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A City Persona Sensitive Social Optimum Mobility Index for Assessing Inclusive Urban Mobility in Florence

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Abstract

This study develops and applies the Social Optimum Mobility Index (SOMI), a persona-sensitive and KPI-based framework for assessing socially inclusive urban mobility solutions. Developed within the Horizon Europe Research and Innovation Action GOLIA, the framework contributes to the operationalisation of Mobility as a Right (MaaR) by translating inclusive-mobility principles into measurable assessment pillars: Acceptability, Accessibility, Affordability, Agency, Availability, Legal Recognition, Participation, and Safety & Security. The methodology combines literature-based and MaaR-informed pillar definition, a participatory persona–pillar scoring procedure for deriving persona-specific significance weights, an Impact Creation Board (ICB) procedure for deriving solution-specific persona-influence weights, KPI normalisation, and spatial accessibility interpretation. A sensitivity analysis is also conducted to examine whether the SOMI results remain robust under alternative persona–pillar and persona-influence weighting assumptions. The framework is applied to the Florence case study, where nine personas and three mobility solutions are assessed: (i) 30 km/h zones and traffic calming, (ii) urban logistics micro-hubs, and (iii) road-space redistribution. The results show a clear ranking among the three solutions. Road-space redistribution achieves the strongest solution-level SOMI performance, with a score of 0.840, followed by urban logistics micro-hubs at 0.630 and 30 km/h zones and traffic calming at 0.388. The equal-weighted city-level SOMI estimate for Florence is 0.619.At persona level, road-space redistribution performs best across all personas, indicating strong performance across most SOMI pillars. The sensitivity analysis confirms that the comparative ranking of the three solutions is robust under alternative weighting assumptions. The persona–pillar weight sensitivity test shows that persona-level SOMI values are most responsive for 30 km/h zones and traffic calming, where pillar performance is more uneven. By contrast, the micro-hub solution shows a more balanced sensitivity pattern, while road-

space redistribution remains the strongest-performing solution across the full perturbation interval. The ICB sensitivity test shows only limited variation in solution-level SOMI values when persona-influence weights are gradually replaced by equal persona weights, indicating that the final ranking does not depend strongly on the exact ICB weighting structure.

Keywords: Social Optimum Mobility Index; inclusive urban mobility; mobility justice; persona-based assessment; multi-criteria decision analysis; Florence; accessibility; urban logistics.

1. Introduction

Urban mobility systems determine whether different users can reach employment, education, services, commercial areas and logistics destinations under acceptable conditions of time, cost, safety and reliability (Geurs and van Wee, 2004). However, accessibility is not only a question of network availability or infrastructure provision. Recent evidence confirms that this access is unevenly distributed across cities. For example, public-transport accessibility to low-wage jobs differs substantially across large urban regions (Alam and Alam, 2026), while demand-supply equity studies show that public transport provision may not correspond to the mobility needs of different areas and populations (Kim et al., 2026). These inequalities are not limited to spatial access. They also concern the conditions under which mobility is experienced. For users with disabilities, inclusive mobility depends on accessible services, adequate assistive technologies and the removal of physical barriers at stops and stations (Mogaji et al., 2026; Salman et al., 2026). For women and other users, exposure to insecurity, harassment and perceived risk can reduce public-transport use and reshape travel behaviour (Sarker et al., 2026). For cost-sensitive users, fare levels and affordability policies directly affect whether public transport can function as an everyday mobility option (Beck et al., 2026). Therefore, a mobility intervention may improve the average performance of the transport system while still producing unequal outcomes across personas.

Urban mobility interventions affect not only passengers but also businesses, delivery operators and public-space management companies, since last-mile delivery systems operate within the same constrained urban networks used by passenger transport (Tang et al., 2026). Cargo-bike and urban freight studies show that sustainable logistics measures must be assessed together with access, safety and public-space conditions (Ceccato and Gastaldi, 2023). Digital mobility-governance research shows that mobility platforms can support access, but can also create risks related to exclusion, accountability and public control (Tafidis, 2026).

Existing methods partially address this problem. Accessibility models measure access to opportunities (Al Mamun and Lownes, 2011), while equity models measure spatial or social imbalance in transport provision (Kim et al., 2026). Safety models measure crash exposure or conflict risk (Liang et al.,

2026), while public-transport policy studies measure affordability, fare effects and user response (Beck et al., 2026). The challenge is to integrate these heterogeneous indicators into a transparent and auditable calculation framework that can show how mobility interventions perform across different personas, solutions and operational urban functions.

The purpose of this paper is therefore to address this challenge through the development and implementation of a Social Optimum Mobility Index (SOMI) for urban mobility assessment. SOMI is structured around eight pillars: Acceptability, Accessibility, Affordability, Agency, Availability, Legal Recognition, Participation, and Safety & Security. The index is designed to convert heterogeneous evidence on mobility performance, social inclusion, governance conditions and operational impacts into a common numerical framework that can be inspected at KPI, pillar, persona, solution and city level.

