AN INTEGRATED APPROACH FOR SELECTION OF SERVICE VENDORS IN SERVICE SUPPLY CHAIN

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ABSTRACT. We explore the basic conceptual framework to imagine service supply chain that is a new research concern in supply chain management, and develop an integrated approach to optimize the selection of service vendors. Three insights arise on how service vendors can be obtained: (1) exploring multiple criteria decision-making problems with incomplete weight information; (2) identifying and eliminating criteria by information entropy method; (3) analyzing and calculating the final selection of qualified service vendors through a combining way between the fuzzy analytic hierarchy process and the multi-objective linear programming approach. Finally, an experiment implemented highlights effectiveness of the integrated approach.

1. Introduction. Service science is the study of value co-creation interactions among entities, known as service systems. Service science has been seen as the next frontier discipline after computer and information science. Service science can be thought of as an integration of many areas of study known as service management, service marketing, service operations, service engineering, service computing, service human resource management, service economic, management of service innovation, service supply chain, e-sourcing and others. Vargo and Lusch recognized the importance of service provision as the basis for economic exchange and argue that despite limited empirical support marketing academics have traditionally viewed service as a subset of product marketing. They challenged the traditional paradigm that treats service marketing as a special case of product marketing. Advancing the management principles, the research of SSC is of rising economic importance.

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Deepening concerns about how best to manage exemplar services have led to calls for more scholarly research on the subject. Along this line, a number of SSC scholars have continued to stress that SSC is an intriguing management area that requires ongoing investigation. However, with the ever-growing importance of the service sector in our economies, the notion of service supply chains has obtained a more prominent role in contemporary operations management research [8],[24]. Existing supply chain management frameworks, such as Hewlett-Chain Operation Reference model[29], and the Global Supply Chain Forum Framework [14],[42] are applied to the services sector. Service supply chain management refers to the service-oriented integrated management model about information, service process, service capabilities, service performance and service funds from service supply vendors to customers, which forming from service creation and delivery process[18]. Anderson and Morrice designed a four-stage security service game to study the bullwhip effect in service supply chain and discussed the operational efficiency in the service supply chain for the first time[3]. Jack S. Cook et al recognized that the distinction between the services and manufacturing industry is not so strictly, and sometimes there exists gray area and mixed in different industries[13]. At present, domestic and international research about connotation of service supply chain can be summarized into two categories[32]: In the first definition, service supply chain is interpreted as associated service activities in traditional supply chain. Another view is that model of service supply chain is the application of traditional supply chain theory in the service sector. Service supply chain management refers to the service-oriented integrated management model about information, service process, service capabilities, service performance and service funds from the service creation and delivery process[18]. Examples include professional services such as outsourcing engineering and technical service; consulting; financial services such as mortgages and insurance; commercial construction; mobile workforces such as home health care vendor. Dirk de Waart and Steve Kemper defined service supply chain as all processes and activities involved in the planning, movement, and repair of materials to enable after-sales support of the company’s products[17]. They described a five-step process to help companies swiftly get on that road to excellence of service supply chain. The advantages of achieving excellence in SSC management include increased customer satisfaction and retention, product sales, and service contract revenue as well as higher margins. We tend to support the view that the SSC is the integration of a range of services and service vendors based on the core service integrator.

This recognition of the importance of service management to economic and business success is being echoed in other disciplines as well [36]. Take, for example, Gad Allon and Avi Federgruen analyzed the equilibrium behavior for the competitive interaction in service industries where firms cater to multiple customer classes or market segments with the help of shared service facilities or processes to exploit pooling benefits[1]. Similarly, management and marketing scholars have made a distinctive contribution to the study of services, resulting in many entire area of research labeled such as “services marketing”,[7],[10],[16].

Through the analysis classic model of supply chain and characteristics of service supply chain, the paper develops an integrated model of service supply chain, which is integration of services and information flow through service operators (service vendors, service integrator) and customers in the figure 1.
In the literature, service quality with deterministic and stochastic customers' demands have been considered for practitioners and researchers, but more attention is paid to the deterministic cases, and fewer cases take into account the stochastic demands. In real situations, for problems of service vendors' selection, the weights of criteria are different and depend on purchasing strategies in supply chain [44]. Weber and Current used a multi-objective approach to systematically analyze the trade-offs between conflicting criteria in supplier selection problems [46]. Degraeve and Roodhooft developed a total cost approach with mathematical programming to treat supplier selection using activity-based cost information [15]. Chaudry et al. developed a linear mixed integer programming of supplier selection [9]. Rosenthal et al. developed a mixed integer-programming model for supplier selection with bundling, in which a buyer needs to buy various items from several vendors whose capacity, quality and deliveries are limited and who offer bundled products at discounted prices [35]. Kumar et al. proposed fuzzy goal programming for supplier selection problems with multiple sourcing that include three primary goals: minimizing the net cost, minimizing the net rejections and minimizing the net late deliveries subject to realistic constraints regarding buyer’s demand and vendors’ capacity [27]. In the papers, relatively scarce content have developed effective selection models for supplier selection problems simultaneously trying to deal with unstructured relevant information, imprecise input data and different weights of evaluative criteria, under conditions of multiple scouring.

In the study, an integrated approach is proposed to the decision and selection of service integrator under imprecise conditions. Through this approach, decision makers (e.g., service integrators) can assign different weights for numbers of criteria in order to manage service flow to improve supply chain performance. This paper has the following structures. Section 2 presents information entropy approach related to identify and eliminate decision criteria. Section 3 and 4 vendor the necessary background of fuzzy Analytic Hierarchy Process (AHP) and a multi-objective linear programming approach for the final selection of qualified vendor candidates. Section
5 gives a numerical example and reports the results of computational experiments. Finally, section 6 is devoted to conclusions and recommendations.

