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A logistics provider evaluation and selection methodology based on AHP, DEA and linear programming integration

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Saaty's AHP is helpful in evaluating alternatives thanks to its effective procedure to determine the relative weights of several comparison criteria. Combining the results of expert interviews, AHP can be very useful for a company in choosing a third party logistics service provider (3PL). However, in the traditional AHP procedure, several results may be rejected when the consistency ratio (CR) of the respondent exceeds a certain threshold. As a consequence, AHP interviews may be repeated several times with a consequent waste of time. In many industrial domains, a faster way to choose a supplier would thus be appreciated. In this paper we propose a mathematical method that combines AHP, DEA and linear programming in order to support the multi-criteria evaluation of third party logistics service providers. The proposed model aims to overcome the limitation of the AHP method, merging experts' indications with objective judgments which originate from historical data analysis. Suppliers' past performance is thus used to correct eventual errors resulting from the acceptance of interviews where the consistency ratio is high. The proposed model has been validated on the real case of an international logistics service provider.

Keywords: 3PL; supplier selection; AHP; consistency ratio

1. Introduction

Business globalisation, 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, p. 129), is widely spreading. In addition, supply chain integration makes logistics strategic in order to obtain a competitive advantage, and this increases the complexity of third party logistics service provider (3PL) activity: industrial firms request strong service customisation and the high service level requirements force 3PLs to adapt to each particular situation, simultaneously managing a large number of different kinds of contracts. Hertz and Alfredsson (2003) emphasise the fundamental role of customer adaptation in the TPL process development, which leads to long-term relationships and risk sharing with partners. To this end, 3PL 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 3PL literature review, identifying a large part of those studies that focus on the selection process, providing empirically-based insights (McGinnis *et al.* 1995, Menon *et al.* 1998), proposing decision-making models based on the analytical network process (ANP) (Meade and Sarkis 2002), the technique for order preference by similarity to ideal solution (TOPSIS) and the fuzzy set theory (Bottani and Rizzi 2006) and providing conceptual frameworks built around IT (Vaidyanathan 2005). We can extend the collection of relevant studies generalising and considering the 3PL selection procedure as a single sourcing supplier selection process. For this purpose, some methods proposed in the literature are described by Timmerman (1986) and seem to 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 *et al.* (2010) reviewed literature about multi-criteria approaches for supplier evaluation and selection, showing that the most popular

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individual methodologies are data envelopment analysis (DEA), applied in roughly 18% of the analysed papers, mathematical programming (11.5%) and the analytical hierarchy process (AHP) (9%). Hamdan and Rogers (2008) apply data envelopment analysis to the 3PL 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 (Hamdan and Rogers 2008, p. 244)." A critical aspect of DEA is the excessive flexibility that, as showed by Chaparro *et al.* (1997), can disguise serious inefficiencies. In addition, Ho *et al.* (2010) identified three specific limitations. The first point is the risk for decision makers to be confused with input and output criteria, for examples see the comparison shown in the aforementioned review of the works by Narasimhan *et al.* (2001), Talluri and Narasimhan (2004) and Seydel (2006), and those by Liu *et al.* (2000), Garfamy (2006) and Wu *et al.* (2007). The second limitation is the subjective assignment of ratings to qualitative criteria, that is to say ranking scales have been proposed (Saen 2006, Seydel 2006) but inconsistencies are not taken into account. The third limitation is the lack of a clear indication about supplier effectiveness (only efficiency seems to be considered).

Analysing multi-criteria decision-making approaches for supplier evaluation and selection, Ho *et al.* (2010) showed a prevalent used of AHP because of its simplicity and flexibility. However, in AHP methodology (Saaty 1980), we identify the following practical problems:

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

Hybrid models seem to be the right solution both to exploit positive points and to overcome the negative ones of DEA and AHP approaches. "One model can be combined with other techniques in order to improve the quality of the tools, when being used in a supplier selection process" (Ha and Krishnan 2008, p. 1305).

