DETERMINING THE APPROPRIATE OPEN INNOVATION MODEL FOR LOGISTICS FIRMS USING AN INTEGRATED FUZZY AHP-VIKOR APPROACH[1]

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Abstract

Open innovation includes making collaborative relationships with other firms and institutions to achieve competitive advantage through innovative products or services. Open innovation has an effect on the logistics firms because they have many services and products and also various relationships with their shareholders. The main purpose of this study is to determine the appropriate open innovation model for logistics firms. In this context, the application process is performed by a Fuzzy Multi Criteria Decision Making model. This approach involves both criteria (control, focus, innovation process, knowledge, cost, capacity, market, utilization, policy, motivation) and alternatives (inbound, outbound and coupled open innovation models). Weights of the criteria were determined by Fuzzy AHP. Furthermore, ranks of the alternatives were performed by Fuzzy VIKOR. According to results, *outbound innovation* is determined as the appropriate open innovation model for logistics firms. The most important three criteria in order to determine the appropriate open innovation model are *innovation process*, *motivation*, and *market* respectively.

Keywords: *Logistics, Open Innovation, Fuzzy AHP-VIKOR.*
JEL Codes: *L91, O30, C44*

BÜTÜNLEŞİK BULANIK AHP-VIKOR YAKLAŞIMI İLE LOJİSTİK FİRMALARI İÇİN EN UYGUN AÇIK YENİLİK MODELİNİN BELİRLENMESİ

Öz

Açık yenilik, yenilikçi ürün ve hizmetler yoluyla rekabet avantajı elde edebilmek için diğer firma ve kuruluşlarla iş birliğine dayalı ilişkiler kurmayı içermektedir. Çok sayıda ürün ve hizmete sahip ve paydaşları ile yoğun ilişkileri olan kuruluşlar olması nedeniyle lojistik firmaları, açık yenilikten etkilenmektedir. Çalışmanın amacı, lojistik firmaları için en uygun açık yenilik modelinin belirlenmesidir. Bu doğrultuda uygulama aşaması, bir Bulanık Çok Kriterli Karar Verme Modeli aracılığıyla gerçekleştirilmiştir. Bu yaklaşım, kriterler (kontrol, odak, yenilik süreci, bilgi, maliyet, kapasite, pazar, kullanım, politika, motivasyon) ve alternatifleri (gelen, giden ve çift yönlü açık yenilik modelleri) içermektedir. Kriter ağırlıkları, Bulanık AHP yöntemiyle belirlenmiştir. Alternatiflerin sıralanması ise Bulanık VIKOR yöntemi aracılığıyla gerçekleştirilmiştir. Sonuçlara göre; *giden yenilik,* lojistik firmaları açısından en uygun açık yenilik modeli olarak tespit edilmiştir. En uygun açık yenilik türünün seçiminde en önemli üç kriter ise sırasıyla; *yenilik süreci*, *motivasyon* ve *pazar* olarak belirlenmiştir.

Anahtar Kelimeler: *Lojistik, Açık Yenilik, Bulanık AHP-VIKOR.*
JEL Sınıflandırması: *L91, O30, C44*

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1. Introduction

In the global markets, organizations look for innovative solutions to improve their competitiveness (Chapman et al., 2003:630). Therefore, innovation has the vital role in firms' strategy for all sectors. Innovation brings with many new approaches. Openness as one of these approaches has increasingly become a stream in innovation management discipline (Lopes and Carvalho, 2018:285).

Today, innovation activities have become more sophisticated, interrelated and open in their nature. Therefore, firms want to increasingly enter into collaborative relationships with their environments to achieve innovative solutions. This trend shapes a recent phenomenon called as Open Innovation (OI). OI is defined as "valuable ideas can come from inside or outside the company and can go to market from inside or outside the company as well" by Chesbrough (2003:43). It includes making collaborative relationships with other firms and institutions to achieve competitive advantage through innovative products or services.

