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A hybrid decomposed fuzzy multi-criteria decision-making model for optimizing parcel lockers location in the last-mile delivery landscape

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HIGHLIGHTS

- Proposing the Decomposed Fuzzy Combinative Distance based Assessment (DF-CODAS).
- Integrating Decomposed Fuzzy Analytical Hierarchy Process and DF-CODAS methods.
- Using the proposed method for evaluating of parcel locker locations for the first time.
- Considering decision-makers' evaluations under optimistic/pessimistic views.

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ABSTRACT

Parcel lockers are considered an effective solution to address inefficiencies in last mile delivery. However, choosing the appropriate location is crucial to provide optimal service and improve logistic performance. Therefore, this research aims to assess the most suitable locations for parcel lockers in Dublin, the capital of Ireland, using a novel hybrid decision-making model. This study seeks to extend the Combinative Distance based Assessment method and integrate the Analytical Hierarchy Process method to handle parcel locker location evaluation problems through Decomposed Fuzzy Sets. The proposed model is a pioneering application in real-life scenarios, contributing to the existing knowledge in this field. The integrated model we propose offers a suitable approach for selecting parcel locker locations. The outcomes of this study will provide valuable insights for policymakers, aiding them in making strategic decisions regarding the selection of parcel locker locations within Dublin city.

1. Introduction

The rapid expansion of Business-to-Consumer (B2C) e-commerce has significantly increased the importance of last-mile delivery in urban areas. Historically, the primary method of distributing goods in the B2C market has been focused on delivering them to residential addresses. Nevertheless, this strategy has resulted in a significant increase in delivery requirements, consequently worsening traffic congestion and presenting intricate environmental issues in urban areas. Therefore, it is crucial to investigate alternate approaches that can mitigate these negative consequences. Parcel lockers are becoming a popular choice for improving last-mile delivery systems, especially due to the significant changes in consumer behavior caused by the COVID-19 epidemic and the resulting new obstacles.

It is crucial to select the best, easily reachable, and safe sites for parcel lockers to improve service quality and enhance customer satisfaction. These lockers are carefully placed in highly accessible and regularly visited public areas, such as parking facilities, transportation hubs, commercial zones, heavily inhabited regions, and pedestrian precincts. The process of selecting the most appropriate and efficient location from a multitude of options presents a formidable undertaking, necessitating judicious consideration of factors encompassing accessibility, reliability, environmental sustainability, operational efficacy, and user security [1–3]. Consequently, the decision-making process assumes paramount significance.

The need to evaluate suitable parcel locker locations in Dublin to improve logistics performance in last-mile delivery is the research problem that is addressed in this study. It is becoming increasingly

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important to ensure that packages are delivered to end consumers in a timely manner, and parcel lockers are being considered as a potential solution to address the inefficiencies that occur in the final mile of delivery procedures. Nevertheless, it is essential to determine the most appropriate locations for these lockers to guarantee the highest possible level of service and to enhance the overall performance of the logistics system in Dublin.

In this study, we introduce a novel decomposed fuzzy decision-making model to ascertain the optimal location of parcel lockers. In the proposed methodology, decomposed fuzzy Analytical Hierarchy Process (AHP) and Combinative Distance based Assessment (CODAS) methods have been integrated. Cebi et al. [31] introduced Decomposed Fuzzy Sets (DFS) to address consistency in decision-making responses to positive and negative questions. DFS infers based on decision-makers' consistency, incorporating optimistic and pessimistic perspectives. The study aims to extend the CODAS method, integrate the AHP method and handle parcel locker location evaluation problems using DFS. Our proposed model represents a pioneering application within real-life contexts, thereby augmenting the existing body of knowledge within this realm.

The research gains relevance within Dublin's logistics and last-mile delivery landscape due to distinct challenges. Foremost among these challenges is the urgent need for sustainable last-mile delivery solutions to align with Dublin's environmental goals and reduce carbon emissions. The city's unique urban layout, marked by congested streets and limited parking, poses logistical hurdles that directly impact the efficiency of last-mile delivery operations. Addressing these specific challenges becomes crucial for enhancing the effectiveness of delivery services. Moreover, the study recognizes the evolving consumer behavior accelerated by the COVID-19 pandemic, where increased reliance on e-commerce has heightened demand for efficient last-mile delivery services. By focusing on Dublin's specific challenges, this research aims to provide insights and solutions that cater to the city's distinctive logistical complexities while offering broader implications for urban areas worldwide.

The innovation of the paper can be summarized as follows:

1. Encouraging assessors to consider both optimistic and pessimistic scoring is demonstrated as an effective strategy for self-assessment and gaining a more profound understanding of participants' thought processes.
2. Developing an extended decomposed fuzzy CODAS (DF-CODAS) approach to handle multi-criteria decision-making (MCDM) problems under pessimistic and optimistic views.
3. Integrating the extended DF-CODAS and DF-AHP methods to evaluate location problem.
4. Comparing with the two existing methods to demonstrate the rationality and availability of the proposed approach.
5. First application of the extended decomposed fuzzy CODAS to optimizing a real-life parcel locker's location.

To achieve these goals, the remainder of the paper is structured as follows: Section 2 provides a brief overview of parcel locker applications and decomposed fuzzy sets. Decomposed fuzzy sets with aggregation operators and fundamental operations are summarized in Section 3. In Section 4, the proposed DF-AHP-CODAS integration is described. In Section 5, the DF-AHP-CODAS extension is applied to the evaluation of parcel locker location selection in Dublin. Section 6 includes a comparative analysis. In Section 7, the study is concluded with some thoughts and recommendations for the future.

2. Literature review

The concept of last-mile logistics is generally agreed upon to represent the final stage of a delivery process. It specifically pertains to the last segment of a business-to-consumer (B2C) service, where the package is transported to the recipient's residence or a designated collection point. In the e-commerce era, a significant challenge arises due to the fragmented nature of customer orders. Individual customers typically make small purchases but expect fast delivery, necessitating dynamic responses from the competitive transport market reducing the efficiency and utilization of the e-retailer companies. Together with the increase in the technological advancements and environmental considerations, various methods are put forward to increase the efficiency of such last-mile deliveries, and one such approach is the utilization of parcel lockers.

According to Gevaers et al. [4], there are five key factors that contribute to an effective last mile delivery. The first one is the level of customer service, or "reliability," which encompasses overall service quality. The second factor is "security," which plays a significant role in the success of last mile delivery businesses. The third factor is the geographical area, which greatly influences delivery efficiencies and can be broadly defined as "accessibility". The fourth factor is defined as the vehicle fleet and technology, which affects last mile delivery performance. In a broader context, this factor falls under the category of "traffic and operation," as businesses seek innovative methods to reduce traffic impact through various vehicle and technology solutions, such as parcel lockers. Finally, the last criterion is "environmental impact," which aims to provide an environmentally friendly and sustainable logistic performance at what we do under last mile delivery.

2.1. Parcel lockers

Dublin, despite its historic infrastructure, thrives as one of Europe's fastest-growing urban economies. With this growth comes the responsibility to address challenges tied to the city's expanding population and limited space. Balancing environmental sustainability and smart city concepts is imperative. Amid various solutions considered, optimizing last-mile delivery stands out as a practical approach to tackle emissions, congestion, and delivery costs while enhancing the customer experience. The complexities of Dublin's logistics and last-mile delivery, influenced by its unique historical landscape and modern economic demands, make this initiative particularly crucial for the city's sustainable development.

In addressing the challenges of Dublin's last-mile delivery landscape, the strategic selection of parcel locker locations emerges as a pivotal component. Placing parcel lockers strategically contributes to reducing emissions, congestion, and delivery costs. It enhances the efficiency of last-mile delivery by providing a centralized and convenient hub for package retrieval. This not only aligns with environmental sustainability goals but also promotes a seamless customer experience. The careful selection of parcel locker locations is a crucial element in reshaping the last-mile delivery process, making it more sustainable, cost-effective, and responsive to the evolving needs of Dublin's dynamic urban environment.

Use of parcel lockers naturally reduce the operational cost of last-mile logistics delivery when applied properly. For this end, the right choice of parcel locker locations holds significant importance in optimizing the efficiency of the overall process within the realm of factors described for last mile logistics. A frequently implemented approach is to locate parcel lockers along the commute route between home and work, as well as in proximity to common destinations where customers typically make stops along the way (railway stations, parking lots, gas stations, and supermarkets), or places of the starting point (homes) or destination (work) of individuals' daily trips (apartment buildings, and corporate buildings) [5].

Analyzing location aspect involves considering the aforementioned factors to assess their influence on the effectiveness of the delivery system. In the field of last mile logistics, parcel lockers have received significant attention, leading to several studies exploring their implementation, effectiveness, and operational considerations. The existing literature offers valuable insights into the utilization and impact of parcel lockers as an innovative solution for enhancing the efficiency of last mile delivery processes. In this section, we concentrate on the related parcel locker literature, with a particular emphasis on location-related matters and the factors influencing them.

For this end, Morganti et al. [6] analyze the performance of final e-commerce deliveries of French and German parcel delivery operators based on the available data and highlight that parcel lockers are increasingly favored as a rapidly growing innovative solution, not only by e-retailers but also by e-shoppers. This preference is primarily driven by their perceived advantages in terms of "reliability," "accessibility," and "traffic and operational" factors when the location selection is appropriate as it enhances the rate of successful first-time deliveries, optimize delivery routes, and reduce operational costs. The qualitative study by Vikingson and Bengtsson [7] present customer-oriented perspective on the application of parcel lockers in Sweden. The primary motivations for utilizing the lockers were their perceived fast-process and the expectation of reduced waiting time. Conversely, factors hindering the adoption of lockers were the absence of personalized service and concerns regarding security. Careful consideration in selecting a secure location can effectively mitigate such concerns. In another research study, Iwan et al. [1] discuss that the key factor determining the effectiveness of parcel locker locations is the willingness of e-retailers to deliver goods to a location that may differ from the purchaser's address. They conduct their study in Szczecin (Poland). While carrying their research, they also come up the fact that effectiveness of the location also depends on the willingness of customers to collect their purchased goods from the parcel lockers. For e-shoppers, the main obstacle to utilize parcel lockers is the necessity to personally complete the final part of the delivery journey. Iwan et al. [1] also present a SWOT analysis for parcel lockers and point out that choosing suitable locations can contribute to reducing pollutants emitted by urban freight transport, benefiting the environment. In addition to the findings in [1], the authors, in another study focusing on Poland [8], conduct a survey analysis regarding the environmental impact of the parcel lockers' locations. Based on the results, they conclude that the costumers are more willing to find parcel locker locations attractive if they are on the way to work /schools especially near the transport network stations especially the tube stations.

