

An Information-Based Decision Framework for Sustainable Urban Mobility in Turkish Metropolitan Cities

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ABSTRACT

The transition towards sustainable urban mobility increasingly depends on the ability of cities to transform diverse sources of mobility data into knowledge that supports coordinated, adaptive and long-term policy decisions. However, data availability does not in itself produce evidence-based decision making. Mobility information is often fragmented across institutions, generated according to different standards and purposes, and characterised by varying levels of quality, accessibility and interoperability. These challenges are particularly significant in metropolitan contexts where transport interacts with land use, economic development, environmental objectives, technological change and social behaviour. This paper develops an information-based decision framework for supporting sustainable urban mobility transitions in Turkish metropolitan cities. Drawing on information-based decision making, data governance, urban mobility planning and socio-technical transition theory, it conceptualises sustainable mobility governance as a continuous process of transforming data into information, information into actionable knowledge, and knowledge into adaptive decisions and institutional learning. The framework extends beyond the concept of a mobility data platform by proposing an urban mobility decision infrastructure encompassing data governance, interoperability, analytical capabilities, institutional arrangements, stakeholder knowledge, decision processes and feedback mechanisms. Particular attention is given to the institutional and governance context of metropolitan mobility in Türkiye, including fragmented responsibilities, heterogeneous data practices, financial and implementation constraints, and interactions between national and metropolitan decision-making. The paper argues that sustainable mobility requires not simply more data or sophisticated analytical tools, but institutionalised capabilities to integrate information, navigate uncertainty and competing interests, evaluate interventions, learn from outcomes and adapt decisions over time.

1. Introduction

Urban mobility is increasingly recognised as a complex policy domain in which environmental sustainability, economic development, accessibility, public health, technological change and social equity must be addressed simultaneously. Conventional transport planning has often focused on

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forecasting travel demand, expanding infrastructure and minimising travel costs, whereas the sustainable mobility paradigm calls for a broader consideration of accessibility, modal choice, environmental impacts, social inclusion and the conditions under which behavioural and institutional change can occur [1]. Sustainable urban mobility therefore involves changes in infrastructures, technologies, institutions, markets, behaviours and cultural practices that collectively shape how mobility systems evolve [2, 3].

The complexity of this transition is particularly pronounced in metropolitan areas, where mobility systems are constituted by multiple interacting actors and infrastructures. Public authorities, transport operators, land-use planners, private mobility providers, technology companies, citizens and other stakeholders generate and use different forms of knowledge, often according to different objectives and institutional responsibilities. Decisions concerning public transport investment, roadspace allocation, land-use development, pricing, active travel, vehicle electrification or emerging mobility services can therefore have consequences extending well beyond the immediate intervention. The multi-level perspective on socio-technical transitions conceptualises such transformations as interactions between established socio-technical regimes, emerging niches and wider landscape pressures rather than as linear processes of technological substitution [4, 5]. From this perspective, sustainable mobility requires not only new technologies and infrastructure but also changes in institutions, rules, practices, knowledge and patterns of decision making.

Information has a potentially important role in navigating this complexity. Contemporary cities generate unprecedented volumes and varieties of mobility-related data through public transport ticketing systems, traffic sensors, automatic vehicle location systems, travel surveys, geographic information systems, mobile telecommunications, connected vehicles, shared mobility platforms and other digital technologies. Big data and real-time urban information have consequently become increasingly associated with the possibility of more responsive and evidence-informed urban governance [6, 7]. In mobility policy, data can support demand estimation, network planning, performance monitoring, impact assessment and the evaluation of policy alternatives. However, the growing availability of data does not necessarily result in better decisions. Liu and Dijk [8], for example, found that emerging forms of big data provide important opportunities for evidence-based mobility policymaking but cannot simply replace conventional sources such as surveys and official statistics. The value of data depends on how different sources are combined, interpreted and incorporated into policy processes.

This distinction between data availability and decision capability is fundamental. Data become useful for policy only when they are transformed into information that is relevant to a particular decision, interpreted within an appropriate analytical and institutional context, and ultimately incorporated into processes through which choices are made and implemented. The proliferation of data can therefore create new challenges alongside new opportunities. Differences in definitions, spatial and temporal scales, quality, ownership, accessibility and methodological assumptions can make datasets difficult to combine or compare. Proprietary data may be inaccessible to public authorities, while privacy and security requirements can constrain data sharing. At the same time, the rapid expansion of digital data can exceed the institutional capacity of governments to manage, analyse and interpret it effectively [9, 10].

These challenges raise questions of data governance as much as questions of technology. In urban environments, these arrangements extend across organisational boundaries because no single institution generally possesses all of the information required to understand the mobility system. The OECD [11] identifies insufficient analytical capacity, fragmented responsibilities, resource constraints, data-sharing barriers and legal and security considerations among the challenges confronting cities seeking to derive public value from urban data. In the mobility sector, similar issues

arise when public authorities seek to obtain and integrate information held by transport operators or private mobility providers. Data sharing can involve competing interests concerning privacy, commercial confidentiality, ownership and control, requiring institutional mechanisms capable of balancing public value with legitimate restrictions on data use [12, 13].

The need for such capabilities becomes even more significant when mobility is considered as a socio-technical transition. Janssen *et al.*, [14] argue that the governance of smart mobility is critical because technological transitions can generate new forms of public value as well as new externalities and governance challenges. The socio-technical transition literature similarly emphasises that transitions are shaped by interactions among technologies, infrastructures, institutions, markets, policies, cultural meanings and user practices [4, 6]. Information and knowledge should therefore not be regarded merely as neutral inputs to a decision process. They are also embedded within institutional arrangements and can influence which problems become visible, which objectives are prioritised, and which alternatives are considered feasible.

This perspective is particularly relevant to metropolitan cities in Türkiye because mobility information is embedded within a broader multi-level information and governance architecture. Nationally, the Türkiye National Geographic Information System (TNGIS) establishes standards, data themes, metadata arrangements, interoperability principles and institutional responsibilities for geographic information, including transportation networks, land use, population and demographic information and other datasets relevant to mobility planning [15]. The 2024–2030 National Geographic Information Strategy and Action Plan further identifies data quality, data sharing, interoperability and the alignment of public institutions and local governments with national standards as continuing priorities [16]. At metropolitan level, municipalities and their affiliated transport organisations operate additional information systems covering public transport operations, traffic management, geographic information, infrastructure and passenger demand. The result is therefore a layered environment in which national standards, municipal systems, operator databases, open-data portals and project-specific analytical systems coexist. The central question is how effectively these different layers are connected to one another and to metropolitan decision processes.