OI is a complex phenomenon because it has multiple aspects (Randhawa et al., 2016:751). Thus, identifying the important factors affecting OI is yet a research challenge (Lopes and Carvalho, 2018:286). So, many researchers have focused on this challenge. For example, Elmquist et al. (2009) identified the areas of interest where OI is focused. Similarly, Bigliardi et al. (2012) aimed to answer the research question on adopting the true OI approach by a multiple case study. Casprini et al. (2017) purposed to clarify on how family firms execute OI strategies by directing knowledge flows with an exploratory case study on an Italian family firm. Hsieh et al. (2016) identified which conditions cause firms to select between outbound and inbound OI.

Multiple environmental trends (sophisticated services, customer expectations, competitive pressure) have recently increased logistics firms' need to be more innovative (Busse and Wallenburg, 2011). Thus, innovation activities have an important role in these firms. Acknowledging the major changes in the economy and business environment, many authors (Hellström and Nilsson, 2011; Su et al., 2011; Wirtz, 2011; De Martino et al., 2013; Anderson and Forslund, 2018) have identified logistics area which provides innovative solutions.

Adaptation of OI model in organizations is very popular topic of innovation management. In this context, it is important to determine the appropriate OI model for firms. This concept involves both qualitative and quantitative factors that should be taken into consideration during the decision making process. The application process is created by a Fuzzy Multi Criteria Decision Making (FMCDM) approach. In this model, the weights of the criteria were determined by Fuzzy AHP and ranking of the alternatives were performed by Fuzzy VIKOR.

The remainder of this paper is organized as follows. Related literature is reviewed in the next section. Thereafter, methods used in this study is described. Proposed approach including the alternatives and criteria is presented in the fourth section. Results of the analysis are presented, before the paper concludes with discussion and suggestions on future researches.

2. Literature Review

This study aims to determine the appropriate OI model for logistics firms. When the related literature is examined, it can be stated that OI is the subject of different sectors such as smart phone (Piller et al., 2004; Shi and Zhang, 2018), automobile (Ili et al., 2010), chemical (Sieg at al., 2010; Bianchi et al., 2011; Michelino et al., 2014; Mazzola et al., 2015), software (Harison and Koski, 2010), petrol and gas (Radnejad and Vredenburg, 2015).

When it is examined the studies focusing on the OI types (inbound, outbound, and coupled), a lot of studies are outstanding. Kutvonen (2011) aimed to examine the strategic dimension of outbound OI by a literature review. Borges (2011) investigated the complexity of sharing and protecting the knowledge in a coupled OI process. Xu and Zheng (2013) examined the impact of the inbound and outbound OI on innovative performance in firms of industrial clusters. Gorbatyuk et al. (2016) reviewed the current intellectual property framework for coupled OI processes. Wu et al. (2016) purposed to understand how pharmaceutical firms can more effectively determine the suitable innovations by a case study analysis on a decision about drug in-licensing. Scuotto et al. (2017) aimed to investigate the key factors that are likely to identify the preference for informal inbound OI modes. Burcharth et al. (2017) purposed to examine how organisational activities explain the performance of inbound and outbound OI. Meynard et al. (2017) provided a heuristic approach to design of coupled innovations in an agrifood system. Zheng (2018) adopted a quantitative method to examine the outbound OI from the perspective of Multinationals' R&D activities in China. Davari et al. (2019) investigated the effect of inbound and outbound OI to discover the entrepreneurial opportunities.

Many researchers (Germain, 1996; Richey et al., 2005; Shen et al., 2009; Grawe, 2009; Busse, 2010; Daugherty et al., 2011; Busse and Wallenburg, 2011; Rossi et al., 2013; Pedrosa et al., 2015; Shou et al., 2017; Björklund and Forslund, 2018) also focused on the relationship between innovation and logistics. However, Hossain and Anees-ur-Rehman (2016) stated that studies on OI are limited to several industries according to results of their extensive literature review. In this point, this study concentrates on the logistics sector as a new aspect in OI literature. Many researchers (Chapman et al., 2003; Flint et al., 2008; Wagner, 2008; Wagner and Franklin, 2008; Wagner and Sutter, 2012) indicated that innovation activities have a very important role in logistics capability. Grawe (2009) stated that innovation in the logistics context have also many partners from professionals to costumers.