The remainder of the paper is organised as follows. Section 2 reviews the relevant literature on socially inclusive urban mobility assessment and derives the eight SOMI pillars used in the proposed framework. Section 3 describes the employed methodological steps while Section 4 presents the mathematical formulation of the SOMI and the weighting models developed. Section 5 applies the methodology to the Florence case study, defines the personas and mobility solutions, identifies the KPI values and reference limits, presents the persona-level, solution-level, and city-level SOMI results and conducts a sensitivity analysis on the weighting parameters employed. Finally, Section 6 discusses the main findings, policy implications, methodological limitations and future research perspectives.

2. Literature Review and SOMI Pillar Definition

The purpose of this Section is twofold. First, it reviews published research efforts on socially inclusive urban mobility assessment to identify what dimensions are already examined in the literature and where methodological gaps remain. Second, it uses this evidence as a methodological basis for defining the pillar structure of the Social Optimum Mobility Index (SOMI).

The first group of studies reviewed focuses on accessibility and access to opportunities. Alam and Alam (2026) examine inequity in access to low-wage jobs by public transit in major U.S. cities, showing that employment accessibility remains unevenly distributed across urban regions. Mishra et al. (2026) develop a multimodal 15-minute city index for South Asian cities, highlighting the need to include formal and informal transport modes when assessing access. Jiang et al. (2026) examine whether the metro system of Shanghai provides fair spatial access to areas that require public transport. Masingi et al. (2026) focus on perceived public transport accessibility and show that accessibility is not only a network property, but also a user-experienced condition. These studies support Accessibility as a core SOMI pillar, because socially inclusive mobility depends on whether different users can reach relevant destinations and opportunities.

A second research stream concerns public transport availability, service provision and operational usability. Kim et al. (2026) analyse horizontal and vertical demand–supply equity in public transit, showing that transport provision may not match mobility needs across areas and user groups. Sevim et al. (2026) use the Gini index to model and optimize mileage homogeneity in public transportation, demonstrating that operational allocation can produce measurable inequality. Wang et al. (2026) provide a national-scale bus–metro operation network dataset for China, showing the importance of detailed service-network data for assessing public transport systems. Azhdari et al. (2026) use explainable machine learning to develop a functional bus stop typology, showing that stops differ in function, performance and policy relevance. These studies support Availability as a separate SOMI pillar, because a mobility option must be present, reliable and practically usable.

A third research stream addresses affordability and fare policy. Dai and Nie (2026) examine how values and policy objectives shape optimal transit fare policy, showing that fare design is directly connected to distributive choices. Beck et al. (2026) review free and low-fare public transport, showing that fare reduction can improve access but also raises questions about financing, operations and service quality. Diaz-Gutierrez and Ranjbari (2026) examine zero-fare policy and security incident frequency, indicating that affordability policies can interact with wider system outcomes. These studies support Affordability as a distinct SOMI pillar, because travel cost directly affects whether users can use mobility services as part of everyday life.

A fourth research stream concerns safety, security and perceived risk. Liang et al. (2026) develop a surrogate measure for bikelane conflict risk, showing that active-mobility safety can be assessed through behavioural and physical dynamics before crashes occur. Sarker et al. (2026) examine how harassment affects women's public transport use, showing that insecurity can reduce use and reshape travel behaviour. Abouelela et al. (2026) study violence against women in buses, while Chisadza et al. (2026) examine public transport, sexual harassment and social norms in South Africa. Adesanya et al. (2026) analyse commuters' safety and security perceptions in bus rapid transit. Shaver et al. (2026) add another safety-related dimension by measuring transit riders' heat exposure during the Vancouver heatwave. These studies support Safety & Security as a SOMI pillar that includes crash risk, conflict exposure, harassment, violence, perceived insecurity and climate-related travel exposure.

A fifth group of studies examines inclusive mobility and disability. Mogaji et al. (2026) analyse the lived experiences of assistive technology use among commuters with disabilities, showing that awareness, availability and adequacy of assistive technologies shape actual mobility outcomes. Gebremariam et al. (2026) examine disability and urban mobility in Mekelle, highlighting the structural barriers faced by disabled users. Salman et al. (2026) assess the accessibility barriers faced by people with disabilities at public transport stops in Hungary, showing that barriers at the stop level

can restrict the use of the wider transport network. Ferizzola et al. (2026) consider universal accessibility as a human's right especially for vulnerable transport users. These studies reinforce the need for SOMI to move beyond average-user assessment and to treat inclusion, accessibility, legal recognition and user-specific constraints as central to mobility evaluation.

