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Barriers and Priority Interventions for Public Transport Implementation in Saudi Metropolitan Cities

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Abstract: This study examines the principal challenges in implementing effective public transport systems in high-income Saudi metropolitan contexts, focusing on Riyadh, Jeddah and the Eastern Region. It adopts a structured decision-support approach that integrates evidence-informed item taxonomy with a modified Delphi process to validate and score implementation barriers and interventions, followed by the Best-Worst Method (BWM) weighting of decision criteria and multi-criteria decision analysis (MCDA) to generate city-specific priority rankings. The findings indicate that implementation constraints are dominated by system-level frictions rather than infrastructure alone, particularly: (1) feeder–trunk integration and transfer penalties, (2) first/last-mile walkability and safety, (3) operational reliability and service credibility and (4) access-chain thermal comfort. The cross-city results identify a "no-regret" intervention set centred on integrated fares and unified customer information, station/stop access upgrades (sidewalk continuity, safe crossings and universal accessibility) and targeted corridor operations (e.g., priority measures) complemented by a stop environment and heat-mitigation packages. Linkage mapping highlights the leverage interventions that simultaneously mitigate multiple high-priority barriers and enable actionable sequencing guidance. This study aligns recommended packages with Saudi Vision 2030/National Transport and Logistics Strategy (NTLS) objectives and Sustainable Development Goal (SDG) targets for inclusive access, safety co-benefits and climate-aligned mobility.

Keywords: Public transport, Multi-criteria decision analysis, Best-Worst Method, First/last-mile connectivity, Saudi Vision 2030

INTRODUCTION

Saudi Arabia's metropolitan regions are accelerating investments in public transport as part of a broader mobility transition aimed at improving accessibility, urban liveability, and system efficiency. This transition is anchored in national transformation agendas, notably Saudi Vision 2030, and is reinforced by a sector strategy through the National Transport and Logistics Strategy (NTLS), which emphasises governance and integration across modes (Government of Saudi Arabia, 2016; Ministry of Transport and Logistic Services, 2025). At the city level, major programmes in Riyadh and

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Jeddah are framed as integrated multimodal networks, whereas the Eastern Region provides a relevant operational baseline through an established urban bus network serving Dammam, Khobar, Dhahran and Qatif (Jeddah Transport Company, 2025; Royal Commission for Riyadh City, 2025; Saudi Public Transport Company, 2025).

Nevertheless, international evidence consistently shows that "delivering infrastructure" does not guarantee successful implementation. In high-income, car-dependent contexts, adoption depends on the combined performance of service attributes (frequency, reliability, comfort and information), door-to-door access chain (walking and feeder connections) and structural constraints imposed by the dispersed urban form. Demand research demonstrates that ridership is sensitive to fares and service quality but is strongly conditioned by car ownership and competing convenience (Paulley et al., 2006). Complementary evidence links urban form and destination accessibility to travel outcomes, implying that station catchment quality and corridor structure are implementation-critical rather than secondary design considerations (Ewing and Cervero, 2010).

Saudi research supports this multi-domain understanding. Stakeholder evidence from Riyadh indicates that urban form is expected to influence uptake, and that public transport implementation may reshape broader socio-urban conditions over time (Alotaibi and Potoglou, 2018). Similarly, empirical work on pedestrian mobility in Riyadh emphasises that the quality of the walking environment affects the feasibility of shifting toward more sustainable modes, reinforcing the significance of first-/last-mile access in the Saudi context (Sultan, Katar and Al-Atroush, 2021; ElSerafi and Aly, 2025).

This study is positioned within the lens of sustainability performance. Sustainable Development Goal (SDG) 11.2 emphasises inclusive access to safe, affordable, accessible and sustainable transport systems, explicitly prioritising public transport and vulnerable groups (UN-Habitat, 2025a; 2025b). SDG 3.6 frames road safety as a core outcome and SDG 13.2 calls for integrating climate measures into policies and planning (United Nations, n.d.; World Health Organization, 2025). Accordingly, the core policy problem is not simply what to build but which barriers and interventions most constrain (and enable) practical implementation in Saudi cities.

Accordingly, this study aims to identify, validate and prioritise: (1) the principal barriers to implementing effective public transport systems in high-income Saudi cities and (2) the interventions most likely to address these barriers, using a modified Delphi process combined with multi-criteria decision analysis (MCDA) and the Best-Worst Method (BWM) for criteria weighting (Hasson, Keeney and McKenna, 2000; Rezaei, 2015; Beiderbeck et al., 2021). The study addresses three research questions:

1. What are the most consequential implementation barriers to public transport systems in Riyadh, Jeddah and the Eastern Region?
2. Which intervention packages are prioritised as both effective and feasible within a near- to medium-term delivery horizon, and which high-priority barriers do they directly mitigate?
3. Which priorities remain robust under the alternative weighting assumptions aligned with SDGs 11.2, 3.6, and 13.2, and the national direction set by Vision 2030/NTLS?

LITERATURE REVIEW

Core Barriers in High-Income, Car-Dependent Contexts

Implementation research converges on a practical point: public transport competes with private cars for door-to-door performance and not for infrastructure presence alone. Demand evidence indicates that ridership responds to fares and service quality; however, car ownership and perceived convenience remain powerful determinants of affluent, car-oriented environments (Paulley et al., 2006). Related valuation studies highlight that users place high value on reliability and convenience attributes, implying that early operational credibility is central to adoption (Wardman, 2014; ElSerafi, 2025).

Urban form and accessibility interact with the service supply to determine whether fixed-route transit attracts sufficient demand. A widely cited synthesis finds that travel outcomes are strongly associated with destination accessibility (and related built-environment features), supporting the proposition that dispersed urban structures can constrain transit effectiveness even with substantial investment (Ewing and Cervero, 2010). This implies that the station catchment quality and corridor intensity must be treated as integral components of the implementation problem.

Saudi Evidence on Uptake Constraints and Access Conditions

Saudi-specific evidence reinforces these mechanisms. Stakeholder research in Riyadh indicates that urban form significantly influences public transport uptake and that system introduction can shape broader social and urban conditions (Alotaibi and Potoglou, 2018). Empirical research on pedestrian mobility in Riyadh points to the importance of walking-environment quality in shaping travel behaviour and the feasibility of shifting toward more sustainable modes, directly implicating first-/last-mile continuity, safety and comfort as adoption enablers (Sultan, Katar and Al-Atroush, 2021). At the national synthesis level, a systematic review work on Saudi urban transport planning highlights that barriers extend beyond infrastructure to include governance and planning challenges, strengthening the case for structured prioritisation methods capable of transparently ranking barriers and interventions (Almatar, 2024; Shaik et al., 2026).

Intervention Packages

The intervention literature suggests that high-performance implementation packages typically combine these three elements. First, service quality and reliability measures—supported by operations management, network legibility and integration—are central to reducing the perceived disadvantages of transit relative to driving (Paulley et al., 2006; Wardman, 2014). Second, priority measures for buses and corridor treatments can accelerate improvements in speed and reliability when road conditions permit, providing early "performance wins" that support habit formation and acceptance (Deng and Nelson, 2011). Third, first-/last-mile interventions are particularly important when walking and waiting costs are high; continuous sidewalks, safe crossings, accessible stop design and climate-responsive comfort measures can reduce access barriers and improve inclusivity (Cordera et al., 2024).

Sustainable Development Goals and Saudi Vision 2030 Framing as Evaluation Criteria

This study uses SDGs and national strategies as evaluative lenses. SDG 11.2 emphasises inclusive access to sustainable transport, while SDG 11.2.1 explicitly frames "convenient access" in measurable terms (UN-Habitat, 2025a; 2025b). SDG 3.6 supports embedding safety co-benefits into implementation priorities and SDG 13.2 supports integrating climate-responsive design into planning and delivery (United Nations, n.d.; World Health Organization, 2025). Saudi Vision 2030 and the NTLS provide a national implementation architecture and emphasise integration and governance as core determinants of outcomes. The vision sets the strategic direction for national transformation, while the NTLS explicitly emphasises integration among transport modes and governance arrangements that facilitate connection and engagement, which directly corresponds to the implementation barriers documented in international evidence (Government of Saudi Arabia, 2016; Ministry of Transport and Logistic Services, 2025). At the city level, Riyadh's integrated metro-bus programme framing and Jeddah's multimodal master plan provide institutional anchors for aligning interventions with measurable outcomes, whereas the Eastern Region bus network provides an operational testbed for interventions targeting reliability, comfort and access (Alganawi and Ibrahim, 2024; Jeddah Transport Company, 2025; Royal Commission for Riyadh City, 2025; Saudi Public Transport Company, 2025).