Although the study of the effects of OI activities on innovation and firm performance has become increasingly popular in the related literature (Hochleitner et al., 2017), the appropriate innovation model for the firms has not confronted in the related literature yet. Furthermore, OI research on logistics firms is very limited. For these reasons, the aim of this study is to determine the appropriate OI model for logistics firms.

3. Methods

This study proposes a Multi Criteria Decision Making (MCDM) approach includes Fuzzy AHP and Fuzzy VIKOR.

3.1. Fuzzy Analytical Hierarchy Process

Fuzzy Analytical Hierarchical Process (AHP) method uses a range of values and decision makers can select a value based on their preferences. Since the comparison procedure has a fuzzy nature, it seems more reliable to decision makers for making interval judgments (Kahraman et al., 2003:386).

After the Van Laarhoven and Pedrycz (1983)'s study on Fuzzy AHP, trapezoidal fuzzy numbers was used by Buckley (1985). Then, the extent analysis method is introduced by Chang (1996), which is a new approach that uses triangular fuzzy numbers in the comparison process. The steps of this extent analysis (Chang, 1996:651-653) is presented as follows:

Let A ($a_1, a_2, \ldots, a_n$) be an object set and B ($b_1, b_2, \ldots, b_m$) be a goal set. M values for each object can be obtained as $M_{bi}^{1}, M_{bi}^{2}, \ldots\ldots\ldots, M_{bi}^{m}, i = 1, 2, \ldots\ldots, n$.

1. Fuzzy extension value for the i_{th} is obtained by Equations (1) and (2).

$$S_i = \sum_{j=1}^{m} M_{bi}^{j} * \left[\sum_{i=1}^{n} \sum_{i=1}^{m} M_{bi}^{j} \right]^{-1} \quad (1)$$

$$\sum_{j=1}^{m} M_{bi}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j \right) \quad (2)$$

2. M_1 and M_2 are triangular fuzzy numbers and the possibility of $M_2 \geq M_1$ is defined as Equation (3):

$$V(M_2 \geq M_1) = \sup_{y \geq x} \left[\min(\mu_{M_1}(x), \mu_{M_2}(y)\right] = hgt(M_2 \cap M_1) \mu\ M_2(d) \quad (3)$$

Where d is the ordinate of the highest intersection point D between μ_{M1} and μ_{M2}. It can be represented in the following manner by Equation (4).

$$= \begin{cases} 1, & \text{if} \quad m_2 \geq m_1 \\ 0, & \text{if} \quad l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise} \end{cases} \quad (4)$$

To compare M_1 and M_2, values of both, $V(M_2 \geq M_1)$ and $V(M_1 \geq M_2)$ are needed.

3. The probability for a convex fuzzy number to be greater than k convex numbers M_i (i=1, 2, ..., k) can be defined by Equation (5).

$$V(M \geq M_1, M_2, \ldots, M_K) V[(M \geq M_1), (M \geq M_2), \ldots, (M \geq M_K)] \min V(M \geq M_i), (i=1,2,3, \ldots, k) \quad (5)$$

Assume that Equation (6) is;

$$(X_i) = \min V(S_i \geq S_k), \text{ for } k=1,2,\ldots,n; k \neq i \quad (6)$$

So, the weight vector is obtained by Equation (7):

$$W = (d^1(X_1), d^1(X_2), \ldots, d^1(X_n))^T \text{ where } X_i (i=1,2,\ldots,n) \text{ consist of n elements.} \quad (7)$$

4. Through normalization, the normalized weight vectors are reduced by Equation (8).

$$W = (d(X_1), d(X_2), \ldots, d(X_n))^T \text{ where W represents nonfuzzy number.} \quad (8)$$