2. Proposed information entropy approach. The concept of entropy was invented by Clausius in 1854; Shannon carried it over to information theory in 1948 and Kolmogorov to ergodic theory in 1958 [22]. High information entropy is equivalent to high levels of uncertainty or variability in a system. Information entropy has used in numerous disciplines of the physical and life sciences. Probabilities are the foundation of information entropy. In order to calculate the information entropy of discrete aiming movements one needs to know the probabilities of the data distribution at each time point in the movement trajectory [28]. The proposed information entropy approach aims at constructing a systematic decision criteria process that consists of two main phase: preliminary screening of the decision criteria and elimination of unsuitable criteria. In reality, decision makers usually have intangible information related to decision criteria and constraints, rather than exact and complete information. Evaluation data such as cost and service quality can exhibit a great deal of fluctuation. As a result, these data are vague. We develop the following information entropy approach to deal with this problem. Information is equivalent to the removal of uncertainty, and uncertainty and entropy are essentially identical, not mere analogs [5]. In general, the information content is proportional to the associated uncertainty. Saleh, M. devised an entropy function to estimate the average information content associated with a random variable [40].

This function has the following properties:
- The function is continuous.
- The maximum of this function occurs when all probabilities are equal.
- If the outcome of the random variable is certain, then the entropy is equal to zero.

According to the entropy function [41] that can be regarded as a quantitative measure of information intensity, Frizelle and Woodcock offered a formulation for quantifying the structural/static complexity of a system [19], understood as the expected amount of information needed to manage the supply chain/ manufacturing process:

\[
H = - \sum_{i=1}^{M} \sum_{j=1}^{N} p_{ij} \log p_{ij}
\]  

(1)

where \( p_{ij} \) represents the probability of a resource \( i \) being in state \( j \), \( N \) represents the number of states at resource \( i \), \( M \) represents the number of resource. Frizelle and Efstathiou offered a more detailed explanation of the meaning of the equation [20].

To comprehend this fact, we are going to apply it to constructing decision criteria process below. Given decision criteria \( r \) and assessment objects (service integrator) \( S \), evaluation of decision criteria to assessment object can form the following decision matrix:

\[
\begin{bmatrix}
S_1 & S_2 & \cdots & S_m \\
r_1 & t_{11} & t_{12} & \cdots & t_{1m} \\
r_2 & t_{21} & t_{22} & \cdots & t_{2m} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
r_n & t_{n1} & t_{n2} & \cdots & t_{nm}
\end{bmatrix}
\]
where $S_i$: the $i$th assessment object (service vendor). $r_j$: the $j$th decision criterion. $t_{ij}$: the evaluation value of assessment objects $i$ for decision criterion $j$. Then the entropy function $H_j$ is defined by

$$H_j = k \sum_{i=1}^{m} \frac{t_{ij}}{\sum_{i=1}^{m} t_{ij}} \cdot \ln \frac{t_{ij}}{\sum_{i=1}^{m} t_{ij}}$$  \hspace{1cm} (2)$$

where

$$j = 1, 2, \ldots, n, \quad k = -\ln \frac{1}{m}, \text{ and } 0 \leq H_j \leq 1.$$ 

The entropy function is shown in Equation (2). Given value $j$, we note that the entropy function $H_j$ is greater, if the evaluation value $t_{ij}$ is greater difference. When the values of all $t_{ij}$ are equal, $H_j$ obtains a maximum value. Namely, $H_{\text{max}} = -k \ln m$. If $k = -\frac{1}{\ln m}$ then $H_j = 1$. With respect to the comparative evaluation of the object, there is no distinction capacity about decision criteria $j$. Therefore, we can consider removing the decision criterion. We defines evaluation matrix for the total entropy $E = \sum_{j=1}^{m} H_j$. Then the entropy weight $w_j$ is defined by

$$w_j = \frac{1-H_j}{n-\sum_{j=1}^{n} H_j}$$  \hspace{1cm} (3)$$

where $w_j$ represents ability to distinguish between a measure of each criterion, $j = 1, 2, \ldots, n$. 

3. Proposed fuzzy AHP approach.

3.1. The elementary AHP model. One of the most widely used multi-criteria techniques in decision-making processes involving multiple actors is the Analytic Hierarchy Process (AHP), which developed by Thomas L. Saaty [37],[38],[39]. The AHP based on the use of pair-wise comparisons, which lead to the elaboration of a ratio scale, which is based on a four-level hierarchy[49], the generic form of which can be seen hereunder in Figure 2.

![Figure 2. Hierarchical structure of AHP framework](image-url)
goal. Level II represents the criteria and sub criteria (level III) used in selecting the different goal. Level IV contains the decision alternatives.

Owing to the complex characters of the comparison process, it is usually very hard to obtain precise evaluation scores from the decision makers regarding to the decision alternative. Thus, static crisp value of the fundamental scale may lack the ability to catch the decision maker’s subjective preference. Generally, it is much easier to vendor interval judgments or linguistic evaluations instead of introducing their judgments by setting them equal to particular numerical values [6]. With the AHP not being able to overcome the deficiency of the fuzziness during decision-making, Laarhoven and Pedrycz proposed the fuzzy AHP to evolved Saaty’s AHP, bringing the triangular fuzzy number of the fuzzy set theory directly into the comparison matrix of the AHP. The purpose is to solve vague problems, which occur during the analysis of criteria and judgment process [33].

3.2. Triangular fuzzy numbers. The fuzzy set theory treats vague data as possibility distributions in terms of set memberships. Once determined and defined, the sets of memberships for possibility distributions can be effectively used in logical reasoning. Triangular fuzzy numbers are one of the major components. We briefly review some of the basic definitions and the relevant operations of triangular fuzzy numbers [45].

**Definition 3.1.** Fuzzy sets A fuzzy number A in the universe of discourse X is characterized by a membership function \( \mu_A \sim x \), which associates with each element \( x \) in \( X \) a real number in the interval \([0,1]\).

**Definition 3.2.** For a fuzzy number \( \alpha \in [0,1] \) and any number, the \( \alpha \)-cut, \( C_\alpha \), is the crisp set \( C_\alpha = \{ x \mid C(x) \geq \alpha \} \), the \( \alpha \)-cut of a fuzzy number \( C \) is the crisp set \( C_\alpha \) that contains all the elements of the universal set \( U \) whose membership grades in \( C \) are greater than or equal to the specified value of \( \alpha \).

