Evaluating Sustainable Last-Mile Delivery (LMD) in B2C E-Commerce Using Two-Stage Fuzzy MCDM Approach: A Case Study from Vietnam

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ABSTRACT As the world attempts to control the spread of COVID-19 and adapt to shifting limitations, routines, and best practices, online ordering is an absolute necessity. With e-commerce activities surging, businesses in the last-mile delivery (LMD) industry find that their services are needed now more than ever before. Higher expectations of customers for speed, convenience, and sustainability have underlined the importance of reliable last-mile providers. This study aims to evaluate some key LMD companies in Vietnam regarding their sustainability performance. For this evaluation, the present research proposes a fuzzy multi-criteria decision-making (FMCDM) based framework combining the fuzzy analytic hierarchy process (FAHP) and the fuzzy weighted aggregated sum product assessment (FWAS-PAS), and triangular fuzzy numbers are applied to express the linguistic evaluation statements of experts. FAHP was utilized for the determination of criteria weights, then based on the most impactful criteria, FWAS-PAS was used to prioritize the companies. Delivery time, order fulfillment, decarbonization, convenience of payment, and real-time tracking systems have been ranked as the most impactful criteria in the LMD sector. The robustness of the proposed model was tested by conducting a sensitivity analysis. The results reach common rankings, in which Grab Express is the best performing company in the LMD landscape. The obtained results can be utilized as a guideline for the LMD managers and decision-makers to take in-depth consideration on their businesses under broader aspects to win customers and compete with other competitors.

INDEX TERMS Last-mile delivery, conflicting criteria, multi-criteria decision-making, fuzzy theory, B2C e-commerce, weight fluctuation, sustainability

I. INTRODUCTION

As smartphones become more popular and internet penetration increases, the adoption of e-commerce in Vietnam is on the rise. New digital business models and competent logistics concepts have enabled quick and same-day delivery, resulting in a substantial increase in e-commerce during the previous decade. The surge in the e-commerce industry coupled with the rise of business-to-customer (B2C) deliveries and international trade services propel the expansion of the Vietnam express delivery services market. The delivery of daily necessities positively impacts the express delivery services industry in Vietnam throughout the COVID-19 outbreak. The Vietnam express delivery services market was valued at USD 0.63 billion in 2019 and is expected to reach USD 2.2 billion by 2027, registering a compound annual growth rate (CAGR) of 19.1% [1]. Since the pandemic has expedited e-commerce expansion, consumer preferences have also grown increasingly important. Besides being provided with ample opportunities, businesses and their logistics service providers also face daunting challenges, especially in last-mile operations. With the total market size of e-commerce delivery in Vietnam at USD 400 million in 2017 and 35 million packages shipped a year, Last-mile delivery (LMD) accounts for 10% of this market size.
Retailers and e-commerce businesses have had difficulty with logistics and fulfillment in general because it is costly yet ineffective. LMD stands for the last leg of product distribution, which is when the product is delivered to end users, and it is considered the most important step in the distribution process [2,3]. This step is one of the most expensive and complex segments of the transportation process and can cost up to 40% more than other delivery steps [4]. Technology, lack of regional knowledge, lack of infrastructure, shortage of delivery employees, and an over-reliance on cash-on-delivery payment are some primary causes of this problem, especially in the Vietnamese context [5]. Recently with the increasing demand for one-hour and same-day deliveries, LMD becomes even more unmanageable. LMD companies have been continually changing their tactics as technology has advanced. A plethora of LMD providers is committed to offering full transparency in their services. Seamless LMD services provide timely delivery, good margins and assure the safety of the products. With the pandemic crisis causing a higher rate of product delivery and returns, LMD performance is the vital strategy of companies to stand out against their competitors.

Vietnam has become fertile land for LMD companies looking to capitalize on the burgeoning e-commerce market. The evolving LMD marketplace became more competitive in 2020 and since then has been more challenging, with local players putting up their game against international giants. Vietnamese and international e-logistics brands are in fierce competition as foreign transport corporations have entered the sector, i.e., Chinese businesses [6]. Aiming at market share and with a solid investment foundation, these overseas rivals are prepared to spend money and offer highly competitive prices, especially for major cities like Ho Chi Minh and Hanoi. Despite the LMD market’s immaturity, many players have emerged with unique competitive edges for the past decade. Realizing the necessity for firms to improve their logistics capabilities to meet the ever-increasing demand for online retail, LMD companies saw an opportunity to thrive. In recent years, an increasing number of local and foreign enterprises have entered the area, creating a tailored, unique solution for the Vietnamese e-logistics sector, and paving the road for unending e-commerce growth. Tiki, Lazada, Shopee, and Sendo are among the first e-commerce businesses with in-house logistics. Second, local and international logistics businesses such as Vietnam Post, Viettel Post, GHN Express, Giaohangtietkiem, Supershops, Ninja Van, Lalamove, to name a few, are bolstering their last-mile delivery services to meet rising demand [7]. International competitors, on the other hand, have operated in various markets and will bring valuable insights from other economies to Vietnam.

The dramatic changes brought forth by COVID-19, along with the acceleration of last-mile logistics transformation, have irrevocably evolved the delivery landscape. New consumption habits, requirements, behaviors, and expectations have emerged. Not only do most people choose their delivery options based on speed and convenience, but they also started to prioritize sustainability. As consumer priorities have changed, LMD firms have had to put sustainability at the forefront of their businesses, as defined by the three pillars of economic, social, and environmental. In the economic circumstance, LMD providers must consider technology investment and delivery costs to provide best-in-class service to win customers. From the social perspective, faster delivery time and contactless deliveries to comply with social distancing requirements have highlighted the need of competent LMD providers in today’s market. Concerning the environmental dimension, COVID-19 has increased congestion problems and the pressure to decarbonize. With the growing number of consumers ordering online, LMD companies must implement green vehicles across their fleets in the logistics system and invest in technology that enhances route optimization to reduce CO₂ emissions per delivery, thereby multiplying the effect of a green fleet. Since there is a consistent relationship between economic, social, and environmental aspects within last-mile space, it is essential for LMD companies to evaluate their businesses’ performance under well-rounded factors to push sustainability goals in the right direction.

Towards the above discussion, this paper proposes a fuzzy multi-criteria decision-making model to assess the sustainable development of the last-mile ecosystems players in Vietnam. Initially, a set of criteria has been identified for this evaluation by means of experts’ opinions and literature, including economic (delivery costs, hybrid fleet management systems, operational capabilities, risk management), service quality (order fulfillment, delivery time, convenience of payment, flexibility and responsiveness, customer experience), technological (real-time tracking systems, delivery management application), environmental (decarbonization, green policies), and social (safety, information security). A list of key LMD companies within e-commerce space in Vietnam analyzed in this research includes AhaMove, GHN Express, Giaohangtietkiem, Grab Express, Lalamove, Lazada Express, Ninja Van, Sendo, Shopee Xpress, Supershops, Tikinow, Viettel Post, and Vietnam Post. An integration of fuzzy analytic hierarchy process (FAHP) and fuzzy weighted aggregated sum product assessment (FWASPAS) was employed to investigate the significance of each selected criterion and prioritize the companies using finalized crucial criteria.