The Turkish context also illustrates why international approaches to sustainable mobility cannot simply be transferred without considering institutional and socio-economic conditions. The transition literature has emphasised that socio-technical change is context dependent, with institutional structures, governance arrangements, established practices and political-economic conditions shaping the possible pathways of transition [4, 5]. This is particularly relevant to metropolitan cities in rapidly urbanising contexts, where infrastructure deficits, competing investment priorities, fiscal constraints, rapid technological change and established transport practices can interact in complex ways. A socio-technical perspective therefore provides a useful basis for understanding sustainable mobility as a process of institutional and systemic change rather than as the cumulative implementation of individual technological or infrastructural interventions [6, 7].

Existing approaches nevertheless tend to address different components of this problem separately. Sustainable mobility research provides extensive guidance on transport policy and planning, while socio-technical transition research explains how mobility systems change. Smart-city and data-governance research examines the generation, management and sharing of urban data, and decision-support research focuses on analytical methods for evaluating alternatives. Yet there remains a need for a framework that connects these perspectives around the practical problem faced by metropolitan decision makers: how to transform fragmented mobility data and distributed knowledge into decisions that can navigate uncertainty, competing objectives and institutional complexity while supporting long-term system transition. In particular, there is limited conceptual

integration between the technical infrastructure required to make mobility information available and the institutional capabilities required to ensure that such information actually influences strategic decisions.

Against this background, this paper develops an information-based decision framework for sustainable urban mobility in Turkish metropolitan cities. The central research question is: How can metropolitan cities in Türkiye institutionalise the capabilities required to transform fragmented mobility data and knowledge into adaptive decisions that support socio-technical transitions towards sustainable urban mobility?

Four subsidiary questions guide the analysis: (1) What is the current mobility-data and decision-making landscape in Türkiye? (2) What institutional, technical and epistemic barriers prevent mobility information from becoming actionable knowledge? (3) What capabilities and institutional arrangements are required to establish a metropolitan urban mobility decision infrastructure? and (4) How can such an infrastructure support long-term socio-technical transitions rather than merely individual transport projects?

The paper therefore seeks to make two related contributions. First, it develops a conceptual framework that connects information-based decision making with data governance and socio-technical transition theory, shifting attention from the availability of mobility data towards the institutional capacity to use information for adaptive decision making. Second, it applies this framework to the institutional context of Turkish metropolitan cities, identifying the capabilities and arrangements required to move from fragmented data resources towards a more integrated decision infrastructure. The objective is to provide a structured basis through which policymakers and metropolitan institutions can assess existing capabilities, identify institutional and informational gaps, and progressively build the infrastructure required for evidence-informed and adaptive sustainable mobility governance.

The remainder of the paper is structured as follows. Section 2 presents the methodology adopted to develop the framework, including the conceptual foundations and the approach used to examine the Turkish metropolitan mobility context. Section 3 examines the current mobility-data and decision-making landscape in Türkiye, focusing on the principal institutional actors, data sources, governance arrangements and existing analytical capabilities. Section 4 identifies the institutional, technical and epistemic barriers that constrain the transformation of mobility data into actionable knowledge. Section 5 develops the proposed urban mobility decision infrastructure and specifies the capabilities, institutional arrangements and information processes required to support evidence-informed decision making. Section 6 concludes with the implications of the framework for metropolitan governance and policy practice in Türkiye, as well as its limitations and opportunities for further research.

2. Methodology

This study adopts a conceptual framework development approach to examine how metropolitan cities in Türkiye can strengthen their capacity to transform fragmented mobility data and distributed sources of knowledge into decisions that support sustainable urban mobility transitions. The approach combines a structured synthesis of relevant conceptual perspectives with an examination of the institutional and mobility-data context within which metropolitan transport decisions are developed and implemented in Türkiye.

The examination of the Turkish context is based on a documentary review of national and metropolitan-level institutional sources, complemented by relevant academic studies. The documentary material includes the Türkiye National Geographic Information System (TUCBS) framework and its data standards and sharing arrangements, municipal open-data and geographic

information initiatives, metropolitan transport information-system documentation, Sustainable Urban Mobility Plan (SUMP) project documentation, and institutional material concerning data collection, modelling and decision-support capabilities. Particular attention is given to Istanbul and Izmir as metropolitan examples for which relatively detailed information is publicly available, while national-level initiatives are used to identify the broader institutional framework within which metropolitan data systems operate. The purpose of this review is not to produce a comprehensive audit or quantitative benchmarking of all metropolitan municipalities, but to identify recurring characteristics of the Turkish mobility-data and governance environment that are relevant to the development of the proposed decision infrastructure.

The conceptual foundations of the framework are drawn from four complementary areas: information-based decision making, urban mobility planning, data governance and socio-technical transition theory. These perspectives are considered jointly because none of them, in isolation, fully explains how mobility information can become a basis for long-term transformation. Information-based decision making highlights the processes through which data are interpreted and used to support choices; urban mobility planning provides the substantive context in which competing transport, land-use, environmental and social objectives must be reconciled; data governance addresses the institutional and technical arrangements that determine how information is collected, shared, managed and accessed; and socio-technical transition theory provides a perspective on the longer-term transformation of mobility systems.

The analytical logic of the study is illustrated in Figure 1. Data represent observations, measurements and records concerning the mobility system, while information emerges when these data are organised, contextualised and made relevant to a particular analytical or policy question. Knowledge is subsequently developed through the interpretation of information using analytical methods, professional experience, stakeholder knowledge, institutional understanding and contextual evidence. Decisions then involve the selection, prioritisation or modification of interventions under conditions of uncertainty, competing objectives, financial constraints, legal responsibilities and institutional interests. Implementation produces observable outcomes, while monitoring and evaluation generate new knowledge that can challenge previous assumptions, reveal unintended consequences and inform subsequent decisions. The sequence is therefore treated as iterative rather than linear. New decisions can generate new information requirements, implementation can expose data gaps, and changing technologies, behaviours or institutional responsibilities can alter the information needed for future decisions.