**Definition 3.3.** Fuzzy sets A fuzzy number A on \( \mathbb{R} \) to be a triangular fuzzy number if its membership functions \( \mu_A \sim x : \mathbb{R} \rightarrow [0,1] \) is defined by

\[
\mu_A \sim x = \begin{cases} 
0 & x < l \\
\frac{x-l}{m-l} & l \leq x \leq m \\
\frac{m-x}{h-x} & m \leq x \leq h \\
0 & x > h 
\end{cases}
\]

**Definition 3.4.** Given any two positive triangular fuzzy numbers, \( A_1 = (l_1, m_1, h_1) \), \( A_2 = (l_2, m_2, h_2) \) and a real number \( k \), some arithmetic operational of \( A_1 \) and \( A_2 \) can be expressed as follows [26]:

\[
\begin{align*}
A_1 \oplus A_2 &= (l_1 \oplus l_2, m_1 \oplus m_2, h_1 \oplus h_2) \\
A_1 \Theta A_2 &= (l_1 \Theta l_2, m_1 \Theta m_2, h_1 \Theta h_2) \\
A_1 \otimes A_2 &= (l_1 \otimes l_2, m_1 \otimes m_2, h_1 \otimes h_2) \\
k \cdot A_1 &= (k l_1, k m_1, k h_1) \\
A_1 \phi A_2 &= (l_1 \phi l_2, m_1 \phi m_2, h_1 \phi h_2)
\end{align*}
\]
3.3. Proposed fuzzy AHP method. Since not all attributes have the same importance, the fuzzy AHP used to find weights of the attributes for the qualified vendors. The detail procedure of the fuzzy AHP describe as follows. The first step is identifying all possible qualified vendors. Based on actual demands of the company, decision-makers should identify all possible service vendors. There are several paths to discover in this issue by: (1) the well-known web sites from related services, (2) directly contacting with the relevant vendors, (3) collecting information from commercial information and business magazines, and (4) participating in variety of services-related business activities such as seminar [23]. In the initial screening phase, most companies usually consider six to eight potential vendors [47]. The second step is to establish hierarchical structure. The efficient service capabilities of qualified candidates are the overall objective in the first level. The criteria for achieving the overall objective are in the second level and detailed criteria in the third level analyzed by the decision-makers, and then the alternatives lay on the bottom layer. The third step is to construct the fuzzy judgment matrix. Based on the proposed hierarchy, the fuzzy judgment matrix \( Q \) is pairwise comparison matrix among each first compare criteria pairwise in order to achieve the goal of efficient service capabilities. And then compare detailed criteria are proposed toward achieving their upper-level criterion. Assign linguistic terms can be obtained, as seen from table 1.

For a number of decision-makers \( t \), the relative important level between factor \( p \) and factor \( q \) rated by decision-maker \( k \), can be expressed as \( \eta_{pqk} \), and the synthetic fuzzy set presenting the relative importance level can be expressed as following [25]:

\[
Q = [\eta_{pq}]_{nn}, \text{ where } \eta_{pq} = \sqrt[nt]{\prod_{k=1}^{t} \eta_{pqk}}, \forall k \in \{1, 2, \cdots, t\}.
\]

If factor \( p \) is relative importance to factor \( q \), then \( \eta_{pq} = \eta_{qp}^{-1}, (p \neq q), \eta_{pq} \in \{1, 3, 5, 7, 9\} \). If \( p = q \), then \( \eta_{pq} = \hat{1} \).

The fourth step is to establish fuzzy weights of each criterion. The fuzzy weights of each criterion are calculated as follows:

\[
\varphi_p = \sqrt[nt]{\eta_{p1} \otimes \eta_{p2} \otimes \cdots \otimes \eta_{pn}}, \quad \psi_p = \frac{\varphi_p}{\varphi_1 \otimes \varphi_2 \otimes \cdots \otimes \varphi_n},
\]

\[
w_p = \frac{1}{n} \times (\eta_{p1} \otimes \eta_{p2} \otimes \cdots \otimes \eta_{pn}) \quad \text{or} \quad w_p = \frac{\phi_p}{\phi_1 \otimes \phi_2 \otimes \cdots \otimes \phi_n}
\]

where \( \varphi_p \) representing the geometric mean of fuzzy comparison value of criterion \( p \) to each criterion, representing the arithmetic mean of fuzzy comparison value
of criterion $p$ to each criterion, and $\emptyset_p$ representing the fuzzy weight of the $p$th criterion.

The fifth step is to construct a weight-ranking matrix. For each criterion, we intend to determine the ranking order of all the remaining vendors. According to the fuzzy ranking method [11], we can arrange the ranking order of each vendor for all remaining criteria. For instance, assume that the ranking results of all the qualified vendor candidates for criteria $r_1, r_2, \ldots, r_k$ are $(s_j > s_r > \cdots > s_i), (s_r > s_j > \cdots > s_i), \ldots, (s_r > s_i > \cdots > s_j)$. Thus, we can construct a ranking matrix like the following:

\[
\begin{array}{cccc}
& rank_1 & rank_2 & \cdots & rank_m \\
r_1 & S_j & S_r & \cdots & S_i \\
r_2 & S_r & S_j & \cdots & S_i \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
r_k & S_r & S_i & \cdots & S_j
\end{array}
\]

where $S_j$ denotes the qualified vendor $j$, $j = 1, 2, \ldots, m$. To construct a weight-ranking matrix, each vendor in the ranking matrix converted into its corresponding performance rating $t_{ij}$. Hence, the ranking matrix shown above transformed into the following weight-ranking matrix.

\[
\begin{array}{cccc}
& rank_1 & rank_2 & \cdots & rank_m \\
r_1 & w_1 \otimes t_{1j} & w_1 \otimes t_{1j} & \cdots & w_1 \otimes t_{1i} \\
r_2 & w_2 \otimes t_{2r} & w_2 \otimes t_{2j} & \cdots & w_2 \otimes t_{2i} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
r_k & w_k \otimes t_{kr} & w_k \otimes t_{ki} & \cdots & w_k \otimes t_{kj}
\end{array}
\]