Since the evaluation involves experts’ judgments that are necessary for qualitative factors in the form of linguistic terms, fuzzy numbers are a practical way to express the assessment [8]. It is intended that FAHP and FWASPAS handle the link between criteria and alternatives, as well as the uncertainty of qualitative criteria. Traditional AHP uses the pair-wise technique due to its theoretical simplicity and ease of implementation [9]. A new MCDM approach, WASPAS, was established in 2012 with the goal of improving evaluation consistency and accuracy. Due to its ability to simplify complex multiplication operations and give ease of calculation...
for ranking alternatives. WASPAS has been widely employed in recent studies to evaluate alternatives [10]. In many real-world circumstances, employing original approaches, exact numbers cannot properly reflect uncertain and imperfect human judgments. This makes triangular fuzzy numbers an attractive alternative to expert assessment scales for determining the relative importance of qualitative factors.

One of the innovations of the current study is to conduct an evaluation of the LMD companies’ performance in Vietnam, which has never been reported in the existing literature. There is a wide range of factors that are taken into account while evaluating the companies’ performance in terms of sustainability, which is a significant advantage of the proposed work. Additionally, FAHP and FWASPAS were combined for the first time in the LMD study area. The proposed work provides insights on businesses’ performance for LMD decision-makers and practitioners towards sustainability development.

The remaining part of this paper is presented as follows. Section 2 discusses related research regarding LMD evaluation. In Section 3, the procedures of FAHP and FWASPAS are explained. The case study of Vietnam is presented in Section 4. Section 5 presents a discussion on the obtained results and a sensitivity analysis on the weight of criteria. The concluding remarks and avenues for further research are discussed in Section 7.

II. LITERATURE REVIEW

In recent years, the logistics and supply chain sectors have attracted the attention of many scholars. Numerous studies consider decision-making approaches for the logistics industry, and specifically, the LMD is one of the most arduous phases of shipment transfer concerning the sustainability of economic, social, and environmental pillars.

Amchang and Song [11] identified a criteria framework for determining locations of LMD centers and approached the AHP method, aiming to enhance LMD capability and sustain customers’ satisfaction. Considering environmental factors besides conventional factors, the authors focused on traffic congestion and emission policy in cities which are considered barriers of LMD in dense areas. The research is significant to improve LMD efficiency to the destination amid conditions of CO₂ emissions and pollution problems.

Datta [12] established a decision framework for selecting LMD performance in Indian e-commerce firms, which pointed out necessary and sufficient conditions for determination of effective LMD practices in India for various products. The practices were compared given different performance dimensions and Indian context towards sustainability.

Jiang et al. [13] identified a set of sustainability influencing factors to measure service quality of the LMD of rural e-commerce logistics using the FAHP, the interpretative structural model (ISM), and cross-impact matrix multiplication applied to classification (MICMAC) methodologies. The most indispensable factors were suggested including “convenience of returning goods”, “integrity of goods”, “advance reservation of goods pickup”, and “delivery costs”, with which the outcomes are directed towards proactive strategies and reinforcement policies to promote sustainable development of rural logistics. Another study that focuses on the green and sustainable development of rural logistics was conducted in [14]. The authors proposed an integrated method that combines fuzzy comprehensive evaluation (FCE) and the interpretative structural model (ISM) to analyze service quality evaluation indexes of rural LMD in five dimensions. One of the practical contributions suggested improving accuracy of goods arrival and timely customer service response.

In the problem of choosing sustainable LMD mode, which is trending and dynamic in the past few years, Švadlenka et al. [15] proposed the picture fuzzy decision-making approach for evaluating a set of alternatives of LMD modes. In the Pardubice context, the “e-cargo bike” was found to be the most sustainable alternative, especially in terms of environmental requirements. Li et al. [16] analyzed and prioritized three potential logistics service modes for LMD, including self-run mode, outsourcing mode, and alliance mode. For this evaluation, a two-dimensional matrix decision model based on delivery service cost advantage and delivery service capability advantage was established. The significant finding is useful for express enterprises to consider cost and capability simultaneously in the LMD modes selection.

Büyüközkan and Uztürk [17] focused on two-staged strategy and solution selection subject for the LMD at smart cities to augment its efficiency for companies and customers. SWOT analysis is coupled with AHP and VIKOR methodologies to implement an in-depth evaluation of LMD from a smart city perspective and generate suitable solutions. Bjørgen et al. [18] investigated the sustainability of e-groceries and indicate potential strategies for incorporating the last-mile distribution of e-groceries in city planning. With providing some significant insights, the paper analyzed how city governments can plan for sustainable mobility and efficient urban freight distribution by incorporating urbanization and digitalization trends.

In the context of the COVID-19 pandemic, Srinivas and Marathe [19] presented a review on several proposed innovative last-mile logistics solutions that possess certain limitations, as the crisis is currently motivating the need for last-mile logistics alternatives. COVID-19 and beyond may benefit from the deployment of “mobile warehouses” under specific scenarios. Trucks used as mobile warehouses are dedicated to one geographic location and carry inventories of various products according to the expected demand for those products in that location. B2C e-commerce providers use trucks as mobile warehouses to sell high-demand items quickly when certain conditions are met, as described by the authors.
In the literature of the logistics industry, FAHP and FWASPAS methodologies are more focused and employed within MCDM methods. Jaller and Otay [20] evaluated sustainable vehicle technologies for freight transportation using spherical FAHP and TOPSIS over multiple criteria for freight transportation in last mile and long-haul distribution. The alternatives were measured using five criteria: financial, business and market-related, environmental and legal, maintenance and repair availability, and safety and vehicle performance factors. Outsourcing logistics in e-commerce has been a key component of any streamlined supply chain. Wang et al. [21] utilized the FAHP and FVIKOR methodologies to select the best third-party logistics providers, with the most impactful factors including logistics cost, reliability and delivery time, voice of customer, network management, and quality of service. On the same note, outsourcing reverse logistics for e-commerce retailers was focused in [22] with the proposed FAHP-FTOPSIS approach. Simić and Dobrodolac [23] proposed the picture fuzzy WASPAS method for selecting LMD mode in a real-world problem in the Belgrade scenario. Four main criteria and 19 sub-criteria for assessing LMD modes are distinguished. Nguyen et al. [24] proposed a FAHP-WASPAS approach for evaluating online food delivery companies in Vietnam. A sustainable set of criteria was determined and analyzed including social and environmental criteria (healthy and safety, information security, and environmental impact), service quality (order fulfillment, delivery speed, convenience of payment, online/offline service level, and customer feedback), economic criteria (delivery cost, operational capability, and risk management), and technology (web design, real-time tracking systems, and marketing techniques).