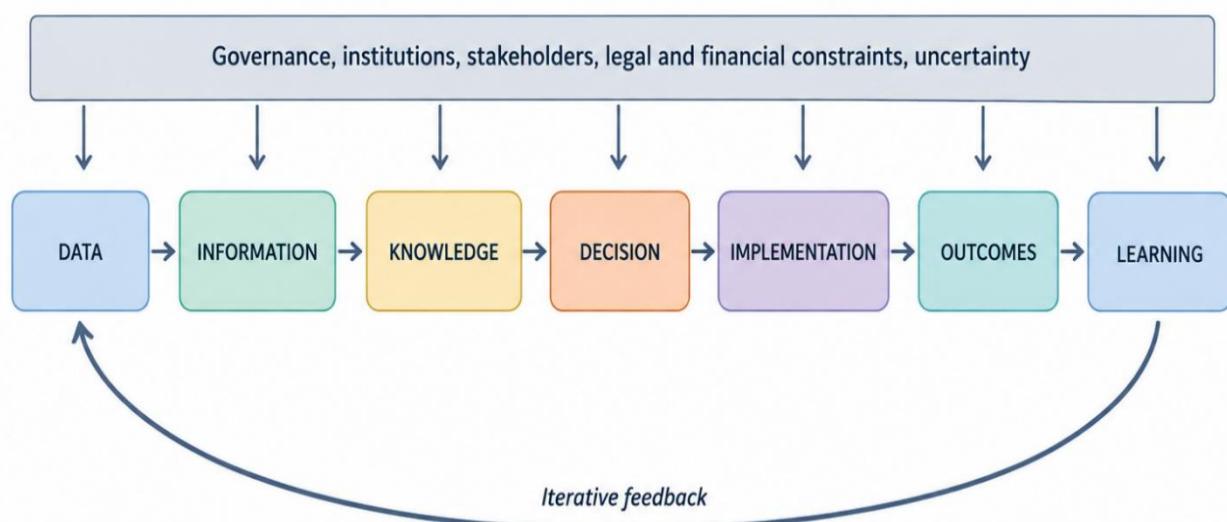


Fig. 1. From Mobility Data to Adaptive Decision Making

A central distinction in the framework is consequently made between information availability and information-use capability. A metropolitan area may possess large volumes of operational, administrative, spatial or sensor-generated data while still lacking the institutional mechanisms necessary to integrate these sources, assess their quality, interpret them consistently and translate them into decisions. The study therefore considers mobility information as an institutional capability. This perspective directs attention to the processes through which information acquires meaning, credibility and practical relevance within decision-making environments.

The Turkish metropolitan mobility context is examined across both data resources and institutional arrangements. The analysis considers the principal categories of information potentially relevant to metropolitan mobility decision making, including public transport operations and performance, travel demand and movement patterns, transport infrastructure and network characteristics, land-use and spatial information, demographic and socio-economic conditions, environmental indicators, road safety information and emerging data from digital and private mobility services. The purpose is to identify the types of information required for integrated decision making and the organisational conditions affecting their availability and use.

The institutional assessment considers the range of actors involved in metropolitan mobility, including national-level institutions, metropolitan and district municipalities, public transport operators, infrastructure organisations, private mobility providers, research institutions and other relevant stakeholders. Rather than treating these organisations as a single governance system, the analysis examines the distribution of mandates, responsibilities, resources, information and decision-making authority among them. This makes it possible to identify different forms of fragmentation that can prevent information from becoming actionable knowledge. Technical fragmentation concerns differences in data formats, standards, systems, interfaces and interoperability. Institutional fragmentation concerns the distribution of responsibilities, resources, authority, ownership and access across organisations. Epistemic fragmentation concerns differences in how organisations define mobility problems, interpret evidence, establish priorities and understand desirable outcomes. These dimensions are analytically distinct but can reinforce one another.

The framework is further connected to socio-technical transition theory by treating sustainable urban mobility as a process of system transformation rather than a collection of individual transport projects. From this perspective, information and decision capabilities must support not only the diagnosis of current mobility conditions but also the exploration of alternative futures, the assessment of emerging technologies and practices, experimentation with new interventions, and learning from their outcomes. This allows data and knowledge to contribute to institutional learning and adaptation rather than being used solely for static monitoring or project-level forecasting.

Rather than treating mobility data as a stand-alone technological resource, the Urban Mobility Decision Infrastructure (UMDI) connects mobility information with governance, analytical capabilities, collective decision processes, implementation and institutional learning. The architecture therefore extends from the physical and socio-economic mobility system through data and information governance towards mobility intelligence and collective decision making, and subsequently to implementation, evaluation and adaptation.

3. The Mobility-Data and Decision-Making Landscape in Türkiye

The mobility-data and decision-making environment in Türkiye is characterised by a diverse and increasingly sophisticated collection of data sources distributed across institutions, transport modes and administrative levels. Metropolitan mobility systems generate substantial quantities of operational, transactional, spatial, demographic and traffic information. At the same time, the institutional responsibilities associated with transport planning, infrastructure provision, public

transport operation, traffic management, land-use planning and environmental policy are distributed across different organisations. The resulting landscape creates both significant opportunities for evidence-informed decision making and challenges associated with the integration, interpretation and institutional use of information.

At the national level, the mobility information environment includes data and analytical activities associated with transport infrastructure, road and rail networks, traffic, public transport, logistics, safety, environmental performance and broader spatial and economic conditions. National institutions also influence the regulatory, investment and strategic environment within which metropolitan transport decisions are made. At the metropolitan level, municipalities and their affiliated transport organisations possess more detailed information concerning local networks and operations, including routes, timetables, vehicle movements, passenger demand, traffic conditions, infrastructure inventories and municipal services. These sources are supplemented by information generated by district municipalities, operators, infrastructure agencies, private mobility providers, universities and other organisations. Consequently, the Turkish metropolitan mobility system can be conceptualised as an information ecosystem rather than as a single data system.