Yuen et al. [9] present a study applying the innovation diffusion theory to analyze the factors influencing customer behavior towards self-collection services. The study, which is carried out with the consumers located in Singapore, emphasizes the significance of selecting appropriate locations for such services. It concludes that the proximity of parcel lockers to an individual's core daily activities is a crucial consideration. This proximity directly influences how customers perceive the innovation, as long as it aligns with their lifestyle. Vakulenko et al. [10] conduct qualitative research on customer value regarding parcel lockers from the Swedish e-consumers' perspectives. This study finds that customers primarily value the functional aspects of parcel lockers, particularly their location and accessibility. Customers prefer the parcel locker stations to be conveniently located along their daily routes, allowing them to access easily and quickly. Additionally, customers appreciate the convenience of using parcel lockers without the need for social interaction or engagement in conversations.

In a more quantitative analysis from South East Queensland region of Australia, Lachapelle et al. [11] state that parcel locker system is at an early stage of development and is planned to expand, hence there are still possibilities to help identify the efficient strategic location decisions for parcel locker stations and how to embed them visibly and accessibly in the cities to enhance their roles as a travel-time and emission reduction infrastructure. Besides these concerns, they also investigate the locations by giving them safety scores and present possible unsecure features. The study by De Oliveira et al. [12] focuses on analyzing accessibility criteria by employing a spatial analysis that incorporates socioeconomic data, preferences, transport infrastructure and population distribution. The case study applied to a neighborhood in Brazil concludes that parcel lockers located in drugstores, gas stations, and post offices can adequately serve a substantial portion of the neighborhood's population as they are located within a 1000-meter radius. Similarly, Kedia et al. [13] analyze the parcel locker locations to find out the locations that encourage consumers to more walk or cycle to receive the parcel as online shopping reduce consumers' shopping trips, but increased retailers' delivery trips. In an application to a neighborhood in New Zealand, supermarkets found out to be the most appropriate locations for parcel lockers when reliability factor is concerned while the results from their proposed p-median location-allocation model suggests that diaries are the most accessible locations when accessibility is concerned. As a result of aforementioned studies, it is clear that different considerations lead to different location preferences for parcel lockers. In another study, Liu et al. [14] considers the environmental criteria, assess the impacts of locations of the collection points to the choice of mode of transportation and concludes in their case study applied in Stockholm, Sweden that relocating only 5% of the stations from urban areas to suburban and rural areas decreases the travelled distance over 20%.

Lee et al. [15] propose a sequential decision-making model that firstly determines the potential locations in Incheon, South Korea based on the reliability, accessibility, and traffic criteria. Next, applying the set-covering and the p-median formulations, they find the necessary number of locations and minimize the total weighted customer walk distance. As e-retailers and e-shoppers have conflicting objectives regarding the location selection of parcel lockers, Yang et al. [16] propose a bilevel programming formulation for the problem where the retailer aims to minimize its total cost in the upper level, the customers optimize their pick-up service satisfaction in the lower level by considering accessibility criteria as the satisfaction level. They employ a numerical example in Changsha, Hunan, China.

Lagorio and Pinto [5] identify the key factors that influence the effectiveness of parcel lockers as a convenient service, aiming to maximize customer satisfaction and usage. They analyze six main factors that impact the selection of appropriate locations for parcel lockers: availability, accessibility, security, environmental impact/land occupation, cost, methods of use, and regulations. The concept of availability, as defined by the authors, primarily relates to the time aspect of accessing the parcel lockers. On the other hand, accessibility focuses on the geographical location and ease of reaching the lockers. Security, environmental impact/land occupation, and cost factors are self-explanatory. Furthermore, methods of use factor can be categorized as part of the reliability criteria. In other words, they examine how reliable and user-friendly the procedures were for utilizing the parcel lockers. Finally, the issue of regulations is highlighted since installing lockers in public places would typically require permits to occupy such public spaces. Lin et al. [17] introduce a quantitative methodology aimed at identifying the ideal location for lockers to maximize the overall service quality offered by the alliance. The study takes into explicit consideration the preferences and choices of customers using multinominal logit model and propose a mathematical formulation together with an alternating algorithm to determine the optimal locker locations. They present a case study based on parcel locker design in Singapore. The service level for a customer is calculated as a decreasing function of the walking distance. However, as customers sometimes prefer a facility that is not the nearest according to their preferences, they apply the multinomial logit model to forecast such discrete choice behaviors.

Tang et al. [18] perform a statistical analysis to quantify customer satisfaction in Shenzhen, China by evaluating the service quality of the parcel lockers. They classify location under the convenience factor and conclude that the convenience of the parcel locker's location will have a significant impact on customer enthusiasm. Schaefer and Figliozzi [19] conduct a data experiment by analyzing the accessibility and equity factors affecting the use of parcel lockers installed on sideways and public areas in Portland, Oregon, United States. In this analysis, they examine the distribution of the parcel locker locations based on available data collected through surveys and Geographic Information System (GIS) shapefiles, and process through relevant packages in R language. The same authors, in another study regarding the same region [2] reconsider the accessibility and equity factors to analyze the potential of public transportation facilities as parcel locker locations. Such transport facilities are assumed to be more accessible if the connectivity and ridership is high and the geometric design is not interfering with the transit activities. Equity factor is concluded to be more related to the distribution of population, employment, and key socioeconomic characteristics. Wang et al. [20] state that the uncertainty in demands should be carefully considered in determining the parcel locker locations hence they propose a robust optimization formulation for the parcel locker location problem. They assume customers are always willing to go to the closest parcel location, which is stationed within an acceptable walking distance, hence only the accessibility factor is considered in their methodology and the experiment is conducted on randomly generated instances.

Crowd-shipping, in conjunction with the utilization of parcel lockers, presents a sustainable solution to improve the efficiency of last mile delivery. In crowd-shipping, individuals who are already traveling to a specific destination can offer to deliver packages or parcels along their route. Although parcel lockers are mainly used for business-to-customer sector, utilizing parcel lockers also for business-to-business sector can also significantly increase the last mile delivery efficiency, reduce low load factors and environmental impact. For this end, Pan et al. [21] propose a mathematical formulation and a solution algorithm for such a joint delivery network where parcel lockers can also serve as transfer points playing the role of transportation mode-exchange nodes. Their formulation largely depends on the location of the parcel lockers as it changes the whole distance matrix and operational cost parameters used in the objective function. They test their solution methodologies in a case study in a last mile delivery network based on metropolitan Melbourne, Australia. Similarly, dos Santos et al. [22] propose a mixed integer programming formulation for such a joint delivery network problem considering parcel lockers as collecting and as intermediate delivery points where the final delivery is accomplished by people that are on their way home or by more environmental local couriers such a cyclist with an experiment on randomly generated instances. In a similar fashion, Ghaderi et al. [23] utilize parcel lockers in a crowd-shipping network and develop a binary integer programming formulation and a solution algorithm for locating parcel lockers and allocating the delivery assignments. Results from the experiment conducted in metropolitan Melbourne, Australia suggests that opening locations on dominating routes of crowd-shippers increases the delivery rate and the possibility of switching the delivery among crowd-shippers through lockers. Kurowski et al. [24] introduce a geometric approach to design a parcel locker network, considering user preferences. Their methodology involves literature reviews, surveys, and statistical analyses conducted in Lubusz Voivodeship, a province in western Poland. The findings indicate that, regardless of the characteristics of the customers, employing a triangular network provides better coverage compared to a square configuration with an equivalent number of parcel lockers. Very recently, Freitas Matinha et al. [25] present a short review analyzing the recent literature on sustainability considerations linked to the adoption of lockers as a substitute for home delivery. According to their findings, reduction of greenhouse gas emissions and atmospheric pollutants, and congestion reduction factors are studied the most while the primary concern is identified as the distance travelled by the customers.

2.2. MCDM for parcel lockers

Multi-criteria decision-making (MCDM) is extensively employed across various domains to assess and address intricate issues [56–59], including those encountered within transportation systems [60–63]. However, when it comes to MCDM studies, a two-phase solution methodology is proposed by Pourmohammadreza and Jokar [26] where the proposed locations are evaluated through a multi-criteria decision-making (MCDM) approach in the first phase and vehicle routing formulation with different service options is proposed in the second phase. They conduct an experiment using a randomly generated dataset. To the best of our knowledge, despite the diverse range of parcel locker location analysis studies, [26] is the one of few studies using MCDM techniques for practical guidance to decision makers in selecting parcel locker locations. To assess the derived criteria, they initially employ the SWARA (stepwise weight assessment ratio analysis) technique. Subsequently, the combined compromise solution (COCOSO) method is used to evaluate the pickup points based on the selected criteria. In this context, nine key factors that influence customer perceptions of the desirability of pickup points are identified: availability, accessibility, security, environmental impact, number of facility staff, disaster resilience, methods of use, regulations, and capacity. The following paragraphs are related to a couple of other studies that utilize MCDM techniques on last mile delivery together with parcel locker location analysis.

