1 \quad x = 1,2,\ldots,n$$

$$\sigma_{c_m - c_1}^{l_x - l_{x+1}} = +\sqrt{{\overline{\sigma}_{c_m}^{l_x}}^2 + {\overline{\sigma}_{c_1}^{l_{x+1}}}^2} \quad \forall\ x = 1,2,\ldots,n-1$$

Finally, in order to define the linear programming model to solve our problem, a new set of variables is introduced. Be $\hat{W}_{c_y}^{l_x}$ the final overall weight of the criterion $c_y^{l_x}$, a first set of constraints can be introduced:

$$W_{c_y - c_{y+1}}^{l_x} - \sigma_{c_y - c_{y+1}}^{l_x} \leq \hat{W}_{c_y}^{l_x} - \hat{W}_{c_{y+1}}^{l_x} \leq W_{c_y - c_{y+1}}^{l_x} + \sigma_{c_y - c_{y+1}}^{l_x} \quad \forall\ y = 1,2,\ldots,m-1 \quad x = 1,2,\ldots,n$$

$$W_{c_m - c_1}^{l_x - l_{x+1}} - \sigma_{c_m - c_1}^{l_x - l_{x+1}} \leq \hat{W}_{c_m}^{l_x} - \hat{W}_{c_1}^{l_{x+1}} \leq W_{c_m - c_1}^{l_x - l_{x+1}} + \sigma_{c_m - c_1}^{l_x - l_{x+1}} \quad \forall\ x = 1,2,\ldots,n-1$$

The above written constraints force the difference between each couple of subsequent variables in a range of variability, defined by the variance. Finally, the resulting Linear Programming (LP) model is the following:

$$Max \quad S_f = \sum_{x=1}^{n} \sum_{y=1}^{m} \hat{W}_{c_y}^{l_x} * P_{c_y\ f}^{l_x}$$

$$s.t.$$

$$W_{c_y - c_{y+1}}^{l_x} - \sigma_{c_y - c_{y+1}}^{l_x} \leq \hat{W}_{c_y}^{l_x} - \hat{W}_{c_{y+1}}^{l_x} \leq W_{c_y - c_{y+1}}^{l_x} + \sigma_{c_y - c_{y+1}}^{l_x} \quad \forall\ y = 1,2,\ldots,m-1 \quad x = 1,2,\ldots,n$$

$$W_{c_m - c_1}^{l_x - l_{x+1}} - \sigma_{c_m - c_1}^{l_x - l_{x+1}} \leq \hat{W}_{c_m}^{l_x} - \hat{W}_{c_1}^{l_{x+1}} \leq W_{c_m - c_1}^{l_x - l_{x+1}} + \sigma_{c_m - c_1}^{l_x - l_{x+1}} \quad \forall\ x = 1,2,\ldots,n-1$$

$$\sum_{x=1}^{n} \sum_{y=1}^{m} \hat{W}_{c_y}^{l_x} = n$$

$$\hat{W}_{c_y}^{l_x} \geq 0 \quad \forall\ x = 1,2,\ldots,n \quad y = 1,2,\ldots,m$$

3. Model validation

The model was validated on the case of a primary international transportation and logistics service provider, specialized in integrated logistics for national and international fairs, general cargo and storage services. The validation focused on the 3PL selection for the following three sectors:

- Industry and Defense
- Perishable products
- Consumer goods

We compared 4 pre-selected suppliers, called A, B, C and D, using an AHP structure composed by 7 criteria and 37 sub-criteria. Due to space requirements, only the following table is reported in the text as a sample and concerns one criterion (l_1) along with its sub criterion ($c_x^{l_1}$) in the Industry and Defense sector. The matrix shows, in the "AHP weights" column, the weights obtained by the straightforward application of the AHP procedure and, in the "proposed model weights" column, the weights obtained through the proposed approach.

Criterion	AHP weights	Proposed model weights	3PLs score in the criteria			
			A	B	C	D
$c_1^{l_1}$	0,0554	0,0912	0,0000	0,2195	0,1571	0,5433
$c_2^{l_1}$	0,0186	0,0215	0,4952	0,3039	0,2686	0,0797
$c_3^{l_1}$	0,0537	0,0596	0,0902	0,1715	0,1419	0,2579
$c_4^{l_1}$	0,0415	0,1361	0,2011	0,4205	0,3581	0,4320
$c_5^{l_1}$	0,0615	0,0407	0,2127	0,2451	0,3715	0,1470
$c_6^{l_1}$	0,0128	0,0149	0,3620	0,3483	0,2324	0,2739
$c_7^{l_1}$	0,0104	0,0241	0,4392	0,3651	0,3299	0,1410
	3PLs AHP total score		6,8%	11,8%	10,4%	13,5%
	3PLs AHP ranking		4	2	3	1
	3PLs proposed model score		4,5%	6,8%	6,5%	7,6%
	3PLs proposed model ranking		4	2	3	1

Table 1 – Evaluation results for the Industry and Defense sector

As it is possible to see, despite the differences in the weights obtained through the AHP and the proposed model, the 3PLs ranking does not change. However, the differences among the values in the resulting ranking are not negligible.

4. Conclusions

The application to a real case showed the proposed model is flexible and business-oriented. The integration of AHP, DEA and Linear Programming results in an efficient and effective methodology, which is able to satisfy firm needs and to consider a huge number of relevant information in a supplier selection process. In particular, the model allows to correct AHP weights keeping into account the past performance of 3PLs and to get over those limitations of standard AHP related to the usage of a rigid threshold on the CR while requiring the experts to be consistent, in the pair-wise comparisons, in spite of considering several criteria all together.

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