A sixth literature stream focuses on acceptability and behavioural response. Beck, Bliemer and Loder (2026) examine public preferences for transport infrastructure improvements and show that attitudes influence support for transport investments. Lopez-Carreiro et al. (2026) analyse the public acceptability of low-emission-zone reinforcement, showing that the acceptance of mobility regulation depends on perceived impacts and user context. Saxena et al. (2026) examine the adoption of demand-responsive transport services and show that perceptions of public transport affect willingness to use new mobility options. Won and Lim (2026) analyse the first voluntary users of autonomous BRT in South Korea, showing that early adoption of smart mobility technologies depends on user characteristics and perceived benefits. These studies support Acceptability as a SOMI pillar, because mobility interventions cannot be evaluated only by technical performance, but they must also be acceptable to users and stakeholders.

A seventh stream concerns agency, digital mobility and platform governance. Tafidis (2026) argues that urban mobility is also shaped by data infrastructures and algorithmic decision systems. Pezoa et al. (2026) examine long-term dynamics of ride-hailing adoption and inequality, showing that platform mobility can expand options for some users while reinforcing unequal adoption patterns. Ay (2026) studies the gentrification of mobility through digital platforms, showing how digital visibility and platform-mediated mobility can reshape public transport use and urban experience. Sun et al. (2026) examine e-scooter governance in Shenzhen, showing how mobility users contest urban space and risk under emerging forms of micromobility regulation. These studies support Agency, because users need practical control over information, mode choice and mobility options. They also support Participation and Legal Recognition, because digital and platform-mediated mobility systems require accountability, representation and enforceable rules.

An eighth stream concerns urban logistics and operational interaction with the mobility system. Tang et al. (2026) examine the spatial relocation of logistics facilities in Beijing and show that logistics systems are affected by land use, urban structure and policy conditions. Tian and Wang (2026) analyse spatial inequality and coordinated logistics development in China's major river basins, highlighting the relationship between logistics efficiency, environmental sustainability and spatial imbalance. Rosner et al. (2026) examine barriers faced by commercial operators in adopting electric vehicles, showing that the transition to sustainable urban logistics depends on operational, infrastructural and business constraints. These studies show that socially inclusive urban mobility assessment should not

be limited to passenger travel. It should also consider logistics, business access, freight operations and public-space management. This supports the inclusion of Availability, Accessibility, Legal Recognition and Safety & Security in SOMI. Table 1 presents the literature-based mapping of published research efforts to the eight SOMI pillars, while Table 2 presents the research gaps derived from the examined literature and how we address them.

Table 1: Literature-based mapping of published research efforts to SOMI pillars

Literature stream	**Indicative studies from the analysed literature**	**Main contribution to the state of the art**	**SOMI pillar derived**
Accessibility and access to opportunities	Alam and Alam (2026); Mishra et al. (2026); Jiang et al. (2026); Masingi et al. (2026)	Measures access to jobs, services, public transport and destination opportunities.	Accessibility
Public transport equity and service availability	Kim et al. (2026); Sevim et al. (2026); Wang et al. (2026); Azhdari et al. (2026)	Measures demand–supply imbalance, service provision, operational allocation and stop/network functionality.	Availability
Affordability and fare policy	Dai and Nie (2026); Beck et al. (2026); Diaz-Gutierrez and Ranjbari (2026)	Examines fare policy, free or low-fare public transport and distributional effects of transport pricing.	Affordability
Safety, security and risk exposure	Liang et al. (2026); Sarker et al. (2026); Abouelela et al. (2026); Chisadza et al. (2026); Adesanya et al. (2026); Shaver et al. (2026)	Measures conflict risk, harassment, violence, perceived insecurity, safety perception and climate-related exposure.	Safety & Security
Inclusive mobility and disability	Mogaji et al. (2026); Gebremariam et al. (2026); Salman et al. (2026); Ferizzola et al. (2026)	Examines assistive technologies, stop-level barriers, universal accessibility and right-to-transport issues.	Accessibility, Availability, Participation, Legal Recognition
Acceptability and behavioural response	Beck, Bliemer and Loder (2026); Lopez-Carreiro et al. (2026); Saxena et al. (2026); Won and Lim (2026); Carvalho and El-Geneidy (2026)	Examines infrastructure preferences, low-emission-zone acceptability, demand-responsive transport adoption and smart mobility adoption.	Acceptability
Digital mobility, agency and platform governance	Tafidis (2026); Pezoa et al. (2026); Ay (2026); Sun et al. (2026)	Examines digital mobility platforms, ride-hailing inequality, platform-mediated mobility and micromobility governance.	Agency, Participation, Legal Recognition
Urban logistics and operational impacts	Tang et al. (2026); Tian and Wang (2026); Rosner et al. (2026)	Examines logistics-facility relocation, spatial inequality in logistics development and barriers to	Availability, Accessibility, Legal Recognition, Safety & Security

		sustainable commercial mobility.	