3.2. Fuzzy VIKOR

Fuzzy VIKOR method is based on positive and negative ideal solving approach in the MCDM process, developed by Opricovic (1998) (Chu et al., 2006:1014). The steps of Fuzzy VIKOR, based on the Opricovic and Tzeng (2004:447-449; 2007:515-518) and Opricovic (2011:12984-12985) are presented as follows:

1. Determine the criteria, alternatives and decision makers.

2. Define the linguistic variables and corresponds the triangular fuzzy numbers. I^b represents criteria of benefits, and I^c for costs by Equation (9).

$$\tilde{f}_{ij} = (l_{ij}, m_{ij}, r_{ij}), \ i=1,\ldots,n. \quad j=1,\ldots,j \quad (9)$$

3. For each criterion, the fuzzy best value f_{ij}^*=(l_{ij}, m_{ij}, u_{ij}) and the fuzzy worst value f_{ij}^-=(l_{ij}, m_{ij}, u_{ij}) are determined by Equations (10) and (11).

$$\tilde{f}_{ij}^* = \max_i \tilde{f}_{ij} \quad , \tilde{f}_{ij}^- = \min_i \tilde{f}_{ij} \quad \text{where } i \in I^b \ (10)$$

$$\tilde{f}_{ij}^- = \min_i \tilde{f}_{ij} \quad , \tilde{f}_{ij}^- = \max_i \tilde{f}_{ij} \quad \text{where } i \in I^c \quad (11)$$

4. Calculate the value of fuzzy difference $\tilde{d}_{ij}^-, j = 1, \ldots \ldots \ldots \ldots, j. \quad i = 1, \ldots \ldots \ldots \ldots, n.$ by Equations (12) and (13).

$$\tilde{d}_{ij}=\frac{\tilde{f}_i^{*}-\tilde{f}_{ij}}{u_i^{*}-l_i^{o}} \quad \text{where } i\in I^{b} \tag{12}$$

$$\tilde{d}_{ij}=\frac{\tilde{f}_{ij}-\tilde{f}_i^{*}}{u_i^{o}-l_i^{*}} \quad \text{where } i\in I^{c} \tag{13}$$

5. Calculate the value of $\tilde{S}_j = (S_j^l, S_j^m, S_j^u), R_j = (R_j^l, R, R_j^u)\ and\ \tilde{Q}_j = (Q_j^l, Q_j^m, Q_j^u)$ by Equations (14), (15), and (16). V value may reflects many approaches. For example, *v* represents the maximum group utility while *1-v* shows the wieght of the individual regret. These approaches could be balanced at the point of v=0.5.

$$\tilde{S}_j=\sum_{i=1}^{n}\left(\tilde{w}_i*\tilde{d}_{ij}\right) \tag{14}$$

$$\tilde{R}_j=\max_i\left(\tilde{w}_i*\tilde{d}_{ij}\right) \tag{15}$$

$$Q_j=\frac{v\left(\tilde{S}_j-\tilde{S}^{*}\right)}{S^{ou}-S^{*l}}+(1-v)\left(\tilde{R}_j-\tilde{R}^{*}\right)/(R^{ou}-R^{*l}) \tag{16}$$

6. Alternatives are ranked by sorting $\tilde{Q}_j$ values in increasing order. Alternative ranked first is compromised solution if the following conditions are satisfied.

Condition 1- Acceptable advantage (Adv ≥ DQ): It includes proving that there is a clear difference between the best and the closest option. The A' value represents the first alternative and A'' shows the second-best alternative in the ranking list.

Adv=[Q(A'') - Q(A')]/[Q(A^t) - Q(A')](t) is number of alternatives) (17)

DQ= 1(t-1) (18)

Condition2- Acceptable stability in decision making: Alternative A’ must also be the best ranked by S or/and R.