### III. MATERIALS AND METHODS

#### A. RESEARCH FRAMEWORK

As shown in Figure 1, the research framework is separated into two parts. According to relevant literature and an expert’s interview, sustainable LMD evaluation criteria and their descriptions are defined (Table 1). The selected criteria include economic, service quality, and technological as well as environmental and social aspects. Assigning fuzzy preference weights to criteria based on pair-wise comparisons is done using fuzzy AHP. Language terms and triangular fuzzy numbers are used to show how each alternative is rated and how each criterion is weighted. As a second step, the fuzzy WASPAS model is used to rank all alternatives. Picture fuzzy decision-making approach for sustainable last-mile delivery evaluation and selection undergoes a sensitivity analysis to assess its robustness and comprehensiveness.

#### TABLE 1. Sustainable last-mile delivery evaluation criteria and their description.

| Main criteria | Criteria | Benefit/Cost | Description |
|---------------|----------|--------------|-------------|
| Economic (C1) | C11. Delivery costs | Cost | Including costs of transportation, labors, administration |
|               | C12. Hybrid fleet management systems | Benefit | Last-mile delivery transportation modes combination and utilization |
|               | C13. Operational capabilities | Benefit | Operational ability expansion |
|               | C14. Risk management | Cost | Including financial risk, operational risk, insurance concern |
| Service Quality (C2) | C21. Order fulfillment | Benefit | Packing quality, right product, right quantity, timely pickup |
|               | C22. Delivery time | Cost | Timeliness of goods arrival |
|               | C23. Convenience of payment | Benefit | Diversity of payment forms |
|               | C24. Flexibility and responsiveness | Benefit | Flexibility of the systems and management |
|               | C25. Customer experience | Benefit | Voice of customer, adaption to customer behaviors |
| Technological (C3) | C31. Real-time tracking systems | Benefit | Smart technology for tracking and tracing |
C32. Delivery management application | Benefit | Vehicle routing and administration optimization
---|---|---
Environmental (C4) | C41. Decarbonization | Benefit | Emission-free delivery
C42. Green policies | Benefit | Green operation, green materials, environmental regulations
Social (C5) | C51. Safety | Benefit | Contactless delivery, health and safety guidelines
C52. Information security | Benefit | Delivery data protection

### B. FUZZY ANALYTIC HIERARCHY PROCESS (FAHP)

In 1965, Zadeh [25] developed fuzzy set theory to handle uncertain factors in decision-making problems. Triangular fuzzy number (TFN), a useful model of fuzzy set, is defined as \((a, b, c)\), which indicate the lowest value (pessimistic value), middle value (most likely value) and highest value (optimistic value), respectively. The triangular membership functions are shown in Figure 2 and Equation (1).

\[
\mu(x/F) = \begin{cases} 
(x-a)/(b-a), & a \leq x \leq b \\
(c-x)/(c-b), & b \leq x \leq c \\
0, & \text{otherwise} 
\end{cases} 
\tag{1}
\]

The representative of each membership function level is presented, Equation (2).

\[
\mathcal{F} = (F'(y), F''(y)) = [a + (b-a)y, c + (b-c)y], y \in [0, 1] 
\tag{2}
\]

where \(F'(y), F''(y)\) are two sides of the fuzzy number.

When comparing fuzzy ratios defined by triangle membership functions, the fuzzy analytical hierarchy process (FAHP) used. Triangular fuzzy numbers are a linguistic word for pairwise comparison scale and assigned fuzzy scale, as illustrated in Table 2. According to assigned linguistic variables, the relative importance of two criteria is quantified on a number scale of 1–9. To indicate imprecise data, a tilde symbol (~) is inserted above the parameter symbols. As a result, the FAHP procedure is outlined in this manner [26].

#### TABLE 2. The fuzzy scale and their definition used in FAHP.

| Fuzzy Set | Definition     | Fuzzy Scale |
|-----------|----------------|-------------|
| 1         | Equal importance | (1, 1, 1)   |
| 2         | Weak importance  | (1, 2, 3)   |

![Figure 2. The triangular membership function.](image)

Step 1: In the FAHP calculation, the geometrical integration is utilized to establish an integrated fuzzy pairwise comparison matrix, as shown in Equation (3). \(\tilde{l}_{ij}\) denotes the significance of the \(i^{th}\) criterion over the \(j^{th}\) criterion.

\[
\tilde{M} = \begin{pmatrix} \tilde{l}_{12} & \cdots & \tilde{l}_{1n} \\ \tilde{l}_{21} & \cdots & \tilde{l}_{2n} \\ \vdots & \ddots & \vdots \\ \tilde{l}_{n1} & \cdots & \tilde{l}_{nn} \end{pmatrix}
\tag{3}
\]

If \(i = j, \tilde{l}_{ij} = 1\). Otherwise, \(\tilde{l}_{ij}\) is \(\tilde{l}_{ij} \in \tilde{g}^{-1}, \tilde{g}^{-1}, \tilde{g}^{-1}, \tilde{g}^{-1}, \tilde{g}^{-1}, \tilde{g}^{-1}, \tilde{g}^{-1}, \tilde{g}^{-1}, \tilde{g}^{-1}\)

Step 2: Fuzzy geometric mean of each criterion is figured by Equation (4).

\[
\tilde{r}_i = \left( \prod_{j=1}^{n} \tilde{l}_{ij} \right)^{1/n} \text{ such that } i = 1, 2, ..., n \tag{4}
\]

where \(\tilde{r}_i\) is the fuzzy geometrical mean, and \(\tilde{l}_{ij}\) is fuzzy comparison value from group of decision-maker concerning the \(i^{th}\) criterion over the \(j^{th}\) criterion.

Step 3: The fuzzy preference weights of each criterion is calculated by Equation (5).

\[
\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus ... \oplus \tilde{r}_n)^{-1} \tag{5}
\]

where \(\tilde{w}_i\) is the fuzzy weights of the \(i^{th}\) criterion.

Step 4: Defuzzify the fuzzy preference weights to obtain a crisp output by using the average weight criteria \(G_i\), as displayed in Equation (6).

\[
G_i = \frac{lw_i + mw_i + uw_i}{3} \tag{6}
\]

where \(\tilde{w}_i\) is the fuzzy weights of the \(i^{th}\) criterion, which can be presented as \(\tilde{w}_i = (lw_i, mw_i, uw_i)\), such that
\( lw_i, mw_i, uw_i \) are the lower-bound, middle-bound, and upper-bound of \( \tilde{w}_i \), respectively.

Step 5: The normalized preference weight of each criterion \( H_i \), is calculated, noted in Equation (7).

\[
H_i = \frac{G_i}{\sum_{i=1}^{n} G_i}
\]  

(7)

C. FUZZY WEIGHTED AGGREGATED SUM PRODUCT ASSESSMENT (FWASPAS)

Fuzzy weighted aggregated sum product assessment (FWASPAS) is one of the novel decision-making techniques based on integrating weighted sum model (WSM) and weighted product model (WPM). FWASPAS is used for many decision-making problems with conflicting criteria by compromising the weighted aggregation of the additive and multiplicative evaluation, which reflects more realistic problems. The FWASPAS process are presented as follows [27].

