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Information flow in supply chain: A fuzzy TOPSIS parameters ranking

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A B S T R A C T

Flow of information in supply chain is as prominent as material and financial flows and among these three aspects of a supply chain, information flow could be of great importance since it provides a basis for a steady flow of goods and finance as well. To help managers control the flow of information in an effective way, first, the parameters which affect the flow of information should be determined. Then, if the parameters can be controlled carefully, the information will be shared correctly and in a timely manner among supply chain members. This paper identifies the influencing parameters on proper flow of information in supply chain and provides a list of parameters based on the literature as well as the industrial and academic experts' opinions. Afterwards, in order to define the degree of importance for each parameter from the experts' perspective, fuzzy TOPSIS method is employed and the parameters are ranked based on three criteria, namely "measurability", "being illustrative" and "parameters relevancy" to the issue of information flow. The research findings show that "Supply Chain Hardware Capabilities", "Supply Chain Network Infrastructure", "Information Software Capabilities", "Information Sharing Timeliness", "Information Recency" and "Organizational Rewards" received the highest priorities, while "Power of Internal and Inter-personal Communications", "Users' Trust" and "Users' Tendency" were standing at the bottom of this ranking. The results of this research could be employed as an input for strategy development process for supply chain information management activities. Thus, the awareness of each parameter's importance in proper flow of information, helps us make appropriate strategies to improve information management in the supply chain.

1. Introduction

Information sharing management is a critical issue for the performance of either an organization or a supply chain. Researches show that sharing information properly in a supply chain leads to a significant reduction in delays, inventory costs, safety stock level and its associated costs. Information management prominence in supply chain makes the "degree of information sharing" as a useful index in managerial decisions. Moreover, in order to reach an integrated supply chain, being aware of different aspects of information flow helps the managers identify their strengths and weaknesses and take appropriate actions to reinforce or correct them. Also, from collaboration point of view, having information of demands, manufacturing, inventories and orders in hand is a vital need to improve

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supply chain members' collaborative actions and to materialize the concept of joint decision making (Heydari, 2014). Furthermore, the state of information flow in supply chain could be a guideline for making investments in information systems and integrated systems implementation projects. It will also be useful in before-after and gap analysis in information technology (IT) projects and from a wider perspective, the degree of information sharing could be employed as an input for making strategic decisions and policy making in organizations and supply chains. On the way to manage flow of information in a supply chain, being aware of the parameters which affect information flow is the most important issue. Supply chain managers' unawareness about such parameters, in addition to the ambiguous nature of the issue caused the managers to fail in reaching a clear understanding of information flow status in supply chain. Therefore, in this paper, we aim to, firstly, identify influencing parameters on information flow in supply chain using previous works in the literature as well as academic and industry experts' opinions, and then, we will determine the relative importance of the parameters by means of fuzzy TOPSIS method and the experts' knowledge.

In next section, the literature of information flow in supply chain will be reviewed and then, in section 3 we will have a look on the research methodology. Developed ranking model is proposed in section 4. Discussion about research findings is provided in section 5 and section 6 includes the conclusion and some insights for future research.

2. Literature review

Among the studies conducted on the subject of information flow in supply chain, Barut et al. (2002) considered the extent and intensity of information sharing as two main factors which affect the flow of information in supply chain. They proposed an assessment model to evaluate the degree of cooperation in supply chain. Shore and Venkatachalam (2003) developed a model in which they used Analytical Hiererchical Process (AHP) (Saaty, 2008) to define the priorities of two main parameters, collaboration and infrastructure capability, and four sub-criteria extracted from the literature. Li et al. (2005) proposed six criteria for supply chain activities evaluation including information sharing and information quality. The six criteria affect two other parameters, namely delivery dependability and time to market. They explained that information flow could include different types of information such as strategic information, logistics information and customer information. Lages et al. (2005) considered the amount of information flow, means frequency and duration of sharing information, containing three criteria: 1) frequency of discussion about strategic issues, 2) sharing confidential information, and 3) frequency of talking to the suppliers about business strategies. They developed a metric to evaluate information quality, as an aspect of information sharing, among import and export companies. They analyzed the data statistically to show that as the quality of information increases, its positive impact on information flow and long term policies, as a result of business partners' satisfaction, will increase as well. Li and Lin (2006) investigated the relationship between information sharing and information quality, as dependent parameters, and intra-organizational relationship, organizational facilitators and environmental uncertainties, as independent parameters. They employed multivariate regression to determine the coefficients and degree of influence of parameters to indicate the desired level of information flow. Fawcett et al. (2007) mentioned "connectivity" and "willingness" as two main parameters which affect the flow of information. Arshinder and Deshmukh (2007) referred to collaboration approach in supply chain including mechanisms such as contract, information sharing, information technology and joint plans. Regarding the importance of inventory level aspect, six indices were introduced for information sharing mechanism. Martínez-Olvera (2008) proposed a model to determine upward or downward trends in performance of information management and information sharing systems, using Shannon's entropy measurement. Considering the uncertainties of supply chain activities, Gong and Zhang (2010) employed soft systems theory to develop a model for information flow evaluation in supply chain. Xiao-rong and Sui-cheng (2010) developed a model to determine the relationships between manufacturer's internal factors, information sharing and information quality, and finally and they tested the model for a case study. They mentioned "information sharing expectations" and "information sharing behavior" as two important factors in information flow. They used statistical hypothesis testing to determine the relationships between the variables. Yang and Maxwell (2011) reviewed the literature of information flow in government institutions. They investigated the influencing parameters from three perspectives: inter-personal, inter-organizational an intra-organizational. They mentioned information extent, type and value, organizational structure, members' belief, rewards and incentives, trust, power game, information technology, social networks and social identity, as the main parameters of intra-organizational information sharing. From inter-organizational perspective, factors such as organizational boundaries, bureaucracy, culture, competitive interests, rewards, trust and information technology capabilities are named as influencing parameters. Yang (2012) developed a model using Analytical Network Process (ANP) to evaluate the information flow capability among supply chain partners. He classified the parameters in three main categories, namely organizational culture, leadership and information technology. Integrated information technologies, internal integration, information quality and sharing costs and benefits among members were mentioned by Baihaqi and Sohal (2013) as the main parameters which influence the flow of information. They illustrated that the first two factors were related directly and positively to information sharing, while the next two factors had no influence on it. De Almeida et al. (2015) mentioned factors such as communication, collaboration, and trust among members of the supply chain lack of which could result in weak flow of information. Information quality is mentioned by Kembro and Selviaridis (2015) as one of the most important issues of information flow which could be determined by accuracy, timeliness, credibility and proper formatting of information.