De Araújo et al. [27], in an MCDM study, aim to answer how logistic service expectations of Brazilian customers shape the new alternative last mile solutions in this more technological and sustainable era. To do so, they develop a fuzzy AHP approach employing six basic criteria to evaluate five different alternatives, one of which is the parcel lockers. The criteria include the location, time, and speed, tracking and tracing, value-added services, security and cost. They conclude that parcel lockers are considered the best alternative as consumers find it the most reliable and accessible. Another MCDM study focusing on the sustainable last mile solutions in general and approving the use of parcel lockers as the most favorable solution, is proposed by Silva et al. [28]. An AHP- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) approach is conducted for the historic center of Porto, Portugal where environmental (air, noise, visual pollution), economic (delivery cost, capacity, speeded) and social (congestion, security, acceptance) criteria are considered to evaluate the alternative sustainable solution methodologies, which are parcel lockers, electric vehicle, cargo bike or crowdsourcing.

There are also a few recent MCDM studies solely focusing on the parcel locker location selection problem. As there are several criteria and uncertainties to be considered while choosing the appropriate parcel locker location, Kavus et al. [29] propose a hybrid fuzzy MCDM approach to compare the alternative parcel locker locations. The hybrid model consists of the Bayesian Best Worst Method (B-BWM) and Pythagorean fuzzy Weighted Aggregated Sum Product Assessment (PF-WASPAS) approaches. They compare five geographical locations in a neighborhood in Istanbul and define a total of thirty-two sub-criteria under six main criteria, namely physical characteristics, resilience, financial, social, convenience and proximity. In a very recent study, Moslem and Pilla [3] employ AHP with spherical fuzzy sets to give the most appropriate location decision for parcel lockers in Dublin, Ireland based on the following criteria: reliability, accessibility, traffic and operation, security, and environmental impact. Rather than specific geographical locations as in [29], the authors evaluate the specific places and facilities, such as public transport stops, private car parking areas, post offices, commercial areas, high population density areas, and pedestrian zones.

2.3. Decomposed fuzzy sets in MCDM

As explained above, the existing research on the appropriate location selection of parcel lockers in last mile delivery is still new and limited hence making it an under-estimated and unexplored area in the literature. Most of the reviewed literature primarily relies on consumer surveys and data analysis to identify potential locations for parcel lockers. However, there is a significant gap in understanding the importance of the location selection process concerning varying social, economic, and environmental factors using MCDM methods. To address this gap, we undertake a relatively new MCDM approach to evaluate the parcel locker location alternatives. By employing this methodology, we aim to gain deeper insights into the optimal location selection for parcel lockers, considering multiple criteria and enhancing our understanding of their impact on overall last mile delivery efficiency.

In this study, we employ the DFS, a recently introduced fuzzy MCDM method, which is an extension of intuitionistic fuzzy sets (IFSs) introduced by Atanassov [30]. Unlike ordinary fuzzy sets, IFSs allow for the sum of degrees of membership and non-membership not necessarily equating one. This feature enables the incorporation of another complementary parameter to the membership function, making IFSs more suitable for representing imprecise and vague information. Various generalizations of IFSs have been proposed in the literature, depending on the problem types and expert judgments.

One such generalization is DFS, which aims to handle inconsistency in expert judgments by considering both optimistic and pessimistic perspectives. While MCDM methods assist in decision-making for complex problems involving multiple criteria and alternatives, fuzzy sets offer a way to handle uncertainty. The evaluation of criteria often relies on the expertise and subjective judgments of specialists. The optimism or pessimism of these professionals can influence their risk assessments, and the way questions are framed (positive or negative) impacts the accuracy of their evaluations. These situations introduce additional uncertainty to the decision-making process. Given the lack of assessment techniques in the literature that account for such additional uncertainty caused by optimistic or pessimistic judgments, Cebi et al. [31] introduce the concept of DFS. With this study, they address the challenge posed by reciprocal questions and introduce the concept of optimistic and pessimistic membership functions. These functions capture the indeterminacy inherent in decision-making processes, particularly when dealing with participant responses that may not align due to the nature of reciprocal questioning. By incorporating these elements, DFS provides a more accurate way to reflect the complexities of decision-making under uncertainty. To achieve this, the decision maker's responses to functional and dysfunctional questions are utilized.

In their another study, Cebi et al. [32] introduce the DFS based AHP approach to assess third-party logistics service providers for pharmaceutical companies. They enhance the AHP method by incorporating DFS approach, thus enhancing the overall reliability of the AHP evaluation by also considering the experts' individual responses to reciprocal questions under vague and imprecise conditions. Finally, Kahraman et al. [33] introduce the DFS based TOPSIS method and apply it to a multicriteria risk-based supplier selection problem under fuzziness to better consider the accuracy and consistency levels of the expert judgments for the supplier selection problem. Furthermore, being a new and rapidly expanding method in the field of MCDM, there have been a few recent DFS-based risk assessment applications, such as failure mode and effects analysis for the food cold chain [34], occupational health and safety risk assessment [35], and the Fine-Kinney method for the electric arc welding process [36]. In addition, there have been a few DFS-based strategy selection applications, such as cost-benefit analysis for ophthalmologic robot selection [37], DFS-based TOPSIS analysis for transfer center location selection [38], decomposed Pythagorean CODAS method for strategy selection for IOT based sustainable supply chain system [39].

This study aims to propose a hybrid DFS based MCDM approach for the parcel locker location selection problem. Firstly, we determine the weights of the essential criteria through the application of the decomposed Fuzzy AHP method. Using pairwise comparisons in a fuzzy environment, AHP proves reliable and effective results in uncertain situations especially when deciding on locations [3]. Subsequently, we employ the newly extended CODAS method using decomposed fuzzy sets to identify the optimal locations for parcel lockers. We especially prefer fuzzy CODAS method as it performs relatively well in capturing and incorporating vague decision-maker preferences, which arise commonly in the location selection problems [39].

The CODAS, a two-phase distance-based ranking method, is first introduced by Ghorabaee et al. [40]. The method allows the application of the two distance measures to the negative-ideal point: the Euclidean distance as the primary, and if it is still incomparable, then the Taxicab distance as the secondary measure, and these distances. As a result, the alternative which has greater distances would be more desirable. Shortly after the first study, Ghorabaee et al. [41] propose the fuzzy CODAS method to solve the MCDM problem by integrating fuzzy logic into the ordinary CODAS method to handle uncertainty. Ren [42] and Karagoz et al. [43] present the intuitionistic fuzzy CODAS method while Bolturk and Kahraman [44] and Deveci et al. [45] extend it to the interval-valued intuitionistic fuzzy CODAS methodology to solve the decision problems. Bolturk and Karaşan [46] and Karaşan et al. [47] extend this model by using neutrosophic fuzzy numbers and introduce the interval-valued neutrosophic CODAS method. Zhou et al. [48] and He et al. [49] present linguistic Pythagorean fuzzy extensions of the CODAS method and apply them on financial strategy assessment problem. Tüysüz and Kahraman [50] develop the Z-fuzzy extension of CODAS method by calculating the criteria weights from the Z-fuzzy pairwise comparison matrix with an application to supplier selection problem. Deveci et al. [51] present another extension of CODAS method under the type-2 neutrosophic number environment and address another location selection decision problem. Finally, Simic et al. [52] present the picture fuzzy extension while Karaşan et al. [53] introduce the spherical fuzzy extension of CODAS method. Notably, for the first time in literature, the CODAS method is extended under decomposed fuzzy sets where we introduce a novel hybrid structure by combining it with DFS based AHP.

3. Decomposed fuzzy sets: preliminaries

DFS has been introduced in the literature to address the inconsistency of expert judgments by taking both optimistic and pessimistic viewpoints into account. DFS considers both the pessimistic (P) and optimistic (O) perspectives of decision-makers on the subject at hand. Therefore, it measures the reliability of the decision maker's judgments to compute the level of ambiguity in the decision environment. This is determined by the decision maker's responses to the functional and dysfunctional queries. When a decision is made in confidence, the total of these evaluations should equal one. Due to the unpredictability of the decision-making environment, however, the sum of both judgments will not equal 1.0. In this instance, the shortage represents the decision-maker's inconsistency. In this section, DFS preliminaries have been shared.

Definition 3.1. . Assume that X be a universe of discourse. A Decomposed Fuzzy Set (DFS) $\widetilde{A}$ is,

$$\widetilde{A} = \left\{ \langle \mathrm{x}, \left(\mathscr{O}\left(\mu_{\underset{\sim}{A}}^{\mathscr{O}}(\mathrm{x}), \vartheta_{\underset{\sim}{A}}^{\mathscr{O}}(\mathrm{x}) \right), \mathscr{P}\left(\mu_{\underset{\sim}{A}}^{\mathscr{P}}(\mathrm{x}), \vartheta_{\underset{\sim}{A}}^{\mathscr{P}}(\mathrm{x}) \right) \right) \middle| \mathrm{x} \in \mathrm{X} \right\} \tag{1}$$

where the function $\mu_{\underset{\sim}{A}}(\mathrm{x}) : \mathrm{X} \rightarrow [0,1], \nu_{\underset{\sim}{A}}(\mathrm{x}) : \mathrm{X} \rightarrow [0,1]$ are the degrees of membership, non-membership of x to $\mathscr{O}$ and $\mathscr{P}$, respectively where $\mathscr{O}$ and $\mathscr{P}$are optimistic and pessimistic sets, satisfying the conditions $0 \le \mu_{\underset{\sim}{A}}^{\mathscr{O}}(\mathrm{x}) + \vartheta_{\underset{\sim}{A}}^{\mathscr{O}}(\mathrm{x}) \le 1, 0 \le \mu_{\underset{\sim}{A}}^{\mathscr{P}}(\mathrm{x}) + \vartheta_{\underset{\sim}{A}}^{\mathscr{P}}(\mathrm{x}) \le 1$, and inconsistency in the judgment is $\mathscr{I}^A = 1 - \left(\mu_{\underset{\sim}{A}}^{\mathscr{O}}(\mathrm{x}) + \vartheta_{\underset{\sim}{A}}^{\mathscr{O}}(\mathrm{x}) + \mu_{\underset{\sim}{A}}^{\mathscr{P}}(\mathrm{x}) + \vartheta_{\underset{\sim}{A}}^{\mathscr{P}}(\mathrm{x}) \right)$ where $-1 \le \mathscr{I}^A \le 1$ and $0 \le \mu_{\underset{\sim}{A}}^{\mathscr{O}}(\mathrm{x}) + \vartheta_{\underset{\sim}{A}}^{\mathscr{O}}(\mathrm{x}) + \mu_{\underset{\sim}{A}}^{\mathscr{P}}(\mathrm{x}) + \vartheta_{\underset{\sim}{A}}^{\mathscr{P}}(\mathrm{x}) \le 2$.