Step 1: Identify the fuzzy relative weights of each criterion. In FWASPAS model, the fuzzy relative weights of each criterion are obtained from the FAHP model.

Step 2: Build the fuzzy decision matrix is built based on the linguistic terms for rating alternatives in Table 3, as shown in Equations (8) and (9).

**TABLE 3.** Linguistic terms for rating alternatives used in FWASPAS.

| Definition          | Fuzzy Scale |
|---------------------|-------------|
| Very poor (VP)      | (0, 0, 1)   |
| Poor (P)            | (0, 1, 3)   |
| Medium poor (MP)    | (1, 3, 5)   |
| Fair (F)            | (3, 5, 7)   |
| Medium good (MG)    | (5, 7, 9)   |
| Good (G)            | (7, 9, 10)  |
| Very good (VG)      | (9, 10, 10) |

\[
\tilde{N} = \begin{bmatrix}
\tilde{x}_{11} & \tilde{x}_{12} & \ldots & \tilde{x}_{1n} \\
\tilde{x}_{21} & \tilde{x}_{22} & \ldots & \tilde{x}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{x}_{m1} & \tilde{x}_{m2} & \ldots & \tilde{x}_{mn}
\end{bmatrix}
\]  

such that \( i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \)  

(8)

\[
\tilde{s}_{ij} = \frac{1}{k} (\tilde{x}_{ij} \circ \tilde{x}_{ij}^2 \circ \ldots \circ \tilde{x}_{ij}^k)
\]  

(9)

where \( \tilde{x}_{ij}^k \) denotes fuzzy rating of \( m \) alternative \( A_i \) with respect to \( n \) criteria \( C_j \) by \( k^{th} \) expert, and \( \tilde{x}_{ij}^k = (a_{ij}^k, b_{ij}^k, c_{ij}^k) \).

Step 3: Normalize fuzzy decision matrix through Equations (10)–(12).

\[
\tilde{S} = [\tilde{s}_{ij}]_{m \times n} \text{ such that } i = 1, 2, \ldots, m; j = 1, 2, \ldots, n
\]  

(10)

\[
\tilde{s}_{ij} = \left( \frac{a_{ij}}{c_{ij}^k}, \frac{b_{ij}}{c_{ij}^k}, \frac{c_{ij}}{c_{ij}^k} \right), c_j^*
\]  

\[
\begin{align*}
\tilde{s}_{ij} & = \max\{c_{ij} | i = 1, 2, \ldots, m \} \text{ for benefit criteria} \\
\tilde{s}_{ij} & = \min\{a_{ij} | i = 1, 2, \ldots, m \} \text{ for cost criteria}
\end{align*}
\]  

(11)

(12)

Step 4: Compute the weighted (\( \tilde{w}_j \)) normalized fuzzy decision matrix for weighted sum model (WSM) through Equation (13).

\[
\tilde{Q}_i = \sum_{j=1}^{n} \tilde{s}_{ij} \tilde{w}_j \text{ such that } i = 1, 2, \ldots, m
\]  

(13)

Step 5: Compute the weighted (\( \tilde{w}_j \)) normalized fuzzy decision matrix for weighted product model (WPM) through Equation (14).

\[
\tilde{P}_i = \prod_{j=1}^{n} \tilde{s}_{ij} \tilde{w}_j \text{ such that } i = 1, 2, \ldots, m
\]  

(14)

Step 6: Defuzzify the fuzzy performance measurement using the practical of center-of-area method, as can be seen in Equations (15) and (16).

\[
Q_i = \frac{1}{3} (Q_{ia} + Q_{ib} + Q_{ic})
\]  

(15)

\[
P_i = \frac{1}{3} (P_{ia} + P_{ib} + P_{ic})
\]  

(16)

where \( \tilde{Q}_i = (Q_{ia}, Q_{ib}, Q_{ic}) \) and \( \tilde{P}_i = (P_{ia}, P_{ib}, P_{ic}) \) are the fuzzy performance measurement of WSM and WPM, respectively.

Step 7: Compute the integrated utility function value of FWASPAS using Equation (17) as follows.

\[
K_i = \lambda \sum_{j=1}^{n} Q_i + (1 - \lambda) \sum_{j=1}^{n} P_i \text{ such that } \lambda \in [0, 1]
\]  

(17)

The value of \( \lambda \) (i.e., preference coefficient value of FWASPAS or trade-off parameter) is based on the premise that the total of all alternatives WSM scores must be equal to the total of WPM score, as shown in Equation (18). In this paper, the value of \( \lambda \) is considered to be 0.5 (\( \lambda = 0.5 \)) for base case analysis.

\[
\lambda = \frac{\sum_{i=1}^{m} Q_i}{\sum_{i=1}^{m} Q_i + \sum_{i=1}^{m} P_i}
\]  

(18)
IV. RESULT ANALYSIS
A. A CASE STUDY FROM VIETNAM

This paper presents an integrated fuzzy multi-criteria decision-making (FMCDM), i.e., two-stage FAHP and FWASPAS for evaluating last-mile delivery industry. A case study of the top 13 last-mile delivery companies (LMDCs) in Vietnam is used to test the efficacy of the proposed model, which are AhaMove, GHN Express, Giaohangtietkiem, Grab Express, Lalamove, Lazada Express, Ninja Van, Sendo, Shopee Xpress, Supership, TikiNOW, Viettel Post, and Vietnam Post (Table 4).

Figure 3 displays the decision hierarchy for evaluation and selection LMDCs including five main criteria and 15 criteria including economic (delivery costs, hybrid fleet management systems, operational capabilities, risk management), service quality (order fulfillment, delivery time, convenience of payment, flexibility and responsiveness, customer experience), technological (real-time tracking systems, delivery management application), environmental (decarbonization, green policies), and social (safety, information security). In this paper, a total of eight experts who were working in the last-mile delivery industry for the past ten years, was interviewed for rating the significantly level of each criterion on the alternatives.

| No. | Last-Mile Delivery Companies | LMDCs   | Symbol |
|-----|------------------------------|---------|--------|
| 1   | AhaMove                      | LMDC-01 | AhaMove |
| 2   | GHN Express                  | LMDC-02 | GHN    |
| 3   | Giaohangtietkiem             | LMDC-03 | GHTK   |
| 4   | Grab Express                 | LMDC-04 | Grab   |
| 5   | Lalamove                     | LMDC-05 | Lalamove |
| 6   | Lazada Express               | LMDC-06 | Lazada |
| 7   | Ninja Van                    | LMDC-07 | Ninja Van |
| 8   | Sendo                        | LMDC-08 | Sendo  |
| 9   | Shopee Xpress                | LMDC-09 | Shopee |
| 10  | Supership                    | LMDC-10 | Supership |
| 11  | TikiNOW                      | LMDC-11 | Tiki   |
| 12  | Viettel Post                 | LMDC-12 | Viettel Post |
| 13  | Vietnam Post                 | LMDC-13 | VN Post |
FIGURE 3. The decision hierarchy for evaluation and selection LMDCs.