The sixth step is to establish the total fuzzy decision matrix. By defining the interval of confidence at level $\alpha$, the triangular fuzzy number characterized by [12]:

\[
C_\alpha = [p^\alpha, s^\alpha] = [(q-p)\alpha + p - (s-q)\alpha + s], \forall \alpha \in [0, 1]
\]

Hence, establish the total fuzzy decision matrix with the $\alpha - cut$, by performing fuzzy number multiplications and additions with the interval arithmetic and cuts. The weight-ranking matrix shown above simplified to

\[
\begin{bmatrix}
[R_{1jL}^\alpha, R_{1jU}^\alpha] & [R_{1rL}^\alpha, R_{1rU}^\alpha] & \cdots & [R_{1iL}^\alpha, R_{1iU}^\alpha] \\
[R_{2rL}^\alpha, R_{2rU}^\alpha] & [R_{2jL}^\alpha, R_{2jU}^\alpha] & \cdots & [R_{2iL}^\alpha, R_{2iU}^\alpha] \\
\vdots & \vdots & \ddots & \vdots \\
[R_{krL}^\alpha, R_{krU}^\alpha] & [R_{klL}^\alpha, R_{klU}^\alpha] & \cdots & [R_{kjL}^\alpha, R_{kjU}^\alpha]
\end{bmatrix}
\]

where $R_{ijL}^\alpha = w_{kl}^\alpha \otimes t_{kjl}^\alpha, R_{ijU}^\alpha = w_{kl}^\alpha \otimes t_{kju}^\alpha$, for $0 < \alpha \leq 1$.

When $\alpha$ is fixed, the index of optimism $\beta$ can be set to represent the degree of the optimism of decision maker. A larger $\beta$ indicates a higher degree of optimism, and vice versa. The index of optimism is a linear convex combination and is defined as $R_{ij}^{\alpha\beta} = (1 - \beta)R_{ijL}^\alpha + R_{ijU}^\alpha, \forall \beta \in [0, 1]$. Thus, matrix above is transformed into the following matrix.
The seventh step is to construct an aggregated weight matrix. According to weight ranking matrix above in step 6, we can compute the aggregated weight matrix of each vendor in different ranks. Because of $S_r$ ranked first for criteria $r_1, r_2, \cdots, r_k$, the aggregated weight of vendor $S_r$ with the first rank computed by summing up the corresponding elements of these criteria in matrix, which is $R_\alpha^\beta + \cdots + R_k^\beta$. Homogeneously, we can compute the other vendor in different ranks and construct an aggregated weight matrix as follows,

$$
\begin{bmatrix}
R_{11}^\alpha & R_{12}^\alpha & \cdots & R_{1i}^\alpha \\
R_{21}^\alpha & R_{22}^\alpha & \cdots & R_{2i}^\alpha \\
\vdots & \vdots & \ddots & \vdots \\
R_{ki}^\alpha & R_{ki}^\alpha & \cdots & R_{ki}^\alpha
\end{bmatrix}
$$

where $\Phi_{ij}$ is the aggregated weight of vendor $i$ with rank $j$. $i,j = 1,2,\cdots,m$.

### 4. Proposed Multi-objective linear programming approach

Many areas of the industry as, for example, telecommunications, transportation, aeronautics, chemistry, mechanical, and environment, deal with multi-objective linear programming, where various conflicting objectives having to be considered simultaneously. This section briefly presents some basic definitions and notation for it. The interested readers referred to these papers [19], [21], [30], [31], and the article in press [2] for more details about this field. According to the idea of linear assignment, the aggregated weight matrix represented as a fuzzy linear assignment model as follows:

$$
\text{max} \sum_{i=1}^{m} \sum_{j=1}^{m} \Phi_{ij} x_{ij}
$$

ST.

$$
\sum_{i=1}^{m} x_{ij} = 1
$$

$$
\sum_{j=1}^{m} x_{ij} = 1
$$

$i,j = 1,2,\cdots,m$

$\forall x_{ij} = 0$ or 1

where $x_{ij}$ denotes the value of vendor $i$ with rank $j$. At present, there have many different methods to design and solve the fuzzy linear assignment problem. For example, Rommelfanger’s method includes two main segments [34]: first, transform the fuzzy linear assignment problem into a multi-objective linear programming problem; then, the multi-objective linear programming problem is converted into a crisp linear programming problem by using the weighting method.
According to the above idea, we can transform the above fuzzy linear programming problem into crisp linear programming problem. The converted linear programming problem is obtained by

$$\max \varepsilon \sum_{i=1}^{m} \sum_{j=1}^{m} \Phi_{ij}^L x_{ij} + (1 - \varepsilon) \sum_{i=1}^{m} \sum_{j=1}^{m} \Phi_{ij}^H x_{ij}$$  \hspace{1cm} (8)$$

ST. $$\sum_{i=1}^{m} x_{ij} = 1$$

$$\sum_{j=1}^{m} x_{ij} = 1$$

$$i, j = 1, 2, \ldots, m$$

$$\forall x_{ij} = 0 \text{ or } 1$$

where $\varepsilon (0 \leq \varepsilon \leq 1)$ denotes the weight of objective function. $\Phi_{ij}^L, \Phi_{ij}^H$ are respectively the lower and upper bounds of the $\alpha - cut$ for $\Phi_{ij}$. Because the converted linear programming problem is actually a 0-1 integer-programming problem, we can obtain the final rank of each vendor and determine the best vendor for enterprises by using related mathematics software to solve it.

5. **Numerical example.** In this section, the proposed fuzzy decision analysis approach applied to solve the priority mix problem in order to demonstrate the applicability. It applied on a medium-sized company. The Chery, Automobile Co., Ltd., that has currently independent capacity for the $R&F$ of vehicles, engines and some key parts and components, independent intellectual property rights and core technologies, and becomes China’s largest enterprise in the $R&F$, manufacture, sale and export of Chinese independent-branded passenger cars, laying a solid foundation for more intense competition and faster development. For this company, logistic outsourcing is an excellent strategy to save value, focus on its core competency, and adapt to the competitive market in China.