Definition 3.2. . Let $\widetilde{\alpha} = \{ \mathscr{O}(a,b), \mathscr{P}(c,d) \}$,$\widetilde{\alpha}_1 = \{ \mathscr{O}(a_1,b_1), \mathscr{P}(c_1,d_1) \}$, and $\widetilde{\alpha}_2 = \{ \mathscr{O}(a_2,b_2), \mathscr{P}(c_2,d_2) \}$ be DFN and basic operators are given as follows:

$$\widetilde{\alpha}_1 \oplus \widetilde{\alpha}_2 = \left\{ \mathscr{O}\left(\frac{a_1 + a_2 - 2a_1a_2}{1 - a_1a_2}, \frac{b_1b_2}{b_1 + b_2 - b_1b_2}\right), \mathscr{P}(c_1 + c_2 - c_1c_2, d_1d_2) \right\} \tag{2}$$

can be used as addition operator.

$$\widetilde{\alpha}_1 \otimes \widetilde{\alpha}_2 = \left\{ \mathscr{O}(a_1a_2, b_1 + b_2 - b_1b_2 \ ), \mathscr{P}\left(\frac{c_1c_2}{c_1 + c_2 - c_1c_2}, \frac{d_1 + d_2 - 2d_1d_2}{1 - d_1d_2}\right) \right\} \tag{3}$$

can be used as multiplication operator.

$$\lambda \cdot \widetilde{\alpha} = \left\{ \mathscr{O}\left(\frac{\lambda a}{(\lambda - 1)a + 1}, \frac{b}{\lambda - (\lambda - 1)b}\right), \mathscr{P}\left(\left(1 - (1 - c)^{\lambda}\right), d^{\lambda}\right) \right\} \text{for} < \text{mmEquation id} = \text{"eqn1"} / > \tag{4}$$

can be used for multiplying by a scalar.

$$\widetilde{\alpha}^{\lambda} = \left\{ \mathscr{O}\left(a^{\lambda}, \left(1 - (1 - b)^{\lambda}\right)\right), \mathscr{P}\left(\frac{c}{\lambda - (\lambda - 1)c}, \frac{\lambda d}{(\lambda - 1)d + 1}\right) \right\} \text{for} < \text{mmEquation id} = \text{"eqn2"} / > \tag{5}$$

λ^{th} power of$\widetilde{\alpha}$ can be calculated as in Eq. (5).

Definition 3.3. : Let $\widetilde{\alpha}_i = \{\mathscr{O}(a_i, b_i), \mathscr{P}(c_i, d_i)\}$be a collection of Decomposed Weighted Arithmetic Mean (DWAM) with respect to, $w_i = (w_1, w_2 \ldots\ldots, w_n), and w_i \in [0,1] and \sum_{i=1}^{n} w_i = 1$, DWAM is introduced as;.

$$DWAM(\widetilde{\alpha}_1, \widetilde{\alpha}_2 \ldots\ldots, \widetilde{\alpha}_n) = w_1 \cdot \widetilde{\alpha}_1 \oplus w_2 \cdot \widetilde{\alpha}_2 \oplus \ldots\ldots \oplus w_n \cdot \widetilde{\alpha}_n = \left\{ \begin{array}{c} \mathscr{O}\left(\dfrac{\sum_{i=1}^{n} w_i a_i}{1 + \sum_{i=1}^{n}\left(w_i a_i - \dfrac{a_i}{n}\right)}, \dfrac{\prod_{i=1}^{n} b_i}{\sum_{i=1}^{n} b_i^{n-1} w_i (1 - b_i) + \prod_{i=1}^{n} b_i}\right), \\ \mathscr{P}\left(\left(1 - \prod_{i=1}^{n} (1 - c_i)^{w_i}\right), \prod_{i=1}^{n} d_i^{w_i}\right) \end{array} \right\} \tag{6}$$

Definition 3.4. . Let $\widetilde{\alpha}_i = \{\mathscr{O}(a_i, b_i), \mathscr{P}(c_i, d_i)\}$ be a collection of Decomposed Weighted Geometric Mean (DWGM) with respect to, $w_i = (w_1, w_2 \ldots\ldots, w_n), and w_i \in [0, 1]$, DWGM is introduced as;.

$$DWGM(\widetilde{\alpha}_1, \widetilde{\alpha}_2 \ldots\ldots, \widetilde{\alpha}_n) = \widetilde{\alpha}_1^{w_1} \otimes \widetilde{\alpha}_2^{w_2} \otimes \ldots\ldots \otimes \widetilde{\alpha}_n^{w_n} = \left\{ \mathscr{O}\left(\prod_{i=1}^{n} a_i^{w_i}, \left(1 - \prod_{i=1}^{n} (1 - b_i)^{w_i}\right)\right), \mathscr{P}\left(\frac{\prod_{i=1}^{n} c_i}{\sum_{i=1}^{n} c_i^{n-1} w_i (1 - c_i) + \prod_{i=1}^{n} c_i}, \frac{\sum_{i=1}^{n} w_i d_i}{1 + \sum_{i=1}^{n}\left(w_i d_i - \frac{d_i}{n}\right)}\right) \right\} \tag{7}$$

Definition 3.5. . The consistency index *(CI)* of decomposed fuzzy number $(\widetilde{\alpha} = \{\mathscr{O}(a, b), \mathscr{P}(c, d)\})$ is introduced as;.

$$CI(\widetilde{\alpha}) = 1 - \left(\sqrt{\frac{(a - d)^2 + (b - c)^2 + (1 - a - b)^2 + (1 - c - d)^2}{2}}\right) \tag{8}$$

The closer the $CI(\widetilde{\alpha})$is to 1, the more reliable the decision maker.

Definition 3.6. . The score index *(SI)* of DFN $(\widetilde{\alpha} = \{\mathscr{O}(a, b), \mathscr{P}(c, d)\})$ is given as follows.

$$SI(\widetilde{\alpha}) = \begin{cases} \dfrac{(a + b - c + d).CI(\widetilde{\alpha})}{2.k}, & SI(\widetilde{\alpha}) > 0 \\ 0, & SI(\widetilde{\alpha}) \le 0 \end{cases} \tag{9}$$

where k is the linguistic scale multiplier. We have calculated that $k \quad is 0.90 and 0.95$ because the maximum score values of the proposed linguistic scales are given in Tables 1 and 2 is 0.90 and 0.95, respectively. k is calculated as in Eq. (10).

$$k = \frac{(a' + b' - c' + d').CI(\widetilde{\alpha}')}{2} \tag{10}$$

Table 1
Decomposed Fuzzy Linguistic Scale [31].

Optimistic Linguistic Terms	μ	ν	Saaty Scale	Pessimistic Linguistic Terms	μ	ν
Exactly Equal Important (EEI)	0.50	0.50	1	Exactly Equal Unimportant (EEU)	0.50	0.50
Slightly More Important (SMI)	0.55	0.45	2	Slightly Equal Unimportant (SMU)	0.45	0.55
Weakly More Important (WMI)	0.60	0.40	3	Weakly More Unimportant (WMU)	0.40	0.60
More Important (WMI)	0.65	0.35	4	More Unimportant (MU)	0.35	0.65
Strongly More Important (StMI)	0.70	0.30	5	Strongly More Unimportant (StMU)	0.30	0.70
Very Strongly More Important (VSI)	0.75	0.25	6	Very Strongly More Unimportant (VSU)	0.25	0.75
Absolutely More Important (AMI)	0.80	0.20	7	Absolutely More Unimportant (AMU)	0.20	0.80
Perfectly More Important (PMI)	0.85	0.15	8	Perfectly More Unimportant (PMU)	0.15	0.85
Exactly More Important (EMI)	0.90	0.10	9	Exactly More Unimportant (EMU)	0.10	0.90

4. Integrated AHP and CODAS methods based on DFS

This study employed the utilization of CODAS and AHP approaches, which are commonly cited multi-criteria decision-making methodologies in the existing literature. Both strategies are extended to the Decomposed fuzzy sets. Initially, the weights of the main criteria were determined using the Decomposed Fuzzy-Analytic Hierarchy Process (DF-AHP). In this section, we also proposed extension version of Combinative Distance-Based Assessment (CODAS) method to DFS. Subsequently, via the DF-CODAS approach, the alternatives are prioritized in descending order based on their respective relative weights. To estimate the desirability of an alternative, CODAS method uses the Euclidean distance as the primary and the Hamming distance as the secondary measure, and these distances are determined according to the negative-ideal solution. The alternative which has bigger distances is more desired in the CODAS approach. One of the notable contributions of this study involves the extension of the CODAS method to incorporate decomposed fuzzy sets. Additionally, the study introduces an integrated approach that combines CODAS and AHP to effectively determine the optimal parcel locker position. The following pseudo-code is divided into three stages. The first stage determines expert consistency; the second stage determines the key criterion weights; and the third stage determines alternate rankings. The proposed methodology steps are given as pseudo code below.

Pseudo Code of DF- AHP-CODAS methods.