Although the parameters which affect the flow of information in supply chain are introduced in different papers, no comprehensive investigation on such factors has been provided in literature. So, in this paper a thorough investigation is performed on the influencing parameters on information flow in supply chain based on the literature as well as the industry and academic experts' knowledge. A complete list of parameters is provided and fuzzy TOPSIS method is employed to prioritize them.

3. Research methodology

In this research, first, we review the literature to extract the list of parameters which influence on the flow of information in supply chain and then, we employed the experts' knowledge to rank the parameters. Since the required data for parameters ranking is mostly based on the industry and academic experts' knowledge and also, due to having few number of people who have enough knowledge and expertise in the area of information management in supply chain, judgmental and purposive sampling is employed. Then, regarding the qualitative nature of such knowledge, the best sample sizes in qualitative researches was investigated. In different researches of various subjects, the sample numbers range from 6 to 12 and 18 and in more complex cases to 20 (Skulmoski et al., 2007; Guest et al., 2006; Patton, 2002; Marshall, 1996; Bernard, 2011; Morse, 1994; Kuzel, 1992; Bertaux; 1981). In this research, despite having a rich sample and working with the experts with highest degree of expertise in the field of study, the quantity of 30 was considered as the minimum sample size. Each questionnaire was made up of two parts: paired comparison table of parameters criteria and the parameters evaluation table subject to those criteria. Finally, 34 questionnaires were returned out of 50 questionnaires given to the experts. "Measurability", "being illustrative" and "relevancy" are three criteria towards which the parameters are prioritized. The parameters that receive the highest priorities have three characteristics; they are highly related to the subject of information sharing in supply chain, measurable in practice by means of quantitative or qualitative measures, and also, easily understood by the managers. Such parameters are manageable and supply chain managers could improve the information flow by planning to enhance them. So, the experts were asked to evaluate the parameters towards the aforementioned criteria using linguistic variables "very low", "low", "medium", "high" and "very high". Finally, fuzzy TOPSIS method is utilized to analyze the results and to rank the information flow influencing parameters. In this research, identifying and ranking the parameters which affect flow of information in supply chain is performed via two main phases: 1) influencing parameters extraction; 2) parameters ranking by fuzzy TOPSIS. These two phases will be discussed hereafter.

1) Influencing parameters extraction

In this phase, the parameters which have influence on information flow in supply chain are determined based on the literature review and they are validated by the experts.