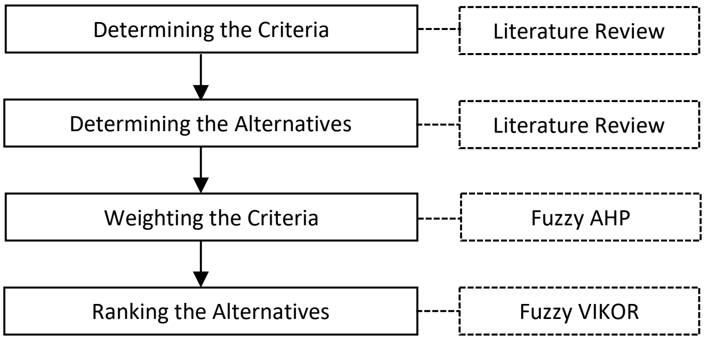
The conditions must be satisfied, otherwise compromised solutions is proposed:

- Alternatives A’ and A’’ if only the second condition is not satisfied or,
- Alternatives A’, A’’,…. A^t if the condition 1 is not satisfied; Q (A^t) - Q (A') < DQ for max T (the position of these alternatives are “in closeness”).

4. Proposed Approach

The aim of this study is to determine the appropriate OI model for logistics firms. For this purpose, an integrated MCDM approach based Fuzzy AHP and VIKOR is proposed. Application steps of the proposed approach are shown in Figure 1.

Figure 1: **Application Steps of the Proposed Approach**



4.1. Determininig The Criteria

In a MCDM problem, choosing the criteria is very important in evaluating the alternatives. So, authors reviewed the related literature. Dahlander and Gann (2010) determined the four openness types as revealing, selling, sourcing and acquiring. Rangus et al. (2016) conceptualized the tendency for OI of a firm, which relates to the firm's predisposition to perform inbound and outbound OI activities. According to it, specific dimensions of OI are inward intellectual propoerty licensing and external participation, outsourcing R&D and external networking, customer involvement, employee involvement, venturing and outward intellectual property licensing. Hsieh et al. (2016) defined the key factors that influence start-ups' OI activities as dedicated asset specificity, human asset specificity, environmental uncertainty, behavioral uncertainty, transaction frequency and number of parties. Lopes and de Carvalho (2018) identified the OI antecedents in two groups as openness (business model, human aspects, innovativeness, number of partners, strategy) and main players (competitors, consultants, customers, government, network partners, suppliers, universities and research institutes).

Van de Vrande et al. (2009) determined the motivation factors to adopt OI practices as control, focus, innovation process, knowledge, cost, capacity, market, utilization, policy, motivation and other. They also specified the hampering factors when adopting OI practices as administration, finance, knowledge, marketing, organization/culture, resources, IPR, quality of partners, adaption, demand, competences, commitment, idea management and other.

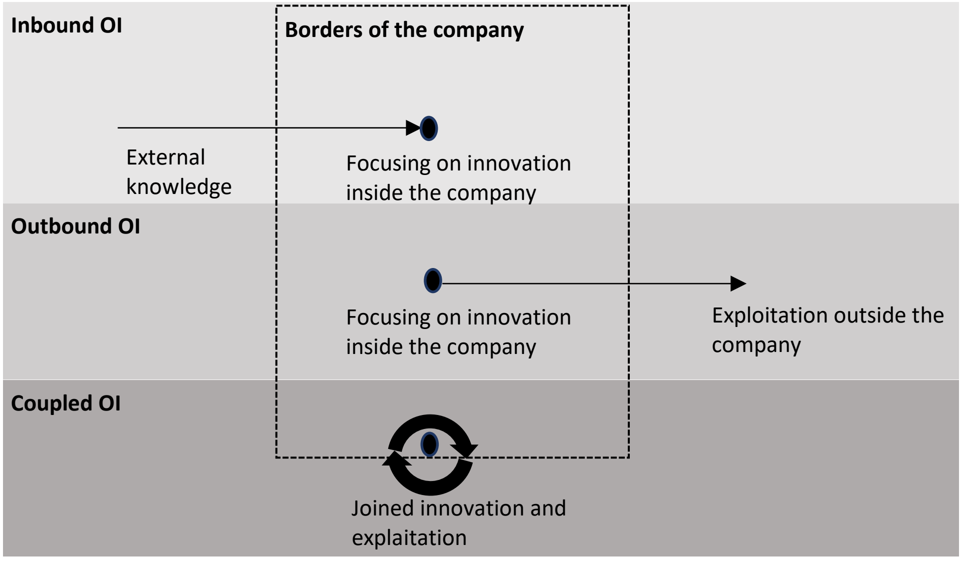
This study also proposes the ten criteria (except for *other*) based on factors by Van de Vrande et al. (2009). These criteria are *Control* (C_1), *Focus* (C_2), *Innovation Process* (C_3), *Knowledge* (C_4), *Cost* (C_5), *Capacity* (C_6), *Market* (C_7), *Utilization* (C_8), *Policy* (C_9) and *Motivation* (C_{10}). There are two main reasons of this selection. Firstly, Van de Vrande et al. (2009) analyzed these factors in terms of firm inside and outside. Thus, these factors have an impact role on both inbound and outbound OI. Furthermore, they include both organisational and behavioural aspects. These two aspects are very important to measure a firm's potential for OI (Rangus et al., 2016).