B. CALCULATION OF FUZZY WEIGHTS WITH FAHP

An example of the computation of the five main FAHP criteria, consisting of economic (C1), service quality (C2), technological (C3), and environmental (C4) is presented in the following FAHP procedure (C5). For FAHP model, Table 5 shows an initial comparison matrix, whereas Table 6 shows an integrated fuzzy comparison matrix.

Fuzzy comparison matrix values of pessimistic and optimistic values (lower and upper bounds) are used to convert linguistic terms to crisp values in order to determine the performance evaluation score's consistency ratio (CR) [28,29]. Table 7 contains the non-fuzzy comparison matrix of the main criteria.

It is possible to obtain the priority vector of the FAHP model's five key criteria by dividing each value in a column by its column sum. Using the normalized matrix, the priority vector is determined by averaging each row's entries as shown in Table 8.

The largest eigenvector \( \lambda_{\text{max}} \) is computed to determine the consistency index (CI), the random index (RI), and the consistency ratio (CR), as below.

\[
\begin{bmatrix}
0.324 & 0.488 & 0.142 & 0.283 & 0.267 \\
0.187 & 0.282 & 0.402 & 0.387 & 0.436 \\
0.187 & 0.058 & 0.082 & 0.058 & 0.054 \\
0.115 & 0.073 & 0.142 & 0.100 & 0.089 \\
0.187 & 0.100 & 0.232 & 0.173 & 0.154
\end{bmatrix}
\times
\begin{bmatrix}
0.301 \\
0.339 \\
0.088 \\
0.104 \\
0.169
\end{bmatrix}
= 
\begin{bmatrix}
1.626 \\
1.822 \\
0.450 \\
0.547 \\
0.890
\end{bmatrix}
\]
In this paper, a total of five main criteria is considered. Hence, we get \( n = 5 \). Consequently, \( \lambda_{\text{max}} \) and \( CI \) are computed as below.

\[
\lambda_{\text{max}} = \frac{5.405 + 5.380 + 5.130 + 5.278 + 5.263}{5} = 5.291
\]

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1} = \frac{5.291 - 5}{5 - 1} = 0.073
\]

such that \( n = 5 \), we get \( RI = 1.12 \), and the consistency ratio (CR) is computed as follows.

\[
CR = \frac{CI}{RI} = \frac{0.073}{1.12} = 0.065
\]

According to the result, \( CR = 0.065 < 0.1 \). Therefore, consistent pairwise comparison matrices are found, and the FAHP model's output is satisfactory. Following that, the same formula is used to compute all of the other factors. Table A1 (Appendix A) provides the integrated fuzzy comparison matrix for all criteria.

**TABLE 5.** The initial comparison matrix used in FAHP model.

| Main criteria | Linguistics Terms |
|---------------|-------------------|
| (8, 9, 10)    | (7, 8, 9)         |
| (6, 7, 8)     | (5, 6, 7)         |
| (4, 5, 6)     | (3, 4, 5)         |
| (2, 3, 4)     | (1, 2, 3)         |
| (1, 1, 1)     | (1, 2, 3)         |
| C1            | x                 |
| C2            | x                 |
| C3            | x                 |
| C4            | x                 |
| C5            | x                 |

**TABLE 6.** The integrated fuzzy comparison matrix used in FAHP model.

| Main criteria | Economic (C1) | Service Quality (C2) | Technological (C3) | Environmental (C4) | Social (C5) |
|---------------|---------------|----------------------|--------------------|--------------------|-------------|
| Economic (C1) | (1, 1, 1)     | (1, 2, 3)            | (1, 2, 3)          | (2, 3, 4)          | (1, 2, 3)   |
| Service Quality (C2) | (1/3, 1/2, 1) | (1, 1, 1)            | (4, 5, 6)          | (3, 4, 5)          | (2, 3, 4)   |
| Technological (C3) | (1/3, 1/2, 1) | (1/6, 1/5, 1/4)     | (1/1, 1)           | (1/3, 1/2, 1)      | (1/4, 1/3, 1/2) |
| Environmental (C4) | (1/4, 1/3, 1/2) | (1/5, 1/4, 1/3)     | (1/2, 3)           | (1/1, 1)           | (1/3, 1/2, 1) |

Following that, the results of FAHP is presented accordingly. In this paper, FAHP combines triangular fuzzy theory and AHP to reduce the subjective judgments in the MCDM process. The assessment of each criterion in FAHP is described by linguistic variables in triangular fuzzy numbers, which include pessimistic (lowest value), most likely (middle value), and optimistic values (highest value). The fuzzy geometrical mean is used to determine the relative weight of each criterion. The relative significant fuzzy weight of each criterion is shown in Table 9. As the result, for example, the triangular fuzzy weight of criteria delivery costs (C11) has the lowest value, the middle value, and the highest value of 0.027, 0.057, and 0.125, respectively. As the same concept, the triangular fuzzy weight of criteria hybrid fleet management systems (C12) has the lowest value of 0.028, the middle value of 0.062, and the highest value of 0.134. The remaining criteria have the same calculation.

The relative significant preference weight of criteria is depicted in Figure 4. The result shows that delivery time (C22), order fulfillment (C21), decarbonization (C41), convenience of payment (C23), and real-time tracking systems (C31) have the most significant impact, at 0.104, 0.079, 0.079, 0.104, and 0.078, respectively. The result suggests that in Vietnam, the decision-makers or policymakers should focus on those five significant criteria for improving the decision-making process of last-mile delivery evaluation and selection.
### Table 7. The non-fuzzy comparison matrix used in FAHP model.

| Main criteria     | Economic (C1) | Service Quality (C2) | Technological (C3) | Environmental (C4) | Social (C5) |
|-------------------|---------------|----------------------|--------------------|--------------------|-------------|
| Economic (C1)     | 1.000         | 1.732                | 1.732              | 2.828              | 1.732       |
| Service Quality (C2) | 0.577         | 1.000                | 4.899              | 3.873              | 2.828       |
| Technological (C3) | 0.577         | 0.204                | 1.000              | 0.577              | 0.354       |
| Environmental (C4) | 0.354         | 0.258                | 1.732              | 1.000              | 0.577       |
| Social (C5)       | 0.577         | 0.354                | 2.828              | 1.732              | 1.000       |
| **Total**         | **3.086**     | **3.548**            | **12.192**         | **10.011**         | **6.491**   |