Integrated AHP–DEA approaches for supplier selection have been proposed by Ramanathan (2007), who considered costs as inputs in the DEA model and AHP weights as outputs, by Saen (2007), who used AHP to determine the relative weights of suppliers and DEA to determine their relative efficiencies, by Sevkli *et al.* (2007), who used AHP to derive overall weights and DEA to calculate the efficiency scores of suppliers, and by Ha and Krishnan (2008), who resorted to AHP in order to evaluate supplier performance and to DEA and artificial neural network with the aim of measuring supplier efficiency.

All the aforementioned works present models that still seem limited by the previously described issues of traditional AHP procedure. In order to fill this gap, we propose an evaluation method that aims at providing an efficient and effective decision support system to select suppliers and which is easy to use, avoids limitation in the application field and is able to effectively manage multi-criterion complexity. The model is based on the integration of AHP, DEA and linear programming (LP). Similar approaches have been proposed by Yang and Kuo (2003) for plant layout design and by Shang and Suevoshi (1995) for a site-selection problem.

2. Building the model

The proposed model aims at being a flexible tool for logistics provider evaluation and selection, getting over the limitation of the AHP method related to determining a rigid threshold on the consistency ratio (CR). The consistency ratio is defined as the ratio of the consistency index (CI) to the average random index (RI) for the same matrix, where the former index represents the deviation from consistency and the latter is the same index of a randomly generated reciprocal matrix from the scale 1 to 9. 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 analysed matrix. In a business environment, problems connected to this limitation are clearly identifiable: every iteration of the same step implies a cost in terms of time and money.

By accepting all results, but still taking inconsistency into account, Saaty's traditional AHP procedure allows us to quantitatively evaluate all criteria of a logistics provider selection process. Then, we resort to DEA and formulate an LP model by using supplier performance to determine coefficients of the objective function and AHP weights to define the constraints.

We consider a set of f logistics providers and a two-level AHP structure, composed of a set of n criteria, denoted as l_x $(x=1,2,\ldots,n)$ and a set of mx sub-criteria, denoted as $c_y^{l_x}(y=1,2,\ldots,mx)$ for each criterion l_x.

The comparison between criteria l_i and 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 pairwise comparison allows for calculating the weight of each criterion (W_{l_x}) and the weights of each sub-criterion for each criterion ($W_{c_y}^{l_x}$). According to the traditional AHP procedure (Saaty 1980), these weights are computed as follows:

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

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

As a result, the final output of the AHP procedure would be the overall weight of each sub-criterion $\bar{W}_{c_y}^{l_x}$ as

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

As already highlighted, the main problem in the traditional AHP procedure is that we should compute $\bar{W}_{c_y}^{l_x}$ rejecting non-consistent matrices. This is the point where the proposed method allows the decision maker to go on toward an efficient and still significant solution: our aim is thus to find a different value of the overall weight of each sub-criterion ($\hat{W}_{c_y}^{l_x}$) without the need for discarding the results from the interviews.

For the aforementioned purpose, inspired by Ng (2008), we first introduce an error correction technique based on past logistic provider performance (score). Analogous to the cited work, all measures are assumed positively related to the score of the logistics providers (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 normalised into a 0–1 scale. Normalised measures, with respect to the score of the other competitors, are denoted as $P_{c_y}^{l_x}z$ and determined as follow:

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

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

We assume that the value of CR_{max} represents a measure of the untrustworthiness of the compiler of the AHP pairwise comparison, which can be related to the overall uncertainty of the procedure. This is the reason why we propose considering only one value of CR_{max} and not one per each criteria or sub-criteria. Thus, we define the variances of the weight of each level ($\sigma_{l_x}^2$), the variance of the weight of each criterion c_y for each level l_x ($\sigma_{c_y}^{l_x}2$) and the variance of the overall weight of each sub-criterion c_y ($\bar{\sigma}_{c_y}^{l_x}2$) as follows:

$$\sigma_{l_x}^2 = CR_{\max} * W_{l_x}$$

$$\sigma_{c_y}^{l_x}2 = CR_{\max} * W_{c_y}^{l_x}$$

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

where covariance is assumed equal to zero. After calculating the overall weights $\bar{W}_{c_y}^{l_x}$, all the criteria are sorted from those with the maximum to those with the minimum weight.