An important part of this landscape is the Türkiye National Geographic Information System (TNGIS), which provides a national framework for the production, standardisation, sharing and use of geographic information. TNGIS covers 32 geographic data themes and 53 associated sub-themes, including transportation networks, land use, population and demography, infrastructure, environmental information and statistical reporting areas. The national platform provides access to geographic data and metadata generated by public institutions, local governments, universities and other data producers, while access to individual datasets is determined according to data-owner permissions and the applicable data-sharing arrangements [15, 16]. The system therefore already incorporates several functions that are central to the proposed decision infrastructure, including metadata, data standards, data responsibility, data sharing and interoperability. However, the existence of this national framework does not mean that all mobility information is automatically integrated at metropolitan decision-making level. TNGIS primarily establishes the conditions for geographic information to be identified, standardised and shared; the subsequent integration of operational, behavioural, financial and analytical information into mobility decisions remains a metropolitan governance challenge.

The increasing sophistication of metropolitan transport information can be illustrated by developments in Istanbul. Municipal systems have incorporated geographical information, public transport information, vehicle tracking, GPS and other operational data into transport management and passenger information applications. Earlier municipal reporting also documented the integration of public transport information with GIS, the use of the General Transit Feed Specification (GTFS), mobility analysis, routing analysis and the development of data warehouse capabilities. More recently, Istanbul's modelling activities have incorporated public transport stop and line information, timetables, road characteristics and Istanbulkart-based travel information into transport modelling and impact assessment processes. These developments demonstrate that substantial technical capabilities for collecting, integrating and analysing mobility information already exist within at least some Turkish metropolitan institutions.

Istanbul provides a particularly clear example of how extensive mobility information can already exist within a metropolitan administration. IBB has developed the Toplu Ulaşım Bilgi Sistemi (TUBS), through which public transport information is integrated using geographic information systems and the General Transit Feed Specification (GTFS). Municipal documentation describes the use of operational data for route planning, mobility analysis, bus-movement simulation and the analysis of Istanbulkart-based passenger-use patterns. The system has also been connected with web services

and public-facing travel-planning applications, while selected transport datasets have been made available through the IBB Open Data Portal [17]. More recent metropolitan initiatives similarly demonstrate the use of open data, geospatial information and data analytics within municipal services. These developments indicate that Istanbul already possesses several of the technical components envisaged by the UMDI, including operational data systems, spatial information, data standards, analytical applications and mechanisms for public data access. The unresolved issue is therefore the extent to which these different resources are institutionally connected to strategic decision making, cross-sectoral analysis and systematic learning.

Izmir provides a complementary example in which the development of data infrastructure has been explicitly linked to organisational responsibilities for data management and decision support. The municipality's open-data initiative has been accompanied by an institutional Smart City Platform intended to bring together data generated by municipal departments, affiliated organisations and external stakeholders. The municipality's 2024 organisational arrangements assign responsibilities for collecting, storing, categorising and analysing data, operating the Open Data Platform, and developing collaborations concerning artificial intelligence, data science and decision-support systems. The same organisational framework assigns responsibility for the development and management of the Smart City Platform [18]. In parallel, Izmir's Open Data Portal has been established as a mechanism for publishing municipal datasets in accessible formats and supporting data-driven urban management [19]. This example is significant because it demonstrates that some Turkish municipalities are already moving beyond the publication of datasets towards organisational arrangements that explicitly connect data, analytics and decision support. At the same time, these capabilities remain embedded within particular municipal organisational structures rather than forming a common metropolitan decision infrastructure across institutions and cities.

The situation is not uniform across metropolitan cities, however. Differences in institutional capacity, financial resources, transport-system characteristics, data maturity and analytical expertise mean that the availability and usability of mobility information can vary considerably [20]. Some cities have developed relatively advanced transport management and modelling capabilities, while others may rely more heavily on externally commissioned studies, periodic surveys, operator-provided information or datasets developed for individual projects. The resulting landscape is therefore heterogeneous. This heterogeneity should not necessarily be interpreted as a deficiency: different metropolitan areas have different mobility problems and information requirements. The more relevant question is whether each city possesses the institutional capabilities required to identify its information needs, access appropriate data, assess their quality and transform them into knowledge for decision making.

The emergence of Sustainable Urban Mobility Planning (SUMP) provides an important institutional development because it explicitly links mobility planning with data, performance assessment, stakeholder participation, implementation and monitoring. The SUMP approach promoted through the Turkish national programme emphasises cooperation across institutional boundaries, assessment of current and future performance, integrated treatment of transport modes, a long-term vision, implementation planning and monitoring and evaluation [21]. Importantly for the present study, recent SUMP Türkiye activities have also treated data collection and modelling as institutional-capacity issues rather than purely technical exercises. A 2025 training programme on data collection for sustainable urban mobility and modelling explicitly identified data availability, data access, inter-institutional coordination, resource constraints, data quality and sustainable data management as practical challenges facing mobility planning in Türkiye [22].

The scale and diversity of SUMP-related activity also illustrate the growing sophistication of the Turkish planning environment. The national programme has supported projects involving

metropolitan and other municipalities including Ankara, Istanbul, Izmir, Kocaeli, Düzce, Trabzon, Gaziantep, Mersin and Denizli. Istanbul's second-stage project included analysis of the existing mobility situation, development of an activity-based transport model, policy and action development and an implementation pipeline [23]. Previous academic analysis of Istanbul's SUMP process has similarly highlighted the strategic and governance dimensions of sustainable urban mobility planning [29]. Izmir's SUMP was developed around a long-term mobility vision covering multiple transport modes and was completed in 2025 [24], while the Düzce SUMP was explicitly designed as a dynamic planning instrument subject to continuous monitoring and evaluation [25]. These initiatives demonstrate that Turkish municipalities are increasingly developing the analytical and planning components required for sustainable mobility governance. The remaining challenge is to ensure that the data, models, planning outputs and monitoring processes generated through these initiatives become durable institutional capabilities rather than remaining primarily associated with individual projects.

Three forms of fragmentation are particularly relevant in the Turkish metropolitan context. The first is technical fragmentation, arising from different data formats, software systems, standards, spatial references, update frequencies and interfaces. Even where two organisations possess information concerning the same mobility phenomenon, technical incompatibility can make integration difficult. The second is institutional fragmentation, arising from the distribution of responsibilities and information resources across organisations with different mandates, budgets, priorities and decision authorities. Data may be available within one organisation but not routinely accessible to another organisation that requires it for planning or evaluation. The third is epistemic fragmentation, which concerns differences in the way mobility problems are defined and interpreted. Transport operators, planners, traffic engineers, environmental specialists, financial authorities, elected decision makers and citizens may attach different meanings and priorities to the same observed mobility conditions. Technical integration alone cannot resolve these differences.