### Table 8. The normalized comparison matrix used in FAHP model.

| Main criteria     | Economic (C1) | Service Quality (C2) | Technological (C3) | Environmental (C4) | Social (C5) | Priority Vector |
|-------------------|---------------|----------------------|--------------------|--------------------|-------------|-----------------|
| Economic (C1)     | 0.324         | 0.488                | 0.142              | 0.283              | 0.267       | 0.301           |
| Service Quality (C2) | 0.187         | 0.282                | 0.402              | 0.387              | 0.436       | 0.339           |
| Technological (C3) | 0.187         | 0.058                | 0.082              | 0.058              | 0.054       | 0.088           |
| Environmental (C4) | 0.115         | 0.073                | 0.142              | 0.100              | 0.089       | 0.104           |
| Social (C5)       | 0.187         | 0.100                | 0.232              | 0.173              | 0.154       | 0.169           |
| **Total**         | **1.000**     | **1.000**            | **1.000**          | **1.000**          | **1.000**   | **1.000**       |

### Table 9. The relative fuzzy weights of each criterion used in FAHP model.

| Main criteria     | Criteria                              | Fuzzy Geometric Mean | Triangular Fuzzy Weights |
|-------------------|---------------------------------------|----------------------|--------------------------|
| Economic (C1)     | C11. Delivery costs                    | 0.593                | 0.878                    | 1.323        | 0.027       | 0.057       | 0.125       |
|                   | C12. Hybrid fleet management systems   | 0.625                | 0.945                    | 1.412        | 0.028       | 0.062       | 0.134       |
|                   | C13. Operational capabilities          | 0.572                | 0.845                    | 1.265        | 0.026       | 0.055       | 0.120       |
|                   | C14. Risk management                   | 0.633                | 0.959                    | 1.437        | 0.028       | 0.063       | 0.136       |
| Service Quality (C2) | C21. Order fulfillment                  | 0.834                | 1.216                    | 1.759        | 0.037       | 0.079       | 0.167       |
|                   | C22. Delivery time                     | 1.166                | 1.624                    | 2.270        | 0.052       | 0.106       | 0.215       |
|                   | C23. Convenience of payment            | 0.836                | 1.206                    | 1.721        | 0.038       | 0.079       | 0.163       |
|                   | C24. Flexibility and responsiveness    | 0.690                | 1.016                    | 1.426        | 0.031       | 0.066       | 0.135       |
|                   | C25. Customer experience               | 0.686                | 1.013                    | 1.445        | 0.031       | 0.066       | 0.137       |
| Technological (C3) | C31. Real-time tracking systems         | 0.806                | 1.156                    | 1.637        | 0.036       | 0.075       | 0.155       |
|                   | C32. Delivery management application    | 0.510                | 0.715                    | 1.056        | 0.023       | 0.047       | 0.100       |
| Environmental (C4) | C41. Decarbonization                    | 0.826                | 1.217                    | 1.738        | 0.037       | 0.079       | 0.165       |
|                   | C42. Green policies                    | 0.566                | 0.818                    | 1.211        | 0.025       | 0.053       | 0.115       |
| Social (C5)       | C51. Safety                            | 0.546                | 0.783                    | 1.166        | 0.025       | 0.051       | 0.111       |
|                   | C52. Information security              | 0.655                | 0.942                    | 1.382        | 0.029       | 0.061       | 0.131       |
In this Section, after calculating the triangular fuzzy weight of criteria from the FAHP model, FWASPAS is applied to determine the ranking of the alternatives, i.e., the top 13 LMDCs in Vietnam including AhaMove, GHN Express, Giaohangtietkiem, Grab Express, Lalamove, Lazada Express, Ninja Van, Sendo, Shopee Xpress, Supership, TikiNOW, Viettel Post, and Vietnam Post. A panel of eight experts in the field of the last-mile delivery industry in Vietnam with more than 10 years of working experience, was interviewed for rating the significant level of each criterion on the alternatives. FWASPAS, an extension of WASPAS to the fuzzy environment, is used for many decision-making problems using triangular fuzzy numbers in rating performance of alternative concerning criteria instead of precise number. FWASPAS can handle conflicting requirements by compromising the weighted aggregation of the additive and multiplicative score, which reflects more actual problems. According to the FWASPAS’s procedures in Section 3.3, the integrated utility function value of crisp $Q_i$, crisp $P_i$, and crisp $K_i$ is shown in Table 10. Moreover, the final ranking order used from the FWASPAS model is visualized in Figure 5 accordingly. The result shows that the top five last-mile delivery companies are Grab Express (LMDC-04), TikiNOW (LMDC-11), Viettel Post (LMDC-12), Giaohangtietkiem (LMDC-03), and GHN Express (LMDC-02) with a score of 0.578, 0.556, 0.332, 0.391, and 0.384, respectively. The integrated fuzzy comparison matrix and the fuzzy normalized matrix used in the FWASPAS model are presented in Tables A2 and A3 (Appendix A).

TABLE 10. The integrated utility function value used in FWASPAS model

| LMDCs   | Last-Mile Delivery Companies | Crisp $Q_i$ | Crisp $P_i$ | Crisp $K_i$ | Ranking |
|---------|------------------------------|-------------|-------------|-------------|---------|
| LMDC-01 | AhaMove                      | 0.447       | 0.306       | 0.377       | 9       |
| LMDC-02 | GHN Express                  | 0.481       | 0.286       | 0.384       | 5       |
| LMDC-03 | Giaohangtietkiem             | 0.472       | 0.310       | 0.391       | 4       |
| LMDC-04 | Grab Express                 | 0.784       | 0.372       | 0.578       | 1       |
| LMDC-05 | Lalamove                     | 0.417       | 0.292       | 0.354       | 10      |
| LMDC-06 | Lazada Express               | 0.500       | 0.266       | 0.383       | 6       |
| LMDC-07 | Ninja Van                    | 0.398       | 0.274       | 0.336       | 11      |
| LMDC-08 | Sendo                        | 0.505       | 0.251       | 0.378       | 8       |
| LMDC-09 | Shopee Xpress               | 0.479       | 0.286       | 0.383       | 7       |
| LMDC-10 | Supership                    | 0.425       | 0.241       | 0.333       | 12      |
| LMDC-11 | TikiNOW                      | 0.736       | 0.377       | 0.556       | 2       |
| LMDC-12 | Viettel Post                 | 0.557       | 0.267       | 0.412       | 3       |
| LMDC-13 | Vietnam Post                 | 0.394       | 0.271       | 0.332       | 13      |
V. SENSITIVITY ANALYSIS

This section performs a sensitivity analysis on the most five significant criteria selecting from the FAHP results, which are delivery time (C22), order fulfillment (C21), decarbonization (C41), convenience of payment (C23), and real-time tracking systems (C31), to investigate the impact of those criteria on the alternative’s ranking. The sensitivity is used to check the efficiency of the proposed FMCDM model and the robustness of the outcomes of the assessment. Prior to making any decisions, it is necessary to examine how changing weights of criteria affected decision quality. These are then utilized to examine data by altering their weights from ±10%, ±20%, and ±30% [30,31]. Hence, there will be 30 scenarios in the framework of sensitivity analysis.