4.2. Determining the Alternatives

Alternatives of this study include the OI models. Although there are a lot of researches about OI models, these models can be grouped as inbound and outbound generally. Many researchers (Naqshbandi and Kaur, 2014; Cheng and Shiu, 2015; Burcharth et al., 2017; Usman and Vanhaverbeke, 2017) used these two OI models. In addition to them, some researchers (Mazzola et al., 2012; Piller and West, 2014; Canık et al., 2017; Battistella et al., 2017) have mentioned a third model, which is the coupled.

Inbound OI touches on the technology and knowledge that flow into the firm's innovation system. Outbound OI intends to technology and knowledge that flow out of the firm's innovation system (Chou et al., 2016). Coupled OI model combines both the inbound and outbound OI model with the goal of commercializing innovation via alliances, cooperation and joint ventures (Enkel et al., 2009; Chou et al., 2016). Theoretical framework of these three OI models can be shown in Figure 2.

Figure 2. **Three OI Models (adapted from Gassmann and Enkel, 2004).**



4.3. Weighting The Criteria

The ideas of the decision makers are gathered through an expert group. This group includes five academicians. Three of them are working on logistics and two are working on OI. The linguistic variable is used for pairwise comparisons of criteria shown in Table 1.

Table 1. **1-9 Fuzzy conversion scale and their reciprocals (Chang, 1996:654)**

Linguistic scale for importane	*Fuzzy numbers for FAHP*	*Triangular fuzzy scale*	*Triangular fuzzy reciprocal scale*
Egual importance	1	(1, 1, 1)	(1/1, 1/1, 1/1)
Weak importance	3	(1, 3, 5)	(1/5, 1/3, 1/1)
Strong importance	5	(3, 5, 7)	(1/7, 1/5, 1/3)
Very strong importance	7	(5, 7, 9)	(1/9, 1/7, 1/5)
Extremely preferred	9	(7, 9, 9)	(1/9, 1/9, 1/7)

After receiving the decision makers' opinions (Appendix 1), Fuzzy AHP is applied to compute the relative weighs. The results, Table 2, indicate that consistency rate is lower than 0.1. According to it, *innovation process* (C_3) is the most important (0.171) criterion, followed by *motivation* (C_{10}) with a weighting of 0.169.

Table 2. **Weights of the criteria**

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Weight	0.073	0.095	0.171	0.074	0.006	0.001	0.142	0.133	0.135	0.169

4.4. Ranking The Alternatives

The linguistic variable is used for comparisons of alternative shown in Table 3.