Table 2: Research Gaps and SOMI Response

Research gap	**How we address it**
Accessibility is often assessed separately from affordability, safety, governance and persona-specific needs.	SOMI treats Accessibility as one component of a wider social-mobility assessment. Access to opportunities is evaluated together with cost, safety, availability, participation, agency and legal recognition, so that accessibility is not interpreted as a standalone network property.
Service provision is often measured as a system property without integration into a broader social-inclusion index.	SOMI separates Availability from Accessibility. Availability captures the presence, coverage or usability of mobility options, while Accessibility captures the ability of personas to reach relevant destinations. This distinction avoids treating the existence of infrastructure or services as sufficient evidence of inclusive mobility.
Affordability is often analysed as a fare-policy problem rather than as one pillar of multidimensional mobility inclusion.	SOMI converts affordability-related evidence, such as transport cost, fare burden, discounts or cost-saving effects, into normalised KPI values. This allows affordability to be compared with non-monetary dimensions such as safety, agency and accessibility within the same calculation structure.
Safety is often assessed in isolated domains and not combined with access, affordability, acceptability or vulnerable-user needs.	SOMI incorporates Safety & Security as a core assessment pillar and allows both objective and perceived safety-related evidence to enter the index. This makes it possible to examine whether an intervention improves mobility conditions not only by increasing access, but also by reducing exposure to risk, insecurity or conflict.
Disability and vulnerable-user evidence is often not embedded in a systematic persona-weighted index.	SOMI uses predefined personas to represent different user needs, constraints and exposure to barriers. Persona-level weighting makes it possible to test whether the same mobility solution performs differently for residents, families, older or less mobile users, students, visitors, commuters, businesses and logistics operators.
Acceptability is often measured through behavioural or preference studies but not converted into normalised index components.	SOMI allows acceptability-related evidence, such as support, willingness to use, perceived usefulness or stakeholder approval, to be transformed into normalised KPIs. In this way, social acceptance becomes part of the formal calculation rather than remaining only a qualitative discussion point.
Digital governance and user agency are often discussed conceptually but remain weakly operationalized in mobility indices.	SOMI introduces Agency, Participation and Legal Recognition as computable assessment pillars. This allows issues such as user choice, control over mobility options, involvement in planning, regulatory readiness and institutional accountability to be included in the numerical assessment.
Logistics and operational impacts are rarely integrated with passenger-focused social-inclusion assessment.	SOMI includes operational actors, such as businesses and logistics operators, within the persona structure and allows freight-related KPIs to be assessed alongside passenger-mobility indicators. This connects social inclusion with last-mile logistics, loading/unloading access, urban freight management and public-space impacts.
Heterogeneous indicators are difficult to compare	SOMI applies a common KPI protocol. Each indicator is defined by its unit, direction of preference, observed or estimated value, lower

Research gap	How we address it
because they use different units, scales and forms of evidence.	reference limit and upper reference limit. Values are then normalised to a common 0–1 scale, making heterogeneous evidence comparable and auditable.

3. Methodology

This section presents the five-step methodological approach followed in the development and application of the Social Optimum Mobility Index (SOMI), as presented in Figure 1. The mathematical formulation of the index and of its weighting layers is given in Section 4.