$$\bar{W}_{c_1}^{l_1} \geq \bar{W}_{c_2}^{l_1} \geq \cdots \geq \bar{W}_{c_m}^{l_1} \geq \bar{W}_{c_1}^{l_2} \geq \cdots \geq \bar{W}_{c_m}^{l_2} \geq \bar{W}_{c_1}^{l_3} \geq \cdots \geq \bar{W}_{c_m}^{l_n}$$

In order to set the constraints of the proposed linear programming model for finding the new overall weights of each sub-criterion $\hat{W}_{c_y}^{l_x}$, we define the difference between each couple of subsequent overall weights and relative standard deviation as follows:

$$W^{l_x}_{c_y\_c_{y+1}} = \bar{W}^{l_x}_{c_y} - \bar{W}^{l_x}_{c_{y+1}} \quad \forall y = 1, 2, \ldots, m-1 \quad x = 1, 2, \ldots, n$$
$$W^{l_x\_l_{x+1}}_{c_m\_c_1} = \bar{W}^{l_x}_{c_m} - \bar{W}^{l_{x+1}}_{c_1} \quad \forall x = 1, 2, \ldots, n-1$$
$$\sigma^{l_x}_{c_y\_c_{y+1}} = +\sqrt{\bar{\sigma}^{l_x}_{c_y}2 + \bar{\sigma}^{l_x}_{c_{y+1}}2} \quad \forall y = 1, 2, \ldots, m-1 \quad x = 1, 2, \ldots, , n$$
$$\sigma^{l_x\_l_{x+1}}_{c_m\_c_1} = +\sqrt{\bar{\sigma}^{l_x}_{c_m}2 + \bar{\sigma}^{l_{x+1}}_{c_1}2} \quad \forall x = 1, 2, \ldots, n-1$$

A set of constraints can be introduced in order to force the difference between each couple of subsequent variables in a range of variability defined by the variance.

$$W^{l_x}_{c_y\_c_{y+1}} - \sigma^{l_x}_{c_y\_c_{y+1}} \le \hat{W}^{l_x}_{c_y} - \hat{W}^{l_x}_{c_{y+1}} \le W^{l_x}_{c_y\_c_{y+1}} + \sigma^{l_x}_{c_y\_c_{y+1}} \quad \forall y = 1, 2, \ldots, m-1 \quad x = 1, 2, \ldots, n$$
$$W^{l_x\_l_{x+1}}_{c_m\_c_1} - \sigma^{l_x\_l_{x+1}}_{c_m\_c_1} \le \hat{W}^{l_x}_{c_m} - \hat{W}^{l_{x+1}}_{c_1} \le W^{l_x\_l_{x+1}}_{c_m\_c_1} + \sigma^{l_x\_l_{x+1}}_{c_m\_c_1} \quad \forall x = 1, 2, \ldots, n-1$$

Finally, the resulting linear programming model for each supplier z is the following:

$$\text{Max} \quad S_f = \sum_{x=1}^{n} \sum_{y=1}^{m} \hat{W}^{l_x}_{c_y} * P^{l_x}_{c_{y_z}} \tag{1}$$

s.t.