Input: ***n****: number of criteria* $(i = 1, 2, \ldots n)$, ***m***: number of alternatives $(j = p = alias = 1, 2, \ldots m)$, s : number of decision-makers $(k = 1, 2, \ldots s)$.

Output: The ranking of the alternatives.

begin.

Stage 1: Decomposed Fuzzy AHP: The consistency analysis.

for $k = 1 : s$ **do:**

Step 1.1: Establish the linguistic decomposed fuzzy pairwise decision matrices for each evaluation by using Table 1.

Step 1.2: Alter linguistic terms into corresponding decomposed fuzzy numbers (DFNs) and then to the corresponding Saaty scale based on Table 1. To calculate the Saaty scale for this DFS numbers, the regression model was constructed to create crisp numbers between 1 to 9. The coefficients of the model are significant, and the coefficient of determination is equal to 1.

for each pairwise comparison matrix **do** classical consistency analysis:

$CR = \frac{CI}{RI}$ where $CI = \frac{\lambda_{\max} - n}{n-1}$, $\lambda_{\max}$ is the eigenvalue, and RI is the.

random consistency index. If the consistency ratio is less than 0.10, the pairwise matrix can be assumed as consistent.

Note that : Due to the difficulty of the problem and the magnitude of the pairwise comparison matrices (PCM), the current evaluation determined the CR threshold to be 0.2; the reason for this is the limited ability of humans to estimate large PCMs [27].

end for.

end for.

Stage 2: Decomposed Fuzzy AHP: Computing global weights.

for $k = 1 : s$ **do:**

Step 2.1: Combine the decomposed fuzzy PCMs and derive the decomposed fuzzy.

weights of the criteria using the DWGM Operator given in Eq. (7) for each individual decision-maker or consensus group. If we have separated decision-makers evaluations, all individual matrices can be integrated by using Eq. (7) as well.

end for.

Step 2.2: Obtain global sub-criteria decomposed fuzzy weights, multiply decomposed fuzzy criteria weights and sub-criteria weights using Eq. (3). The same steps should be taken again to obtain alternate scores.

Step 2.3: Convert the decomposed fuzzy global weights of the criteria into crisp values.

for $i = 1 : n$ **calculate** consistency ratio:

$$w_i^{\;CI(\widetilde{\alpha})} = 1 - \left(\sqrt{\frac{(a_i - d_i)^2 + (b_i - c_i)^2 + (1 - a_i - b_i)^2 + (1 - c_i - d_i)^2}{2}} \right) \tag{11}$$

end for.

for $i = 1 : n$ **compute** score values of weights:

if $w_i^{\;SI(\widetilde{\alpha})} \geq 0 : w_i^{\;SI(\widetilde{\alpha})} = \frac{(a_i + b_i - c_i + d_i).CI(\widetilde{\alpha})}{2.k}$ where $k = 0.90$.

else *return*0;.

end for.

Stage 3: Decomposed fuzzy CODAS: Ranking of the alternatives.

for $\boldsymbol{k} = \mathbf{1}$: s do:

Step 3.1: Collect the decomposed linguistic decision matrices $\left[\widetilde{L}_k\right]$ as in Eq. (12) from each decision-maker.

$$\widetilde{L}_k = \begin{array}{cccccc} & A_1 & A_2 & \cdots & A_m \\ C_1 & \left(\left(\mu_{11}^{\mathscr{O}k}(x), v_{11}^{\mathscr{O}k}(x)\right), \left(\mu_{11}^{\mathscr{P}k}(x), v_{11}^{\mathscr{P}k}(x)\right)\right) & \left(\left(\mu_{12}^{\mathscr{O}k}(x), v_{12}^{\mathscr{O}k}(x)\right), \left(\mu_{12}^{\mathscr{P}k}(x), v_{12}^{\mathscr{P}k}(x)\right)\right) & \cdots & \left(\left(\mu_{1m}^{\mathscr{O}k}(x), v_{11}^{\mathscr{O}k}(x)\right), \left(\mu_{1m}^{\mathscr{P}k}(x), v_{1m}^{\mathscr{P}k}(x)\right)\right) \\ C_2 & \left(\left(\mu_{21}^{\mathscr{O}k}(x), v_{11}^{\mathscr{O}k}(x)\right), \left(\mu_{21}^{\mathscr{P}k}(x), v_{21}^{\mathscr{P}k}(x)\right)\right) & \left(\left(\mu_{22}^{\mathscr{O}k}(x), v_{22}^{\mathscr{O}k}(x)\right), \left(\mu_{22}^{\mathscr{P}k}(x), v_{22}^{\mathscr{P}k}(x)\right)\right) & \cdots & \left(\left(\mu_{2m}^{\mathscr{O}k}(x), v_{21}^{\mathscr{O}k}(x)\right), \left(\mu_{1m}^{\mathscr{P}k}(x), v_{2m}^{\mathscr{P}k}(x)\right)\right) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & \left(\left(\mu_{n1}^{\mathscr{O}k}(x), v_{n1}^{\mathscr{O}k}(x)\right), \left(\mu_{n1}^{\mathscr{P}k}(x), v_{n1}^{\mathscr{P}k}(x)\right)\right) & \left(\left(\mu_{n2}^{\mathscr{O}k}(x), v_{12}^{\mathscr{O}k}(x)\right), \left(\mu_{n2}^{\mathscr{P}k}(x), v_{n2}^{\mathscr{P}k}(x)\right)\right) & \cdots & \left(\left(\mu_{nm}^{\mathscr{O}k}(x), v_{11}^{\mathscr{O}k}(x)\right), \left(\mu_{nm}^{\mathscr{P}k}(x), v_{nm}^{\mathscr{P}k}(x)\right)\right) \end{array} \tag{12}$$

Step 3.2: Convert $\left[\widetilde{L}_k\right]$ matrices into the corresponding DFNs by using Table 2.

end for.

Step 3.3: Obtain the aggregated decision matrix $\left[\widetilde{L}_{agg.}\right]$ using DWGM operator (Eq. (7)).

Step 3.4: Multiply aggregated expert group judgments $\left[\widetilde{L}_{agg.}\right]$ and compromise criteria weights $\left(w_i^{SI(\widetilde{\alpha})}\right)$ to get aggregated weighted decision matrix $((L_w)_{m\times n})$ based on Eq. (3).

Step 3.5: Compute the score values $((R_w)_{m\times n})$ of DFNs by using the Step 2.4 formula and determine the Decomposed Fuzzy Negative Ideal Solution ($\widetilde{DFNIS_i}$) through the low scores as in Eq. (13).

$$\widetilde{DFNIS_i} = \begin{pmatrix} \left(\left(\mu_1^{\mathscr{O}-}(x), v_1^{\mathscr{O}-}(x)\right), \left(\mu_1^{\mathscr{P}-}(x), v_1^{\mathscr{P}-}(x)\right)\right), \left(\left(\mu_2^{\mathscr{O}-}(x), v_2^{\mathscr{O}-}(x)\right), \left(\mu_2^{\mathscr{P}-}(x), v_2^{\mathscr{P}-}(x)\right)\right) \\ \ldots, \left(\left(\mu_n^{\mathscr{O}-}(x), v_n^{\mathscr{O}-}(x)\right), \left(\mu_n^{\mathscr{P}-}(x), v_n^{\mathscr{P}-}(x)\right)\right) \end{pmatrix} \tag{13}$$

Step 3.6: Calculate the intervals connecting alternatives X_l and the $\widetilde{DFNIS_i}$ by using normalized Euclidean distance and Hamming distance equations as in Eqs. (14) and (15), respectively.

for $j = 1 : m$ **calculate:**

$$S_j^{E} = \sqrt{\frac{1}{4n}\sum_{i=1}^{n}\left\{\left(\mu_{ij}^{o} - \mu_i^{o-}\right)^2 + \left(v_{ij}^{o} - v_i^{o-}\right)^2 + \left(\mu_{ij}^{p} - \mu_i^{p-}\right)^2 + \left(v_{ij}^{p} - v_i^{p-}\right)^2\right\}} \tag{14}$$

$$S_j^{H} = \sqrt{\frac{1}{4n}\sum_{i=1}^{n}\left\{\left|\left(\mu_{ij}^{o} - \mu_i^{o-}\right)\right| + \left|\left(v_{ij}^{o} - v_i^{o-}\right)\right| + \left|\left(\mu_{ij}^{p} - \mu_i^{p-}\right)\right| + \left|\left(v_{ij}^{p} - v_i^{p-}\right)\right|\right\}} \tag{15}$$

Step 3.7: Compute the relative assessment matrix $\left[S_{jp}\right]_{mxm}$ based on Eq. (16):

$$\left[S_{jp}\right]_{mxm} = \left(S_j^E - S_p^E\right) + \left(\Gamma\left(S_j^E - S_p^E\right) \bullet \left(S_j^H - S_p^H\right)\right) \tag{16}$$

where threshold function Γ is;

$$\Gamma(x) = \begin{Bmatrix} 1 if |x| \geq \gamma \\ 0 if |x| < \gamma \end{Bmatrix} \text{and} \gamma = 0.02.$$

Step 3.8: Compute the appraisal scores (Eq. (17)) and ranking them from highest to lowest.

$$AS_j = \sum\nolimits_{p=1}^{m} S_{jp} \tag{17}$$

end for.

end.

Stage 4: Validation and verification.

Input: The importance of the alternatives.

Output: Understanding of the results in terms of policy implications.

Perform Comparative performance through two different MCDM methods.

end.

Table 2
The decomposed fuzzy linguistic terms for CODAS [31].

