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Operational Feasibility of Metro-Assisted Crowdshipping for Urban Freight: An AHP–MCDM Assessment of Logistics Operators along the Delhi Metro Blue Line

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Abstract - *Urban freight distribution in rapidly growing cities is increasingly constrained by road congestion, limited load-ing and unloading space, and the high operational dependence of last-mile delivery on road-based modes. Existing urban parcel movement in Delhi remains largely road-oriented, with light commercial vehicles supporting inbound freight and two-wheelers dominating local deliveries, while most consignments are small, light, and moved over short-to-medium urban dis-tances. This study evaluates the feasibility of integrating metro-based freight movement with collaborative crowdshipping using the Delhi Metro Blue Line as a case study. A 5 km catchment was delineated along the corridor, within which 241 logistics establishments were mapped and 141 operators were surveyed, supplemented by interviews with Delhi Metro Rail Corporation and logistics stakeholders. Physical, operational, and attitudinal characteristics were analyzed to assess shipment suitability, operator readiness, preferred operating arrangements, and implementation barriers. The results indicate high willingness to use metro for suitable freight categories, with the platform locker system emerging as the most preferred model, followed by a dedicated cargo coach, while mixed passenger-freight operation received minimal support. Off-peak daytime operation was preferred, whereas additional cost, station suitability, and platform-level cargo transfer emerged as key concerns. The study con-tributes an India-specific, stakeholder-based framework linking shipment characteristics, operator profiles, and metro operating alternatives for crowdshipping adoption. Policy implications include station-based parcel lockers, designated freight-handling areas, off-peak freight windows, improved loading and unloading arrangements, and institutional coordination for first- and last-mile transfer.*

Key Words: Crowdshipping, urban freight logistics, metro-based freight, public transport, last-mile delivery, parcel lockers, stakeholder perception

1. INTRODUCTION

Rapid urbanization and the growth of e-commerce have in-creased the demand for efficient urban parcel distribution, while conventional last-mile logistics remains largely dependent on road-based vehicles. This contributes to congestion, emissions, loading and unloading conflicts, and increasing operational pres-sure within dense urban areas. Integration of urban freight with existing public transport infrastructure has therefore emerged as a potential sustainable logistics strategy [1].

Crowdshipping extends this concept by allowing travellers to transport parcels along their pre-planned trips. Public-transport-based crowdshipping can utilize metro, rail, or bus passengers for selected parcel movements without generating an entirely separate freight trip. Previous studies have demonstrated its po-tential through stated-preference analysis, parcel allocation, and operational modelling [2, 3]. Parcel lockers at public transport stations have also been proposed as transfer points between logistics operators, crowdshippers, and recipients [4,5]. However, successful implementation depends not only on passenger par-ticipation but also on shipment characteristics such as logistics-operator requirements, transfer facilities, operating periods, and associated costs.

The present study investigates these issues using the Delhi Metro Blue Line as a case-study corridor. Logistics establishments lo-cated within a 5 km catchment were mapped, and 141 operators were surveyed to examine their physical, operational, and attitu-dinal characteristics. The study evaluates shipment suitability, existing delivery practices, willingness to shift suitable freight to metro, preferred operating periods, and alternative arrangements including platform parcel lockers, dedicated cargo coaches, and mixed passenger–freight operations.

1.1 Background

The proposed system integrates conventional logistics opera-tions, metro-based trunk movement, and collaborative first- and last-mile delivery. Previous studies indicate that small parcels, short detours, suitable incentives, and convenient transfer facil-ities strongly influence the feasibility of public-transport-based crowdshipping [6, 7]. The Delhi Metro provides an appropriate context for examining such integration because of its extensive urban coverage and previous

freight pilot operations.

1.2 Research Gap and Objectives

Existing research has largely focused on passenger willingness, parcel allocation, and optimization of public-transport-based crowdshipping. Comparatively limited empirical evidence ex-ists on the requirements and perceptions of logistics operators, particularly in the Indian context. This study therefore aims to:

- characterize logistics establishments, shipment types, and existing delivery operations within the study corridor;
- assess the suitability and willingness of operators to shift selected freight movements to the metro;
- identify preferred freight operating periods and operational models, including parcel lockers and dedicated cargo coaches; and
- identify major implementation barriers and derive planning and policy implications for metro-assisted crowdshipping.