Table 1
List of influencing parameters on information flow in supply chain

Code	Parameter	Definition	Reference
F1	Information Content & Relevancy	The information shared, is the information needed by the suppliers and the buyers.	Zhou and Benton (2007)
F2	Accuracy	Conformity between the recorded and the actual data values	McCormack (1998)
F3	Timeliness	Availability of information at the required time	Li et al. (2005)
F4	Recency	The shared information is up to date and compatible with the most recent changes in documents	Rashed et al. (2010)
F5	Frequency	Information sharing and keeping the information up to date, is done on a	Rashed et al. (2010)
F6	Adequacy	All information needed by supply chain members is shared	Li et al. (2005)
F7	Information Credibility	Shared information can be trusted	McCormack (1998)
F8	Assigned Resources	Amount of resources employed for gathering, analysis and using information (including people, analyzing software, etc.)	Martínez-Olvera (2008)
F9	Users' Tendency	Users' (employees') tendency for preparing and sharing information	Fawcett et al. (2007)
F10	Users' Trust	Users' (employees') trust to each other for communicating and sharing information	Yang (2012)
F11	Information Scope of Use	How deep into the supply chain network (in either direction of customers or suppliers) the information is shared and used?	Barut et al. (2002)
F12	IT based Ordering	The amount of orders placed using Information Technology	Arshinder and Deshmukh (2007)
F13	Two-way Trust &	Honesty and two-way trust between supply chain members	Li and Lin (2006)
F14	Sharing Confidential Information	Sharing confidential information between supply chain members	Lages et al. (2005)
F15	Information Refinement	Sharing selected, categorized and specific part of information (instead of sharing the whole available information)	Zailani et al. (2008)
F16	Supply Chain Partners' Commitment	All supply chain members are aware of information sharing policies and plans and they tend to implement these policies using the recommended procedures, solutions and systems	Li and Lin (2006)
F17	Shared Supply Chain Strategies (Internal)	Supply chain strategies are introduced and implemented in all supply chain members organizations	Fawcett et al. (2007); Lages et al. (2005)
F18	Shared Supply Chain Strategies (External)	Supply chain members frequently discuss together about supply chain strategies	Fawcett et al. (2007); Lages et al. (2005)
F19	Power of Internal &	Power of formal and informal groups in the organization	Lages et al. (2005)
F20	Interpersonal Trust	Interpersonal trust for sharing information	Zárraga and Bonache (2003)
F21	Learning Orientation	The emphasis on organizational learning and knowledge sharing among employees	Taylor and Wright (2004);Omar Sharifuddin Syed-Ikhsan and Rowland (2004); Zárraga and Bonache (2003)
F22	Organizational Rewards	The rewards and incentives for participating in information sharing activities	Kim and Lee (2006)
F23	Hardware Capabilities	- Speed of information exchange - Hardware age: best hardware is under one year and the oldest one is more than five years old.	Arshinder and Deshmukh (2007)
F24	Information Software Capabilities	Existence of shared information systems between supply chain partners and updating the recorded information upon changes	Fawcett et al. (2007)
F25	Network Infrastructure	Existence of computer network among supply chain members	Yang (2012)
F26	IT Acceptance	Acceptance to use information technology by supply chain members and their employees	Arshinder and Deshmukh (2007)
F27	Benefits	Benefits gained from information sharing	Rashed et al. (2010)
F28	Costs	The costs of information sharing	Rashed et al. (2010)
F29	Connectivity	How fast the information is updated and exchanged among supply chain members?	Fawcett et al. (2007)
F30	Intensity	-How extended is the time horizon for information sharing? -How much is the shared information employed in making plans in the supply chain?	Carr and Pearson (1999)
F31	Accessibility	The degree of availability and accessibility of information among supply chain partners	Zhou and Benton (2007)
F32	Consistency	When the representation of the data values is the same in all cases	Zailani et al. (2008)

As mentioned in section 2, although many researches have been conducted on the subject of information flow in supply chain, lack of a comprehensive view on the influencing parameters is evident and most papers considered a few number of parameters in their investigations. At the end of this phase, 32 parameters were identified. The definitions of parameters are presented in Table 1.

2) Parameters ranking by fuzzy TOPSIS

Importance of determining the priorities of parameters which affect flow of information in supply chain will be more evident when making strategic information plans or deciding about information sharing activities in supply chain. The managers wish to invest on projects and activities with the highest efficiency and effectiveness. So, providing them with a ranking for the influencing parameters on information flow would help the managers to make more rational and effective investments. The main steps to rank the parameters are as follows:

i. Defining criteria weights;
ii. Providing experts' evaluation matrices;
iii. Quantifying the qualitative matrices;
iv. Aggregating the matrixes;
v. Normalizing and making weighted matrix;
vi. Calculating positive and negative ideals;
vii. Calculating distances and ranking the parameters;

In section 4 the aforementioned steps will be explained in detail.

4. Fuzzy TOPSIS model for parameters ranking

As mentioned before, 32 parameters obtained from the literature are prioritized towards three criteria, namely "measurability", "being illustrative" and "relevancy". Due to the vagueness inherited in qualitative nature of the parameters, it will be too complex to quantify their values directly. Therefore, the experts were asked to make their assessment using linguistic expressions "very low", "low", "medium", "high" and "very high". Validity of the questionnaire in this phase was confirmed by academic experts and also it was considered reliable due to having the Cronbach's alpha of 0.87. Then, the linguistic terms are quantified in the form of triangular fuzzy numbers. Finally, a unique matrix will be obtained which will be used as the input for fuzzy TOPSIS method. Hereafter, the main steps for ranking the influencing parameters on information flow in supply chain will be discussed.

4.1. Defining criteria weights

As one of preliminary steps in fuzzy TOPSIS ranking, relative importance of each should be determined. Here, to make comparison between "measurability", "being illustrative" and "relevancy", paired comparison method is utilized and the experts were asked to compare the criteria pairwise. From total number of 50, 34 questionnaires were returned by the experts, among which 31 questionnaires demonstrated an inconsistency ratio of less than 0.1 and were used for the rest of process.

The questionnaire included a matrix (like Table 2) and the expert was asked to put a number from 1 to 9 in the intersection of criterion "*a*" in row and criterion "*b*" in column, in case he/she reckon that "a" is more important than "b". When relative importance of "*a"* is significantly more than "*b*" the number will be closer to 9, and vice versa. In contrast, when criterion "*a*" is less important than "*b*", a number between $\frac{1}{9}$ and 1 should be selected.

Table 2
Paired comparison matrix

	Measurability	Being Illustrative	Relevancy
Measurability	1		
Being Illustrative		1	
Relevancy			1

P_k is paired comparison matrix completed by the expert *k* (*k=1, 2,…, K*) and it is shown as Eq. (1).

$$P_k = \begin{array}{r} \\ \text{Measurability} \\ \text{Being Illustrative} \\ \text{Relevancy} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Measurability} & \text{Being Illustrative} & \text{Relevancy} \end{array} \\ \begin{bmatrix} 1 & x_{12}^k & x_{13}^k \\ x_{21}^k & 1 & x_{23}^k \\ x_{31}^k & x_{32}^k & 1 \end{bmatrix} \end{array} \tag{1}$$

where, $x_{ji}^k = \frac{1}{x_{ij}^k}; i, j = 1,2,3$.