Linguistic Terms	μ	ν
Absolutely Low (AL)	0.05	0.95
Very Low (VL)	0.2	0.8
Low (L)	0.35	0.65
Medium (M)	0.5	0.5
High (H)	0.65	0.35
Very High (VH)	0.8	0.2
Absolutely High (AH)	0.95	0.05

5. Application to parcel locker's location selection in Dublin

In this section, we apply the proposed a hybrid Decomposed Fuzzy AHP and CODAS model to address the problem of locating parcel lockers in Dublin City. It was initially implemented in the development of the decomposed fuzzy sets CODAS method, and utilizing the same fuzzy set mathematics, this distance-based method was combined with AHP. The method was implemented to address a practical issue that holds significance for the municipality of Dublin: the selection of a parcel locker. Subsequently, a comparative analysis is conducted to comprehensively evaluate both the model and the problem at hand.

Building on an extensive review of the literature and expert insights in the relevant field, this study has identified potential locations for parcel lockers and the corresponding criteria [54,55]. The researchers have carefully selected six evaluation alternatives, namely Public Transport Stops (A1), Private Car Parking (A2), Post Office (A3), Commercial Area (A4), High Population Density Area (A5), and Pedestrian Area (A6). To establish a hierarchical structure for the selection of parcel

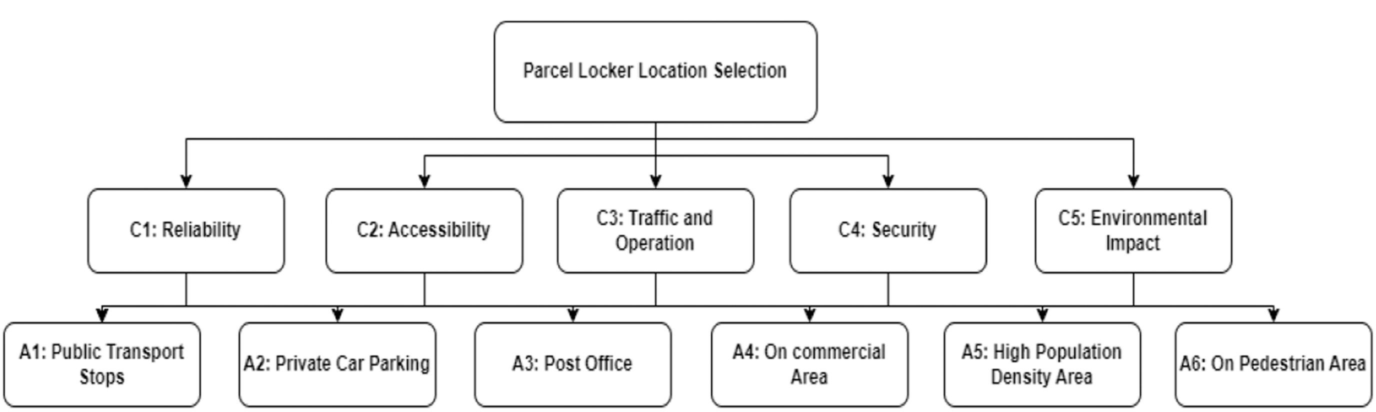

Fig. 1. The problem structure of the parcel locker location selection (PLLS) [27].

Table 3
The pairwise matrix in terms of main criteria.

Expert Group	C1. Reliability		C2. Accessibility		C3. Traffic and Operation		C4. Security		C5. Environmental Impact	
	O*	P**	O*	P**	O*	P**	O*	P**	O*	P**
C1	EEI	EEU	EEI	EEU	StMI	VSU	WMU	WMI	EEI	EEU
C2	EEU	EEI	EEI	EEU	VSI	AMU	StMU	WMI	EEI	EEU
C3	VSU	StMI	AMU	VSI	EEI	EEU	StMU	StMI	StMU	StMI
C4	WMI	WMU	WMI	StMU	StMI	StMU	EEI	EEU	AMI	VSU
C5	EEU	EEI	EEU	EEI	StMI	StMU	VSU	AMI	EEI	EEU

*Optimistic view, **: Pessimistic view

Table 4
The main criteria based on Expert Groups' evaluations.

Criterion	Expert Group					
		$\mathscr{O}(\mu_{ii}^k)$	$\mathscr{O}(\vartheta_{ii}^k)$	$\mathscr{P}(\mu_{ii}^k)$	$\mathscr{P}(\vartheta_{ii}^k)$	*Normalized Value*
C1	CR= 0.056	0.511	0.489	0.387	0.530	0.211
C2		0.490	0.510	0.338	0.540	0.208
C3		0.295	0.705	0.663	0.330	0.131
C4		0.632	0.368	0.270	0.650	0.256
C5		0.466	0.534	0.453	0.480	0.194

locker locations, the authors have developed a criteria and alternative framework (depicted in Fig. 1) based on the alternatives and five main criteria: Reliability (C1), Accessibility (C2), Traffic and Operation (C3), Security (C4), and Environmental Impact (C5). The problem structure of the parcel locker location is illustrated in Fig. 1. References such as Iwan et al. [5], Lagorio and Pinto [2] and Keeling et al. [18] contribute to the development of this framework.

In this PLLS problem, five criteria which are "reliability, accessibility, traffic and operation, security, and environmental impact" have been considered in the evaluation of six location alternatives. The consistency ratio of the pairwise comparison matrix which is given in Table 3 is calculated as 0.056 based on the linking Saaty values in Stage 1 for the linguistic scale. Using the scale presented in Table 1, the linguistic terms in Table 3 are converted to their corresponding decomposed fuzzy numbers for the expert group.

After that, applying decomposed fuzzy geometric mean operator, the global weights were obtained for each criterion. Next, the application of Step 2.4 and 2.5 yields the acquisition of precise weights for the evaluation criteria. Table 4 present the aggregated decomposed fuzzy values and normalized weights (w) for the evaluation criteria, along with their corresponding consistency ratios (CR).

Based on consensus expert evaluations, the most essential main criterion is "C4-Security". The least significant criterion is "C3: Traffic and Operation". Then, the decision matrix which is given in Table 5 are filled by three experts as consensus to assess six alternatives with respect to five criteria by using Table 2 linguistic scale.

The verbal evaluations are transformed into decomposed fuzzy

Table 7
Consistency Index of each alternative with respect to main criterion.

	C1. Reliability	C2. Accessibility	C3. Traffic and Operation	C4. Security	C5. Environmental Impact
A1	0.567	0.511	0.490	0.738	0.468
A2	0.490	0.545	0.636	0.645	0.558
A3	0.567	0.691	0.579	0.645	0.558
A4	0.570	0.545	0.374	0.456	0.558
A5	0.490	0.471	0.374	0.548	0.398
A6	0.493	0.291	0.446	0.171	0.488

Table 8
Score index values of each alternative with respect to main criterion.

	C1. Reliability	C2. Accessibility	C3. Traffic and Operation	C4. Security	C5. Environmental Impact
A1	0.502	0.513	0.362	0.670	0.411
A2	0.434	0.443	0.402	0.649	0.437
A3	0.502	0.562	0.428	0.649	0.437
A4	0.457	0.443	0.322	0.458	0.437
A5	0.434	0.420	0.322	0.498	0.350
A6	0.396	0.292	0.329	0.172	0.382

Table 5
Expert linguistic evaluations for decomposed fuzzy CODAS method.

Expert Group	C1. Reliability		C2. Accessibility		C3. Traffic and Operation		C4. Security		C5. Environmental Impact	
	O*	P**	O*	P**	O*	P**	O*	P**	O*	P**
A1	VH	VL	AH	AL	H	L	AH	VL	H	VL
A2	H	VL	H	L	VH	M	AH	AL	H	L
A3	VH	VL	AH	L	AH	L	AH	AL	H	L
A4	H	L	H	L	H	VL	H	AL	H	L
A5	H	VL	H	VL	H	VL	H	VL	M	VL
A6	M	L	M	AL	M	L	VL	AL	M	L

Table 6
Weighted aggregated decision matrix.

	C1. Reliability	C2. Accessibility	C3. Traffic and Operation	C4. Security	C5. Environmental Impact
A1	((0.41,0.59),(0.15,0.84))	((0.47,0.53),(0.05,0.95))	((0.19,0.81),(0.30,0.70))	((0.60,0.40),(0.13,0.85))	((0.30,0.70),(0.16,0.83))
A2	((0.33,0.67),(0.15,0.84))	((0.32,0.68),(0.21,0.75))	((0.24,0.76),(0.40,0.60))	((0.60,0.40),(0.04,0.95))	((0.30,0.70),(0.25,0.74))
A3	((0.41,0.59),(0.15,0.84))	((0.47,0.53),(0.21,0.75))	((0.28,0.72),(0.30,0.70))	((0.60,0.40),(0.04,0.95))	((0.30,0.80),(0.25,0.74))
A4	((0.33,0.67),(0.23,0.75))	((0.32,0.68),(0.21,0.75))	((0.19,0.81),(0.18,0.82))	((0.41,0.59),(0.04,0.95))	((0.30,0.70),(0.25,0.74))
A5	((0.33,0.67),(0.15,0.84))	((0.32,0.68),(0.14,0.84))	((0.19,0.81),(0.18,0.82))	((0.41,0.59),(0.13,0.85))	((0.23,0.77),(0.16,0.83))
A6	((0.26,0.74),(0.23,0.75))	((0.24,0.76),(0.05,0.95))	((0.15,0.85),(0.30,0.70))	((0.13,0.87),(0.04,0.95))	((0.23,0.77),(0.25,0.74))

values using the linguistic rating scale outlined in Table 2. In this case, we do not need to use aggregation operator since Table 5 is already aggregated judgments by decision-making group. The weighted aggregated expert judgments have been obtained by using Eq. (3) and indicated in Table 6.

To determine decomposed fuzzy negative ideal solution, The score index of each alternative with respect to each criterion must be calculated. First, the consistency index has been computed and then score index is obtained as in Step 2.4. The consistency index of Alternative 1 to C1. Reliability is obtained as 0.567 as in Step 2.4.

$$CI_{A1-C1} = 1 - \left(\sqrt{\frac{(0.41-0.84)^2 + (0.59-0.15)^2 + (1-0.41-0.59)^2 + (1-0.15-0.84)^2}{2}} \right)$$

$CI_{A1-C1} = 0.567$

Based on the below example, the score index values are computed as in Table 8.

$$SI_{A1-C1} = \frac{(0.41+0.59-0.15+0.84)\times 0.567}{2\times 0.95} = 0.502$$

where k = 0.95.