The Turkish metropolitan landscape consequently presents an important intermediate position. Significant mobility data, analytical systems and planning initiatives already exist, and recent developments such as SUMP demonstrate growing recognition of integrated and evidence-informed approaches. At the same time, these capabilities remain distributed across systems, organisations and planning processes. The resulting challenge is to determine how existing resources can be connected into a more coherent decision-making capability without assuming that a single technological platform or organisational structure is appropriate for all metropolitan cities.

4. Barriers to Transforming Mobility Information into Actionable Knowledge

The preceding analysis indicates that the principal challenge facing metropolitan mobility decision making in Türkiye cannot be reduced to the availability of transport data. Mobility information is produced by numerous organisations and through increasingly diverse technological systems, while strategic planning initiatives have strengthened the emphasis on evidence, integration and monitoring. The more fundamental challenge concerns the capacity to connect these resources to decision processes in a consistent and continuous manner.

These barriers are also visible in recent institutional work on sustainable mobility in Türkiye. The 2025 SKUP Türkiye training programme on mobility-data collection identified data availability, access to data, coordination between stakeholders, resource constraints and operational difficulties as practical challenges in the collection and use of mobility information [21]. The programme also emphasised the need for sustainable processes covering data collection, processing, storage, sharing and analysis, and linked these processes to decision-support systems and before-and-after evaluation [26].

One important barrier is the fragmentation of data across systems and organisational boundaries. Mobility data are commonly generated for specific operational, administrative or planning purposes rather than for an integrated metropolitan information architecture. Differences in data structures, definitions, spatial and temporal resolutions, update frequencies and access arrangements can make it difficult to combine these sources. A transport authority may therefore have access to extensive information about public transport operations while having limited ability to combine it systematically with land-use, socio-economic, environmental or privately generated mobility information.

A related barrier concerns data quality and comparability. Data used in metropolitan decision making can differ substantially in terms of accuracy, completeness, temporal coverage, spatial resolution and collection methodology. Administrative data may provide continuous observations but reflect the operational priorities of the organisation collecting them. Surveys can provide behavioural and attitudinal information that is not available from automated systems but are necessarily more episodic and resource-intensive. Sensor and location-based data can offer detailed information on movements while introducing questions concerning representativeness, privacy and methodological consistency. Private-sector data can complement public sources but may be subject to commercial restrictions or changes in access conditions. Consequently, the existence of a dataset does not establish that it is suitable for every decision context. Decision infrastructure must include mechanisms for assessing data provenance, quality, uncertainty and fitness for purpose.

Interoperability represents a further challenge. Technical interoperability is often understood in terms of whether different systems can exchange data, but effective interoperability also requires semantic and institutional compatibility. Two systems may technically exchange files or data streams while using different definitions for the same concept. A passenger trip, vehicle movement, transport mode or network segment may be represented differently according to the operational or analytical purpose for which the data were generated. Similarly, different organisations may apply different geographical units, classification systems or performance indicators. Without shared definitions and metadata, technically connected datasets may still produce ambiguous or misleading analytical results.

Another major barrier is institutional fragmentation. Metropolitan mobility involves multiple organisations whose responsibilities are complementary but not necessarily aligned. Data ownership, regulatory authority, financial responsibility and operational control can be distributed across different institutions. This can create situations in which the organisation possessing relevant information is not the organisation responsible for the decision for which that information is required. Information sharing may then depend on bilateral relationships, individual initiatives or project-specific agreements rather than established institutional processes. Such arrangements can be effective in particular circumstances but are vulnerable to organisational change, staff turnover and changing priorities. A sustainable decision infrastructure therefore requires institutionalised mechanisms for information sharing rather than relying primarily on informal coordination.

Institutional fragmentation also affects accountability for analytical outputs. When information is generated by one organisation, analysed by another and ultimately used by a third to justify a policy decision, responsibility for assumptions, uncertainties and interpretations can become unclear. A model output, for example, may appear to provide an objective basis for a decision even though it depends on assumptions concerning demand, behaviour, land use, costs or future technological conditions. If these assumptions are not transparent and traceable, analytical outputs can acquire an authority that exceeds the strength of the underlying evidence. Decision infrastructure should therefore make the provenance of information and analytical assumptions visible to those responsible for interpreting and using them.

A further institutional barrier is the uneven distribution of analytical capacity. Metropolitan institutions may possess substantial operational data but have limited capacity to combine them with other information sources or to develop more advanced forms of analysis. Conversely, external consultants or research organisations may possess specialised analytical capabilities without being continuously embedded within the institutional decision process. This can produce a recurring cycle in which analytical capacity is assembled for individual projects but not necessarily retained as an organisational capability. Building decision infrastructure therefore requires attention to institutional memory and knowledge retention as well as analytical tools.

Another key barrier is epistemic fragmentation, which is particularly important because mobility decisions involve competing interpretations of the same urban conditions. Different professional and institutional communities may understand mobility through different conceptual lenses. Traffic engineers may focus on network performance and vehicle movement; public transport operators may prioritise reliability, capacity and operational efficiency; planners may emphasise accessibility and land-use integration; environmental specialists may focus on emissions and exposure; social policy perspectives may emphasise affordability and distributional effects; and elected decision makers may need to consider broader public preferences, political commitments and financial constraints. These perspectives are not necessarily incompatible, but they can result in different definitions of what constitutes a successful mobility intervention.

This creates a distinction between evidence and decision relevance. An indicator can be statistically robust and still be insufficient for a particular decision if it does not capture the relevant dimensions of the problem. For example, an intervention that improves average traffic speed may simultaneously alter public transport reliability, pedestrian conditions, emissions, accessibility or the distribution of benefits between different groups. A decision infrastructure must therefore enable multiple dimensions of performance to be considered together rather than allowing a single indicator or analytical model to define the problem in advance. This is particularly important in sustainable mobility, where environmental, economic, accessibility and social objectives can conflict.

Uncertainty constitutes another fundamental barrier. Metropolitan mobility systems are influenced by demographic change, economic conditions, land-use development, technological innovation, behavioural adaptation, infrastructure investment and policy interventions. Long-term decisions therefore cannot be based solely on the assumption that historical relationships will remain stable. Forecasts and models remain important, but their outputs should be interpreted in relation to assumptions and uncertainty rather than treated as deterministic predictions. A decision infrastructure should consequently support scenario exploration, sensitivity analysis, monitoring and adaptive management [26–28].