2. LITERATURE REVIEW

The integration of urban freight with public transportation has received increasing attention as cities seek to reduce the envi-ronmental and operational impacts of conventional road-based freight distribution. Elbert and Rentschler [8] reviewed different forms of freight transport using urban public transportation and showed that existing infrastructure, vehicles, and available ca-pacity can potentially be shared between passenger and freight movements. Their review identified metro, rail, tram, and bus systems as possible modes for freight integration, while emphasizing operational constraints related to capacity, scheduling, handling, and transfer. More recent reviews similarly indicate that research has progressed from conceptual and pilot stud-ies toward optimization, transshipment planning, and integrated passenger–freight operations [1, 9].

Urban rail systems are particularly attractive for freight integra-tion because of their fixed routes, high carrying capacity, and potential availability of unused capacity during off-peak peri-ods. Li et al. [10] developed an urban rail service design model for collaborative passenger and freight transport in which freight could be accommodated either through dedicated freight trains or available space within passenger services. Ye et al. [11] further investigated mixed passenger and freight operations by considering train capacity, loading and unloading time, service headway, and freight operating cost. More recently, Li et al. [12] examined the use of residual metro capacity during off-peak hours and demonstrated that passenger and freight flows can be jointly scheduled while maintaining a balance between passen-ger service quality and freight demand. These studies establish the technical potential of metro-assisted freight movement but mainly concentrate on service design and optimization.

Within this broader concept, public-transport-based crowdship-ping has emerged as an alternative approach for utilizing ex-isting passenger trips for parcel movement. Gatta et al. [13] examined a mass-transit-based crowdshipping system in Rome in which automated parcel lockers located at or near public trans-port stations were used as collection and transfer points. The study highlighted potential environmental and economic bene-fits resulting from the use of passenger trips that would occur regardless of parcel delivery. Fessler et al. [2] subsequently used a stated-choice experiment to analyse passenger willing-ness to carry parcels on public transport and found that parcel size, weight, number of parcels, compensation, and additional travel time significantly affected participation.

The operational potential of public-transport-based crowdship-ping has also been demonstrated through case-study and op-timization approaches. Zhang et al. [3] evaluated crowd-shipping using public transport in Singapore and reported re-ductions in vehicle kilometres travelled, emissions, and de-livery cost when parcels were assigned to suitable passen-ger trips. Their findings also indicated that potential bene-fits could be achieved even when crowdshipping was restricted to off-peak periods. Cheng et al. [14] similarly demonstrated that public-transport-based crowdshipping could reduce con-ventional delivery-vehicle travel, driver working hours, and the number of vans required. However, both studies emphasized that system performance is strongly dependent on the availabil-ity of suitable crowdshippers and the practical organization of parcel transfers.

Parcel lockers and station-based transfer facilities have therefore become important elements of public-transport crowdshipping systems. Zhang and Cheah [4] proposed a framework in which parcels suitable for crowdshipping were first identified and sub-sequently matched with public transport passengers through se-lected parcel lockers. Their study demonstrated that only a portion of total parcel demand may be appropriate for crowd-shipping, highlighting the need for shipment-level suitability assessment. Wyrowski et al. [5] further developed an opti-mization framework in which public transport passengers trans-Yang et al. [15] extended this idea through a crowdsourced co-modality transportation system integrating passenger and freight

flows with a digital management platform and parcel-assignment mechanism.

Along with infrastructure and operational design, stakeholder willingness is critical for successful implementation. Mohri et al. [6] examined the intention of public transport passengers to participate as crowdshippers and identified time availability, physical effort, demographic characteristics, and previous fa-miliarity with parcel lockers as important factors affecting par-ticipation. Using a latent-class approach, Mohri et al. [7] further showed that crowdshippers are heterogeneous in their response to incentives, parcel weight, and required detour distance. These studies demonstrate that technological and operational feasibil-ity alone does not guarantee adoption and that stakeholder char-acteristics and perceptions must be incorporated into planning decisions.