Figure 6 depicts that the final decision-making results of the 13 last-mile delivery companies (LMDCs) are fundamentally stable. The results reveal that Grab Express (LMDC-04), TikiNOW (LMDC-11) are always ranked at the first and second on the 10%, 20%, 30% more weight and 10%, 20%, 30% less weight than the base case. Generally, the curve is relatively smooth, suggesting that the result of the proposed FMCADM model is reliable. It means that the final ranking results of all the alternative last-mile companies remain unchanged. Grab Express (LMDC-04) is still the optimal alternative with the highest prospect value compared to other alternatives. According to the findings, regardless of the weight fluctuation, it can be said that the final ranking results of the alternative (i.e., last-mile delivery companies) remain consistent, and the proposed model has a high level of stability and applicability. This work successfully proposed an integrated fuzzy multi-criteria decision-making model by combining FAHP and FWASPAS to support the decision-making process in evaluating and selecting last-mile delivery for the e-commerce industry.
VI. DISCUSSIONS

In this study, a hybrid fuzzy MCDM framework for the evaluation of LMD companies in Vietnam is established for sustainable-focused aspects: economic (delivery costs, hybrid fleet management systems, operational capabilities, risk management), service quality (order fulfillment, delivery time, convenience of payment, flexibility and responsiveness, customer experience), technological (real-time tracking systems, delivery management application), environmental (decarbonization, green policies), and social (safety, information security). Further, this is the first effort to conduct the combination of FAHP and FWASPAS in the logistics and LMD sectors. To ensure that the expert's input was consistent, a consistency test was conducted, and a sensitivity analysis was performed to verify the robustness of the approach. By successfully addressing the case study given, the applied model is reliable. The results show that the proposed integrated framework reaches general sustainable LMD company rankings.

From the FAHP analysis of criteria, delivery time, order fulfillment, decarbonization, convenience of payment, and real-time tracking systems have been ranked as the most significant LMD evaluation criteria. Fast delivery and order fulfillment, as always, are the topmost considerations in the logistics industry. It is even more of a daunting stress for brands and LMD providers when efficient same-day and instant delivery has almost become mandatory to ensure customer loyalties not to choose competitors. Shoppers also highly prioritize convenience of payment, in which the cash-on-delivery (COD) fulfillment is one of the arduous tasks that often causes inefficiencies in LMD, especially in the Vietnamese context. COD is still the preferred payment method for 85% of online buyers in Vietnam, according to Vietnam E-Commerce and Digital Economy Agency [32]. Many shoppers distrust digital payment and prefer the tangibility of cash, which is related to both a limited population of bank card owners and habit. Decarbonization is not only a catchphrase that belongs to the environmental concerns that both governments and logistics companies commit to moving towards a decarbonized future of LMD to reduce traffic congestion and air pollution. The last-mile's carbon footprint has long been a concern for the environment and society. In recent years, consumers have become more aware of a company's environmental practices, and LMD can
be particularly detrimental, especially speedy single deliveries. Finally, with the increasing demand for one-hour and same-day deliveries, real-time tracking systems is a critical component of on-demand deliveries and provides various edges for companies and benefits for all stakeholders in the LMD competition: route optimization, more deliveries, higher customer satisfaction, real-time visibility on delivery personnel, and improved delivery personnel performance [33].

FWASPAS analysis indicates the most sustainable LMD companies in today’s market in Vietnam concerning the selected evaluation criteria including Grab Express, TikiNOW, Viettel Post, Giaohangtietkiem, and GHN Express. The major players are striving to lead the LMD race. For example, GrabExpress now integrates all delivery fleet options with new features for the everyday needs of individuals and businesses. On-demand logistics services are part of Grab’s current strategic drive to become an everyday super-app that supports the daily essential needs of its users. TikiNOW’s integrated order management, fulfillment, and in-house delivery capabilities give it an edge over the competition. New services are added regularly to meet the ever-growing demands of customers. In addition to same-day deliveries, the company also offers a heavy/bulky delivery and installation service. Giaohangtietkiem was a pioneer in Vietnam’s B2C last-mile delivery market. Consumers can book a shipper to deliver their package and track it in real-time with the company’s service. There is a 6-hour delivery guarantee for requests within the city, and a 24-hour guarantee for requests between Hanoi and Ho Chi Minh City.

VII. CONCLUSIONS

E-commerce competition is vast and constantly expanding, and Vietnam’s e-commerce market has entered a trajectory of accelerated growth. LMD has become one of the most critical concepts on the ever-changing and evolving e-commerce stage. The traditional supply chain management is being turned on its head by consumer demands for more options and higher expectations for the last mile experience. The competitive LMD landscape has the participation of numerous dynamic players, with a competition for both domestic and foreign participants. Thus, to keep up with the ever-changing market dynamics and win customers, LMD companies must examine their businesses towards sustainable development, for not only costs, technology, society, and service quality but also towards a greener future of the logistics industry.

The most important contributions and achievements of this study can be summarized as follows.

- First, through interviews with experts and literature reviews, the study selected and assessed the most main priorities in the LMD for e-commerce in Vietnam, which is a significant advantage of this study.
- Second, this is the first study to give a case study of the suggested framework being used to analyze LMD enterprises in Vietnam (i.e., FAHP and FWASPAS). Sensitivity analysis was performed for the decision-makers to test the observation stability.
- For managerial implications, all selected evaluation criteria and experts’ assessments presented in this research are directed towards enabling LMD businesses and related firms to handle numerous challenges and encourage them to look at the efforts of sustainable development.

Signifying some avenues for future research, the proposed method in this study can be combined with many more advanced factors that affect the industry. The applied method or relevant approaches, i.e., a combination of different MCDM techniques such as DEA, PROMETHEE, COPRAS, to name a few [34,35], are recommended for specific industry circumstances, particularly e-commerce-related groups, to test the general validity of the results.

APPENDIX

**TABLE A1.** The integrated fuzzy comparison matrix used in FAHP model.

| Criteria                          | C11  | C12  | C13  | C14  |
|----------------------------------|------|------|------|------|
| Delivery costs                   | 1.00 | 1.00 | 1.00 | 0.95 |
| Hybrid fleet management systems  | 0.46 | 0.70 | 1.05 | 1.00 |
| Operational capabilities         | 0.80 | 1.30 | 2.01 | 0.70 |
| Risk management                  | 1.19 | 2.03 | 3.00 | 0.70 |
| Order fulfillment                | 0.67 | 1.04 | 1.61 | 0.70 |
| Delivery time                    | 0.50 | 0.77 | 1.25 | 0.59 |
| Convenience of payment           | 0.50 | 0.77 | 1.25 | 0.59 |
| Flexibility and responsiveness   | 0.70 | 1.09 | 1.76 | 0.67 |
| Customer experience              | 1.41 | 2.28 | 3.27 | 0.88 |
| Real-time tracking systems       | 0.63 | 0.95 | 1.40 | 1.04 |
| Delivery management application  | 1.19 | 1.82 | 2.61 | 0.32 |
### Table 1: Criteria Ratings