In order to aggregate the experts' paired comparison matrixes, each matrix should be firstly normalized using Eq. (2):

$$a_{ij}^k = \frac{x_{ij}^k}{\sum_{i=1}^{3} x_{ij}^k} \tag{2}$$

P_k^n is the normalized paired comparison matrix related to the expert *k* and it is shown as Eq. (3):

$$P_k^n = \begin{array}{r} \\ \text{Measurability} \\ \text{Being Illustrative} \\ \text{Relevancy} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Measurability} & \text{Being Illustrative} & \text{Relevancy} \end{array} \\ \begin{bmatrix} a_{11}^k & a_{12}^k & a_{13}^k \\ a_{21}^k & a_{22}^k & a_{23}^k \\ a_{31}^k & a_{32}^k & a_{33}^k \end{bmatrix} \end{array} \tag{3}$$

To obtain aggregated paired comparison matrix, geometric mean of normalized matrixes of *K* experts is calculated as per Eq. (4) (Saaty, 2008):

$$r_{ij} = \sqrt[K]{\prod_{k=1}^{K} a_{ij}^k} \tag{4}$$

P is the aggregated paired comparison matrix of *K* experts (*K*=31) and it is shown as Eq. (5):

$$P = \begin{array}{r} \\ \text{Measurability} \\ \text{Being Illustrative} \\ \text{Relevancy} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Measurability} & \text{Being Illustrative} & \text{Relevancy} \end{array} \\ \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \end{array} \tag{5}$$

So, in this paper, *P* is obtained as follows:

$$P = \begin{array}{r} \\ \text{Measurability} \\ \text{Being Illustrative} \\ \text{Relevancy} \end{array} \begin{array}{ccc} \text{Measurability} & \text{Being Illustrative} & \text{Relevancy} \\ 0.29 & 0.34 & 0.27 \\ 0.18 & 0.21 & 0.24 \\ 0.39 & 0.31 & 0.36 \end{array} \quad (6)$$

Using Eq. (6), the weights for "measurability", "being illustrative" and "relevancy" were calculated as 0.34, 0.24 and 0.41, respectively. So, the criteria weights vector was obtained as $W = (0.34, 0.24, 0.41)$.

4.2. Providing experts' evaluation matrix

In this step, experts' assessment matrixes, in which each parameter was evaluated towards three criteria using linguistic variables, are received. Each assessment matrix is labeled as D^k and it is shown as follows:

$$D^k = [b_{ij}^k]_{32\times 3} \quad (7)$$

where b_{ij}^k $(i = 1,2,...,32;\ j = 1,2,3)$ is a linguistic expression "very low", "low", "medium", "high" or "very high". These linguistic variables should be quantified through next steps.

4.3. Quantifying the qualitative matrixes

Here, each linguistic expression is mapped to a triangular fuzzy number according to Fig. 1.

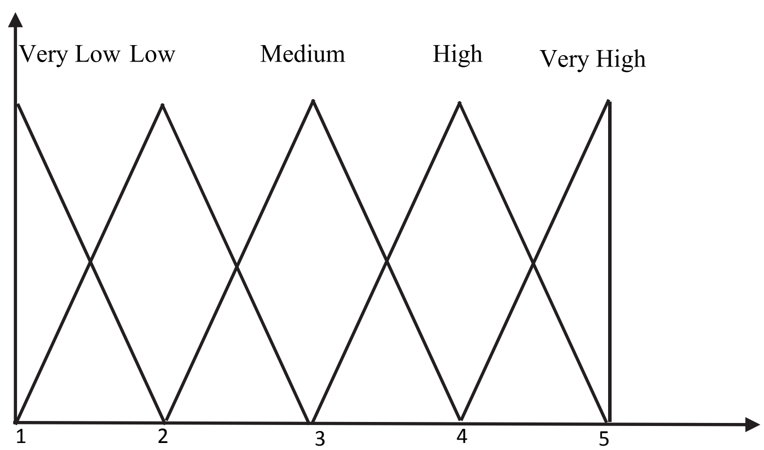

Fig. 1. Triangular fuzzy numbers

So, the assessment matrix D^k is transformed to a fuzzy assessment matrix ($\widetilde{D}^k$) as follows:

$$\widetilde{D}^k = [\widetilde{b}_{ij}^k]_{32\times 3} \quad (8)$$

where, each $\widetilde{b}_{ij}^k = (b_{ijL}^k, b_{ijM}^k, b_{ijR}^k), (i = 1,2,...,32;\ j = 1,2,3)$ is a triangular fuzzy number.

4.4. Aggregating the matrixes

Having the assessment matrixes quantified, 37 (number of questionnaires) fuzzy matrixes should be aggregated in a unique matrix. To this end, fuzzy average is utilized as per Eq. (9) (Zimmermann, 2011):

$$\tilde{b}_{ij} = (\frac{\sum_{k=1}^{K} b_{ijL}^{k}}{K}, \frac{\sum_{k=1}^{K} b_{ijM}^{k}}{K}, \frac{\sum_{k=1}^{K} b_{ijR}^{k}}{K}); j = 1,2,...,32; \; j = 1,2,3 \quad (9)$$

So, aggregated fuzzy matrix $\tilde{D}$ is obtained as follows:

$$\tilde{D} = [\tilde{b}_{ij}]_{32\times 3} \quad (10)$$

where $\tilde{b}_{ij} = (b_{ij}^{L}, b_{ij}^{M}, b_{ij}^{R})$ is the triangular fuzzy number related to evaluation of parameter i towards criterion j, which is obtained from aggregation of the experts' evaluations.