CONCEPTUAL FRAMEWORK AND ANALYTICAL LENS

Conceptualising "Implementation" as A Multi-domain System Problem

This study conceptualises public transport implementation in high-income, car-dependent Saudi cities as a system outcome produced by interacting domains rather than a single infrastructure-delivery task. The conceptual starting point is that travel behaviour and mode choice are jointly shaped by:

1. Service offer (frequency, reliability, travel time, comfort and integration).
2. Built environment and accessibility structure (density, land use configuration, network design and destination accessibility).
3. The access chain connects users to the system (walking/feeder access, safety and transfer experience).

This framing is consistent with evidence that accessibility and urban form correlate with travel outcomes and automobile dependence (Ewing and Cervero, 2010) and with demand evidence showing that ridership responds to service quality while being strongly conditioned by car ownership and competing convenience (Paulley et al., 2006; Wardman, 2014).

Saudi evidence reinforces that urban form and broader socio-urban impacts are expected to condition uptake. In Riyadh, stakeholder perspectives explicitly identify urban form as influential for future public transport use and anticipate impacts beyond mobility, indicating that implementation must be treated as a cross-sector urban transition rather than an isolated transport project (Alotaibi and Potoglou, 2018). This is particularly relevant when comparing Riyadh, Jeddah and the Eastern Region, given the differences in network maturity and operational baselines.

Barrier-Intervention Logic Aligned to Sustainable Development Goals and Vision 2030/National Transport and Logistics Strategy

The framework operationalises implementation challenges as barriers and interventions connected through an explicit mitigation logic. These barriers are grouped into four domains:

1. Governance and delivery interfaces (institutional coordination, contracting and performance management).
2. Urban structure and access (land-use dispersion, corridor intensity and station catchments) (Bakri and Ibrahim, 2023).

3. Service and integration quality (reliability, frequency, network legibility and fare/ticket integration) (AbouBakr and ElSerafi, 2023).
4. Sociocultural and equity conditions (acceptance, perceived comfort/ safety and inclusive access needs) (Asaad et al., 2024).

Interventions are specified as bundled packages (e.g., reliability-first operations and accountability, integrated fares and legible networks, continuous and safe station access, shading and thermal-comfort measures, feeder restructuring, and station-area land-use coordination). The evaluation of interventions is explicitly aligned to outcomes implied by SDG targets and national strategy: SDG 11.2 emphasises convenient access to public transport and highlights that such access is often walking-based, motivating the prominence of first-/ last-mile measures (UN-Habitat, 2025b; 2025c). In parallel, Vision 2030 and the NTLS provide a national delivery context, with the NTLS emphasising sector integration and strategic orientation and supporting the inclusion of governance and integration as core implementation domains (Government of Saudi Arabia, 2016; Ministry of Transport and Logistic Services, 2025).

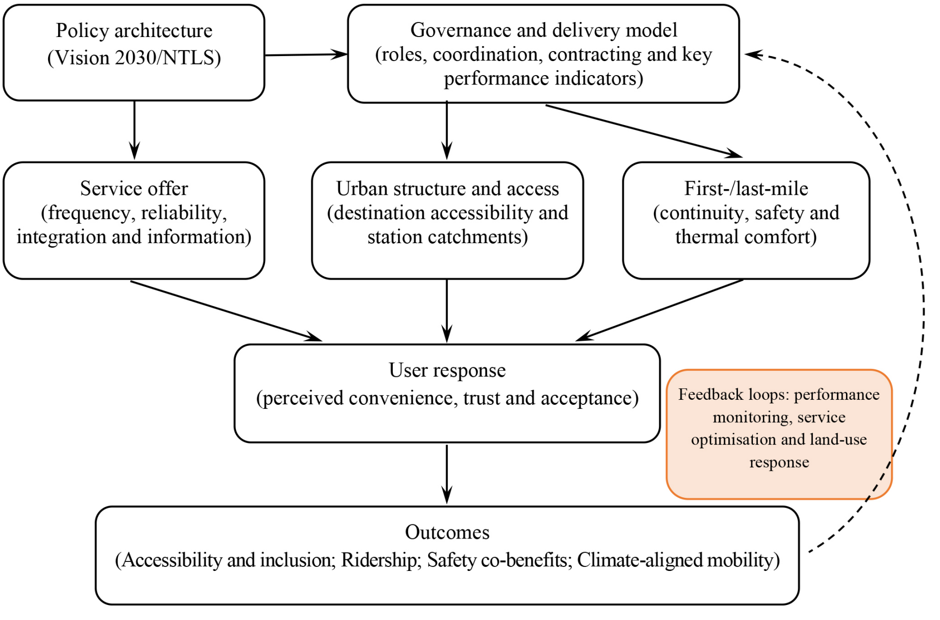

Figure 1. Conceptual framework for public transport implementation in high-income Saudi cities

Figure 1 illustrates the conceptual framework of this study. Implementation is treated as a system outcome in which national policy architecture (Vision 2030 and NTLS) shapes governance and delivery arrangements that condition three proximal domains: service offer, urban structure and access context, and first-/last-mile conditions. These domains jointly influence user responses, particularly perceived convenience, trust and acceptance, which are expected to mediate downstream outcomes including accessibility and inclusion (SDG 11.2), ridership performance, safety co-benefits (SDG 3.6) and climate-aligned mobility (SDG 13.2). The dashed feedback loop emphasises that implementation is iterative, with performance monitoring and service optimisation influencing governance decisions and, over time, shaping land use responses around stations and corridors.

METHODOLOGY

Study Design and Rationale

This study employs a modified Delphi process with MCDA weighted using the BWM. This design is selected for two reasons. First, public transport implementation in high-income, car-dependent cities is a multidomain problem spanning governance, urban form and access, service operations and sociocultural acceptance, which cannot be easily reduced to a single empirical variable. Second, Saudi metropolitan programmes are evolving quickly and are characterised by heterogeneous implementation contexts (Riyadh, Jeddah and the Eastern Region). A structured consensus process enables transparent elicitation and refinement of locally relevant barriers and interventions, whereas MCDA provides an auditable framework for prioritising items under explicit evaluation criteria (Hasson, Keeney and McKenna, 2000; Rezaei, 2015; Beiderbeck et al., 2021).

The study is designed to produce two linked outputs for each city: (1) a ranked set of implementation barriers and (2) a ranked set of interventions, supplemented by a barrier-intervention linkage identifying which interventions most directly mitigate the highest-priority barriers. The evaluation criteria align with the SDGs and Saudi Vision 2030. Figure 2 illustrates an overview of the research workflow, from evidence-informed item generation and Delphi scoring to the BWM-weighted MCDA ranking and sensitivity testing. The outputs comprise city-specific priorities and an implementation roadmap derived from barrier–intervention linkage mapping.

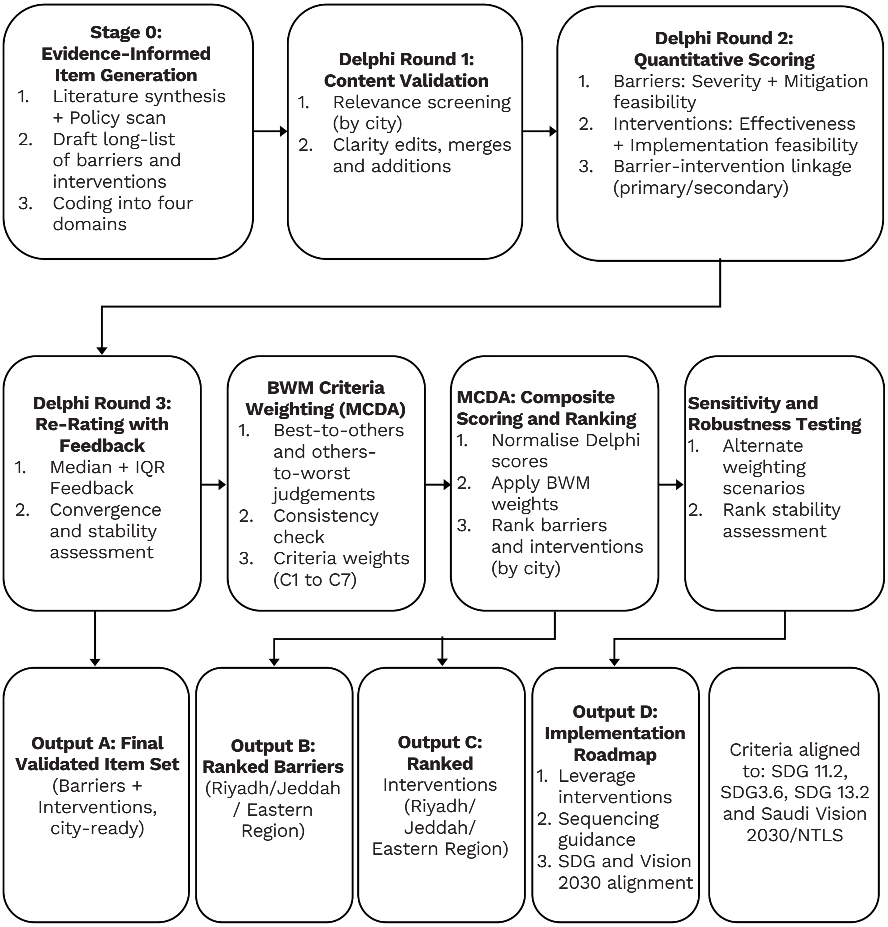

Figure 2. Study workflow integrating modified Delphi and BWM-MCDA to prioritise barriers and interventions