Overall, the literature confirms the technical and operational po-tential of integrating passenger transport, metro systems, parcel lockers, and crowdshipping for sustainable urban freight dis-tribution. However, most existing studies focus primarily on passenger willingness, parcel-to-crowdshipper matching, opti-mization of train or parcel movements, and estimation of en-vironmental or economic benefits. Comparatively limited em-pirical attention has been given to the logistics-operator side of the system, particularly to how existing establishment charac-teristics, parcel profiles, storage requirements, delivery radius, operating cost, travel time, and freight-handling preferences in-fluence the feasibility of shifting freight to public transport. Fur-thermore, evidence from Indian metropolitan contexts remains limited. This creates a need for an operator-oriented assessment that links shipment characteristics, operational requirements, willingness to shift, preferred metro freight arrangements, and implementation barriers within an existing urban logistics envi-ronment.

3. STUDY AREA AND DATA COLLECTION

3.1 Delhi Metro Blue Line

The Delhi Metro Blue Line was selected as the case-study corri-dor because of its extensive urban coverage and concentration of logistics establishments within its influence area. A 5 km GIS-based catchment was delineated along the corridor to identify logistics establishments potentially suitable for metro-assisted freight integration. From 18,678 courier-service establish-ments identified in Delhi NCR, 241 establishments were mapped within the catchment, of which 141 were covered through pri-mary surveys.

Table -1: Study area and sample framework

Item	Study Details
Case-study corridor	Delhi Metro Blue Line
Main corridor	Dwarka Sector 21–Noida Electronic City
Branch corridor	Yamuna Bank–Vaishali
Catchment distance	5 km from Blue Line
Total courier population	18,678 establishments in Delhi NCR
Mapped establishments	241 within the 5 km catchment
Surveyed establishments	141 establishments
Major operators covered	DTDC, Blue Dart DHL, Tirupati Courier Services
Survey period	Primary surveys, 2025

3.2 Survey Design

Primary data collection covered logistics establishments, logistics operators, and the Delhi Metro Rail Corporation (DMRC). The surveys captured establishment characteristics, shipment and delivery operations, storage and cost conditions, willing-ness to shift freight, and operational requirements for metro-based crowdshipping.

Table -2: Survey and stakeholder data collection

Survey	Stakeholder	Key information collected
Establishment Survey	Owners / vendors / franchisees	Establishment type, land use, built-up area, commodities, storage, de-livery practices and freight con-cerns
Operator Survey	Logistics operators	Fleet, service radius, deliveries, travel time, operating cost, delivery cost, vehicle use and willingness to shift
Public Transport Interview	DMRC	Freight-pilot experience, station space, off-peak capacity, load-ing/unloading, safety and policy constraint

4. METHODOLOGY

The methodological framework was developed to evaluate the feasibility of integrating urban freight movement with the Delhi Metro system. As shown in the

adopted workflow, the pri-mary survey data were first processed and classified into three groups: physical characteristics, operational characteristics, and attitudinal responses. These variables represent shipment characteristics, operator capability, existing delivery conditions, willingness to shift, and perceived operational barriers.

The analysis was carried out in two stages. First, descriptive and segmentation analyses were used to profile shipment categories, logistics operators, and operational preferences. Subsequently, an Analytic Hierarchy Process (AHP)-based Multi-Criteria Decision-Making (MCDM) framework was applied to determine the relative importance of the evaluation criteria and to obtain composite suitability scores. The framework was ap-plied to assess: (i) suitability of shipment types, (ii) suitability of logistics operators, and (iii) feasibility of alternative metro-freight operational designs. The Multinomial Logit (MNL) modelling stage shown in the broader research framework is not included in the present analysis.

4.1 Variable Classification

The variables obtained from the survey were classified into three major groups:

- Physical characteristics: parcel size, commodity type, goods received, delivery volume, parking and access conditions;
- Operational characteristics: establishment type, land use, built-up area, service radius, travel time, delivery cost, vehicle type, and station suitability; and
- Attitudinal responses: willingness to shift to Metro, pre-ferred operational model, time suitability, additional cost, cargo transfer, safety, loading/unloading, and regulatory con-cerns.

These variables were subsequently converted into evaluation criteria and sub-criteria for the AHP–MCDM analysis.