By taking three aforementioned steps, aggregated fuzzy assessment matrix is obtained as per Eq. (11).

$\tilde{D} =$ (11)

	Measurability	Being Illustrative	Relevancy
F1	(2.63, 3.63, 4.5)	(3.5, 4.5, 4.88)	(3.88, 4.88, 5)
F2	(2.75, 3.75, 4.63)	(3.75, 4.75, 5)	(4, 5, 5)
F3	(3.75, 4.75, 5)	(3.88, 4.88, 5)	(3.63, 4.5, 4.63)
F4	(3.63, 4.63, 5)	(3.88, 4.88, 5)	(3.63, 4.5, 4.63)
F5	(3.25, 4.25, 4.75)	(3.63, 4.63, 4.88)	(3, 3.75, 4.13)
F6	(2.5, 3.5, 4.25)	(3.38, 4.38, 4.75)	(3.5, 4.38, 4.63)
F7	(2.38, 3.38, 4.13)	(3.13, 4.13, 4.5)	(3.5, 4.5, 4.88)
F8	(3.13, 4.13, 4.63)	(3.25, 4.13, 4.5)	(2.63, 3.63, 4.5)
F9	(2, 3, 3.88)	(3.13, 4.13, 4.63)	(3, 4, 4.5)
F10	(2.13, 3.13, 4)	(3.13, 4.13, 4.63)	(3, 4, 4.5)
F11	(2.88, 3.88, 4.63)	(3.88, 4.88, 5)	(3.38, 4.38, 4.88)
F12	(3.38, 4.38, 5)	(3.88, 4.88, 5)	(2.88, 3.88, 4.63)
F13	(1.75, 2.75, 3.75)	(3.63, 4.63, 4.88)	(3.75, 4.75, 5)
F14	(2.25, 3.25, 4.13)	(3.63, 4.63, 5)	(3.75, 4.75, 5)
F15	(2.38, 3.38, 4.38)	(3.38, 4.38, 4.75)	(2.63, 3.63, 4.5)
F16	(2, 3, 4)	(3.5, 4.5, 4.88)	(3.63, 4.63, 5)
F17	(2.38, 3.25, 4.25)	(3.13, 4.13, 4.88)	(3.13, 4.13, 4.63)
F18	(2, 2.88, 3.88)	(3.13, 4.13, 4.75)	(3.38, 4.38, 4.75)
F19	(2, 2.88, 3.88)	(3.25, 4.25, 4.63)	(3.13, 4.13, 4.63)
F20	(1.63, 2.5, 3.5)	(3.63, 4.63, 5)	(3.25, 4.25, 4.75)
F21	(2.25, 3.25, 4.25)	(3.5, 4.5, 5)	(3, 4, 4.5)
F22	(3.63, 4.63, 5)	(3.88, 4.88, 5)	(3.5, 4.5, 4.75)
F23	(3.75, 4.75, 5)	(3.88, 4.88, 5)	(4, 5, 5)
F24	(3.63, 4.63, 4.75)	(3.88, 4.88, 5)	(3.88, 4.88, 5)
F25	(3.75, 4.75, 5)	(3.88, 4.88, 5)	(3.88, 4.88, 5)
F26	(2.25, 3.13, 4)	(3.5, 4.5, 4.88)	(3.88, 4.88, 5)
F27	(2.38, 3.38, 4.25)	(3.38, 4.38, 4.88)	(3.88, 4.88, 5)
F28	(3, 4, 4.63)	(3.63, 4.63, 5)	(3.88, 4.88, 5)
F29	(2.88, 3.88, 4.5)	(3.13, 4.13, 4.75)	(3.38, 4.38, 4.88)
F30	(2.38, 3.38, 4.13)	(2.88, 3.88, 4.5)	(3.75, 4.75, 5)
F31	(2.75, 3.75, 4.75)	(3.75, 4.75, 5)	(3.75, 4.75, 5)
F32	(3.13, 4.13, 4.63)	(3.63, 4.63, 4.88)	(3.88, 4.88, 5)

4.5. Normalizing and making weighted matrix

Having the assessment matrixes aggregated, $\tilde{D}$ should be normalized now. To this end, Eq. (12) is employed (Chen, 2000):

$$\tilde{c}_{ij} = (\frac{b_{ij}^{L}}{R_j}, \frac{b_{ij}^{M}}{R_j}, \frac{b_{ij}^{R}}{R_j}) \quad (12)$$

where $R_j = \max_i b_{ij}^{R}$.

So, the normalized assessment matrix $N\tilde{D}$ is shown as follows:

$$N\tilde{D} = [\tilde{c}_{ij}]_{32\times 3} \quad (13)$$

Next step is to calculate weighted assessment matrix $\tilde{V} = [\tilde{v}_{ij}]_{32\times 3}$, by multiplying $N\tilde{D}$ by weights vector W, which was obtained in section 4.1 (Chen, 2000):

$$\tilde{v}_{ij} = \tilde{c}_{ij}(.)w_j; \; i = 1,2,...,32; \; j = 1,2,3 \quad (14)$$

So, weighted assessment matrix is obtained as per Eq. (15).

4.6. Calculating positive and negative ideals

Taking into account that all three criteria in this paper (measurability, being illustrative and relevancy) have positive impacts, the maximum and the minimum scores for each criterion in matrix (15) are considered as positive and negative ideal solutions, respectively. It is noteworthy that this is done using fuzzy maximum and minimum operators (Zimmermann, 2011).