Case Study Selection

This study examines three metropolitan contexts: Riyadh, Jeddah and the Eastern Region’s urban clusters (Dammam, Khobar, Dhahran and Qatif). This selection provides variation in implementation maturity and operational baselines: Riyadh and Jeddah represent large-scale, planned integrated systems, whereas the Eastern Region provides a relevant operational bus context for service delivery and user uptake considerations.

Phase 0: Evidence-informed item generation and coding

Prior to Delphi Round 1, a structured evidence synthesis is conducted to generate a "long list" of candidate barriers and interventions. Items are derived from: (1) peer-reviewed evidence on public transport demand determinants and implementation barriers in car-dependent contexts and (2) Saudi-focused studies on uptake constraints, pedestrian access and governance/planning challenges. Candidate items are then coded into the four-domain taxonomy introduced in this study: (1) governance/delivery, (2) urban form and access, (3) service and integration and (4) sociocultural and equity. To reduce ambiguity, each item is written as a single testable statement with an operational definition and examples.

In parallel, interventions are framed as implementable packages rather than single measures (e.g., "reliability-first operations and accountability", "continuous shaded station catchments" and "integrated fares and legible networks"), to reflect the evidence that implementation success in car-dependent cities typically depends on bundled measures (Paulley et al., 2006; Wardman, 2014).

Expert survey: Sampling strategy and eligibility

A purposive stratified expert survey is conducted to represent the core actor groups that shape implementation outcomes in Saudi cities. Experts include: (1) transport authorities and regulatory stakeholders, (2) municipal planning/public realm stakeholders, (3) operators and service planners, (4) infrastructure delivery and systems integration professionals, (5) accessibility, safety and public space specialists and (6) academic researchers with demonstrated publication or project experience in transport/urban mobility.

Eligibility criteria include: (1) ≥7–10 years relevant professional experience, (2) documented involvement in public transport planning, delivery, operations or governance in Saudi Arabia and/or The Cooperation Council for the Arab States of the Gulf and (3) ability to provide city-specific judgements for at least one of the study cities. The target expert sample size is selected to balance diversity with practicality across iterative rounds and to reduce the risk of single-sector dominance, consistent with Delphi guidance emphasising expertise and structured feedback over large samples.

Delphi procedure (three rounds)

The study implements a three-round modified Delphi design using online instruments and anonymised, controlled feedback.

Round 1: Content validation and contextual relevance (barriers and interventions)

Participants rate each barrier and intervention for relevance on a five-point scale separately for Riyadh, Jeddah and the Eastern Region. They also assess item clarity and propose additional changes, deletions or consolidations. The items are revised based on recurring feedback themes and prespecified rules. This round establishes content validity and ensures that subsequent scoring reflects locally meaningful constructs.

Round 2: Quantitative scoring for prioritisation (city-specific)

Participants score retained barriers and interventions on a seven-point scale:

1. Barriers (per city)
   i. Severity/impact on successful implementation and
   ii. Feasibility of mitigation within three to five years.
2. Interventions (per city)
   i. Expected effectiveness,
   ii. Feasibility of implementation within three to five years and
   iii. Barrier linkage: selection of up to two primary and three secondary barrier codes addressed by the intervention.

The three- to five-year horizon is selected to reflect practical programme cycles and policy delivery windows while maintaining relevance to ongoing national strategies.

Round 3: Re-rating with controlled feedback

Participants receive anonymised group feedback for each item (median, interquartile range [IQR] and short synthesis of rational themes) and are invited to revise their scores. This approach supports convergence while preserving anonymity and avoiding dominant voices, which is consistent with the established Delphi practice.

Consensus, Stability and Item Retention Rules

Consensus is assessed using non-parametric statistics appropriate for ordinal Likert data. For each item (per city):

1. Median (central tendency),
2. IQR (dispersion) and
3. Stability as change in median between Rounds 2 and 3.

Pre-specified thresholds are applied to enhance transparency. For example, an item is treated as having reached acceptable consensus if IQR is at or below a defined threshold (e.g., IQR ≤ 1 on a seven-point scale) and stable if median change between rounds is limited (e.g., ≤ 0.5). Items may be retained even with a lower consensus if they are consistently rated as high severity in one city context and are supported by a strong qualitative rationale; however, such exceptions are flagged explicitly. The Round 1 relevance screen removes items that are persistently low in all city contexts while preserving those that are context-critical for a single city. In addition to median/IQR reporting, the study assesses agreement and stability using non-parametric statistics appropriate for ordinal Delphi data. Where items are ranked, it reports Kendall's coefficient of concordance (W) as a measure of inter-rater agreement, and for round-to-round stability it applies Wilcoxon signed-rank tests comparing Rounds 2 and 3 item scores (two-tailed, $p < 0.05$) to identify items with statistically meaningful shifts.

Multi-Criteria Decision Analysis Framework and Criteria

The MCDA is used to convert Delphi ratings into prioritised barriers and intervention rankings under an explicit set of evaluation criteria. The criteria set is designed to be interpretable by practitioners and aligned with the SDGs and national objectives:

1. C1 System impact (ridership and network performance consequences).
2. C2 Implementation risk (delivery, operations and interface risks).
3. C3 Equity and inclusion (women, persons with disabilities and affordability; SDG 11.2).
4. C4 Time-to-impact (speed of observable benefits).
5. C5 Feasibility within three to five years (institutional and technical tractability).
6. C6 Scalability (replicability across corridors/districts).
7. C7 Co-benefits (safety and climate alignment; SDG 3.6 and SDG 13.2).

The SDG 11.2 framing is operationalised through the emphasis on "convenient access" and inclusion, consistent with SDG 11.2.1 metadata logic. Safety and climate integration are explicitly included as co-benefits through SDG 3.6 and SDG 13.2. National alignment is addressed through governance and integration emphasis, consistent with Vision 2030 and the NTLS.

Best-Worst Method for Criteria Weighting

To weight criteria (C1 to C7), this study applies the BWM, which requires fewer pairwise judgements than traditional analytic hierarchy process while producing consistent weights through a formal optimisation framework (Rezaei, 2015). Each expert:

1. Identifies the best (most important) and worst (least important) criterion.
2. Rates the preference of the best criterion over each other criterion on a 1 to 9 scale (Best-to-Others vector).
3. Rates the preference of each criterion over the worst criterion on a 1 to 9 scale (Others-to-Worst vector).

The BWM weights are computed using the standard optimisation formulation described by Rezaei (2015). Individual weights are aggregated (e.g., by central tendency across respondents) to derive a collective weight vector for each city or pooled sample, depending on whether experts provide city-specific criterion judgements. This study reports the BWM consistency metrics, as recommended in the BWM framework. Let $C = \{1, \ldots, n\}$ be the set of criteria with weight w_j. Each respondent identifies the best criterion, B and a worst criterion, W. The respondent provides a Best-to-Others vector $A_B = (a_{B1}, \ldots, a_{Bn})$ and an Others-to-Worst vector $A_W = (a_{1W}, \ldots, a_{nW})$ on a scale of 1 to 9. Following Rezaei (2015), the weights are obtained by solving $\underset{w,\xi}{\min}$ subject to:

$$\left| \frac{w_B}{w_j} - a_{Bj} \right| \leq \xi, \quad \forall j \in C;$$

$$\left| \frac{w_j}{w_w} - a_{jw} \right| \leq \xi, \quad \forall j \in C;$$

$$\sum_{j=1}^{n} w_j = 1, \qquad w_j \geq 0, \forall j \in C.$$

The resulting w constitutes the respondent's criterion weights and ξ^* provides an inconsistency indicator. This study reports the respondent-level inconsistency indicator ξ^* and summarises its distribution, which is consistent with the BWM framework and subsequent work on inconsistency measurement and reporting.