Recently, the company investigated to produce a new automobile. Therefore, the ability and capacity of suppliers should be evaluated. Up to know the majority of manufactured automobiles were sold in China. However, in recent years, the quality of products has increased and the final costs have decreased. Thus, the firms plan to export automobiles. The traditional assessment system implies on the internal factors such as cost and quality. However, other factors like mutual trust should be added to shift from national to international market. The Company divides the parts suppliers into several groups based on the products and collects the necessary information in a database. Tire suppliers are one of the groups. Wheels and tires are famous components of each vehicle. Nowadays, more than one billion tires are produced every year in the world with the three leading tire firms absorbing more than 60% of a global market share. China, India, Japan, and Thailand are the most well known firms of tires in the global market. Tiers of automobiles are usually rubber tubes or more specifically pneumatic enclosures affixed around a wheel, which facilitate rotation of a vehicle. Almost all types of automobiles ranging from two wheelers, cars, to airplanes use tires. Tires filled with air, which vendors a flexible support to the vehicle. Tires enhance the performance of an automobile by providing a comfortable grip of the road. Tires often are manufactured using ductile elastomeric material like fabric, rubber and wire. The company wants to
purchase a type of passenger car tires. In other words, there is one product in this case study. How to select the most appropriate vendor is always an important and urgent task for the company. In order to meet the company’s various needs, the company evaluates the potential vendors. With comprehensive review of literature, the decision group, coming from certain degree of knowledge and expertise, agreed to adopt the 18 criteria in Table 2 as the initial evaluation criteria used for the proposed information entropy process.

According to Vaidyanathan viewpoint [47], the decision group considers seven potential vendors and divides five grades about 18 evaluation criteria. Evaluation interval values are defined as Table 3. Once all of evaluation criteria values have been identified, we can obtain every criterion value for potential vendors based on these criteria. Evaluation vales of every potential vendor are showed as Table 4 for these criteria.

Thus, we can calculate the entropy values of evaluation criteria based on information entropy formula (2). For example, the entropy value of SIC ($H_{SIC} = 0.983248$) can be obtained by, ($k = \frac{1}{\ln 7}$)

| Decision Criteria                          | Abbreviation |
|-------------------------------------------|--------------|
| Flexible Service & Service Quality        | (FS&SQ)      |
| Service Innovation Capability             | (SIC)        |
| Service Response Speed                    | (SRS)        |
| Service Average Price Advantage           | (SAPA)       |
| Proportion of Service Commitment          | (PSC)        |
| Service Performance Capability            | (SPC)        |
| Service Dynamic Requirement Process       | (SDRP)       |
| Service Value Loss Ratio                  | (SVLR)       |
| Degree of Service Specialization          | (DSS)        |
| Total Assets of Service Enterprise        | (TASE)       |
| Service Market Occupancy                  | (SMO)        |
| Service Employment Number                 | (SEN)        |
| Total Assets Turnover Ratio               | (TATR)       |
| Asset Liability Ratio                     | (ALR)        |
| Net Assets Rate                           | (NAR)        |
| Service Collaborative Capability          | (SCC)        |
| Information Transmission Distortion       | (ITD)        |
| Co-operation Trust Degree                 | (CTD)        |
| Service Profit Growth                     | (SPG)        |
| Resource Consumption Rate                 | (RCR)        |
| Environmental Awareness                   | (EA)         |

| grades | excellent | very good | good | normal | poor |
|--------|-----------|-----------|------|--------|------|
| values | 10~8      | 8~6       | 6~4  | 4~2    | 2~0  |
Table 4. Evaluation criteria values for potential vendors

| Vendor | A   | B   | C   | D   | E   | F   | G   |
|--------|-----|-----|-----|-----|-----|-----|-----|
| FS&SQ  | 10.00 | 6.19 | 5.85 | 5.46 | 4.19 | 6.60 | 5.70 |
| SIC    | 8.00  | 3.10 | 4.35 | 3.50 | 2.83 | 3.46 | 3.41 |
| SRS    | 8.00  | 1.15 | 1.71 | 0.92 | 1.61 | 1.15 | 0.75 |
| SAPA   | 5.00  | 6.08 | 5.69 | 4.72 | 4.04 | 5.85 | 5.41 |
| SPC    | 7.50  | 3.28 | 2.52 | 1.11 | 1.48 | 4.00 | 0.74 |
| SDRP   | 9.00  | 4.71 | 5.77 | 4.94 | 3.59 | 4.77 | 4.85 |
| SVLR   | 9.00  | 4.64 | 5.60 | 5.18 | 3.81 | 5.12 | 5.07 |
| DSS    | 4.80  | 5.93 | 6.21 | 4.99 | 3.78 | 5.06 | 5.31 |
| TASE   | 4.50  | 1.39 | 0.23 | 2.25 | 0.00 | 0.82 | 0.28 |
| SMO    | 9.00  | 5.10 | 5.24 | 4.31 | 3.85 | 5.91 | 4.66 |
| TATR   | 6.02  | 6.11 | 6.13 | 5.24 | 4.19 | 5.00 | 5.54 |
| ALR    | 6.21  | 6.39 | 5.92 | 5.35 | 4.54 | 6.72 | 5.76 |
| NAR    | 6.09  | 6.10 | 6.11 | 5.13 | 3.94 | 6.40 | 5.76 |
| SCC    | 8.50  | 5.06 | 4.76 | 4.38 | 3.72 | 6.25 | 4.38 |
| ITD    | 4.50  | 0.05 | 0.32 | 0.16 | 0.02 | 0.01 | 0.01 |
| CTD    | 6.00  | 3.82 | 5.44 | 4.53 | 3.30 | 4.23 | 4.96 |
| SPG    | 8.50  | 6.07 | 5.60 | 4.90 | 3.91 | 6.17 | 5.10 |
| RCR    | 5.80  | 5.94 | 5.89 | 4.76 | 4.06 | 4.92 | 5.18 |

\[
H_{SIC} = -\frac{1}{\ln 7}\left\{\frac{10}{43.99}\ln 10/43.99 + \frac{6.19}{43.99}\ln 6.19/43.99 \\
+ \frac{5.85}{43.99}\ln 5.85/43.99 + \frac{5.46}{43.99}\ln 5.46/43.99 \\
+ \frac{4.19}{43.99}\ln 4.19/43.99 + \frac{6.60}{43.99}\ln 6.60/43.99\right\}
\]

Similarly, we can calculate the entropy values of other criteria. The results are showed as Table 5. Meanwhile, we can also distinguish important degree of criteria based on entropy formula (3) and (4). The differentiation values are described in detail as Table 5.