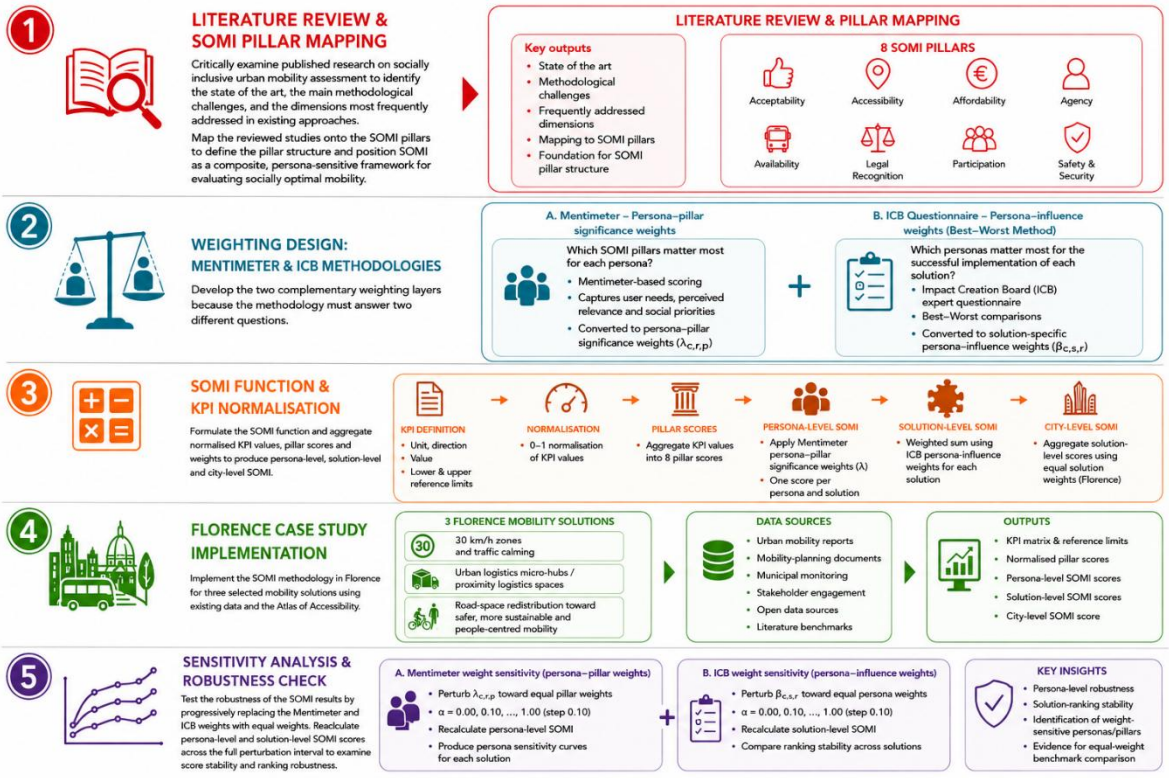


Figure 1: SOMI Methodological Steps

The first step critically examines published research on socially inclusive urban mobility assessment to identify the state of the art, the main methodological challenges, and the dimensions most frequently addressed in existing approaches. The reviewed studies are then mapped onto the SOMI pillars, allowing the literature synthesis to serve as the methodological basis for defining the pillar structure of SOMI and for positioning it as a composite, persona-sensitive framework for evaluating socially optimal mobility.

The second step develops the weighting structure required for the SOMI calculation. Two complementary weighting layers are introduced because the methodology must answer two different questions. The first question is: which SOMI pillars matter most for each persona? This is addressed through a Mentimeter-based persona–pillar scoring exercise. The second question is: which personas

matter most for the successful implementation of each mobility solution? This is addressed through an Impact Creation Board (ICB) expert questionnaire.

The Mentimeter exercise is used to estimate persona–pillar significance weights because this part of the methodology focuses on user needs, perceived relevance and social priorities. The use of stakeholder input is consistent with co-design and participatory planning approaches, in which stakeholders help clarify needs, priorities and assessment criteria (Sanders and Stappers, 2008). Audience-response systems such as Mentimeter provide a practical way to collect participant judgements in real time during workshops (Kay and LeSage, 2009). In SOMI, these judgements are converted into explicit persona-pillar weights, following multi-criteria decision analysis principles, where weights express the relative importance of criteria before aggregation (Belton and Stewart, 2002). This makes stakeholder values and trade-offs visible and traceable within the decision process (Gregory et al., 2012), while the use of normalisation, weighting and aggregation follows composite-indicator guidance on transparency and methodological sensitivity (OECD/EU/JRC, 2008).

The ICB questionnaire is used to capture expert judgement on how strongly each persona may affect the successful implementation of each selected Florence mobility solution. Influence refers to the extent to which a persona can affect the implementation and performance of a mobility solution. This may occur through behavioural uptake, acceptance or opposition, operational relevance, exposure to impacts, political salience, or practical dependence on the intervention. The concept is consistent with stakeholder theory, where actors are considered influential when they have the power, legitimacy, or urgency to affect decision-making processes (Mitchell et al., 1997). It is also consistent with multi-actor transport appraisal approaches, which recognise that different stakeholder groups can shape the feasibility, acceptance, and implementation outcomes of mobility measures (Macharis et al., 2012).

The ICB process is therefore appropriate because it addresses an implementation questionnaire which follows the Best-Worst Method logic, suitable for deriving ratio-scale weights from structured comparisons between the most and least influential alternatives (Rezaei, 2015). In the Florence implementation, the personas are treated as predefined user groups, while the selected Florence mobility solutions are used as the objects of assessment. The ICB questionnaire captures expert judgement on how strongly each persona may affect the success, feasibility, acceptance, or operational functioning of each selected intervention, consistent with multi-actor appraisal approaches that assess how different stakeholder groups influence the implementation and evaluation of mobility measures (Macharis et al., 2012). The resulting weights are therefore interpreted as solution-specific persona-influence weights (Rezaei, 2015).