Based on the minimum score index values, the decomposed fuzzy negative ideal solution for each criterion can be determined as in Table 9.

$$\widetilde{L}_k = \begin{array}{cccccc} & A_1 & A_2 & \cdots & A_m \\ C_1 & \left(\left(\mu_{11}^{\mathscr{O}^k}(x), v_{11}^{\mathscr{O}^k}(x)\right), \left(\mu_{11}^{\mathscr{P}^k}(x), v_{11}^{\mathscr{P}^k}(x)\right)\right) & \left(\left(\mu_{12}^{\mathscr{O}^k}(x), v_{12}^{\mathscr{O}^k}(x)\right), \left(\mu_{12}^{\mathscr{P}^k}(x), v_{12}^{\mathscr{P}^k}(x)\right)\right) & \cdots & \left(\left(\mu_{1m}^{\mathscr{O}^k}(x), v_{11}^{\mathscr{O}^k}(x)\right), \left(\mu_{1m}^{\mathscr{P}^k}(x), v_{1m}^{\mathscr{P}^k}(x)\right)\right) \\ C_2 & \left(\left(\mu_{21}^{\mathscr{O}^k}(x), v_{11}^{\mathscr{O}^k}(x)\right), \left(\mu_{21}^{\mathscr{P}^k}(x), v_{21}^{\mathscr{P}^k}(x)\right)\right) & \left(\left(\mu_{22}^{\mathscr{O}^k}(x), v_{22}^{\mathscr{O}^k}(x)\right), \left(\mu_{22}^{\mathscr{P}^k}(x), v_{22}^{\mathscr{P}^k}(x)\right)\right) & \cdots & \left(\left(\mu_{2m}^{\mathscr{O}^k}(x), v_{21}^{\mathscr{O}^k}(x)\right), \left(\mu_{1m}^{\mathscr{P}^k}(x), v_{2m}^{\mathscr{P}^k}(x)\right)\right) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & \left(\left(\mu_{n1}^{\mathscr{O}^k}(x), v_{n1}^{\mathscr{O}^k}(x)\right), \left(\mu_{n1}^{\mathscr{P}^k}(x), v_{n1}^{\mathscr{P}^k}(x)\right)\right) & \left(\left(\mu_{n2}^{\mathscr{O}^k}(x), v_{12}^{\mathscr{O}^k}(x)\right), \left(\mu_{n2}^{\mathscr{P}^k}(x), v_{n2}^{\mathscr{P}^k}(x)\right)\right) & \cdots & \left(\left(\mu_{nm}^{\mathscr{O}^k}(x), v_{11}^{\mathscr{O}^k}(x)\right), \left(\mu_{nm}^{\mathscr{P}^k}(x), v_{nm}^{\mathscr{P}^k}(x)\right)\right) \end{array} \tag{18}$$

The subsequent procedure involves computing the distances of each alternative from the negative ideal solutions using two distinct distance measurement methods. The computation of the Euclidean and Hamming distances is achieved through the utilization of Eqs. (14) and (15), respectively.

Based on Table 10, the appraisal scores are calculated by using Steps 3.7 and 3.8. For instance, to calculate relative assessment of A1 to A2, the following calculation can be used.

$$R[S_{jp}]_{mxm} = \left(S_j^{E} - S_p^{E}\right) + \left(\Gamma(S_j^{E} - S_p^{E})\cdot(S_j^{H} - S_p^{H})\right) = (0.182-0.184) + \Gamma(0.182-0.184).(0.121-0.131) \quad where \quad \Gamma(|0.182-0.184|) = 0 since \quad |0.182-0.184| < 0.02$$

Hence, the appraisal scores and the ranking of the alternatives are given in Table 11.

According to the appraisal scores, the third location "*A3- Post Office*" is the most appropriate alternative, and the sixth location is the least appropriate alternative "*A6*-Pedestrian Area". Other alternative ranking are as follows: *A2 >A1 >A4 >A5*.

6. Comparative Analyses

To demonstrate the strength and dependability of the suggested approach, a comparative analysis has been conducted utilizing the decomposed fuzzy TOPSIS method. The steps of the decomposed fuzzy TOPSIS are given as Pseudo-codes as follows.

Pseudo-Code Representation of Decomposed Fuzzy TOPSIS Method.

Input: n: number of criteria ($i = 1, 2, \ldots n$), **m**: number of alternatives ($j = p = alias = 1, 2, \ldots m$), s : number of decision-makers ($k = 1, 2, \ldots s$).

Output: The ranking of the alternatives.

for $\boldsymbol{k} = \mathbf{1}$: s do:

Step 1: Collect the decomposed linguistic decision matrices $\left[\widetilde{L}_k\right]$ as in Eq. (18) from each decision-maker.

Step 2: Convert $\left[\widetilde{L}_k\right]$ matrices into the corresponding decomposed fuzzy numbers (DFNs) based on Table 2.

end for.

Step 3: Obtain the aggregated decision matrix $\left[\widetilde{L}_{agg.}\right]$ using DWGM operator (Eq. (7)).

Step 4: Multiply aggregated expert group judgments $\left[\widetilde{L}_{agg.}\right]$ and compromise criteria weights $\left(w_i^{SI(\widetilde{\alpha})}\right)$ to get aggregated weighted decision matrix $\left((L_w)_{m\times n}\right)$.

Step 5: Calculate the score values of DFNs by using the Step 2.4 formula and determine the Decomposed Fuzzy Positive and Negative

Table 9
Decomposed fuzzy negative ideal solution.

	Decomposed Fuzzy Negative Ideal Solution (DF-NIS)
C1	((0.26,0.74), (0.23,0.75))
C2	((0.24,0.76), (0.05,0.95))
C3	((0.19,0.81), (0.18,0.82))
C4	((0.13,0.87), (0.04,0.95))
C5	((0.23,0.77), (0.16,0.83))

Table 10
Distances to decomposed fuzzy negative ideal solution.

	S_j^E	S_j^H
A1	0.182	0.121
A2	0.184	0.131
A3	0.193	0.147
A4	0.118	0.078
A5	0.109	0.071
A6	0.049	0.025

Ideal Solutions ($\widetilde{DFPIS_i} and \widetilde{DFNIS_i}$) through the high and low scores as given in Eqs. (19) and (20).

$$\widetilde{DFPIS_i} = \begin{pmatrix} \left(\left(\mu_1^{\mathscr{O}^*}(x), v_1^{\mathscr{O}^*}(x)\right), \left(\mu_1^{\mathscr{P}^*}(x), v_1^{\mathscr{P}^*}(x)\right)\right), \left(\left(\mu_2^{\mathscr{O}^*}(x), v_2^{\mathscr{O}^*}(x)\right), \left(\mu_2^{\mathscr{P}^*}(x), v_2^{\mathscr{P}^*}(x)\right)\right) \\ \ldots, \left(\left(\mu_n^{\mathscr{O}^*}(x), v_n^{\mathscr{O}^*}(x)\right), \left(\mu_n^{\mathscr{P}^*}(x), v_n^{\mathscr{P}^*}(x)\right)\right) \end{pmatrix} \tag{19}$$

$$\widetilde{DFNIS_i} = \begin{pmatrix} \left(\left(\mu_1^{\mathscr{O}^-}(x), v_1^{\mathscr{O}^-}(x)\right), \left(\mu_1^{\mathscr{P}^-}(x), v_1^{\mathscr{P}^-}(x)\right)\right), \left(\left(\mu_2^{\mathscr{O}^-}(x), v_2^{\mathscr{O}^-}(x)\right), \left(\mu_2^{\mathscr{P}^-}(x), v_2^{\mathscr{P}^-}(x)\right)\right) \\ \ldots, \left(\left(\mu_n^{\mathscr{O}^-}(x), v_n^{\mathscr{O}^-}(x)\right), \left(\mu_n^{\mathscr{P}^-}(x), v_n^{\mathscr{P}^-}(x)\right)\right) \end{pmatrix} \tag{20}$$

Step 6: Calculate the distances from alternatives to the $\widetilde{DFPIS_i}$ and $\widetilde{DFNIS_i}$ by using normalized Euclidean distance based on Eqs. (21) and (22), respectively.

for $j = 1 : m$ calculate:

$$S_j^P = \sqrt{\frac{1}{4}\sum_{i=1}^{n}\left\{\left(\mu_{ij}^o - \mu_i^{o*}\right)^2 + \left(v_{ij}^o - v_i^{o*}\right)^2 + \left(\mu_{ij}^p - \mu_i^{p*}\right)^2 + \left(v_{ij}^p - v_i^{p*}\right)^2\right\}} \tag{21}$$

$$S_j^N = \sqrt{\frac{1}{4}\sum_{i=1}^{n}\left\{\left(\mu_{ij}^o - \mu_i^{o-}\right)^2 + \left(v_{ij}^o - v_i^{o-}\right)^2 + \left(\mu_{ij}^p - \mu_i^{p-}\right)^2 + \left(v_{ij}^p - v_i^{p-}\right)^2\right\}} \tag{22}$$

Step 7: Compute the closeness ratio of each alternative (Eq. (23)) and rank in descending order.

$$£_j = \frac{S_j^N}{S_j^N + S_j^P} \tag{23}$$

Table 11
Relative assessment matrix ($\gamma = \mathbf{0.02}$).