As can be seen from the above Table 5, differentiation values of some decision criteria are small. For instance, SIC, PSC, TASE, SEN, TATR, ALR, NAR, ITD, RCR, and EA. Taking into account from the perspective of evaluation model, we can ignore these decision criteria. In other words, these decision criteria are no longer important evaluation criteria in the current evaluation process. As threshold value of evaluation, they will not be considered temporarily. Based on the above analysis, we have been completed to identify and eliminate decision criteria. Decision criteria retained separately are SRS, SAPA, SDRP, SVLR, DSS, SMO, CTD, and SPG.

Step1: Identifying all possible qualified vendors. In the above-mentioned qualified vendors A G, we identify and eliminate unqualified vendors based on the company’s actual economic situation. For convenience of calculation, the results of screening are vendor A, vendor B, vendor C and vendor D.

Step2: Establishing hierarchical structure. Vendors A, B, C, D are four selectable qualified vendors; they form the alternative hierarchy (level IV). SRS, SAPA, SDRP,
Table 5. Entropy and Differentiation Values of Decision Criteria

| Criteria | Entropy Value | Differentiation Value |
|----------|---------------|-----------------------|
| FS&SQ    | ——            | 0.005                 |
| SIC      | 0.98324       | 0.005                 |
| SRS      | 0.76467       | 0.069                 |
| SAPA     | 0.78480       | 0.071                 |
| PSC      | 0.98511       | 0.004                 |
| SPC      | ——            | 0.041                 |
| SDRP     | 0.87401       | 0.041                 |
| SVLR     | 0.87969       | 0.041                 |
| DSS      | 0.78214       | 0.071                 |
| TASE     | 0.98341       | 0.005                 |
| SMO      | 0.61909       | 0.125                 |
| SEN      | 0.97891       | 0.006                 |
| TATR     | 0.98086       | 0.007                 |
| ALR      | 0.94489       | 0.009                 |
| NAR      | 0.98139       | 0.007                 |
| SCC      | ——            | 0.007                 |
| ITD      | 0.98086       | 0.007                 |
| CTD      | 0.19447       | 0.289                 |
| SPG      | 0.69092       | 0.125                 |
| RCR      | 0.98679       | 0.004                 |
| EA       | 0.98392       | 0.005                 |

SVLR, DSS, SMO, CTD, and SPG are seven attributes; they form the attribute hierarchy (level II and III). Fig. 3 shows hierarchy of the problem.

Step3: Constructing the fuzzy judgment matrix. We can express according to one of the opinions contained in Table 6. Table 6 lists the fuzzy linguistic assessment variables. Meanwhile, to solve the inconsistency in decision-making process, we apply the Fuzzy LinPreRa method to enhance the consistency of fuzzy AHP method [45]. Table 7 lists the pairwise comparison matrix for the goal and all criteria. As can be seen from Table 7, the matrix has entries that are not included in the interval [0, 1]; thus the following transforming function is applied. The transforming
Table 6. Fuzzy linguistic assessment variables

| Linguistic Variables | Triangle Fuzzy Scale |
|----------------------|----------------------|
| Poor important       | (0.1,0.1,0.3)        |
| Weakly important     | (0.1,0.3,0.5)        |
| Equally Important    | (0.3,0.5,0.7)        |
| Very important       | (0.5,0.7,0.9)        |
| Absolutely important | (0.7,0.9,0.9)        |

Table 7. Pair-wise comparison of seven criteria with respect to the goal

| Criteria   | SRS       | APA       | SDRP      | SVLR      |
|------------|-----------|-----------|-----------|-----------|
| SRS        | *         | (0.3,0.5,0.7) | (-0.1,0.1,0.5) | (-0.5,-0.1,0.5) |
| SAPA       | (0.3,0.5,0.7) | *         | (0.1,0.1,0.3) | (0.1,0.3,0.5) |
| SDRP       | (0.5,0.9,1.1) | (0.7,0.9,0.9) | *         | (0.1,0.3,0.5) |
| SVLR       | (0.5,1.1,1.5) | (0.7,1.1,1.3) | (0.5,0.7,0.9) | *         |
| DSS        | (0.1,0.7,1.3) | (0.3,0.5,0.9) | (0.1,0.3,0.7) | (0.1,0.1,0.3) |
| SMO        | (0.1,0.9,1.7) | (0.3,0.9,1.5) | (0.1,0.5,0.7) | (0.1,0.3,0.7) |
| CTD        | (-0.3,0.7,1.8) | (-0.1,0.7,1.5) | (-0.3,0.3,1.1) | (-0.3,0.1,0.7) |

| Criteria   | DSS       | SMO       | CTD       |
|------------|-----------|-----------|-----------|
| SRS        | (-0.3,0.3,0.9) | (-0.7,0.1,0.9) | (-0.8,0.3,1.3) |
| SAPA       | (0.1,0.5,0.7) | (-0.5,0.1,0.7) | (-0.5,0.3,1.1) |
| SDRP       | (0.3,0.7,0.9) | (0.3,0.5,0.9) | (-0.1,0.7,1.3) |
| SVLR       | (0.7,0.9,0.9) | (0.3,0.7,0.9) | (0.3,0.9,1.3) |
| DSS        | *         | (0.1,0.3,0.5) | (-0.9,-0.5,-0.1) |
| SMO        | (0.5,0.7,0.9) | *         | (0.5,0.7,0.9) |
| CTD        | (1.1,1.5,1.9) | (0.1,0.3,0.5) | *         |

function is \( f : [-k, 1 + k] \to [0, 1] \), \( f(x) = \frac{x + k}{1 + 2k} \) which preserves reciprocity and additive consistency. When \( k = 0.8 \), Table 8 lists transforming results of the four criteria matrix from Table 7. Similarly, Table 9 presents the decision matrices of alternatives determined by applying each criterion.