Barrier-Intervention Linkage Mapping

A structured barrier-intervention linkage matrix is constructed from Round 2 responses, where experts identify which barriers are directly mitigated by each intervention (primary and secondary links). Link strength is computed based on the frequency of selection and can be combined with intervention priority to identify leverage interventions that mitigate multiple high-priority barriers. The linkage matrix supports an implementation roadmap that moves beyond "ranked lists" to actionable sequencing logic.

Table 1 illustrates the finalised barrier set and operational definitions used for Delphi scoring and subsequent MCDA ranking. Domain classification supports the interpretation and comparison across city contexts. Table 2 lists the intervention set assessed using the Delphi method and ranked using MCDA. Interventions are specified at an appropriate level to support policy packaging and sequencing.

Table 1. Barrier set, domains and operational definitions

Code	Barrier	Domain	Operational Definition	Source
B1	Feeder–trunk integration/ transfer friction	Service/ integration	Weak coordination between feeder services and trunk lines; poor transfer design, timing or penalties that increase door-to-door time and inconvenience	Iseki and Taylor (2009); Chowdhury and Ceder (2013)
B2	Pedestrian access discontinuity/ unsafe crossings	Access	Disconnected sidewalks, unsafe crossing conditions and poor pedestrian priority near stops/stations that reduce catchment usability	Wang and Cao (2017); Pucher and Dijkstra (2003)
B3	Reliability risk under congestion/ headway instability	Service/ operations	Unstable headways, delays and congestion-induced unreliability that reduce confidence and perceived convenience	Daganzo (2009); Diab, Badami and El-Geneidy (2015)
B4	Network legibility and information gaps	Service/ integration	Low clarity of routes/ services and insufficient wayfinding/real-time information that increases cognitive burden and discourages use	Grotenhuis, Wiegmans and Rietveld (2007); Watkins et al. (2011)
B5	Stop environment quality (shelter, seating and shading)	Access	Poor-quality waiting environments that reduce comfort, perceived safety and willingness to use services, especially in heat exposure contexts	Shi et al. (2021); Lanza and Durand (2021); Dzyuban et al. (2022)

(*Continued on next page*)

Table 1. *Continued*

Code	Barrier	Domain	Operational Definition	Source
B6	Fragmented station-area public realm governance	Governance	Misaligned roles/mandates across agencies responsible for station-area access, public realm quality and maintenance	Sharaby and Shiftan (2012)
B7	Phased delivery risk/weak early operational wins	Governance/delivery	Programme sequencing that fails to deliver early, legible performance gains, reducing trust and political/financial momentum	Anderson and Daganzo (2020); Cheng, Liu and Pei (2023)
B8	First/last-mile thermal comfort exposure	Access	Heat exposure and lack of shading/cooling on approach routes and at stops/stations that raise generalised cost of access	Manville and Pinski (2021); Diehl, Ranjbari and Goodchild (2021)
B9	Fare/ticketing fragmentation (if applicable)	Service/integration	Lack of integrated ticketing, fare policy or payment interoperability that discourages multi-leg trips and transfers	Veeneman and van de Velde (2014); Allansson, Pettersson-Löfstedt and Hrelja (2023)
B10	Weak enforcement of bus priority/curb management	Governance/operations	Inadequate enforcement of bus lanes, stop protection, loading/parking controls and curb discipline that undermines service performance	Flyvbjerg, Holm and Buhl (2002); Allansson, Pettersson-Löfstedt and Hrelja (2023)
B11	Car competitiveness and preference (hard-to-mitigate)	Socio-cultural/market	High attractiveness of private cars (comfort, speed, status and convenience) and related preference structures that inhibit mode shift	Abdelraouf, Abdel-Latif and ElSerafi (2025); Paulley et al. (2006); Altieri, Silva and Terabe (2020)
B12	Limited universal accessibility at stops/stations	Access/equity	Barriers to access for people with disabilities/limited mobility; gaps in universal design, step-free access and inclusive station environments	Mwaka et al. (2023); Ravensbergen et al. (2022)

Table 2. Intervention set, categories and operational definitions

Code	Intervention	Category	Operational Definition	Source
I1	Integrated fares + Unified customer information	Integration	Fare integration and unified customer information across modes/operators, reducing payment and information friction	Grotenhuis, Wiegmans and Rietveld (2007); Watkins et al. (2011)
I2	Seamless transfers + Timed coordination (feeder–trunk)	Integration/ operations	Coordinated timetables, transfer design and operational policies to minimise transfer penalties	Ceder, Golany and Tal (2001); Liu, Cats and Gkiotsalitis (2021)
I3	Feeder network redesign/ coverage optimisation	Network/ service design	Feeder restructuring to improve catchment coverage, transfer quality and network coherence	Almasi et al. (2014)
I4	Reliability package (headway management and dispatch control)	Operations	Active operations management (dispatching, headway control and incident response) to stabilise service reliability	Daganzo (2009)
I5	Bus priority + Corridor operations (select corridors)	Operations/ infrastructure	Priority measures (lanes, signal priority and stop spacing) combined with operational reforms to improve corridor performance	Anderson and Daganzo (2020); Xian, Nelson and Moylan (2025)
I6	Station/ stop access package (sidewalks, crossings and universal access)	Access/safety/ equity	Continuous sidewalks, safe crossings and universal accessibility upgrades around stops/ stations and along access routes	Shi et al. (2021); Lanza and Durand (2021)
I7	Stop/shelter upgrade package (seating, shading and amenities)	Access/user experience	High-quality shelters, seating, lighting and stop amenities to improve waiting experience and perceived safety	Dzyuban et al. (2022); Lanza and Durand (2021); Abuwaer et al. (2025)
I8	Thermal comfort package (shaded routes and cooling measures)	Access/ climate adaptation	Shaded walk routes, microclimate design and cooling measures at key access paths and waiting points	Manville and Pinski (2021); Diehl, Ranjbari and Goodchild (2021)

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Table 2. *Continued*

Code	Intervention	Category	Operational Definition	Source
I9	Wayfinding + Real-time information rollout	Information/ integration	System-wide wayfinding and real-time passenger information to improve legibility and reduce uncertainty	Sharaby and Shiftan (2012)
I10	Curb/parking management + Enforcement support	Governance/ operations	Curb regulation, parking management and enforcement mechanisms to protect bus operations and stop functioning	Paulley et al. (2006); Göransson and Andersson (2023)

Ethics and Data Management

Participation in the surveys is voluntary and responses are anonymised to protect confidentiality and reduce social desirability bias. To date, only aggregated results have been reported. Any potential conflicts of interest are declared and managed through anonymisation and balanced sampling across sectors.

Validity, Bias Controls and Triangulation Strategy

The Delphi panel prioritises expertise variety over statistical representativeness. Hence, the outcomes should be regarded as expert-informed priorities rather than population estimates. This study uses structured expert judgement to rank barriers and interventions in the context of an evolving system rollout, in which numerous implementation challenges (such as integration interfaces, governance coordination and access chain usability) cannot be completely observed from a single dataset. To reduce subjectivity, the following approach was employed:

1. Anonymised rounds and controlled feedback to reduce the effects of dominance and conformity.
2. Predefined consensus and stability criteria for ordinal data (median/ IQR and round-to-round stability).
3. Robustness checks under different weighting scenarios.

To address external validity, this research clearly presents the outputs as decision support prioritisation instead of a causal impact estimate. This study suggests the following empirical triangulation:

1. Passenger stated-preference and revealed-preference indicators (walk time, transfers and reliability).

2. Station-area access audits (sidewalk continuity, crossings and universal accessibility).
3. Operational key performance indicators (headway variability, on-time performance and transfer wait times).

RESULTS

Experts Survey Characteristics and Response Rates

A purposive expert survey was conducted across seven stakeholder strata as explained in the earlier section of this study. Of the 60 invited experts, 34 consented and completed Round 1 (56.7% response rate). Thirty experts completed Round 2 and 28 completed Round 3 (overall attrition from round 1 to round 3:17.6%), consistent with typical Delphi participation patterns.