$$W^{l_x}_{c_y\_c_{y+1}} - \sigma^{l_x}_{c_y\_c_{y+1}} \le \hat{W}^{l_x}_{c_y} - \hat{W}^{l_x}_{c_{y+1}} \le W^{l_x}_{c_y\_c_{y+1}} + \sigma^{l_x}_{c_y\_c_{y+1}} \quad \forall y = 1, 2, \ldots, m-1 \quad x = 1, 2, \ldots, n \tag{2}$$

$$W^{l_x\_l_{x+1}}_{c_m\_c_1} - \sigma^{l_x\_l_{x+1}}_{c_m\_c_1} \le \hat{W}^{l_x}_{c_m} - \hat{W}^{l_{x+1}}_{c_1} \le W^{l_x\_l_{x+1}}_{c_m\_c_1} + \sigma^{l_x\_l_{x+1}}_{c_m\_c_1} \quad \forall x = 1, 2, \ldots, n-1 \tag{3}$$

$$\sum_{x=1}^{n} \sum_{y=1}^{m} \hat{W}^{l_x}_{c_y} = n \tag{4}$$

$$\hat{W}^{l_x}_{c_y} \ge 0 \quad \forall x = 1, 2, \ldots, n \quad y = 1, 2, \ldots, m \tag{5}$$

We let the model determine final overall weights for each supplier. We note that the constraints in Equations (2) and (3) solve the issue related to the high flexibility for determining weights through DEA: they impose bounds to the value of weights on the basis of what has been determined through the AHP procedure. The constraints in Equations (4) and (5) respectively guarantee that objective function converges to a finite value and that weights assume only positive values.

Finally, multiplying the overall weights of sub-criteria (model outputs) by the supplier performance with respect to the interested period, we can obtain the final score of each logistics provider.

3. Model validation

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

- Industry and defence
- Perishable products
- Consumer goods

We compared four pre-selected suppliers, A, B, C and D, using an AHP structure composed of seven criteria and 37 sub-criteria, which are reported in the Appendix.

The following matrix (Table 1) shows the results of the pairwise comparison of the criteria (the first level of the decision hierarchical structure) with the highest CR among the ones relevant to the evaluation of the logistic supplier in industry and defence.

Table 1. Pairwise comparison matrix with the highest value of CR for the industry and defence sector.

	l_1	l_2	l_3	l_4	l_5	l_6	l_7
l_1	1.0000	5.0000	2.0000	4.0000	7.0000	8.0000	9.0000
l_2	0.2000	1.0000	0.5000	0.3333	2.0000	4.0000	6.0000
l_3	0.5000	2.0000	1.0000	2.0000	5.0000	7.0000	8.0000
l_4	0.2500	3.0000	0.5000	1.0000	5.0000	7.0000	9.0000
l_5	0.1429	0.5000	0.2000	0.2000	1.0000	3.0000	4.0000
l_6	0.1250	0.2500	0.1429	0.1429	0.3333	1.0000	3.0000
l_7	0.1111	0.1667	0.1250	0.1111	0.2500	0.3333	1.0000

Table 2. Local weight and standard deviation of criteria for the industry and defence sector.

Criteria	Local Weight W_{l_x}	Variance $\sigma^2_{l_x}$
l_1	0.1619	0.0281
l_2	0.2570	0.0446
l_3	0.0859	0.0149
l_4	0.0568	0.0099
l_5	0.0325	0.0056
l_6	0.3859	0.0669
l_7	0.0199	0.0034

Table 3. Original and normalised supplier performance for criterion l_1.

	Original supplier performance				Normalised supplier performance			
Criterion	$\gamma^{l_1}_{c_yA}$	$\gamma^{l_1}_{c_yB}$	$\gamma^{l_1}_{c_yC}$	$\gamma^{l_1}_{c_yD}$	$P^{l_1}_{c_yA}$	$P^{l_1}_{c_yB}$	$P^{l_1}_{c_yC}$	$P^{l_1}_{c_yD}$
$c^{l_1}_1$	98.3696	98.8528	97.8142	99.4792	0.3336	0.6238	0.0000	1.0000
$c^{l_1}_2$	96.1957	97.3231	88.5246	91.6667	0.8719	1.0000	0.0000	0.3571
$c^{l_1}_3$	99.4565	99.0440	98.9071	100	0.5027	0.1253	0.0000	1.0000
$c^{l_1}_4$	97.6449	95.6023	96.1749	90.1042	1.0000	0.7291	0.8051	0.0000
$c^{l_1}_5$	98.7319	98.4704	100	98.4375	0.1884	0.0211	1.0000	0.0000
$c^{l_1}_6$	97.8261	97.7055	90.1639	95.3125	1.0000	0.9843	0.0000	0.6719
$c^{l_1}_7$	98.7319	99.4264	98.3607	87.5000	0.9418	1.0000	0.9106	0.0000