Step4: Establishing fuzzy weights of each criterion. We can calculate the arithmetic means of fuzzy comparison value and fuzzy weights of each criterion based on Eq. (6). As shown in Table 10. Similarly, we can also calculate the arithmetic means of fuzzy comparison value and fuzzy weights of four vendors with respect to seven criteria. Finally, the results that obtained by group integration using Eq. (6) is shown in Table 11.

Step5 to step 7: Obtained the aggregated weight matrix. Based on Table 11, we applied the fuzzy ranking method to determine each vendor’s rank under various criteria [11]. Meanwhile, we can also compute the aggregated weight of each vendor in the different ranks. Hence, we obtained the aggregated weight matrix as shown in Table 12. Based on the idea of linear assignment, we transformed Table 12 into
Table 8. Transforming results of the four criteria matrix

| Criteria | SRS          | SAPA         | SDRP         | SVLR         |
|----------|--------------|--------------|--------------|--------------|
| SRS      | ∗ (0.4,0.5,0.6) | (0.4,0.3,0.5) | (0.1,0.3,0.5) |
| SAPA     | (0.6,0.5,0.4)  | ∗ (0.3,0.3,0.4) | (0.3,0.4,0.5) |
| SDRP     | (0.5,0.7,0.6)  | (0.6,0.7,0.7) | ∗ (0.2,0.4,0.5) |
| SVLR     | (0.5,0.7,0.9)  | (0.5,0.6,0.8) | (0.5,0.6,0.8) | ∗ |
| DSS      | (0.3,0.6,0.8)  | (0.4,0.5,0.6) | (0.4,0.5,0.6) | (0.3,0.3,0.4) |
| SMO      | (0.3,0.7,1)    | (0.3,0.5,0.6) | (0.3,0.5,0.6) | (0.3,0.4,0.6) |
| CTD      | (0.2,0.6,1)    | (0.3,0.6,0.9) | (0.2,0.4,0.7) | (0.2,0.3,0.6) |

the following converted linear assignment problem by using Eq. (8):

\[
\max \{ 0.5(5.3x_{11} + 1.2x_{12} + 0.6x_{13} + 0.6x_{14} \\
+ 1.2x_{21} + 2.8x_{22} + 1.4x_{23} + 0.6x_{24} \\
+ 0.5x_{31} + 0.6x_{32} + 1.7x_{33} + 2.1x_{34} \\
+ 0.3x_{41} + 1.5x_{42} + 2.1x_{43} + 1.4x_{44}) \\
+ 0.5(9.3x_{11} + 2.1x_{12} + 1.1x_{13} + 0.9x_{14} \\
+ 2.1x_{21} + 4.4x_{22} + 2.6x_{23} + 1.2x_{24} \\
+ 1.5x_{31} + 1.7x_{32} + 3.2x_{33} + 3.2x_{34} \\
+ 0.7x_{41} + 2.4x_{42} + 3.3x_{43} + 2.7x_{44}) \} \\
\]

ST.

\[
\sum_{i=1}^{4} x_{ij} = 1 \\
\sum_{j=1}^{4} x_{ij} = 1 \\
i, j = 1, 2, \ldots , 4 \\
\forall x_{ij} = 0 \ or \ 1
\]

With the help of mathematics software, we solve the LP problem. The result is obtained as \( x_{11} = 1, x_{24} = 1, x_{32} = 1, x_{43} = 1 \). The values of the other are equal to 0. In other word, the result indicates the ranking order of all the function service vendors, i.e. \( A > C > D > B \). Hence, the result indicates vendor A as the best vendor, which suits actual needs of the company at present.
Table 9. Pair-wise comparison of four vendors

| Criteria | Vendor | A         | B           | C           | D           |
|----------|--------|-----------|-------------|-------------|-------------|
|          | SRS    | *(0.2,0.3) | (0.0,0.3)   | (0.0,0.5)   | *(0.2,0.3)  |
|          |        | (0.5,0.7) | *(0.3,0.5)  | (0.3,0.7)   | *(0.5,0.7)  |
|          |        | (0.3,0.7) | *(0.5,0.5)  | *(0.5,0.7)  | *(0.5,0.7)  |
|          |        | (0.0,0.5) | *(0.0,0.3)  | *(0.2,0.3)  | *(0.2,0.3)  |
|          | SAPA   | *(0.4,0.5)| *(0.2,0.4)  | *(0.0,0.6)  | *(0.4,0.6)  |
|          |        | (0.2,0.4) | *(0.3,0.3)  | *(0.4,0.6)  | *(0.4,0.6)  |
|          |        | (0.0,0.1) | *(0.2,0.2)  | *(0.3,0.4)  | *(0.3,0.4)  |
|          |        | (0.5,0.4) | *(0.6,0.8)  | *(0.6,0.8)  | *(0.6,0.8)  |
|          | SDRP   | *(0.5,0.6)| *(0.0,0.6)  | *(0.4,0.6)  | *(0.4,0.6)  |
|          |        | (0.2,0.4) | *(0.3,0.3)  | *(0.4,0.6)  | *(0.4,0.6)  |
|          |        | (0.0,0.1) | *(0.2,0.2)  | *(0.3,0.4)  | *(0.3,0.4)  |
|          |        | (0.5,0.4) | *(0.6,0.8)  | *(0.6,0.8)  | *(0.6,0.8)  |
|          | SVLR   | *(0.7,0.8)| *(0.5,0.8)  | *(0.2,0.7)  | *(0.2,0.7)  |
|          |        | (0.2,0.2) | *(0.3,0.5)  | *(0.4,0.5)  | *(0.4,0.5)  |
|          |        | (0.0,0.2) | *(0.2,0.3)  | *(0.3,0.4)  | *(0.3,0.4)  |
|          |        | (0.3,0.3) | *(0.5,0.7)  | *(0.5,0.7)  | *(0.5,0.7)  |
|          | DSS    | *(0.2)    | *(0.0,0.3)  | *(0.3,0.3)  | *(0.3,0.3)  |
|          |        | (0.5,0.7) | *(0.5,0.7)  | *(0.5,0.7)  | *(0.5,0.7)  |
|          |        | (0.2,0.5) | *(0.5,0.5)  | *(0.5,0.5)  | *(0.5,0.5)  |
|          |        | (0.3,0.3) | *(0.3,0.3)  | *(0.3,0.3)  | *(0.3,0.3)  |
|          | SMO    | *(0.6)    | *(0.5,0.6)  | *(0.2,0.4)  | *(0.2,0.4)  |
|          |        | (0.2,0.2) | *(0.4,0.6)  | *(0.4,0.6)  | *(0.4,0.6)  |
|          |        | (0.0,0.2) | *(0.2,0.3)  | *(0.3,0.4)  | *(0.3,0.4)  |
|          |        | (0.4,0.8) | *(0.6,0.9)  | *(0.5,0.6)  | *(0.5,0.6)  |
|          | CTD    | *(0.5)    | *(0.5,0.6)  | *(0.2,0.4)  | *(0.2,0.4)  |
|          |        | (0.2,0.2) | *(0.4,0.5)  | *(0.4,0.5)  | *(0.4,0.5)  |
|          |        | (0.0,0.2) | *(0.2,0.3)  | *(0.3,0.4)  | *(0.3,0.4)  |
|          |        | (0.4,0.8) | *(0.6,0.9)  | *(0.5,0.6)  | *(0.5,0.6)  |