The third step formulates the SOMI function. Each selected KPI is defined by its unit, direction of preference, observed or estimated value, lower reference limit and upper reference limit. KPI values

are normalised to a common 0–1 scale and then aggregated into pillar scores. These pillar scores are combined with the Mentimeter-derived persona-pillar significance weights to calculate persona-level SOMI values. The persona-level SOMI results are aggregated to the solution level using the ICB-derived solution-specific persona-influence weights. For each solution, this aggregation is calculated as a weighted sum, in which each persona-level SOMI score is multiplied by the corresponding ICB weight and the resulting products are added together. This produces a solution-level SOMI score that reflects both the performance of the solution for each persona and the relative influence of each persona on the implementation of that solution. Finally, the solution-level SOMI scores are aggregated to obtain the city-level SOMI. In the Florence case, equal solution weights are used at the final aggregation stage because the three selected solutions are treated as parallel assessed interventions, and no additional strategic, budgetary, or stakeholder-defined solution-priority weighting is introduced.

The fourth step implements the SOMI methodology in the city of Florence. The implementation covers three selected Florence mobility solutions: 30 km/h zones and traffic calming, urban logistics micro-hubs / proximity logistics spaces, and road-space redistribution toward safer, more sustainable and people-centred mobility. For each solution, measurable KPIs are identified for the eight SOMI pillars using existing Florence data. These data are derived from published urban mobility reports, metropolitan mobility-planning documents, municipal monitoring material, stakeholder-engagement outputs, open-data sources and selected literature benchmarks. This step produces the numerical KPI matrix, reference limits, normalised pillar scores, persona-level SOMI scores and solution-level SOMI scores.

The fifth step conducts a sensitivity analysis of the SOMI weighting structure to examine whether the results are robust to alternative weighting assumptions. This step focuses on the two judgement-based weighting layers of the model: the persona–pillar significance weights derived from the participatory scoring exercise and the solution-specific persona-influence weights derived from the ICB questionnaire. A progressive perturbation approach is applied, in which the original weights are gradually replaced by equal weights using a sensitivity parameter α, ranging from 0 to 1. In the numerical implementation, α is evaluated in 0.10 increments, so that the analysis examines the full transition from the original stakeholder, or expert-derived weighting structure to an equal-weighting structure. For the persona–pillar weights, the analysis recalculates persona-level SOMI values and examines how sensitive each persona's assessment is to changes in pillar priorities. For the ICB persona-influence weights, the analysis recalculates solution-level SOMI values and examines whether the final ranking of the three Florence solutions remains stable when persona-influence weights are replaced by equal persona weights.

4. SOMI Calculation and Weighting Model Development

Let $s \in S_c$ represent an examined mobility solution or policy package of city c, where S_c is the set of solutions evaluated in city c. Let $r \in R_c$ represent a persona considered in city c, where R_c is the set of representative mobility personas. Let $p \in P$ represent a SOMI pillar, where P is the common set of SOMI pillars: Acceptability, Accessibility, Affordability, Agency, Availability, Legal Recognition, Participation, and Safety & Security. For each solution s, and pillar p, let $K_{c,s,p}$ represent the set of KPIs assigned to pillar p for solution s in city c, and let $k \in K_{c,s,p}$ represent a generic KPI belonging to that set.

Because the selected KPIs are expressed in heterogeneous units, such as minutes, euros, percentages, shares, rates, counts or Likert-scale responses, they are transformed onto a common normalised scale from 0 to 1. On this scale, 1 denotes the best achievable or desired performance and 0 denotes the worst reference performance. Let $x_{c,s,r,p,k}$ denote the observed or estimated value of KPI k, under pillar p, for persona r, solution s, and city c. Let $L_{c,r,p,k}$ denote the lower reference limit of KPI k for persona r and pillar p in city c, while $U_{c,r,p,k}$ denotes the corresponding upper reference limit, with $U_{c,r,p,k} \neq L_{c,r,p,k}$. Finally, let $z_{c,s,r,p,k}$ denote the normalised KPI value.

For KPIs where higher values indicate better performance, such as accessibility coverage, service availability, participation inputs or regulatory recognition, normalisation is calculated as:

$$z_{c,s,r,p,k} = \frac{x_{c,s,r,p,k} - L_{c,r,p,k}}{U_{c,r,p,k} - L_{c,r,p,k}} \qquad \text{Eq. (1)}$$

For KPIs where lower values indicate better performance, such as travel time, waiting time, affordability burden or crash exposure, normalisation is calculated as:

$$z_{c,s,r,p,k} = \frac{U_{c,r,p,k} - x_{c,s,r,p,k}}{U_{c,r,p,k} - L_{c,r,p,k}} \qquad \text{Eq. (2)}$$