$\widetilde{V}=$ (15)

	Measurability	Being Illustrative	Relevancy
F1	(0.18, 0.25, 0.31)	(0.17, 0.22, 0.24)	(0.32, 0.4, 0.41)
F2	(0.19, 0.26, 0.32)	(0.18, 0.23, 0.24)	(0.33, 0.41, 0.41)
F3	(0.26, 0.33, 0.34)	(0.19, 0.24, 0.24)	(0.3, 0.37, 0.38)
F4	(0.25, 0.32, 0.34)	(0.19, 0.24, 0.24)	(0.3, 0.37, 0.38)
F5	(0.22, 0.29, 0.33)	(0.18, 0.23, 0.24)	(0.25, 0.31, 0.34)
F6	(0.17, 0.24, 0.29)	(0.16, 0.21, 0.23)	(0.29, 0.36, 0.38)
F7	(0.16, 0.23, 0.28)	(0.15, 0.2, 0.22)	(0.29, 0.37, 0.4)
F8	(0.22, 0.28, 0.32)	(0.16, 0.2, 0.22)	(0.22, 0.3, 0.37)
F9	(0.14, 0.21, 0.27)	(0.15, 0.2, 0.23)	(0.25, 0.33, 0.37)
F10	(0.15, 0.22, 0.28)	(0.15, 0.2, 0.23)	(0.25, 0.33, 0.37)
F11	(0.2, 0.27, 0.32)	(0.19, 0.24, 0.24)	(0.28, 0.36, 0.4)
F12	(0.23, 0.3, 0.34)	(0.19, 0.24, 0.24)	(0.24, 0.32, 0.38)
F13	(0.12, 0.19, 0.26)	(0.18, 0.23, 0.24)	(0.31, 0.39, 0.41)
F14	(0.16, 0.22, 0.28)	(0.18, 0.23, 0.24)	(0.31, 0.39, 0.41)
F15	(0.16, 0.23, 0.3)	(0.16, 0.21, 0.23)	(0.22, 0.3, 0.37)
F16	(0.14, 0.21, 0.28)	(0.17, 0.22, 0.24)	(0.3, 0.38, 0.41)
F17	(0.16, 0.22, 0.29)	(0.15, 0.2, 0.24)	(0.26, 0.34, 0.38)
F18	(0.14, 0.2, 0.27)	(0.15, 0.2, 0.23)	(0.28, 0.36, 0.39)
F19	(0.14, 0.2, 0.27)	(0.16, 0.21, 0.23)	(0.26, 0.34, 0.38)
F20	(0.11, 0.17, 0.24)	(0.18, 0.23, 0.24)	(0.27, 0.35, 0.39)
F21	(0.16, 0.22, 0.29)	(0.17, 0.22, 0.24)	(0.25, 0.33, 0.37)
F22	(0.25, 0.32, 0.34)	(0.19, 0.24, 0.24)	(0.29, 0.37, 0.39)
F23	(0.26, 0.33, 0.34)	(0.19, 0.24, 0.24)	(0.33, 0.41, 0.41)
F24	(0.25, 0.32, 0.33)	(0.19, 0.24, 0.24)	(0.32, 0.4, 0.41)
F25	(0.26, 0.33, 0.34)	(0.19, 0.24, 0.24)	(0.32, 0.4, 0.41)
F26	(0.16, 0.22, 0.28)	(0.17, 0.22, 0.24)	(0.32, 0.4, 0.41)
F27	(0.16, 0.23, 0.29)	(0.16, 0.21, 0.24)	(0.32, 0.4, 0.41)
F28	(0.21, 0.28, 0.32)	(0.18, 0.23, 0.24)	(0.32, 0.4, 0.41)
F29	(0.2, 0.27, 0.31)	(0.15, 0.2, 0.23)	(0.28, 0.36, 0.4)
F30	(0.16, 0.23, 0.28)	(0.14, 0.19, 0.22)	(0.31, 0.39, 0.41)
F31	(0.19, 0.26, 0.33)	(0.18, 0.23, 0.24)	(0.31, 0.39, 0.41)
F32	(0.22, 0.28, 0.32)	(0.18, 0.23, 0.24)	(0.32, 0.4, 0.41)

Positive and negative ideal solutions are calculated as per Eq. (16) and Eq. (17).

$$\widetilde{F}^{*}=\{\widetilde{F}_1^{*},\widetilde{F}_2^{*},\widetilde{F}_3^{*}\}$$
$$\widetilde{F}_j^{*}=\max_i\ \widetilde{v}_{ij}=(\max_i\ v_{ij}^{L},\ \max_i\ v_{ij}^{M},\ \max_i\ v_{ij}^{R}) \tag{16}$$

$$\widetilde{F}^{-}=\{\widetilde{F}_1^{-},\widetilde{F}_2^{-},\widetilde{F}_3^{-}\}$$
$$\widetilde{F}_j^{-}=\min_i\ \widetilde{v}_{ij}=(\min_i\ v_{ij}^{L},\ \min_i\ v_{ij}^{M},\ \min_i\ v_{ij}^{R}) \tag{17}$$

Therefore, positive and negative ideal solutions for matrix (15) are as follows:

$$\widetilde{F}^{*}=\{(0.26,0.33,0.34),(0.19,0.24,0.24),\ (0.33,0.41,0.41)\} \tag{18}$$

$$\widetilde{F}^{-}=\{(0.11,0.17,0.24),\ (0.14,0.19,0.22),\ (0.22,0.30,0.34)\} \tag{19}$$