The relationship between information and political and financial constraints also requires explicit consideration. Transport decisions are not made in an analytical vacuum. Metropolitan authorities operate within legal mandates, available budgets, procurement rules, implementation capacities and broader strategic priorities. Some interventions that appear desirable from a purely analytical perspective may be difficult to implement because of financial, institutional or legal constraints. Conversely, decisions may be advanced because they respond to immediate operational or political priorities even when their long-term effects are uncertain. This does not imply that evidence is irrelevant. Rather, it demonstrates that evidence becomes meaningful when it is incorporated into a decision process that explicitly recognises trade-offs between objectives, constraints and possible consequences.

5. An Urban Mobility Decision Infrastructure for Metropolitan Cities in Türkiye

This study proposes an Urban Mobility Decision Infrastructure (UMDI) as a conceptual framework, illustrated in Figure 2, for organising an integrated capability through which

heterogeneous information can be transformed into knowledge, decisions, implementation and institutional learning. The concept deliberately extends beyond the conventional notion of a mobility data platform. Whereas a data platform primarily concerns the collection, storage, management and exchange of information, a decision infrastructure connects these functions to analytical interpretation, institutional deliberation, implementation, evaluation and learning. Its purpose is therefore to create the conditions under which relevant information can consistently influence metropolitan mobility decisions.

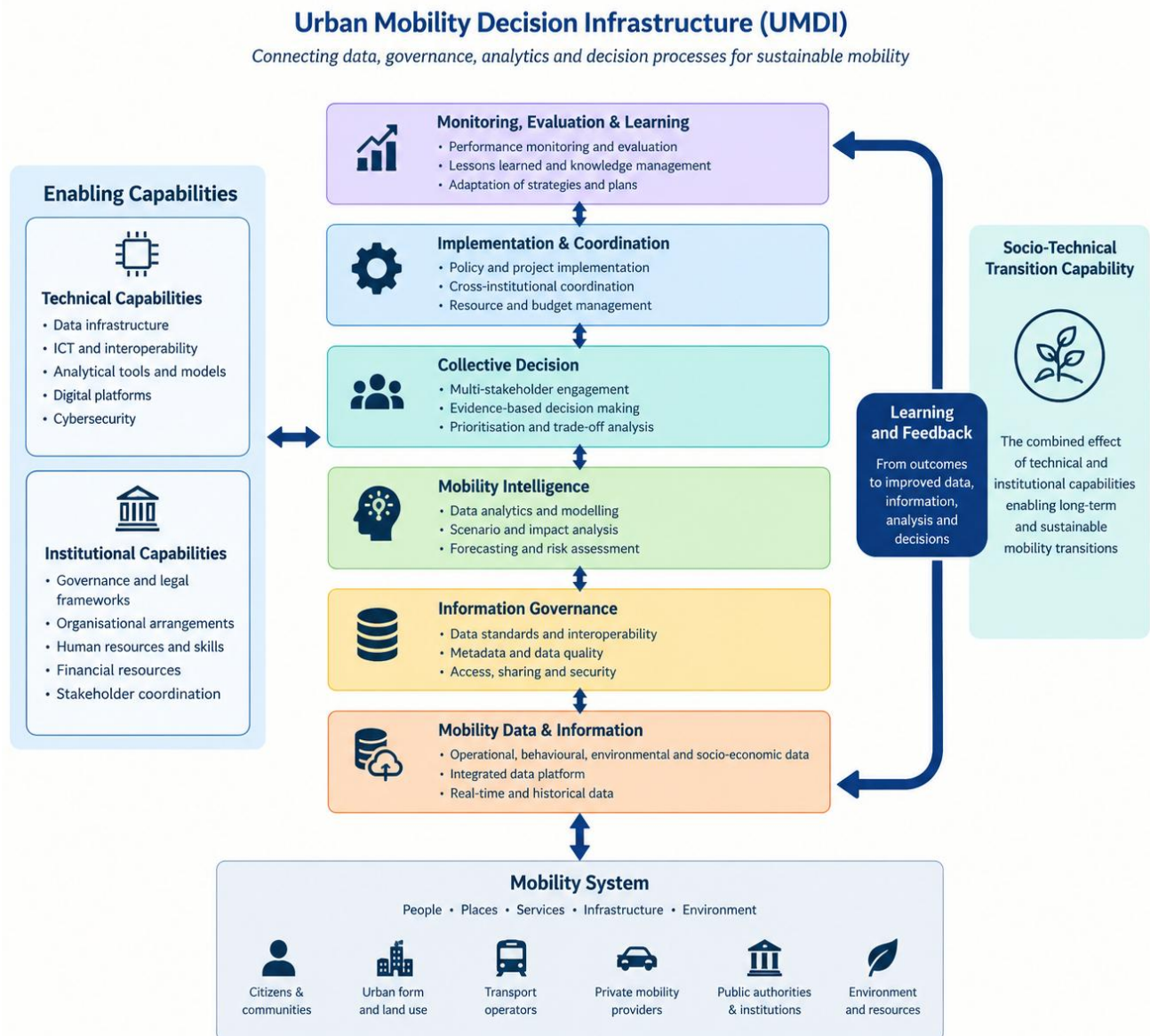


Fig. 2. Urban Mobility Decision Infrastructure (UMDI)

This chain should not be interpreted as a linear sequence in which information is progressively processed until a final decision is produced. Instead, it represents a set of interconnected capabilities through which metropolitan authorities continuously observe the mobility system, interpret changing conditions, consider alternative interventions, implement decisions, evaluate their consequences and revise subsequent decisions. The infrastructure therefore contains both forward flows, from data towards action, and feedback flows, from observed outcomes towards new information and learning.

At its foundation, the infrastructure requires a shared mobility information base. This includes the diverse sources of information required to understand metropolitan mobility, such as public transport operations, passenger demand, traffic conditions, infrastructure, land use, population and socio-economic characteristics, environmental conditions, safety, travel behaviour and emerging forms of digital mobility data. The objective is not to centralise every dataset in a single physical repository. Different organisations may continue to own and manage their own systems. Instead, the infrastructure should establish mechanisms through which relevant information can be identified, accessed, understood and combined when required for a particular decision. This distinction is important because institutional centralisation is neither necessary nor necessarily desirable for information integration.