The experts' experience was substantial; the median professional experience was 13 years (IQR: 10 years to18 years). City familiarity (self-reported) was highest for Riyadh (71% "High Familiarity"), followed by Jeddah (61%) and the Eastern Region (57%). Sector composition was "Authorities/Regulators" (26%), "Municipal planning/Public realm" (18%), "Operators/Service planning" (14%), "Delivery/Systems integration" (18%), "Traffic/Enforcement" (7%), "Accessibility/Safety" (7%) and "Academia" (10%).

Round 1 Outcome: Item Refinement and Contextual Relevance

The evidence-informed long list initially contained 31 barrier and 24 intervention items. Following round 1 relevance screening and qualitative refinement, the instrument was consolidated into 24 barriers and 18 interventions. Specifically, five barriers and four interventions were merged owing to conceptual overlap (e.g., multiple items describing transfer friction and weak network integration), three items were removed owing to consistently low relevance across all city contexts and three new items were added based on recurring expert comments (two related to station-area access governance and one related to thermal comfort at stops/stations). Items were retained if their median relevance rating was ≥ 4 on a five-point scale in at least one city context.

Delphi Consensus Results: Barriers

Barriers were rated on seven-point scale for severity (impact on implementation outcomes) and mitigation feasibility (tractability within three years to five years). Consensus was assessed using IQR (acceptable consensus threshold: IQR ≤ 1.5) and stability as absolute median change between Rounds 2 and 3 (stable if Δmedian ≤ 0.5).

Riyadh

Riyadh's highest-ranked barriers were clustered in service/integration and first/last-mile access. The top barrier was "Weak feeder-trunk integration and transfer friction" (median severity 6.5, IQR 1.0; feasibility 4.5, IQR 1.5). The second was "Pedestrian access discontinuity and unsafe crossings near stations" (severity 6.0, IQR 1.0; feasibility 5.0, IQR 1.0). A third high-ranked barrier was "Reliability risk under congestion and inconsistent headways" (severity 6.0, IQR 1.5; feasibility 4.0, IQR 1.5). Overall, 8 of the top 10 Riyadh barriers achieved acceptable consensus (IQR ≤ 1.5) and were stable between rounds, indicating convergence in expert judgements.

Jeddah

Jeddah's barrier profile emphasised phasing and corridor readiness along with access chain issues. The highest-ranked barrier was "Phased delivery risk: lack of early, legible operational wins" (severity 6.5, IQR 1.0; feasibility 4.0, IQR 1.5). The second was "Poor first/last-mile comfort (heat exposure + low-quality waiting environments)" (severity 6.0, IQR 1.0; feasibility 5.0, IQR 1.0). The third was "Fragmented governance for station-area public realm and access management" (severity 5.5, IQR 1.5; feasibility 3.5, IQR 1.5). Consensus was slightly lower than Riyadh for governance-related items (IQR often 1.5 to 2.0), reflecting variability in perceived institutional tractability.

Eastern Region (Dammam-Khobar-Dhahran-Qatif)

Given the operational bus baseline, the Eastern Region's barrier priorities shifted toward service legibility and user experience. The top barrier was "Network legibility and information gaps (route understanding, wayfinding and real-time info)" (severity 6.0, IQR 1.0; feasibility 5.5, IQR 1.0). The second was "Stop environment quality and comfort (shelters, shading and seating)" (severity 5.5, IQR 1.0; feasibility 6.0, IQR 1.0). The third was "Reliability and schedule adherence enforcement" (severity 5.5, IQR 1.5; feasibility 5.0, IQR 1.5).

Across cities, a consistent cross-cutting barrier was car competitiveness and preference, rated high severity but lower mitigation feasibility (e.g., median severity 5.5 to 6.0, feasibility 3.5 to 4.0), reinforcing the need for bundled measures. Table 3 illustrates Round 3 medians and IQRs for barrier severity and mitigation feasibility by city context. The ratings are on a 1 to 7 scale and most barriers meet the consensus threshold (IQR ≤ 1.5) while B6, B7 and B10 show slightly higher dispersion in feasibility in some cities (IQR = 2), reflecting persistent implementation uncertainty.

Table 3. Delphi Round 3 summary for barriers by city (severity and mitigation feasibility)

Code	Barrier	Riyadh Severity Med (IQR)	Riyadh Feas Med (IQR)	Jeddah Severity Med (IQR)	Jeddah Feas Med (IQR)	Eastern Severity Med (IQR)	Eastern Feas Med (IQR)
B1	Integration/transfer friction	6 (1)	4 (1)	5 (1)	4 (1)	5 (1)	4 (1)
B2	Pedestrian access discontinuity	6 (1)	5 (1)	6 (1)	5 (1)	5 (1)	5 (1)
B3	Reliability under congestion	6 (1)	4 (1)	5 (1)	4 (1)	5 (1)	4 (1)
B4	Info/legibility gaps	5 (1)	5 (1)	4 (1)	5 (1)	6 (1)	5 (1)
B5	Stop environment comfort deficits	4 (1)	5 (1)	4 (1)	5 (1)	6 (1)	5 (1)
B6	Fragmented station-area governance	5 (1)	4 (1)	6 (1)	3 (2)	4 (1)	3 (2)
B7	Phasing/early wins risk	4 (2)	3 (2)	6 (1)	3 (2)	3 (2)	3 (2)
B8	Thermal exposure (first/last mile)	4 (1)	4 (1)	6 (1)	4 (1)	4 (1)	4 (1)
B9	Fare/ticketing fragmentation	5 (1)	4 (1)	3 (1)	4 (1)	4 (1)	4 (1)
B10	Weak enforcement/ curb conflicts	5 (1)	3 (2)	4 (1)	3 (2)	4 (1)	3 (2)
B11	Car competitiveness/ preference	5 (1)	2 (1)	4 (1)	2 (1)	4 (1)	2 (1)
B12	Universal accessibility gaps	3 (1)	4 (1)	3 (1)	4 (1)	3 (1)	4 (1)

Note: *n* (paired valid Round 3 responses): Riyadh = 28; Jeddah = 28; Eastern Region = 28.

Table 4 summarises the cross-city ranking of the 12 highest-priority implementation barriers and enables a direct comparison of the binding constraints across Riyadh, Jeddah and the Eastern Region. The heatmap highlights both shared priorities, particularly integration and access-chain constraints, and city-specific differences, reflecting the implementation stage and operational baseline.

Table 4. Comparative heatmap of top 12 implementation barrier priorities across Riyadh, Jeddah and the Eastern Region

Barriers		Riyadh	Jeddah	Eastern Region
Service/ Integration	B1: Feeder-trunk integration/ transfer friction	1	5	5
Access	B2: Pedestrian access discontinuity/unsafe crossings	2	3	4
Service/ Integration	B3: Reliability risk under congestion/headway instability	3	6	3
Service/ Integration	B4: Network legibility and information gaps	8	9	1
Access	B5: Stop environment quality (shelter, seating, shading)	9	8	2
Governance	B6: Fragmented station-area public realm governance	7	4	10
Governance	B7: Phased delivery risk/weak early operational wins	11	1	11
Access	B8: First/last-mile thermal comfort exposure	10	2	7
Service/ Integration	B9: Fare/ticketing fragmentation (if applicable)	4	11	8
Governance	B10: Weak enforcement of bus priority/curb management	6	10	9
Sociocultural	B11: Car competitiveness and preference (hard-to-mitigate)	5	7	6
Access	B12: Limited universal accessibility at stops/stations	12	12	12

1 Priority rank (1 = Highest; Darker = Lower priority) 12

Delphi Consensus Results: Interventions

The interventions were rated for expected effectiveness and implementation feasibility on a seven-point scale. A small set of interventions consistently emerged as top-tier across cities.

Cross-city "no-regret" interventions

1. Integrated fares + seamless transfers + unified customer information (median effectiveness 6.5, IQR 1.0; feasibility 5.0, IQR 1.5).

2. Station/stop access package: Continuous sidewalks, safe crossings and universal accessibility (effectiveness 6.0, IQR 1.0; feasibility 5.5, IQR 1.0).
3. Thermal comfort package: Shaded walking routes and high-quality shelters at key stops (effectiveness 5.5, IQR 1.0; feasibility 6.0, IQR 1.0)

City differentiation

1. Riyadh: The highest-ranked intervention was "Feeder network redesign + timed transfer coordination" (effectiveness 6.5, feasibility 4.5), reflecting integration as a binding constraint.
2. Jeddah: The highest-ranked intervention was phased "Early win" corridors using bus priority + legible trunk services (effectiveness 6.0, feasibility 5.0), reflecting the need to build trust early.
3. Eastern Region: The highest-ranked intervention was "Stop environment upgrades + real-time information rollout" (effectiveness 5.5, feasibility 6.0), reflecting quick wins in user experience.