Let $R_{c,s,r,p}$ represent the score of SOMI pillar p for city c, solution s, and persona r. When a pillar is represented by more than one KPI, the pillar score is calculated as the arithmetic mean of all normalised KPI values assigned to that pillar:

$$R_{c,s,r,p} = \frac{1}{\left|K_{c,s,p}\right|} \sum_{k \in K_{c,s,p}} z_{c,s,r,p,k} \qquad \text{Eq. (3)}$$

where $\left|K_{c,s,p}\right|$ denotes the number of KPIs assigned to pillar p for solution s in city c. Eq. (3) means that each pillar score is the average normalised performance of the KPI portfolio used to represent that pillar for a given city, solution and persona. For each city c, persona r, and SOMI pillar p, the Mentimeter score is first recorded as a mean relevance score:

$$\bar{x}_{c,r,p} = \frac{1}{n_{c,r,p}} \sum_{i=1}^{n_{c,r,p}} x_{i,c,r,p} \quad \text{Eq. (4)}$$

where $x_{i,c,r,p}$ is the score assigned by respondent i to pillar p, for persona r, in city c, and $n_{c,r,p}$ is the number of valid Mentimeter responses for that city-persona-pillar combination.

The value $\bar{x}_{c,r,p}$ represents the displayed Mentimeter average score used as input for the persona–pillar weighting calculation. Since the Mentimeter exercise was conducted as a structured expert/stakeholder workshop using a 1–5 Likert-type agreement scale, the resulting scores are interpreted as workshop-derived judgement scores rather than statistically representative population estimates (Belton and Stewart, 2002). This interpretation is consistent with guidance on the careful treatment of Likert-type data (Sullivan and Artino, 2013). Because the Mentimeter exercise used a 1–5 Likert-type agreement scale, the mean scores are rescaled to a 0–1 relevance scale:

$$q_{c,r,p} = \frac{\bar{x}_{c,r,p} - 1}{4} \quad \text{Eq. (5)}$$

where 1 is the minimum possible score and 5 is the maximum possible score. This transformation converts the original Mentimeter scale into a relevance score where 0 indicates the lowest perceived relevance and 1 indicates the highest perceived relevance (OECD/EU/JRC, 2008; Likert, 1932). The final persona-pillar significance weight is obtained by normalizing the adjusted relevance scores across the eight SOMI pillars for the same persona:

$$\lambda_{c,r,p} = \frac{q_{c,r,p}}{\sum_{p' \in P} q_{c,r,p'}} \quad \text{Eq. (6)}$$

This normalisation ensures that, for each persona in each city, the eight SOMI pillar weights sum to one:

$$\sum_{p \in P} \lambda_{c,r,p} = 1 \quad \text{Eq. (7)}$$

The resulting value $\lambda_{c,r,p}$represents the Mentimeter-derived persona–pillar significance weight, namely the relative importance of SOMI pillar $p$for persona $r$in city c. These weights are then used in the persona-level SOMI calculation. This treatment is consistent with multi-criteria decision analysis, where weights express the relative importance of criteria before aggregation (Belton and Stewart, 2002), and with composite-indicator guidance, which emphasises transparency in normalisation, weighting and aggregation choices (OECD/EU/JRC, 2008).

Let $SOMI_{c,s,r}$ represent the persona-level SOMI score for persona r, solution s, and city c. It is calculated by aggregating the pillar scores using the corresponding Mentimeter-derived persona-pillar significance weights:

$$SOMI_{c,s,r} = \sum_{p \in P} \lambda_{c,r,p} \, R_{c,s,r,p} \qquad \text{Eq. (8)}$$

Substituting Eq. (3) into Eq. (8), the persona-level SOMI score can be expressed directly from the normalised KPI values:

$$SOMI_{c,s,r} = \sum_{p \in P} \lambda_{c,r,p} \left(\frac{1}{\left| K_{c,s,p} \right|} \sum_{k \in K_{c,s,p}} z_{c,s,r,p,k} \right) \qquad \text{Eq. (9)}$$

Eq. (9) shows that the persona-level SOMI score remains traceable to the KPI layer. It prevents the assessment from relying only on average city-level performance and allows the model to identify whether a solution performs differently for different personas. In this way, the same mobility solution can receive different persona-level SOMI values, because each persona attaches different importance to the SOMI pillars.

The second weighting layer concerns the relative influence of each persona on the successful implementation of each mobility solution. This layer is derived through the ICB expert-elicitation process, which captures which personas matter most for making each solution work in practice. The ICB process combines an initial direct point-allocation exercise with a structured Best-Worst Method weighting round. Direct point allocation is commonly used in weight-elicitation procedures to convert expert judgements into preliminary relative-importance scores (Riabacke et al., 2012), while the Best-Worst Method (BWM) is suitable for deriving ratio-scale weights from structured comparisons between the most and least influential alternatives (Rezaei, 2015, 2016).