4.7. Calculating distances and ranking the parameters

The last step for prioritizing the influencing parameters on information flow in supply chain is to calculate the distance of each parameter from positive and negative ideal solutions. Here, we utilized the concept of distance between two fuzzy numbers (Chen, 2000). So, the distances between each parameter score in each criterion ($\widetilde{v}_{ij}$) and positive and negative ideal solutions ($\widetilde{F}_j^{*}$ and $\widetilde{F}_j^{-}$) are calculated as follows:

$$d^{*}(\widetilde{v}_{ij},\widetilde{F}_j^{*})=\sqrt{\frac{1}{3}[(v_{ij}^{L}-F_j^{*L})^2+(v_{ij}^{M}-F_j^{*M})^2+(v_{ij}^{R}-F_j^{*R})^2]} \tag{20}$$

$$d^-(\tilde{v}_{ij}, \tilde{F}_j^-) = \sqrt{\frac{1}{3}[(v_{ij}^L - F_j^{-L})^2 + (v_{ij}^M - F_j^{-M})^2 + (v_{ij}^R - F_j^{-R})^2]} \quad (21)$$

Now, having the distances from positive and negative ideal solutions obtained for each parameter in each criterion, total distances of parameter *i* from positive and negative ideals should be calculated as per Eq. (22) and Eq. (23) (Chen, 2000):

$$d_i^* = \sum_{j=1}^{3} d^*(\tilde{v}_{ij}, \tilde{F}_j^*) \quad (22)$$

$$d_i^- = \sum_{j=1}^{3} d^-(\tilde{v}_{ij}, \tilde{F}_j^-) \quad (23)$$

Employing the Eqs. (20-23) for matrix (15), parameters distances from positive and negative ideal solutions are obtained as it is shown in Table 3.

Table 3
Distances from positive and negative ideal solutions

Parameter	d_i^*	d_i^-	Parameter	d_i^*	d_i^-
Information Content & Relevancy	0.09	0.19	Shared Supply Chain Strategies (Internal)	0.18	0.11
Accuracy	0.06	0.22	Shared Supply Chain Strategies (External)	0.19	0.10
Timeliness	0.03	0.25	Power of Internal &Inter-personal Communications	0.20	0.08
Recency	0.04	0.24	Interpersonal Trust	0.20	0.08
Frequency	0.13	0.16	Learning Orientation	0.18	0.11
Adequacy	0.14	0.14	Organizational Rewards	0.04	0.24
Information Credibility	0.15	0.13	Hardware Capabilities	0.00	0.28
Assigned Resources	0.16	0.13	Information Software Capabilities	0.02	0.26
Users' Tendency	0.21	0.07	Network Infrastructure	0.01	0.27
Users' Trust	0.20	0.08	IT Acceptance	0.12	0.16
Information Scope of Use	0.09	0.19	Benefits	0.11	0.17
IT based Ordering Activities	0.10	0.19	Costs	0.06	0.22
Two-way Trust & Honesty	0.15	0.13	Connectivity	0.13	0.16
Sharing Confidential Information	0.12	0.17	Intensity	0.14	0.14
Information Refinement	0.20	0.10	Accessibility	0.08	0.21
Supply Chain Partners' Commitment	0.15	0.14	Consistency	0.06	0.22

Final ranking of parameters will be done based on total distance index which is calculated as per Eq. (24):

$$FI_i = \frac{d_i^-}{d_i^- + d_i^*} \quad (24)$$

From Table 3 and Eq. (24), we have total distance indices of parameters as it is shown in Table 4.

Table 4
Total distance indices

Parameter	FI_i	Parameter	FI_i
Information Content & Relevancy	0.68	Shared Supply Chain Strategies (Internal)	0.38
Accuracy	0.78	Shared Supply Chain Strategies (External)	0.34
Timeliness	0.88	Power of Internal &Inter-personal Communications	0.29
Recency	0.85	Interpersonal Trust	0.30
Frequency	0.55	Learning Orientation	0.38
Adequacy	0.50	Organizational Rewards	0.85
Information Credibility	0.46	Hardware Capabilities	1.00
Assigned Resources	0.44	Information Software Capabilities	0.93
Users' Tendency	0.25	Network Infrastructure	0.97
Users' Trust	0.28	IT Acceptance	0.57
Information Scope of Use	0.67	Benefits	0.61
IT based Ordering Activities	0.66	Costs	0.78
Two-way Trust & Honesty	0.47	Connectivity	0.56
Sharing Confidential Information	0.58	Intensity	0.49
Information Refinement	0.33	Accessibility	0.72
Supply Chain Partners' Commitment	0.48	Consistency	0.80

5. Research Findings and Discussion

After prioritizing 32 parameters which affect the flow of information in supply chain, based on the experts' knowledge and using fuzzy TOPSIS method, parameters ranking scores were obtained as per Table 4. Fig. 2 illustrates the parameters sorted based on their ranking.