	A1	A2	A3	A4	A5	A6	Appraisal Scores	Rank
A1	0.000	-0.002	-0.011	0.107	0.122	0.229	0.445	3
A2	0.002	0.000	-0.009	0.120	0.134	0.241	0.489	2
A3	0.011	0.009	0.000	0.145	0.160	0.266	0.590	1
A4	-0.107	-0.120	-0.145	0.000	0.009	0.122	-0.241	4
A5	-0.122	-0.134	-0.160	-0.009	0.000	0.107	-0.318	5
A6	-0.229	-0.241	-0.266	-0.122	-0.107	0.000	-0.965	6

Table 12
Euclidean distances to $\widetilde{DFPIS_i}$ and $\widetilde{DFNIS_i}$ and ranking of the alternatives.

Alternatives	S_j^P	S_j^N	$£_j$	Rank
A1	0.219	0.111	0.663	3
A2	0.240	0.089	0.729	2
A3	0.224	0.049	0.821	1
A4	0.190	0.121	0.610	4
A5	0.169	0.122	0.581	5
A6	0.225	0.213	0.514	6

end for.
end.

In contrast to the CODAS method, the positive ideal solution was identified and only the Euclidean distance was computed. The results of the DF-TOPSIS method are shared in Table 12.

For the second comparative analysis, the decomposed fuzzy AHP (DF-AHP) method introduced by Cebi et al. [31] was applied to the problem of parcel locker location selection. To implement the DF-AHP, it was necessary to evaluate each alternative based on each criterion. The same experts assessed each alternative based on each criterion and compiled pairwise comparison matrices as given in Appendix in Table A.1. The DWGM operator was then used to compute local weights. By multiplying the criterion weights in the proposed method with the decomposed fuzzy alternative scores using Eq. (3), the global weights shown in Table 13 were calculated.

The outcome of the comparative study reveals that the suggested methodology maintains the same best and worst alternatives; however, the research reveals that the second and third alternatives changed considering the new approach.

7. Discussion and conclusion

This research is particularly relevant in Dublin's logistics and last-mile delivery due to unique challenges like the urgent need for eco-friendly solutions, congested urban streets, and evolving consumer behavior post-COVID-19. Addressing these challenges is crucial for enhancing delivery efficiency, offering insights applicable globally.

In this study, Decomposed Fuzzy Sets based CODAS method was developed and the proposed method was integrated with decomposed fuzzy AHP method under fuzziness. The purpose of the proposed study was to improve the decision-making process in situations where linguistic data is uncertain and ambiguous. By incorporating the DF AHP-

Table 13
The results of the decomposed fuzzy AHP.

	Decomposed fuzzy global weights	Consistency Index	Score Index	Numerical weights	Rank
A1	((0.25,0.66), (0.21,0.71))	0.534	0.420	0.171	2
A2	((0.24,0.71), (0.19,0.69))	0.505	0.406	0.165	3
A3	((0.27,0.72), (0.22,0.69))	0.533	0.433	0.176	1
A4	((0.22,0.76), (0.27,0.65))	0.534	0.406	0.165	4
A5	((0.22,0.75), (0.28,0.65))	0.541	0.404	0.164	5
A6	((0.19,0.76), (0.31,0.64))	0.546	0.390	0.159	6

CODAS method, we were able to resolve the shortcomings of traditional decision-making techniques regarding the precision and consistency of assigned expert judgments. According to the results, the "security" criterion was shown to be the most significant for the selection of parcel locker location. Considering the importance of security, it is found that a post office is the best location for a parcel locker. Through the application of the DF AHP-CODAS, the method effectively captured the inherent uncertainty in the data and enabled decision-makers to make informed decisions based on exhaustive assessments related to the selection of parcel locker location. An important advantage of the proposed method is its ability to deal with uncertain and complicated data sets by permitting the representation and analysis of fuzzy and imprecise information, thereby providing decision-makers with a clearer understanding of the decision space via functional and dysfunctional questions. Encouraging assessors to consider both optimistic and pessimistic scoring has been demonstrated as an effective strategy for self-assessment and gaining a more profound understanding of participants' thought processes.

However, the proposed study is limited by the fact that asking two-way questions complicates data collection, as the method generates effective results in the collected data by asking optimistic and pessimistic view questions.

Future research is proposed to develop interval-valued decomposed fuzzy set-based decision-making methods to capture and represent the imprecision and uncertainty present in real-world data more accurately. In addition, most common MCDM techniques, such as Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [64], Multi-Objective Analysis by Ratio Analysis plus the Full Multiplicative Form (MULTIMOORA) [65], the Additive Ratio Assessment (ARAS) method [66], TOmada de Decisao Interativa e Multicrit'evio (TODIM) [67], and Evaluation based on distance from average solution (EDAS) [68] can be extended to DFS and implemented to select parcel locker locations and compare them. By growing the quantity of criteria and choices, the identical challenge can be addressed once more with the same methodology or different MCDM techniques [69,70]. Also, more stakeholder groups can be involved in the evaluation process to get more reliable outcome and support the policy makes in their future decision-making plans.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix

Table A.1
The linguistic terms for decomposed fuzzy AHP.

C1	A1		A2		A3		A4		A5		A6	
	O*	P**	O*	P**	O*	P**	O*	P**	O*	P**	O*	P**
A1	EEI	EEU	StMI	MU	WMI	WMU	AMI	AMU	AMI	AMU	AMI	VSU
A2	MU	StMI	EEI	EEU	WMU	WMI	StMI	MU	AMI	AMU	StMI	MU
A3	WMU	WMI	WMI	WMU	EEI	EEU	StMI	StMU	AMI	AMU	EMI	PMU
A4	AMU	AMI	MU	StMI	StMU	StMI	EEI	EEU	WMI	SMU	SMI	WMU
A5	AMU	AMI	AMU	AMI	AMU	AMI	SMU	WMI	EEI	EEU	WMI	WMU
A6	VSU	AMI	MU	StMI	PMU	EMI	WMU	SMI	WMU	WMI	EEI	EEU
C2	**A1**		**A2**		**A3**		**A4**		**A5**		**A6**	
	O*	**P****	**O***	**P****	**O***	**P****	**O***	**P****	**O***	**P****	**O***	**P****
A1	EEI	EEU	WMI	WMU	StMU	StMI	StMU	StMI	WMU	WMI	WMI	WMU
A2	WMU	WMI	EEI	EEU	AMU	PMI	StMU	StMI	MU	WMI	VSI	StMU
A3	StMI	StMU	PMI	WMU	EEI	EEU	WMI	WMU	WMI	WMU	AMI	PMU
A4	StMI	StMU	StMI	StMU	WMU	WMI	EEI	EEU	WMI	MU	AMI	AMU
A5	WMI	WMU	WMI	MU	WMU	WMI	MU	WMI	EEI	EEU	AMI	AMU
A6	WMU	WMI	StMU	VSI	PMU	AMI	AMU	AMI	AMU	AMI	EEI	EEU
C3	**A1**		**A2**		**A3**		**A4**		**A5**		**A6**	
	O*	**P * ***	**O***	**P * ***	**O***	**P * ***	**O***	**P * ***	**O***	**P * ***	**O***	**P * ***
A1	EEI	EEU	WMI	WMU	StMI	StMU	StMI	StMU	StMI	StMU	StMI	StMU
A2	WMU	WMI	EEI	EEU	StMI	StMU	StMI	StMU	StMI	StMU	AMI	VSU
A3	StMU	StMI	StMU	StMI	EEI	EEU	WMI	WMU	WMI	WMU	WMI	WMU
A4	StMU	StMI	StMU	StMI	WMU	WMI	EEI	EEU	WMI	WMU	WMI	WMU
A5	StMU	StMI	StMU	StMI	WMU	WMI	WMU	WMI	EEI	EEU	EEI	EEU
A6	StMU	StMI	VSU	AMI	WMU	WMI	WMU	WMI	EEU	EEI	EEI	EEU
C4	**A1**		**A2**		**A3**		**A4**		**A5**		**A6**	
	O*	**P * ***	**O***	**P * ***	**O***	**P * ***	**O***	**P * ***	**O***	**P * ***	**O***	**P * ***

(continued on next page)

Table A.1 (*continued*)

C1	A1		A2		A3		A4		A5		A6	
	O*	P**	O*	P**	O*	P**	O*	P**	O*	P**	O*	P**
A1	EEI	EEU	WMU	WMI	StMU	StMI	StMU	StMI	StMU	StMI	WMU	SMI
A2	WMI	WMU	EEI	EEU	StMU	StMI	SMU	SMI	MU	MI	SMI	WMU
A3	StMI	StMU	StMI	StMU	EEI	EEU	MI	MU	MI	MU	SMI	SMU
A4	StMI	StMU	SMI	SMU	MU	MI	EEI	EEU	MI	MU	StMI	StMU
A5	StMI	StMU	MI	MU	MU	MI	MU	MI	EEI	EEU	SMI	SMU
A6	SMI	WMU	WMU	SMI	SMU	SMI	StMU	StMI	SMU	SMI	EEI	EEU
C5	**A1**		**A2**		**A3**		**A4**		**A5**		**A6**	
	O*	**P * ***	**O***	**P * ***	**O***	**P * ***	**O***	**P * ***	**O***	**P * ***	**O***	**P * ***
A1	EEI	EEU	WMI	WMU	WMI	WMU	AMI	AMU	WMI	SMU	WMU	SMI
A2	WMU	WMI	EEI	EEU	AMI	AMU	AMI	AMU	SMI	SMU	SMU	SMI
A3	WMU	WMI	AMU	AMI	EEI	EEU	WMI	WMU	WMU	MI	StMU	StMI
A4	AMU	AMI	AMU	AMI	WMU	WMI	EEI	EEU	VSU	VSI	StMU	MI
A5	SMU	WMI	SMU	SMI	MI	WMU	VSI	VSU	EEI	EEU	StMU	StMI
A6	SMI	WMU	SMI	SMU	StMI	StMU	MI	StMU	StMI	StMU	EEI	EEU

O*: Optimistic view; P**: Pessimistic view

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