The Turkish examples discussed in Section 3 suggest that the proposed UMDI should not be interpreted as a proposal to replace existing municipal information systems. Rather, it can be understood as an integrative architecture for connecting capabilities that already exist in partial form. Istanbul's transport information systems demonstrate the availability of operational and passenger data, geographic integration, standardised public transport information and mobility analysis; TNGIS provides a national framework for geographic-data standards, metadata and sharing; and Izmir has developed organisational arrangements linking data analytics, open data, smart-city systems and decision-support activities [15, 17, 18]. SUMP projects add modelling, strategic planning, stakeholder engagement, implementation and monitoring functions. The broader SUMP methodology and principles are discussed by Canitez [21]. Examples from implementation in Turkish cities can be observed in Istanbul [23], Izmir [24] and Düzce [25]. The conceptual contribution of the UMDI is therefore to connect these otherwise differentiated capabilities into a continuous decision-and-learning process. Its novelty lies in specifying how existing data, governance, analytical and planning capabilities can be institutionally connected to decisions, implementation and learning.

The second component is an information governance and interoperability layer. This layer provides the standards, metadata, data dictionaries, interfaces, access arrangements, quality procedures and governance rules required to connect heterogeneous information sources. It should establish common definitions for key mobility concepts while allowing organisations to retain appropriate operational systems and responsibilities. Data provenance and quality information should also form part of this layer so that users can understand where information originated, when it was collected, how it was processed and what limitations it contains. Interoperability is consequently treated as both a technical and institutional capability. The purpose is to make information sufficiently consistent and traceable to support joint analysis without assuming that all organisations must use identical systems.

The third component is a mobility intelligence layer through which information is transformed into knowledge relevant to decision making. This includes descriptive and diagnostic analysis, transport modelling, forecasting, scenario development, accessibility analysis, environmental assessment, equity analysis, performance monitoring and other analytical approaches appropriate to particular questions. Importantly, the infrastructure should not privilege a single analytical method. Different decisions require different combinations of quantitative evidence, qualitative knowledge, modelling, professional judgement and stakeholder perspectives. The function of the mobility intelligence layer is therefore to provide decision makers with structured evidence about system conditions, possible interventions, expected consequences and associated uncertainties.

A critical principle at this stage is the explicit treatment of uncertainty and assumptions. Analytical outputs should not be presented as objective facts independent of the assumptions through which they are generated. Models depend on input data, parameter choices, behavioural assumptions and representations of future conditions. The proposed infrastructure should therefore enable users to

understand the provenance of analytical results, compare scenarios and identify areas of uncertainty. This is particularly important for long-term mobility decisions, where structural changes in land use, technology, demographics, economic conditions or travel behaviour can make historical relationships unreliable. Rather than attempting to eliminate uncertainty, the infrastructure should make uncertainty visible within the decision process.

The fourth component is the collective decision layer. This is where analytical knowledge is connected to institutional mandates, policy objectives and practical constraints. Metropolitan mobility decisions frequently involve several legitimate objectives, including accessibility, network performance, environmental sustainability, economic development, social inclusion, safety, financial feasibility and quality of public space. These objectives may conflict, and no analytical model can determine their relative importance independently of the decision-making context. The collective decision layer therefore provides a structured environment in which evidence can be considered alongside institutional responsibilities, stakeholder perspectives, legal requirements, financial constraints and political priorities.

This component is particularly important for distinguishing decision support from decision automation. The proposed infrastructure is not intended to replace human judgement or convert complex policy choices into algorithmic outputs. Instead, it should improve the quality, transparency and traceability of the information available to those responsible for making decisions. It should allow decision makers to understand what is known, what is uncertain, which assumptions underpin an analysis, which objectives are affected and what trade-offs may arise from alternative interventions.

The fifth component concerns implementation and institutional coordination. A decision becomes meaningful only when it can be translated into an intervention, programme, regulation, investment or operational change. The infrastructure should therefore connect decisions with responsibilities, resources, implementation schedules and measurable outcomes. This requires coordination between organisations that may have different statutory mandates or operational roles. It also requires that intended outcomes and performance indicators are defined sufficiently clearly to enable subsequent monitoring. Without this connection, analytical work risks remaining separate from the practical processes through which metropolitan mobility systems are changed.

The sixth component is monitoring, evaluation and learning. Once an intervention has been implemented, its actual effects should be compared with the expectations and assumptions that informed the original decision. Relevant outcomes may include changes in travel behaviour, public transport performance, accessibility, congestion, emissions, safety, operating costs or distributional effects. Evaluation should not be restricted to determining whether a project met a predefined target. It should also examine why observed outcomes differed from expectations and what this implies for future decisions. This creates an institutional feedback mechanism through which implementation becomes a source of knowledge.

An important feature of the proposed infrastructure is that it separates capabilities from organisational structures. A metropolitan city does not necessarily need to create a new institution responsible for every component. Existing municipal departments, transport operators, planning organisations, universities and external partners may already perform many of these functions. The purpose of the framework is to identify the functions that need to be connected, regardless of which organisation performs them. One metropolitan authority may integrate several capabilities within a dedicated mobility unit, while another may distribute them across existing departments and establish coordination mechanisms between them.

The infrastructure also requires a distinction between operational intelligence and strategic intelligence. Operational intelligence concerns the real-time or short-term functioning of the mobility system, such as vehicle movements, service reliability, incidents, congestion and passenger demand.

Strategic intelligence concerns longer-term questions relating to land-use change, infrastructure investment, modal transformation, technological developments, behavioural change and sustainability objectives. Both are necessary, but they operate on different temporal scales and require different analytical approaches. A decision infrastructure should enable information generated for operational purposes to contribute, where appropriate, to strategic learning while ensuring that short-term operational priorities do not completely determine long-term system transformation.

Similarly, the infrastructure should incorporate multiple forms of knowledge. Quantitative datasets and analytical models provide important evidence, but professional experience, operational knowledge, stakeholder perspectives and user experiences can reveal conditions that are difficult to capture through conventional datasets. Incorporating these forms of knowledge requires mechanisms for identifying, documenting and critically assessing different types of evidence according to their relevance and limitations. This is particularly significant in metropolitan mobility because some consequences of transport interventions, such as perceived safety, accessibility barriers or changes in travel behaviour, may not be fully represented in conventional operational datasets.