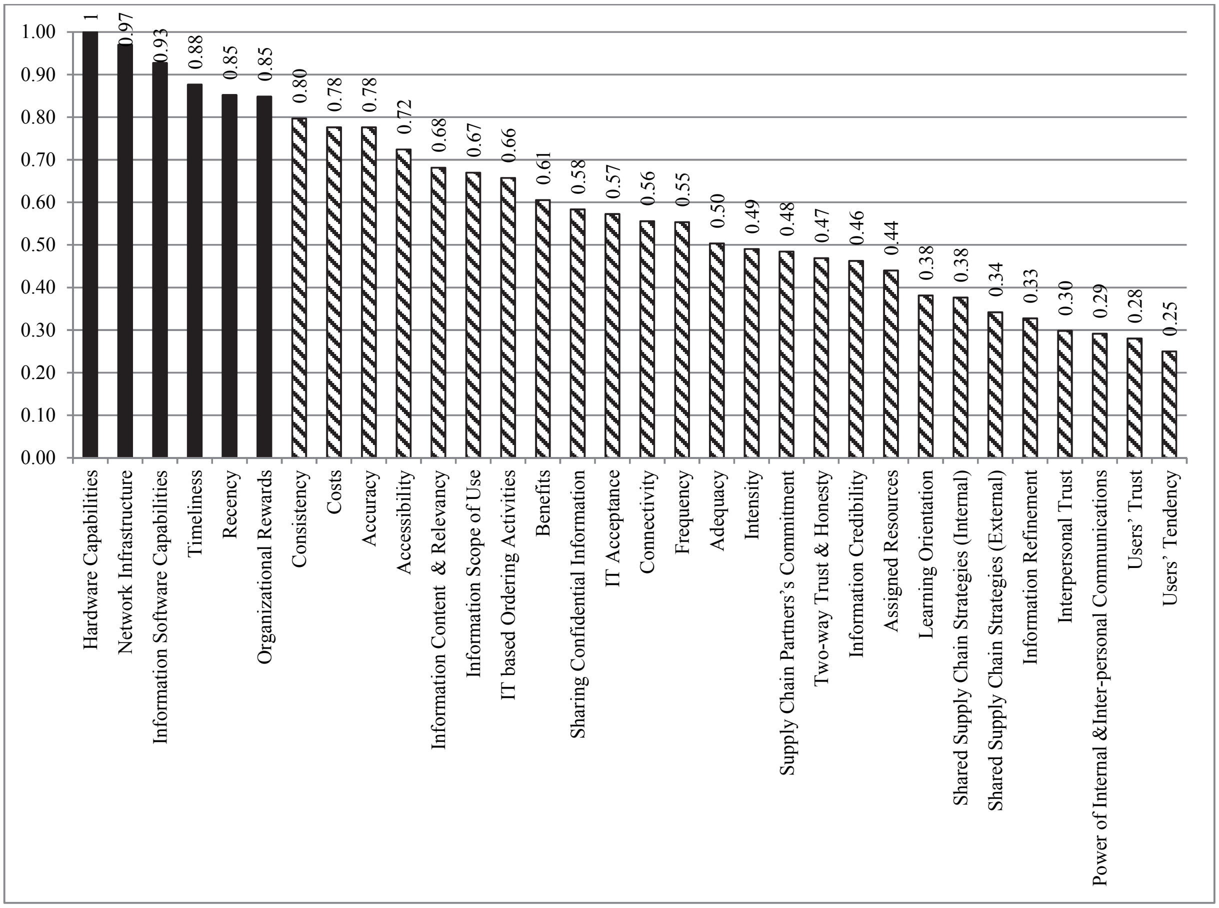

Fig. 2. Parameters ranking

Investigating the parameters ranking, it is significant that six parameters, namely, "Supply Chain Hardware Capabilities", "Supply Chain Network Infrastructure", "Information Software Capabilities", "Information Sharing Timeliness", "Information Recency" and "Organizational Rewards", constitute top 20% of the ranking. This result magnifies the prominence of information technology in managing, controlling and improving the flow of information in supply chain. Having the business world so competitive today, in order to reach competitive advantage and sufficient agility in ever-changing market, supply chains are inevitably forced to benefit from IT infrastructures and computer networks such as internet, intranets, suppliers' portals and also, integrated software and organizational and inter-organizational information systems. In addition to information technology issues, from the experts' point of view, it is very important to have the information shared in proper time and with the recent changes and updates. Moreover, this research demonstrates the importance of personnel motivation by offering rewards for positive contributions to the information sharing activities. Therefore, in case of resources constraints, the managers who aim to enhance information flow in supply chain are recommended to make improvements to the six aforementioned parameters, since, this research shows that improving deficiencies in these parameters will encompass significant influences on information flow in supply chain.

6. Conclusion

Regarding the importance of information flow management and control in supply chain and critical role of proper and effective flow of information to competitiveness of supply chains, in this paper, the influencing parameters on information flow of supply chains are identified and ranked. Without knowing such parameters and their importance it would be hard to make any plan or put any target for future improvements in the area of information flow management in supply chain. So, in this research, first, a list of influencing parameters was extracted by reviewing the literature of information flow in supply chain. Then, industry and academic experts were asked to evaluate the parameters towards three criteria, "measurability", "being illustrative" and "relevancy", using linguistic expressions, "very low", "low", "medium", "high" or "very high". Moreover, they were requested to determine the relative importance of three aforementioned criteria in the form of paired comparison matrix. Finally, the parameters were ranked employing fuzzy TOPSIS method. The results show that six parameters, "Supply Chain Hardware Capabilities", "Supply Chain Network Infrastructure", "Information Software Capabilities", "Information Sharing Timeliness", "Information Recency" and "Organizational Rewards", placed on the top 20% of the ranking, which illustrates the prominence of information technology as well as employees motivation in information flow management. As an extension of this research readers are encouraged to investigate the way the parameters correlate and how they affect the flow of information in supply chain.

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