Across the three cities, Table 5 presents round 3 medians and IQRs for intervention effectiveness and implementation feasibility by city context (1 to 7 scale). The results indicate that interventions combining integration, access-chain improvements and reliability/priority packages tended to score higher on effectiveness and near-term feasibility.

Table 5. Delphi Round 3 summary for interventions by city (effectiveness and implementation feasibility)

Code	Intervention	Riyadh Eff Med (IQR)	Riyadh Feas Med (IQR)	Jeddah Eff Med (IQR)	Jeddah Feas Med (IQR)	Eastern Eff Med (IQR)	Eastern Feas Med (IQR)
I1	Integrated fares + Unified info	6 (1)	5 (1)	5 (1)	5 (1)	5 (1)	5 (1)
I2	Timed transfers + Coordination	6 (1)	5 (1)	4 (1)	4 (1)	4 (1)	3 (1)
I3	Feeder redesign/ coverage	6 (1)	4 (1)	4 (1)	3 (1)	4 (1)	3 (1)
I4	Reliability operations control	5 (1)	5 (1)	4 (1)	4 (1)	4 (1)	4 (1)
I5	Bus priority + Corridor operations	5 (1)	4 (1)	6 (1)	5 (1)	4 (1)	4 (1)
I6	Station/stop access package	5 (1)	5 (1)	5 (1)	5 (1)	5 (1)	5 (1)

(*Continued on next page*)

Table 5. *Continued*

Code	Intervention	Riyadh Eff Med (IQR)	Riyadh Feas Med (IQR)	Jeddah Eff Med (IQR)	Jeddah Feas Med (IQR)	Eastern Eff Med (IQR)	Eastern Feas Med (IQR)
I7	Stop/shelter upgrades	4 (1)	5 (1)	5 (1)	5 (1)	6 (1)	5 (1)
I8	Thermal comfort package	4 (1)	4 (1)	6 (1)	5 (1)	4 (1)	4 (1)
I9	Wayfinding + Real-time info	4 (1)	4 (1)	4 (1)	4 (1)	6 (1)	5 (1)
I10	Curb management + Enforcement	3 (1)	4 (1)	4 (1)	3 (1)	4 (1)	4 (1)

Table 6 summarises the cross-city intervention rankings and highlights the convergence of high-impact and context-specific accelerators. This visualisation facilitated a rapid comparison of near-term priorities across Riyadh, Jeddah and the Eastern Region.

Table 6. Comparative heatmap of prioritised intervention ranks across Riyadh, Jeddah and the Eastern Region

Intervention	Riyadh	Jeddah	Eastern Region
I1: Integrated fares + Unified customer information	3	4	3
I2: Seamless transfers + Timed coordination (feeder–trunk)	1	8	9
I3: Feeder network redesign/coverage optimisation	2	10	10
I4: Reliability package (headway management, dispatch control)	4	7	5
I5: Bus priority + Corridor operations (select corridors)	6	1	7
I6: Station/stop access package (sidewalks, crossings and universal access)	5	3	4
I7: Stop/shelter upgrade package (seating, shading and amenities)	8	5	2
I8: Thermal comfort package (shaded routes and cooling measures)	9	2	6

(*Continued on next page*)

Table 6. *Continued*

Intervention	Riyadh	Jeddah	Eastern Region
I9: Wayfinding + Real-time information rollout	7	6	1
I10: Curb/parking management + Enforcement support	10	9	8

1 Priority rank (1 = Highest; Darker = Higher priority) 10

Best-Worst Method Criteria Weights and Multi-Criteria Decision Analysis Rankings

BWM weighting (Criteria C1 to C7) showed that experts prioritised system impact and feasibility most strongly. The pooled BWM weights were as follows: C1 System impact 0.24, C5 Feasibility (three years to five years) 0.21, C4 Time-to-impact 0.14, C3 Equity/inclusion (SDG 11.2) 0.13, C2 Implementation risk 0.11, C6 Scalability 0.09 and and C7 Co-benefits (SDG 3.6/13.2) 0.08. The average BWM consistency ratio (or equivalent fit index) was 0.08, indicating an acceptable consistency under commonly used thresholds (Rezaei, 2015).

Using these weights, MCDA produced the final composite rankings. In Riyadh, feeder–trunk integration, pedestrian access continuity and reliability under congestion constituted the top barrier tier. In Jeddah, the phased operational wins, thermal comfort and access conditions dominated. In the Eastern Region, information/legibility and stop environment quality ranked the highest.

Sensitivity analyses (equity-weighted vs feasibility-weighted scenarios) showed that the top three interventions remained stable across scenarios, while Ranks 4 to 8 shifted moderately, suggesting a robust “no-regret” set with a flexible second tier. Table 7 presents the MCDA criteria and the BWM-derived weights used to compute the composite priorities. The resulting weights emphasise the system impact and implementability within a practical policy horizon.

Table 7. MCDA criteria definitions and BWM weights

Code	Criterion	Definition (What is Being Weighted)	Mean Weight	Median	Standard Deviation	IQR
C1	System impact	Expected effect on ridership, accessibility and overall system performance	0.24	0.24	0.05	0.06
C2	Implementation risk	Exposure to institutional, operational or delivery risk	0.11	0.11	0.04	0.05
C3	Equity and inclusion	Contribution to inclusive access to public transport	0.13	0.13	0.04	0.05
C4	Time-to-impact	Speed at which benefits are likely to be realised	0.14	0.14	0.04	0.05
C5	Feasibility (three years to five years)	Practical deliverability within near-term budgets/capacity	0.21	0.21	0.05	0.06
C6	Scalability	Potential for replication across corridors/areas	0.09	0.09	0.03	0.04
C7	Co-benefits	Safety and climate-aligned mobility co-benefits	0.08	0.08	0.03	0.03

Notes: Inconsistency indicator ξ^* (respondent-level; $n = 28$), mean $\xi^* = 0.09$, median $\xi^* = 0.09$, IQR $\xi^* = 0.03$ (0.08 to 0.11) and range $\xi^* = 0.06$ to 0.13. ξ^* is the BWM inconsistency indicator; lower values indicate higher internal consistency in pairwise comparisons.

Barrier-Intervention Linkage and Leverage Interventions

The linkage matrix (expert-selected primary/secondary mappings) identified several leverage interventions that simultaneously addressed multiple high-priority barriers. The strongest leverage intervention was "Integrated fares + information + transfer policy", mapped as a primary mitigator to 7 of the top 10 barriers in Riyadh and 6 of the top 10 in Jeddah. The station/stop access package was mapped to 6 of the top 10 barriers in all three contexts, indicating broad coverage and high practical value.