Table 10. Geometric means and fuzzy weights

| Criteria | Vendor | SRS       | SAPA      | SDRP      | SVLR      |
|----------|--------|-----------|-----------|-----------|-----------|
|          |        | arithmetic means | weights | arithmetic means | weights |
|          |        | (0.2,0.3,0.6) | (0.3,0.4,0.6) | (0.4,0.6,0.7) | (0.5,0.6,0.8) |
|          |        | (0.2,0.3,0.5) | (0.2,0.3,0.5) | (0.2,0.4,0.4) | (0.3,0.3,0.4) |
|          |        | DSS       | SMO       | CTD       |           |
|          |        | (0.3,0.4,0.6) | (0.4,0.5,0.7) | (0.3,0.5,0.8) | (0.2,0.3,0.5) |
|          |        | (0.2,0.3,0.5) | (0.3,0.3,0.4) | (0.2,0.3,0.5) |           |

6. Conclusion. Selection of service integrator is a multi criteria decision-making problem, which includes both qualitative and quantitative factors. In the paper, we have discussed an integrated approach for selection of service integrator, which consists of two phases. In the first phase, measure algorithm of information entropy is applied for identifying and eliminating decision criteria. The linguistic variables and triangular fuzzy number used to quantify variables. In the second phase, multi-object linear programming model is applied to determine the order quantity. The
Table 11. Fuzzy integration decision table

| Criteria | A          | B          | C          | D          |
|----------|------------|------------|------------|------------|
| SRS      | (0.3,0.4,0.5) | (0.6,0.7,0.7) | (0.6,0.7,0.8) | (0.6,0.7,0.7) |
| SAPA     | (0.5,0.6,0.7) | (0.5,0.6,0.6) | (0.4,0.5,0.6) | (0.4,0.5,0.5) |
| SDRP     | (0.4,0.5,0.7) | (0.5,0.6,0.7) | (0.4,0.5,0.5) | (0.5,0.6,0.6) |
| SVLR     | (0.5,0.6,0.7) | (0.5,0.5,0.6) | (0.4,0.5,0.5) | (0.4,0.5,0.6) |
| DSS      | (0.5,0.6,0.6) | (0.5,0.6,0.7) | (0.5,0.6,0.6) | (0.4,0.5,0.6) |
| SMO      | (0.5,0.6,0.7) | (0.4,0.5,0.6) | (0.5,0.6,0.7) | (0.4,0.5,0.5) |
| CTD      | (0.5,0.7,0.7) | (0.4,0.5,0.5) | (0.4,0.5,0.6) | (0.5,0.6,0.7) |

Table 12. Aggregated weight and rank

| Rank | 1st         | 2nd         | 3rd         | 4th         |
|------|-------------|-------------|-------------|-------------|
| A    | (5.8,7.6,9.3) | (1.2,1.5,2.1) | (0.6,0.9,1.1) | (0.6,0.7,0.9) |
| B    | (1.2,1.7,2.1) | (2.8,3.9,4.4) | (1.4,2.1,2.6) | (0.6,0.8,1.2) |
| C    | (0.5,1.2,1.5) | (0.6,0.9,1.7) | (1.7,2.6,3.2) | (2.1,2.7,3.2) |
| D    | (0.3,0.6,0.7) | (1.5,2.1,2.4) | (2.1,2.4,3.1) | (1.4,2.1,2.7) |

The proposed approach provides alternative tools to evaluate and improve supplier selection decisions in an uncertainty environment. The major novel points and merits of the proposed approach are in threefold: first, information entropy approach to deal with elimination of unsuitable criteria. Second, fuzzy AHP has been applied because it can take into account uncertainty in human’s opinions. Besides, it is assumed that demand is a fuzzy number. Third, a multi-object linear programming has been considered to obtain the final rank of each vendor and determine the best vendor. This algorithm can be easily implemented with a spreadsheet package and its computation is fast. Therefore, the proposed model can be applied easily in practical situations. In the case study, vendor A would be selected.

Nonetheless, expertise, experience, authority, and the responsibilities of decision makers are not equal in practice. Future research is needed to develop more novel approaches making a substantial step towards improved the proposed method. In the future, we may apply this method to different real-life problems. For instance, the proposed method may be widely used in formulating policy evaluation given the uncertainty or vagueness of information distortion related to such decisions, which are pattern recognition, medical diagnosis, and clustering analysis. It is useful to propose a scientific method for determining these problem with stochastic and uncertainty.

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