Table 3. **Linguistic variables for alternative (Mohammady and Amid, 2011:424.)**

Linguistic Variable	*Fuzzy numbers*
Very Low (VL)	(1/2, 1, 3/2)
Low (L)	(1, 3/2, 2)
Medium (M)	(3/2, 2, 5/2)
High (H)	(2, 5/2, 3)
Very High (VH)	(5/2, 3, 7/2)
Equal	(1, 1, 1)

Following the criteria weights from Fuzzy AHP, Fuzzy VIKOR is applied to evaluate the three OI models. The decision matrix of Fuzzy VIKOR is shown in Appendix 2. According to VIKOR methodology, Table 4 presents the ranking of the three OI models with different v values. As shown in Table 4, outbound OI model is the most appropriate OI model for each v value.

Table 4. **Ranks of the alternatives**

Alternative	***S***	***R***	***Q Values***				***Rank***
			V=0.25	***V=0.50***	***V=0.75***	***V=1.00***	
Inbound OI	0.7505	1.0000	0.9376	0.8752	0.8129	0.7505	3
Outbound OI	0.1014	0.5789	0.4595	0.3401	0.2207	0.1014	1
Coupled OI	0.6374	1.0000	0.9093	0.8187	0.7280	0.6374	2

5. Discussion and Conclusion

Firms make collaborative relationships with other firms and institutions to achieve competitive advantage. They also desire to enter into these relationships with their environments to gain innovative ideas. So, OI is a hot topic subject for both academicians and practitioners. However, the appropriate innovation model for the firms has not confronted in the related literature yet. Furthermore, OI researches on logistics firms is very limited. For these reasons, the aim of this study is to determine the appropriate OI model for logistics firms. For this purpose, an integrated Fuzzy MCDM approach based on Fuzzy AHP and VIKOR is proposed.

The proposed Fuzzy MCDM approach includes ten criteria (control, focus, innovation process, knowledge, cost, capacity, market, utilization, policy, and motivation) and three alternatives (inbound OI, outbound OI, and coupled OI). According to Fuzzy AHP results, *innovation process* is the most important criterion in determining the appropriate OI model. This process includes the long steps from choosing the suitable idea to developing the products or services. Therefore, it affect the OI selection decision.

The results of the Fuzzy VIKOR method indicate that outbound OI is the appropriate OI model for logistics firms. It means that outflow of ideas or knowledge more suitable for logistics firms. These firms should also focus on external exploitation of internal knowledge because they can make profits by bringing ideas to the market. Firms should also sell licenses to other firms to gain more benefit from their innovation efforts. It should be noted that logistics firms want to implement this model should transform the whole of their business process with the help of the outbound OI approach. Xu and Zheng (2013) also indicated that firms will achieve higher innovative performance through outbound OI in a cluster with more trust between the firms. However, Huang et al. (2015) stated that if firms are to successfully implement inbound OI, they need acquisition of external sources. Greco et al. (2016), as a different perspective, showed that coupled OI is related with the radical product innovations.

The findings of this study provide many contributions both in practical and theoretical perspective. It shows how logistics managers can put into appropriate OI strategies practically. It also suggests some recommendations for future researches theoretically. Further studies may verify how the implementation process of OI models in logistics firms vary across different organizational sizes and cultures.

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Appendix1: Fuzzy AHP Decision Matrix