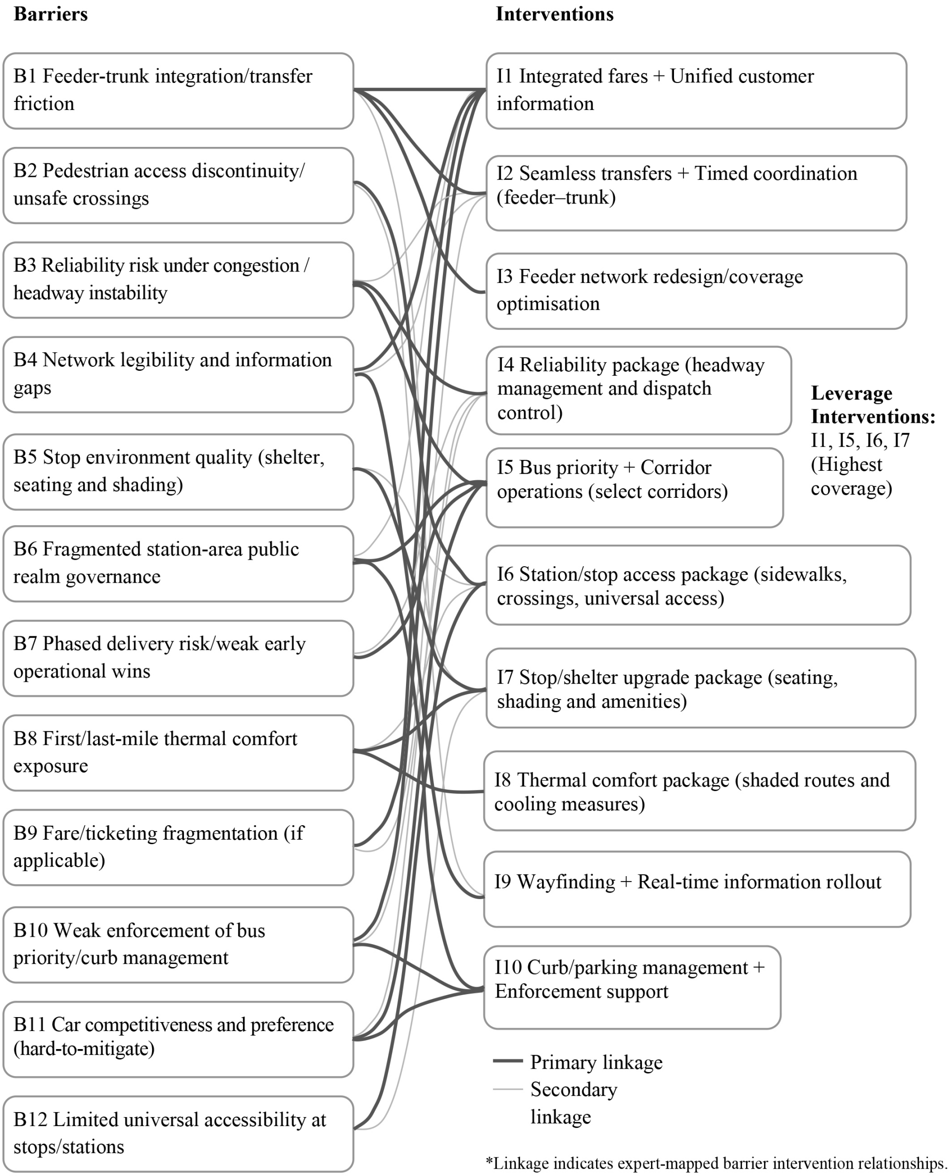

Figure 3. Barrier-intervention linkage network highlighting leverage interventions

These results support an implementation sequence emphasising: (1) access chain usability, (2) service reliability and integration and (3) the institutionalisation of governance and performance monitoring, consistent with the conceptual framework and SDG-aligned criteria. Figure 3 visualises the expert-mapped barrier-intervention relationships and identifies leverage interventions with the widest coverage across the prioritised constraints. The linkage structure supports packaging and sequencing decisions by highlighting interventions that mitigate multiple barriers simultaneously rather than addressing constraints in isolation.

Table 8 illustrates the linkage matrix used to identify the leverage interventions and shows the top primary and secondary intervention links selected for each barrier (counts and percentages of respondents selecting each link). Mapping indicates which interventions mitigate multiple high-priority constraints, supporting packaging and sequencing decisions rather than isolated single-issue actions.

Table 8. Barrier-intervention linkage: top primary and secondary links (n = 28)

Barrier	Primary Link(s)	Secondary Link(s)
B1	I2 (18; 64%), I3 (14; 50%), I1 (14; 50%)	I9 (7; 25%)
B2	I6 (20; 71%)	I7 (9; 32%)
B3	I4 (16; 57%), I5 (12; 43%)	I2 (6; 21%)
B4	I9 (17; 61%), I1 (12; 43%)	I2 (7; 25%)
B5	I7 (18; 64%)	I6 (9; 32%)
B6	I10 (14; 50%), I5 (12; 43%)	I1 (8; 29%)
B7	I5 (15; 54%)	I4 (7; 25%)
B8	I8 (16; 57%), I7 (12; 43%)	I6 (8; 29%)
B9	I1 (17; 61%)	I2 (6; 21%)
B10	I10 (15; 54%), I5 (12; 43%)	I4 (7; 25%)
B11	I5 (13; 46%), I1 (12; 43%), I10 (12; 43%)	I4 (6; 21%)
B12	I6 (18; 64%)	I7 (9; 32%)

Overall, based on Wilcoxon signed-rank stability checks, Rounds 2 and 3 comparisons indicated stable ratings for most barriers and interventions. Only a small subset of items exhibited statistically detectable shifts under Wilcoxon testing which are illustrated in Table 9; these shifts were concentrated in implementation-feasibility dimensions for governance/enforcement and phasing-related barriers, consistent with persistent uncertainty around institutional coordination and on-street compliance.

Table 9. Wilcoxon signed-rank stability checks (Round 2 vs Round 3)

City	Item	Dimension	*N* Paired	Median Round 2	Median Round 3	*p*-Value	Interpretation
Riyadh	B7	Feasibility	28	3	3	0.03	Minor shift flagged
Riyadh	I10	Feasibility	28	4	4	0.04	Minor shift flagged
Jeddah	B6	Feasibility	28	3	3	0.02	Minor shift flagged
Eastern Region	B7	Severity	28	3	3	0.04	Minor shift flagged

DISCUSSION

Key Implementation Constraints

The results indicate that public transport implementation constraints in high-income Saudi metropolitan contexts are not dominated by a single factor; rather, they form an interdependent set in which integration, accessibility and operational credibility emerge as the most binding constraints. This pattern is consistent with evidence that transit demand is sensitive to service quality and fares but is strongly conditioned by car ownership and the perceived convenience of driving in affluent, car-oriented settings. Prioritisation also aligns with valuation evidence, highlighting the disproportionate influence of reliability and convenience attributes on user choice, implying that implementation must rapidly establish trust in a system's day-to-day performance.

Across the three cities, two recurring barrier themes were structurally important. First, door-to-door friction—created by discontinuous pedestrian networks, unsafe crossings and weak feeder integration—raises the generalised cost of transit beyond what trunk infrastructure alone can offset. Second, integration failures, including transfer friction, fragmented information and perceived complexity, reduce legibility and discourage trials, particularly among users accustomed to direct private car trips. These themes are compatible with built environment syntheses that emphasise the role of accessibility and urban structures in shaping travel outcomes. They also match the Saudi-specific evidence that urban form is expected to influence transit uptake in Riyadh and that sustainable mobility requires a walkable environment that supports access to transport services.

The consistently high severity of passenger "car competitiveness and preference", paired with the lower perceived mitigation feasibility, is notable. This suggests that behavioural and cultural attachments to private vehicle use will remain resilient unless public transport implementation simultaneously reduces access and service penalties and improves user experience. This reinforces the rationale for bundled implementation packages that reduce multiple friction points simultaneously, rather than isolated measures that produce marginal improvements that are insufficient to shift perceptions.

City-Specific Priorities

A key analytical value of the three-city design is that it reveals how the implementation constraints vary with network maturity, phasing and operational baselines.

Riyadh has a barrier structure dominated by feeder-trunk integration and transfer friction, followed closely by pedestrian access discontinuity and reliability risk under congestion. This implies that the principal constraint is not merely the presence of a backbone network but also the performance of the system interface: timed transfers, coordinated feeder structures, station catchment usability and operational discipline. These results are consistent with stakeholder expectations in Riyadh that urban form and system introduction will influence uptake and wider urban outcomes. Practically, this supports a Riyadh implementation narrative centred on integration-first operations and station area accessibility as preconditions for sustained ridership growth.

Jeddah is differentiated by the prominence of phased delivery risk—specifically, the absence of early, visible operational wins—alongside challenges related to thermal comfort, first-/last-mile conditions and fragmented governance in station-area access management. This suggests that in a city where the system is still evolving, the primary implementation hazard is credibility formation. If early phases do not provide clearly usable services with acceptable access conditions, adoption may remain low, even as major investments progress. This finding supports an implementation strategy that prioritises demonstrable corridor performance and visible access-chain upgrades early in the programme timeline, helping to establish a transit "habit" and reduce reputational risk for subsequent expansion stages.

In the Eastern Region, the barrier profile shifts to network legibility and information gaps, and stops environmental quality, with reliability and schedule adherence also ranked highly. This reflects an operational baseline in which the system exists, but requires improvements that enable users to understand it, trust it and experience acceptable comfort at stops. The higher feasibility scores observed for stop environment upgrades and information improvements indicate a practical "quick wins" pathway that may be implementable within three years to five years and could be replicated across corridors.

Intervention Prioritisation and Sequencing

The intervention results provide a coherent response to the barrier structure. The top cross-city intervention set—(1) integrated fares, seamless transfers and unified customer information, (2) station/stop access upgrades (continuous sidewalks, safe crossings and universal accessibility) and (3) thermal comfort packages (shaded routes and high-quality shelters)—were logically aligned with the highest-ranked barriers. These interventions directly reduce access chain friction and improve legibility and trust, which are essential in high-income, car-dependent cities where private cars provide perceived control and comfort. The MCDA results further suggest an implementation of sequencing logic grounded in what is both impactful and feasible within three years to five years.