Table 4. Evaluation results for criterion l_1 for the industry and defence sector.

			3PLs score in the criteria			
Sub-criterion	AHP weight $\bar{W}^{l_x}_{c_y}$	New weight $\hat{W}^{l_x}_{c_y}$	A	B	C	D
$c^{l_1}_1$	0.0554	0.0912	0.0000	0.2195	0.1571	0.5433
$c^{l_1}_2$	0.0186	0.0215	0.4952	0.3039	0.2686	0.0797
$c^{l_1}_3$	0.0537	0.0596	0.0902	0.1715	0.1419	0.2579
$c^{l_1}_4$	0.0415	0.1361	0.2011	0.4205	0.3581	0.4320
$c^{l_1}_5$	0.0615	0.0407	0.2127	0.2451	0.3715	0.1470
$c^{l_1}_6$	0.0128	0.0149	0.3620	0.3483	0.2324	0.2739
$c^{l_1}_7$	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 5. Final score for the three sectors.

Sector	Best supplier	Score
Industry and defence sector	A	12.7774
Perishable products	A	12.4152
Consumer goods	B	12.4101

Local weights and standard deviation of criteria and sub-criteria are then computed on the selected matrix. Table 2 shows the W_{l_x} and $\sigma^2_{l_x}$ values, with regards to the seven criteria.

Logistics provider performance is then analysed with DEA and normalised as it has been described in the previous section. Table 3 shows the results with respect to the criteria l_1.

Finally, we set the optimisation model to obtain the final overall weight for each criterion per each supplier and the final supplier scores. Table 4 reports the results with respect to criterion l_1 along with its sub-criteria ($c^{l_1}_x$) for the industry and defence sector. The AHP weight column shows the weights obtained by the straightforward application of the AHP procedure, and the new weight column shows the weights obtained through the proposed approach.

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.

Finally, for the sake of completeness, we report here the best supplier and related score of each analysed sector.

4. Conclusions

In the AHP procedure, experts are asked to provide a numerical quantification in pairwise comparisons in order to determine the weights of predefined selection criteria. However, when dealing with several criteria, it is not so easy to obtain coherent results from interviews. Thus, inconsistency may rise, and Saaty's consistency ratio threshold helps in identifying those weight matrices to be rejected. As a consequence, some results may be discarded, which causes a decrease in the amount of usable data, or interviews may need to be repeated, which results in a waste of time. Neither case obviously is desirable, and companies would appreciate a method which could take into account the CR though considering all the collected interviews. A solution has been proposed in this paper and applied to the evaluation of third party logistics service providers. A hierarchical tree of criteria and sub-criteria has been defined for the evaluation of 3PLs in three sectors: industry and defence, perishable products and consumer goods. Then, pairwise comparisons have been asked to experts and a first set of weights has been computed according to the traditional AHP approach. The maximum CR value computed per each expert, which is a value related to the expert's judgement inconsistency, has been used as a measure of the weights' uncertainty. Instead of discarding the interviews of the respondent who obtained a higher CR in respect to Saaty's suggested threshold, a linear programming model has been solved in order to correct the AHP weights taking into account the 3PLs' past performance with the DEA approach. Thus, the weights resulting from the analysis of the interviews of respondents who generated high CR values, that is to say less consistent results, have been corrected by the PL model more so than the weights of respondents who generated low CR values, that is to say very reliable experts. The paper shows in detail the numerical results of the application of the proposed method to a selection of four 3PLs in the industry and defence sector; despite the final results not changing in terms of 3PLs ranking, the value of the weights of the criteria and the score of each alternative changes significantly. With the proposed method, the spread among minimum and maximum alternative scores resulted to be reduced. Thus, the integration of AHP, DEA and linear programming resulted in an efficient and effective methodology, which allows to satisfy firm needs while considering a huge number of relevant information in a supplier selection process. The proposed methodology takes into account the past performance of 3PLs, thus getting over the limitations of standard AHP related to the requirement of consistent data.