Criteria	C_1	C_1	C_1	C_2	C_2	C_2	C_3	C_3	C_3	C_4	C_4	C_4	C_5	C_5	C_5	C_6	C_6	C_6	C_7	C_7	C_7	C_8	C_8	C_8	C_9	C_9	C_9	C_{10}	C_{10}	C_{10}
C_1	1.00	1.00	1.00	0.59	0.80	1.05	0.19	0.24	0.33	0.24	0.28	0.36	0.71	0.96	1.32	0.65	0.84	1.06	0.20	0.22	0.25	0.17	0.21	0.28	0.18	0.22	0.29	0.15	0.18	0.22
C_2	0.95	1.25	1.70	1.00	1.00	1.00	0.39	0.46	0.56	0.42	0.55	0.79	0.42	0.52	0.63	0.59	0.69	0.85	0.19	0.23	0.31	0.23	0.27	0.34	0.21	0.27	0.40	0.18	0.22	0.28
C_3	3.03	4.10	5.14	1.78	2.15	2.54	1.00	1.00	1.00	2.14	2.65	3.09	3.14	3.83	4.48	2.57	3.24	4.04	1.46	2.12	2.80	0.78	0.87	0.97	0.98	1.23	1.62	0.74	0.92	1.20
C_4	2.80	3.52	4.19	1.26	1.81	2.36	0.32	0.38	0.47	1.00	1.00	1.00	2.35	3.07	3.89	0.93	1.24	1.65	0.85	0.96	1.12	0.50	0.52	0.55	0.59	0.64	0.71	0.40	0.49	0.66
C_5	0.76	1.04	1.40	1.59	1.94	2.40	0.22	0.26	0.32	0.26	0.33	0.43	1.00	1.00	1.00	0.79	1.15	1.70	0.66	0.80	0.98	0.52	0.65	0.82	0.40	0.49	0.59	0.35	0.46	0.69
C_6	0.95	1.20	1.54	1.18	1.44	1.70	0.25	0.31	0.39	0.61	0.81	1.07	0.59	0.87	1.26	1.00	1.00	1.00	0.34	0.50	0.71	0.43	0.57	0.78	0.39	0.49	0.66	0.30	0.38	0.52
C_7	3.96	4.60	5.13	3.24	4.26	5.28	0.36	0.47	0.69	0.89	1.04	1.18	1.02	1.25	1.52	1.41	1.99	2.94	1.00	1.00	1.00	1.70	1.97	2.29	0.97	1.24	1.66	0.97	1.25	1.63
C_8	3.62	4.70	5.75	2.96	3.69	4.36	1.03	1.14	1.28	1.82	1.91	2.00	1.21	1.54	1.91	1.28	1.74	2.33	0.44	0.51	0.59	1.00	1.00	1.00	0.74	1.01	1.41	0.76	1.07	1.59
C_9	3.46	4.55	5.60	2.49	3.69	4.79	0.62	0.81	1.02	1.41	1.57	1.70	1.69	2.06	2.52	1.51	2.03	2.57	0.60	0.81	1.03	0.71	0.99	1.35	1.00	1.00	1.00	0.73	0.91	1.18
C_{10}	4.58	5.59	6.60	3.60	4.65	5.68	0.83	1.09	1.35	1.51	2.04	2.49	1.46	2.17	2.88	1.93	2.61	3.30	0.61	0.80	1.03	0.63	0.93	1.32	0.85	1.09	1.37	1.00	1.00	1.00

Appendix 2: Fuzzy VIKOR Decision Matrix

Alternatives	C_1	C_1	C_1	C_2	C_2	C_2	C_3	C_3	C_3	C_4	C_4	C_4	C_5	C_5	C_5	C_6	C_6	C_6	C_7	C_7	C_7	C_8	C_8	C_8	C_9	C_9	C_9	C_{10}	C_{10}	C_{10}
Inbound OI	0.30	0.41	0.51	0.38	0.49	0.59	0.46	0.57	0.67	0.52	0.63	0.74	0.32	0.43	0.53	0.24	0.35	0.45	0.41	0.52	0.63	0.38	0.49	0.59	0.36	0.47	0.58	0.49	0.60	0.71
Outbound OI	0.62	0.72	0.82	0.38	0.49	0.59	0.49	0.59	0.69	0.51	0.62	0.72	0.36	0.47	0.58	0.41	0.51	0.62	0.43	0.53	0.63	0.51	0.62	0.73	0.63	0.73	0.83	0.80	0.90	1.00
Coupled OI	0.55	0.65	0.75	0.34	0.45	0.55	0.44	0.54	0.65	0.46	0.56	0.66	0.41	0.51	0.62	0.46	0.56	0.66	0.44	0.54	0.65	0.43	0.53	0.63	0.46	0.56	0.66	0.62	0.72	0.82