Access-chain usability as an early deliverable

Prioritising continuous sidewalks, safe crossings, universal accessibility and shaded waiting environments is consistent with SDG 11.2, which emphasises inclusive access to public transport. It is also consistent with the SDG 11.2.1 measurement logic that treats "convenient access" as a measurable attribute frequently achieved through walkable access to stops/stations. Because the stop environment and shading packages were rated as relatively feasible, they represent early visible improvements that could support adoption.

Integration and reliability as the central adoption engine

Integrated fares and unified information reduce cognitive and transactional barriers, whereas feeder redesign and transfer coordination address system-level frictions, particularly in Riyadh. Reliability measures remain essential because they support perceived convenience and reduce the risk of a trial trip, converting negative long-term perceptions. This stage should be tied to explicit performance indicators and accountability arrangements consistent with national integration objectives under the NTLS and Vision 2030.

City-specific accelerators

Jeddah's top-ranked "early win" corridor packages using bus priority and legible trunk services align with evidence that bus priority and bus rapid transit features can accelerate performance improvements when designed appropriately. In the Eastern Region, stop upgrades and real-time information rollouts can serve as scalable accelerators of ridership growth and system trust.

The prioritisation results should be interpreted as a structured decision-support output rather than a fully specified behavioural model, because implementation dynamics may be nonlinear. First, interventions such as reliability operations control (I4) and bus priority/corridor operations (I5) may require minimum corridor continuity and enforcement intensity before producing measurable improvements in reliability and perceived quality; below that threshold, the expected gains in system impact (C1) can be muted. Second, access chain interventions, particularly station/stop access upgrades (I6) and thermal comfort measures (I8), can function as bottlenecks, limiting uptake even when service integration (I1) or coordination (I2) improves. Third, integration interventions (I1, I2) and feeder network measures (I3) are likely to be complementary. Unified fares and information reduce transaction costs, whereas coordinated transfers and coverage improvements reduce transfer penalties and access time, jointly improving perceived feasibility and time-to-impact (C5, C4). Accordingly, future work could test interaction-aware variants (e.g., scenario packages, Technique for Order of Preference by Similarity to Ideal Solution [TOPSIS] cross-checks or fuzzy/robust MCDA) and empirically validate package effects using operational key performance indicators and passenger stated-preference data.

Leverage Actions and Governance

Linkage mapping adds a critical implementation insight: integrated fares/information/transfer policies and station access packages were mapped to a large share of the top barriers, confirming them as leverage interventions. Their leverage arises because they address multiple dimensions simultaneously—user understanding, physical access, comfort and transfer experience—thereby reducing the generalised cost of using public transport.

Governance appears to be both a barrier (notably in Jeddah) and an enabling condition for implementing leverage interventions. The prominence of “fragmented governance for station-area public realm and access management” indicates that many high-impact interventions depend on cross-agency coordination (street design, enforcement, maintenance and operations). This supports framing governance not as an abstract institutional concern but as a direct determinant of user outcomes and SDG alignment. In particular, the safety and accessibility benefits implied by SDG 3.6 and SDG 11.2, require consistent delivery across agencies that manage the pedestrian realm and traffic environment.

Sustainable Development Goals and Saudi Vision 2030 Alignment and Robustness

The BWM weights placed the greatest emphasis on system impact and feasibility, followed by time-to-impact and equity/inclusion. This weighting pattern is consistent with a pragmatic implementation posture: interventions must produce visible performance improvements and be deliverable within institutional and operational horizons. Importantly, equity/inclusion still receives meaningful weight, supporting decisions that strengthen universal and inclusive access, which is consistent with SDG 11.2. The sensitivity results—showing a stable top three interventions under equity-weighted and feasibility-weighted scenarios—support presenting these actions as "no-regret" priorities. Rank shifts in the second-tier can be interpreted as strategic choices contingent on whether agencies prioritise rapid deliverability, equity emphasis or broader co-benefits (including safety and climate integration under SDGs 3.6 and 13.2). The Delphi–MCDA approach provides explicit prioritisation, but does not replace empirical causal identification. Consequently, this study considers priorities as binding-constraint hypotheses appropriate for focused pilot programmes. Future validation may integrate passenger choice models (e.g., sensitivity to walking time and transfers), station-access evaluations and operational monitoring to see if changes deemed "no-regret" provide quantifiable increases in ridership and accessibility.

Illustrative Appraisal Logic

To facilitate practical decision-making, interventions can be evaluated using a streamlined benefit-cost framework that corresponds to implementation limitations: (1) benefits related to travel time and reliability (regularity of headways and diminished transfer penalties), (2) benefits related to access chains (lowered pedestrian risk, enhanced universal accessibility and thermal comfort) and (3) additional external benefits (safety and emission reductions through mode shift). The current analysis does not quantify monetised benefits. Nevertheless, the prioritisation outcomes indicate which packages are most likely to yield multidomain advantages—specifically, integration and station-access packages—which can be selected for pilot programmes and subsequently assessed before and after monitoring.

Car competitiveness is influenced not only by overall costs, but also by habit persistence, perceived control and loss aversion. Strategies for implementation that mitigate uncertainty through real-time information, decrease transaction costs via integrated payment systems and enhance first/last-mile comfort might diminish the perceived "risk" associated with utilising transportation and encourage repeated usage.

CONCLUSION

This study developed a decision-support framework to prioritise public transport implementation barriers and interventions in three high-income Saudi metropolitan contexts—Riyadh, Jeddah and the Eastern Region (Dammam-Khobar-Dhahran-Qatif)—using a methodology that integrates a modified Delphi process with BWM-weighted MCDA. The findings indicate that implementation constraints are primarily systemic and interdependent, rather than confined to infrastructure delivery. Across cities, the most influential constraints emerged around: (1) feeder-trunk integration and transfer friction, (2) first-/last-mile accessibility and safety and (3) operational credibility (notably, reliability). These constraints are consistent with international evidence showing that ridership is highly responsive to service quality and convenience but is strongly conditioned by car ownership in affluent, car-oriented contexts, and with evidence linking destination accessibility and urban form to travel outcomes.

City differentiation was policy relevant. Riyadh's top priorities centred on integration and reliability under congestion, suggesting that the principal implementation of a "binding constraint" is the system interface between trunk services, feeders and station access. Jeddah's results emphasised the phased delivery risk and the need for early, visible operational wins, along with thermal comfort and access-chain quality, indicating that credibility and user experience should be established early to support long-term system maturation. The Eastern Region prioritised network legibility/information and stopped environmental quality, reflecting an operational baseline in which usability and comfort improvements represent feasible near-term accelerators.

The intervention rankings converged on a robust cross-city "no-regret" set: integrated fares and unified customer information, seamless transfers with feeder coordination and station/stop access packages (continuous sidewalks, safe crossings and universal accessibility), complemented by thermal comfort measures (shaded routes and high-quality shelters). Linkage mapping indicated these actions as "leverage interventions", because they mitigate multiple top-ranked barriers simultaneously – reducing door-to-door friction, improving legibility and strengthening trust.

The prioritised interventions align directly with SDG 11.2 by improving inclusive and convenient access to public transport, consistent with the measurement logic of SDG 11.2.1. Safety-related access upgrades support SDG 3.6, and climate-responsive access and mode-shift enabling measures support SDG 13.2. The framework also reflects the national direction under Vision 2030 and the NTLS, particularly the emphasis on the integration and governance capacity to deliver connected, user-centred transport systems.

This study has several limitations. The primary limitations include the reliance on structured expert judgement and the sensitivity of MCDA rankings to criteria selection and weighting, although the BWM and scenario testing improve transparency. Another limitation relates to the limited number of experts who responded to the survey, as the Delphi process is time-consuming and requires substantial commitment from respondents. Another key limitation is that prioritisation relies on expert judgement and does not include a parallel passenger survey, which limits the inferences about user heterogeneity. Future studies should triangulate the prioritisation of passenger stated-preference models and access chain audits. Additionally, it should validate priorities through empirical measurements: station-area access audits (including thermal comfort and universal accessibility), passenger experience surveys and before-and-after evaluations of pilot interventions (e.g., integrated fares/information, stop upgrades and corridor bus priority). Integrating these data with ridership and reliability monitoring would support causal inference and benefit–cost appraisal, strengthening the evidence base for scaling interventions across Saudi metropolitan regions.

ETHICAL STATEMENT

The ethical approval has been granted by the Research Ethics Committee of Effat University under decision number RCI_REC/6.Januaray.2026/7-7.1.Exp./1(75).

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