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Appendix. Criteria and sub-criteria of AHP structure for the analysed case of a primary international transportation and logistics service provider.

Table A1. Criteria for logistics provider evaluation.

Criterion	Definition
l_1	Quality and reliability
l_2	Speed of service
l_3	Flexibility
l_4	Costs
l_5	Equipment
l_6	Operators' safety
l_7	Environmental safeguard

Table A2. Sub-criteria of criterion l_1.

Sub-criterion	Definition
$c_1^{l_1}$	% of orders delivered damage free
$c_2^{l_1}$	% of orders checked at loading time
$c_3^{l_1}$	% of orders delivered that are complete
$c_4^{l_1}$	% of orders managed on time
$c_5^{l_1}$	% of orders managed without security breaches
$c_6^{l_1}$	% of orders managed with correct shipping docs
$c_7^{l_1}$	% of orders managed without administrative problems

Table A3. Sub-criteria of criterion l_2.

Sub-criterion	Definition
$c_1^{l_2}$	Average shipping lead time
$c_2^{l_2}$	Average packaging lead time

Table A4. Sub-criteria of criterion l_3.

Sub-criterion	Definition
$c_1^{l_3}$	Flexibility to increase delivery volumes
$c_2^{l_3}$	Flexibility to decrease delivery volumes
$c_3^{l_3}$	Flexibility to increase shipping volumes
$c_4^{l_3}$	Flexibility to decrease shipping volumes
$c_5^{l_3}$	Capability to dispatch orders in 24 h
$c_6^{l_3}$	Possibility to negotiate special conditions

Table A5. Sub-criteria of criterion l_4Table A.4 – Sub-criteria of criterion $l_{3.}$

Sub-criterion	Definition
$c_1^{l_4}$	Packaging costs
$c_2^{l_4}$	Transportation costs
$c_3^{l_4}$	Auxiliary shipment procedure costs
$c_4^{l_4}$	Payment terms
$c_5^{l_4}$	Discount opportunities

Table A6. Sub-criteria of criterion l_5Table A.5 – Sub-criteria of criterion l_4.

Sub-criterion	Definition
$c_1^{l_5}$	Quality system certification/assessment
$c_2^{l_5}$	Subcontracting of key processes
$c_3^{l_5}$	Efficiency of transportation processes
$c_4^{l_5}$	Electronic Data Interchange capabilities
$c_5^{l_5}$	Fleet size
$c_6^{l_5}$	% of vehicles with satellite antitheft devices
$c_7^{l_5}$	% of vehicles with ADR certification
$c_8^{l_5}$	% of refrigerated vehicles for perishable goods

Table A7. Sub-criteria of criterion $l_{6.}$

Sub-criterion	Definition
$c_1^{l_6}$	Accident rate
$c_2^{l_6}$	National Insurance contribution regularity
$c_3^{l_6}$	% of employees able to give medical treatment
$c_4^{l_6}$	% of employees able to manage emergencies
$c_5^{l_6}$	% of employees with qualification to transport dangerous and perishable goods

Table A8. Sub-criteria of criterion $l_{7.}$

Sub-criterion	Definition
$c_1^{l_7}$	Average age of vehicles
$c_2^{l_7}$	Quantity of NO_x pollution
$c_3^{l_7}$	Quantity of greenhouse gas pollution
$c_4^{l_7}$	Quantity of HC pollution