The proposed infrastructure can therefore be understood through three overarching capabilities: situational intelligence, transition intelligence and learning intelligence. Situational intelligence concerns the ability to understand the current mobility system and identify emerging problems. Transition intelligence concerns the ability to explore alternative futures, assess possible interventions and understand how technological, behavioural and institutional changes may affect mobility pathways. Learning intelligence concerns the ability to evaluate implemented interventions, identify discrepancies between expectations and outcomes, and incorporate these lessons into subsequent decisions. Together, these capabilities connect day-to-day evidence use with long-term system transformation.

The framework developed in this section provides the conceptual basis for considering how metropolitan information capabilities can contribute to sustainable mobility transitions. The next section therefore examines the relationship between decision infrastructure and socio-technical transformation, focusing on how information, experimentation, feedback and institutional learning can support changes extending beyond individual transport projects towards longer-term changes in mobility systems.

6. Discussion and Conclusions

This study has argued that the central challenge of sustainable urban mobility decision making in Türkiye is not simply the availability of transport data, but the institutional capacity to transform heterogeneous information into actionable knowledge and adaptive decisions. Metropolitan mobility systems already generate substantial operational, spatial, demographic, environmental and behavioural information, while initiatives such as Sustainable Urban Mobility Planning have strengthened the emphasis on integration, monitoring and evidence-informed policy. However, data, analytical tools and planning processes do not automatically constitute a coherent decision-making capability. The critical issue is how these resources are connected to processes through which problems are defined, alternatives assessed, decisions implemented, outcomes evaluated and knowledge retained.

The Urban Mobility Decision Infrastructure (UMDI) proposed in this study addresses this challenge by extending the conventional concept of a mobility data platform towards a broader institutional and decision-oriented architecture. A data platform primarily makes information

available; a decision infrastructure additionally establishes the analytical, organisational and governance capabilities through which information can influence decisions and generate learning.

The proposed infrastructure connects six functions: mobility information resources; information governance and interoperability; analytical and interpretive capabilities; collective decision processes; implementation and monitoring; and evaluation and institutional learning. This architecture emphasises that data governance is also a form of decision governance. Issues such as data ownership, access, standards, interoperability and quality influence which evidence can enter a decision process and how that evidence can be interpreted. Similarly, analytical capacity needs to be embedded within institutions so that methods, assumptions and findings become part of organisational memory rather than remaining temporary project outputs.

The framework also highlights the importance of plural and transparent evidence. Sustainable mobility involves potentially competing objectives, including accessibility, environmental performance, economic efficiency, safety, public transport quality, social equity and financial feasibility. An information-based decision system should therefore not seek to eliminate these trade-offs; its role is instead to clarify evidence, assumptions, uncertainty and trade-offs for those responsible for making decisions.

For metropolitan cities in Türkiye, the evidence reviewed in this study suggests that the starting point for such an infrastructure is considerably more substantial than a simple data-deficit narrative would imply. Nationally, TNGIS provides a formal framework for geographic-data standards, metadata, interoperability and data sharing. At metropolitan level, Istanbul has developed integrated public transport information and mobility-analysis capabilities, while Izmir has established open-data, smart-city and data-analytics functions within its municipal organisation. SUMP initiatives in Istanbul, Izmir, Ankara, Düzce and other cities have further expanded modelling, strategic planning, stakeholder engagement, implementation and monitoring capabilities. At the same time, recent national mobility-planning activities continue to identify data access, coordination, resources and data-management processes as practical challenges. Turkish municipalities need to strengthen the institutional connections between systems that already exist, while addressing differences in data quality, access, standards, analytical capacity and decision authority.

The framework has several limitations. It is primarily a conceptual framework rather than an empirically validated organisational model, and its propositions require further testing through metropolitan case studies. The Turkish metropolitan landscape is also heterogeneous, while broader political, financial, legal and administrative conditions can influence the effectiveness of decision infrastructure. Future research could therefore apply the framework comparatively across cities, using institutional mapping, documentary analysis, interviews and stakeholder workshops to identify capability gaps and examine alternative governance arrangements. Further work could also develop maturity indicators for monitoring the development of metropolitan decision infrastructure over time.

The empirical basis of the Turkish contextual analysis should nevertheless be interpreted with caution. The study does not undertake a systematic audit of all metropolitan municipalities or quantitatively compare their data maturity, interoperability or decision-making performance. The examples of Istanbul and Izmir are used because their institutional and information systems are relatively well documented, while national TNGIS and SUMP materials provide evidence of broader institutional developments. These sources are sufficient to establish the existence of relevant capabilities and recurring governance issues, but they cannot establish that the same configuration exists in every metropolitan municipality. Comparative empirical research is therefore required to determine the extent to which the UMDI capabilities identified in this study are present, connected or missing across different metropolitan contexts.

Emerging technologies, including artificial intelligence, provide another important research direction. Such technologies may strengthen mobility intelligence by processing large datasets, identifying patterns and supporting scenario development. However, their effectiveness will depend on data quality, transparency, institutional capacity and governance. They should therefore be treated as components of mobility intelligence rather than substitutes for the wider decision infrastructure.

The principal contribution of this study is consequently the integration of perspectives that are often considered separately. Sustainable mobility research emphasises integrated transport objectives; socio-technical transition theory focuses on systemic transformation; data governance addresses the institutional conditions of information; and decision-support research focuses on analytical assistance. The UMDI connects these perspectives around a common question: how can metropolitan institutions continuously transform information into decisions and the consequences of those decisions into knowledge for future action?

The answer proposed here is that sustainable urban mobility requires not simply more data or more sophisticated analytical tools, but an institutional capability that connects data, knowledge, decisions, implementation and learning. For metropolitan cities in Türkiye, such an infrastructure can provide a means of connecting existing information resources and planning initiatives while allowing different cities to develop capabilities appropriate to their own circumstances. The shift from data platform to decision infrastructure therefore represents a shift from viewing data as an end in itself towards viewing information capability as part of metropolitan institutional capacity. Ultimately, the value of mobility data lies in the ability of cities to use it to understand change, make informed decisions, evaluate consequences and adapt over time.

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Conflicts of Interest

The authors declare no conflicts of interest.

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