4.2 Analytic Hierarchy Process

AHP was used to determine the relative weights of the criteria and sub-criteria. For n criteria, a pairwise comparison matrix A was constructed as:

$$\mathbf{A} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \quad (1)$$

where a_{ij} represents the relative importance of criterion i with respect to criterion j. The reciprocal property is expressed as:

Each element of the pairwise comparison matrix was normalized column-wise:

$$\bar{a}_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (3)$$

The priority weight of criterion i was then obtained from the mean of the normalized row:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \bar{a}_{ij} \quad (4)$$

Such that:

$$\sum_{i=1}^{n} w_i = 1 \quad (5)$$

The consistency of the pairwise comparison matrix was evaluated using the maximum eigenvalue:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(\mathbf{Aw})_i}{w_i} \quad (6)$$

The Consistency Index (CI) was calculated as:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (7)$$

and the Consistency Ratio (CR) was obtained as:

$$CR = \frac{CI}{RI} \quad (8)$$

where RI is the Random Consistency Index corresponding to the size of the comparison matrix. A value of

□ □ < 0.10 (9)

was considered to indicate acceptable consistency of the pair-wise judgements.

4.3 MCDM-Based Suitability Assessment

Following AHP weighting, the observed values of each alter-native were converted into normalized criterion scores. For a beneficial criterion, where a higher value

indicates greater suit-ability, normalization can be expressed as:

$$r_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \qquad (10)$$

whereas for a cost or barrier criterion, where a lower value is preferred:

$$r_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \qquad (11)$$

where $xi\ j$ is the observed or assigned score of alternative i under criterion j , and $ri\ j$ is its normalized score.

The overall suitability score of alternative i was then obtained using the weighted-sum formulation:

$$S_i = \sum_{j=1}^{m} w_j r_{ij} \qquad (12)$$

where wj is the AHP-derived weight of criterion j , $ri\ j$ is the normalized performance score, and m is the total number of evaluation criteria.

The alternatives were ranked according to their composite suit-ability score:

$$Si > Sk \rightarrow Ai \text{ is preferred over } Ak \qquad (13)$$

The resulting scores were used to classify and rank shipment cat-egories, logistics operator types, and alternative metro-freight operational designs according to their relative suitability for metro-assisted freight movement.

5. RESULTS AND DISCUSSION

5.1 Adoption Readiness and Barriers

The adoption-readiness analysis indicates strong acceptance of Metro-based freight, with nearly 80–85% willingness across the major shipment categories. However, responses towards complete freight shifting remain more conditional, indicating that Metro is presently perceived as a complementary freight mode.

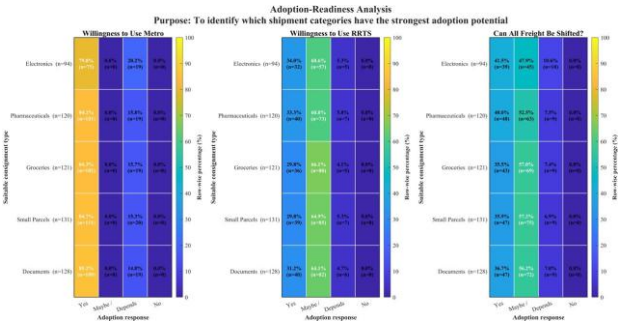
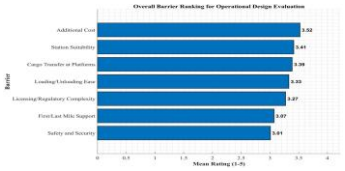
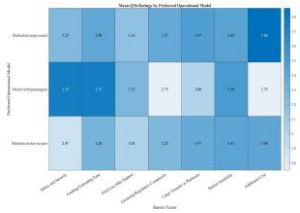


Fig -1: Adoption readiness for Metro-based freight movement

The barrier assessment identifies additional cost as the major concern (3.52), followed by station suitability (3.41) and cargo transfer at platforms (3.39). Thus, adoption is influenced pri-marily by economic and station-level operational requirements.



(a) Barrier ratings by operational model



(b) Overall barrier ranking

Fig -2: Perceived barriers influencing Metro-freight adoption

5.2 Physical Suitability of Shipments

The physical profile shows that compact consignments dominate across all major shipment categories. Average parcel sizes are concentrated in the lowest weight class, while maximum parcel sizes are predominantly within 0.5–1 kg. This supports the suit-ability of documents, small parcels, groceries, pharmaceuticals and electronics for initial Metro-based freight movement.