| Criteria                              | C21 | C22 | C23 | C24 |
|---------------------------------------|-----|-----|-----|-----|
| Delivery costs                        | 0.62| 0.96| 1.49| 0.80|
| Hybrid fleet management systems       | 0.57| 0.92| 1.44| 0.71|
| Operational capabilities              | 0.57| 0.92| 1.44| 0.76|
| Risk management                       | 0.95| 1.57| 2.33| 0.76|
| Order fulfillment                     | 1.00| 1.00| 1.00| 0.71|
| Delivery time                         | 0.63| 0.95| 1.40| 1.00|
| Convenience of payment                | 0.61| 0.92| 1.33| 0.30|
| Flexibility and responsiveness        | 0.25| 0.31| 0.41| 0.37|
| Customer experience                   | 0.25| 0.31| 0.41| 0.37|
| Real-time tracking systems            | 0.53| 0.77| 1.16| 0.27|
| Delivery management application       | 0.57| 0.84| 1.33| 0.27|
| Decarbonization                       | 1.00| 1.62| 2.39| 0.27|
| Green policies                        | 0.41| 0.59| 0.95| 0.32|
| Safety                                | 0.41| 0.59| 0.95| 0.19|
| Information security                  | 0.92| 1.38| 2.01| 0.28|

| Criteria                              | C25 | C31 | C32 | C41 |
|---------------------------------------|-----|-----|-----|-----|
| Delivery costs                        | 0.31| 0.44| 0.71| 0.71|
| Hybrid fleet management systems       | 0.54| 0.76| 1.13| 0.38|
| Operational capabilities              | 0.66| 0.95| 1.33| 0.46|
| Risk management                       | 0.57| 0.92| 1.44| 0.57|
| Order fulfillment                     | 2.43| 3.27| 4.04| 0.86|
| Delivery time                         | 1.04| 1.57| 2.33| 2.17|
| Convenience of payment                | 0.85| 1.10| 1.60| 1.00|
| Flexibility and responsiveness        | 0.89| 1.44| 2.03| 0.40|
| Customer experience                   | 1.00| 1.00| 1.00| 0.89|
| Real-time tracking systems            | 0.49| 0.70| 1.12| 1.00|
| Delivery management application       | 1.07| 1.61| 2.48| 0.33|
| Decarbonization                       | 0.49| 0.70| 1.12| 0.59|
| Green policies                        | 0.43| 0.64| 1.05| 0.33|
| Safety                                | 0.43| 0.64| 1.05| 0.33|
| Information security                  | 0.70| 1.09| 1.76| 0.59|

| Criteria                              | C42 | C51 | C52 |
|---------------------------------------|-----|-----|-----|
| Delivery costs                        | 0.65| 1.00| 1.53|
| Hybrid fleet management systems       | 0.38| 0.59| 0.96|
| Operational capabilities              | 0.31| 0.44| 0.71|
| Risk management                       | 0.68| 1.01| 1.54|
| Order fulfillment                     | 1.05| 1.68| 2.46|
| Delivery time                         | 1.67| 2.28| 3.09|
| Convenience of payment                | 1.62| 2.50| 3.29|
| Flexibility and responsiveness        | 1.49| 2.33| 3.11|
### TABLE A2. The integrated fuzzy comparison matrix used in FWASPAS model.

| LMDCs  | C11  | C12  | C13  | C14  | C21  |
|--------|------|------|------|------|------|
| AhaMove| 1.50 | 2.50 | 4.13 | 1.50 | 2.25 | 3.63 |
| GHN    | 2.00 | 3.75 | 5.75 | 1.75 | 3.75 | 5.75 |
| GHTK   | 1.75 | 3.75 | 5.75 | 2.25 | 3.25 | 4.63 |
| Grab   | 7.25 | 8.75 | 9.50 | 7.00 | 8.50 | 9.38 |
| Lalamove| 1.38 | 2.00 | 3.13 | 1.88 | 2.50 | 3.63 |
| Lazada | 0.13 | 0.75 | 2.25 | 7.25 | 8.75 | 9.38 |
| Ninja Van| 0.88 | 2.38 | 4.25 | 1.00 | 2.63 | 4.50 |
| Sendo  | 0.13 | 0.75 | 2.25 | 0.13 | 0.75 | 2.25 |
| Shopee | 0.63 | 1.63 | 3.25 | 0.63 | 1.63 | 3.25 |
| Supership| 6.00 | 7.75 | 9.13 | 6.50 | 8.13 | 9.25 |
| Tiki   | 8.00 | 9.38 | 9.88 | 8.00 | 9.38 | 9.88 |
| Viettel Post| 6.25 | 8.25 | 9.63 | 0.00 | 0.63 | 2.25 |
| VN Post| 0.50 | 1.88 | 3.75 | 1.00 | 2.38 | 4.25 |

| LMDCs  | C22  | C23  | C24  | C25  | C31  |
|--------|------|------|------|------|------|
| AhaMove| 1.50 | 2.50 | 4.13 | 2.63 | 4.00 | 5.63 |
| GHN    | 0.50 | 1.75 | 3.50 | 0.75 | 1.75 | 3.50 |
| GHTK   | 2.25 | 3.25 | 4.63 | 2.63 | 4.38 | 6.13 |
| Grab   | 5.50 | 7.50 | 9.13 | 6.50 | 8.38 | 9.50 |
| Lalamove| 1.63 | 2.38 | 3.63 | 1.63 | 2.38 | 3.63 |
| Lazada | 5.75 | 7.50 | 8.88 | 0.13 | 0.75 | 2.25 |
| Ninja Van| 2.88 | 4.25 | 5.88 | 2.88 | 4.25 | 5.88 |
| Sendo  | 6.50 | 8.13 | 9.00 | 6.25 | 8.00 | 9.13 |
| Shopee | 0.63 | 1.63 | 3.25 | 0.63 | 1.63 | 3.25 |
| Supership| 5.50 | 7.50 | 9.00 | 0.25 | 1.13 | 2.75 |
| Tiki   | 2.25 | 3.50 | 5.00 | 3.00 | 4.63 | 6.25 |
| Viettel Post| 6.25 | 8.25 | 9.63 | 6.25 | 8.25 | 9.63 |
| VN Post| 0.63 | 1.38 | 3.00 | 1.13 | 2.50 | 4.50 |

| LMDCs  | C32  | C34  | C31  |
|--------|------|------|------|
| AhaMove| 2.63 | 4.00 | 5.63 |
| GHN    | 1.75 | 3.75 | 5.75 |
| GHTK   | 1.63 | 2.63 | 4.13 |
| Grab   | 7.75 | 9.13 | 9.75 |
| Lalamove| 2.50 | 4.25 | 6.25 |
| Lazada | 0.13 | 0.75 | 2.25 |
| Ninja Van| 0.88 | 1.38 | 2.63 |

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