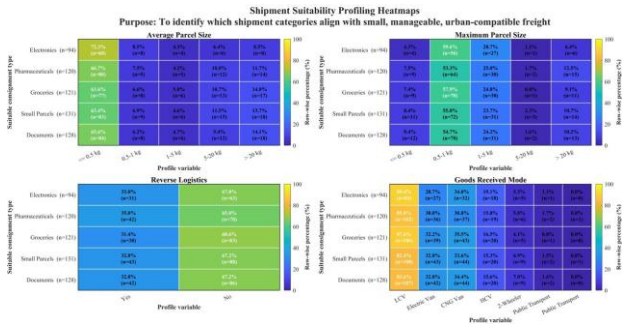


Fig -3: Physical suitability profiling of shipment categories

5.3 Operational Suitability of Logistics Operators

The suitability assessment indicates that hubs, delivery stations and pick-up/drop-off points are comparatively better prepared for Metro integration. Smaller proprietorship and self-operated establishments rank lower because of relatively limited infras-tructure and operational preparedness.

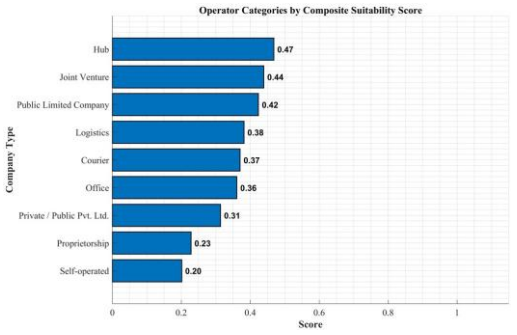


Fig -4: Suitability assessment of logistics operators

5.4 AHP–MCDA Assessment of Shipment Suitability

The AHP results indicate that physical and operational charac-teristics are the dominant considerations for selecting shipments suitable for Metro-based freight movement. Physical suitabil-ity received the highest weight (30%), followed by operational compatibility (23%), time sensitivity (18%), economic feasibil-ity (15%), and adoption and perception (14%). The consistency ratio was below the acceptable threshold of 0.10, confirming consistency of the pairwise comparisons.

Table -3: AHP weights for shipment suitability criteria

Main Criterion	Weight
Physical Suitability	30%
Operational Compatibility	23%
Time Sensitivity	18%
Economic Feasibility	15%
Adoption & Perception	14%
λmax	5.0003
Consistency Index (CI)	0.00006
Consistency Ratio (CR)	0.00006
Consistency Check	Acceptable
	($CR < 0.10$)

Physical suitability and operational compatibility together ac-count for 53% of the total decision weight. This indicates that the suitability of a shipment for Metro integration is governed primarily by its physical handling requirements and operational compatibility rather than by economic considerations alone.

The AHP weights were subsequently combined with the normal-ized performance of each shipment category through the MCDM weighted-sum procedure. Electronics achieved the highest suit-ability score (0.740), followed by groceries (0.624). Documents were moderately feasible, whereas small parcels and pharma-ceuticals received relatively lower scores.

Table -4: MCDA ranking of shipment alternatives

Shipment Type	Score	Rank	Feasibility
Electronics	0.740	1	Highly feasible
Groceries	0.624	2	Moderately feasible
Documents	0.405	3	Moderately feasible
Small Parcels	0.331	4	Weakly feasible
Pharmaceuticals	0.315	5	Weakly feasible

The ranking suggests that Metro-based freight movement is more suitable for commodities combining compact physical characteristics, operational simplicity, and predictable delivery requirements. The results therefore support selective shipment integration rather than uniform shifting of all parcel categories.

5.5 AHP–MCDA Assessment of Operational Alternatives

The operational-model assessment considered design compat-ibility, operator compatibility, temporal suitability, willingness to adopt, storage feasibility, and perception and usability. De-sign compatibility received the highest weight (25%), followed by operator compatibility (20%) and temporal suitability (18%). Together, design and operator compatibility represent 45% of the total decision weight, emphasizing the importance of practical system compatibility.

Table -5: AHP weights for operational-model evaluation

Main Criterion	Weight
Design Compatibility	25%
Operator Compatibility	20%

Temporal Suitability	18%
Willingness to Adopt	15%
Storage Feasibility	12%
Perception & Usability	10%
λmax	6.000
Consistency Index (CI)	0.00006
Consistency Ratio (CR)	0.00006
Consistency Check	Acceptable
	($CR < 0.10$)

The subsequent MCDA evaluation produced closely grouped suitability scores for all three operational alternatives. Mixed passenger–freight operation achieved a score of 0.678, followed by the dedicated cargo coach (0.674) and platform locker system (0.668). All three alternatives fall within the moderately feasible category, indicating that no single configuration is overwhelm-ingly superior.

The results instead reveal functional trade-offs among the alter-natives. The dedicated cargo coach performs relatively better for structured freight handling and storage requirements, while the platform locker system is better aligned with controlled and quick-turnover parcel transfer. Mixed passenger–freight oper-ation achieves the highest overall composite score, although the narrow difference between alternatives indicates that the preferred implementation should depend on shipment charac-teristics, operator capability, station conditions, and available operating windows.

6. PLANNING AND POLICY IMPLICATIONS

The findings indicate that Metro-assisted crowdshipping should initially be planned for compact and operationally manageable consignments and implemented through logistics operators with stronger infrastructure and handling capability. Since additional cost, station suitability, and cargo transfer emerged as major bar-riers, station-level planning should provide designated freight handling areas, simplified loading/unloading arrangements, and adequate temporary storage without interfering with passenger movement.

The preferred operating window should focus on off-peak day-time periods, supported where required by early-morning opera-tions. Platform locker systems can support small, quick-turnover consignments, while dedicated cargo coaches may be more ap-propriate for structured freight flows requiring greater storage and handling control. The close MCDA scores of the operational alternatives suggest that a flexible rather than uniform operating model should be adopted, depending on shipment type, station characteristics, and operator capability.

First- and last-mile integration remains essential because the existing logistics system continues to depend heavily on road-based collection and delivery. Metro freight should therefore function as an intermediate trunk movement system supported by local delivery vehicles and organized transfer points. In-stitutional implementation would require coordination among DMRC, logistics operators, and potentially third-party service providers for parcel handling, storage, platform transfer, and station operations. Clear responsibilities, operating protocols, cost-sharing arrangements, and regulatory provisions would be necessary for gradual scaling of the system.

7. CONCLUSIONS

This study evaluated the feasibility of integrating urban freight movement with the Delhi Metro system through a stakeholder-based AHP–MCDA framework. The analysis combined phys-ical characteristics, operational characteristics, and attitudinal responses to identify shipment types, logistics operators, and op-erational arrangements most suitable for Metro-assisted crowd-shipping. The results indicate strong stakeholder willingness to use Metro for selected freight movements, although additional cost, station suitability, and platform-level cargo transfer remain important implementation concerns.

The suitability assessment shows that compact and manage-able shipment categories are more appropriate for initial integration, with electronics and groceries obtaining the highest MCDA scores. At the operator level, hubs, delivery stations, and pick-up/drop-off points demonstrate relatively higher readi-ness because of stronger operational and infrastructure capa-bility. The AHP results further show that physical suitability and operational compatibility together contribute 53% of the shipment-selection weight, while design and operator compati-bility contribute 45% of the operational-model decision. These findings confirm that practical compatibility and handling fea-sibility are more influential than cost considerations alone.

The evaluation of operational alternatives indicates that all three models platform locker systems, dedicated cargo coaches, and mixed passenger–freight operations are moderately feasible, with only marginal differences in their composite scores. There-fore, no single operational arrangement can be considered uni-versally superior. A flexible implementation strategy is more appropriate, where the operational model is selected according to shipment characteristics, operator capability, station condi-tions, storage requirements, and available time windows.

As a future extension, the present AHP–MCDA framework can be complemented by a Multinomial Logit (MNL) model to esti-mate the probability of selecting alternative crowdshipping op-tions. A stated-

preference survey can be used to generate the required choice data by varying attributes such as cost, travel time, handling arrangement, operating window, and freight-transfer mode. The MNL model can then quantify the relative influence of these attributes on stakeholder choice and estimate the potential demand for each Metro-based crowdshipping alternative under different operational scenarios. This would extend the current suitability-based assessment into a behavioural demand-estimation framework and support more detailed planning and policy evaluation.

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