Let $\beta_{c,s,r}$ represent the ICB-derived persona-influence weight of persona r for solution s in city c. This parameter is interpreted as an expert-derived implementation-influence weight, not as a population share, vulnerability score, benefit share, cost share or general stakeholder-importance score (Belton and Stewart, 2002). The weight is bound as follows:

$$0 \leq \beta_{c,s,r} \leq 1 \qquad \text{Eq. (10)}$$

For each solution s, the persona-influence weights sum to one across all representative personas considered in that city:

$$\sum_{r \in R_c} \beta_{c,s,r} = 1 \qquad \text{Eq. (11)}$$

Let $e \in E_{c,s}$ represent an expert input associated with the weighting of personas for solution s in city c, where $E_{c,s}$ is the set of valid expert inputs for that solution and city. Let $\left| E_{c,s} \right|$ represent the number of valid expert inputs.

In Round 0, experts allocate 100 points across the personas relevant to each solution. Let $a_{e,c,s,r}^{(0)}$ represent the number of Round 0 points allocated by expert e to persona r for solution s in city c. The individual Round 0 persona-influence weight is calculated as:

$$\beta_{e,c,s,r}^{(0)} = \frac{a_{e,c,s,r}^{(0)}}{\sum_{r' \in R_c} a_{e,c,s,r'}^{(0)}} \quad \text{Eq. (12)}$$

where r' represents a generic persona used as a summation index across the persona set of city c. Since experts allocate 100 points, the denominator equals 100 when the response is complete and valid (OECD/EU/JRC, 2008; Riabacke et al., 2012). The aggregated Round 0 persona-influence weight is calculated as the arithmetic mean of the valid individual Round 0 weights:

$$\beta_{c,s,r}^{(0)} = \frac{1}{|E_{c,s}|} \sum_{e \in E_{c,s}} \beta_{e,c,s,r}^{(0)} \quad \text{Eq. (13)}$$

Round 0 is retained for transparency, diagnostics and sensitivity interpretation. The final SOMI-ready persona-influence weights are derived from the more structured Round 1 Best-Worst Method. In Round 1, the Best-Worst Method is used to derive ratio-scale persona-influence weights (Rezaei, 2015). Let $B_{e,c,s}$ represent the persona identified by expert e as the most influential persona for solution s in city c, while $W_{e,c,s}$ represents the persona identified by expert e as the least influential persona for the same solution and city. The expert provides two sets of comparisons. Let $a_{Br}^{e,c,s}$ represent the Best-to-Others comparison value, expressing how strongly the best persona is more influential than persona r. Similarly, let a(rW) represent the Others-to-Worst comparison value, expressing how strongly persona r is more influential than the least influential persona. These comparison values are provided on a 1–9 scale, consistent with the Best-Worst Method comparison structure.

Let $b_{e,c,s,r}$ represent the BWM weight assigned by expert e to persona r for solution s in city c. Let $\xi_{e,c,s}$ represent the BWM deviation or consistency indicator for expert e, solution s, and city c. The BWM optimisation problem's objective is to minimise the maximum deviation between the expert's stated comparison judgments and the comparison ratios derived from the estimated weights (Rezaei, 2015).

$$\min \xi_{e,c,s} \quad \text{Eq. (14)}$$

subject to the Best-to-Others deviation constraints:

$$\left| \frac{b_{e,c,s,B_{e,c,s}}}{b_{e,c,s,r}} - a_{Br}^{e,c,s} \right| \leq \xi_{e,c,s}, \quad \forall r \in R_c \quad \text{Eq. (15)}$$

subject to the Others-to-Worst deviation constraints:

$$\left| \frac{b_{e,c,s,r}}{b_{e,c,s,W_{e,c,s}}} - a_{rW}^{e,c,s} \right| \leq \xi_{e,c,s}, \quad \forall r \in R_c \qquad \text{Eq. (16)}$$

subject to the normalisation constraint:

$$\sum_{r \in R_c} b_{e,c,s,r} = 1 \qquad \text{Eq. (17)}$$

and subject to the non-negativity constraint:

$$b_{e,c,s,r} \geq 0, \quad \forall r \in R_c \qquad \text{Eq. (18)}$$

Lower values of $\xi_{e,c,s}$ indicate that the expert's Best-to-Others and Others-to-Worst comparison statements can be represented more consistently by a single weight vector. The Best-to-Others constraints in Eq. (15) are imposed for every persona other than the best persona, and the Others-to-Worst constraints in Eq. (16) for every persona other than the worst persona, since the comparison of a persona with itself is by definition equal to one. The individual Round 1 BWM persona-influence weight is therefore defined as:

$$\beta_{e,c,s,r}^{(1)} = b_{e,c,s,r} \qquad \text{Eq. (19)}$$

The final SOMI-ready weights are aggregated across valid expert inputs using a normalised geometric mean. The geometric mean is appropriate for aggregating ratio-scale and pairwise-comparison-based judgements because it preserves the multiplicative structure of comparative preferences (Aczél and Saaty, 1983; Forman and Peniwati, 1998). Since the geometric mean is defined only for strictly positive arguments, the non-negativity condition in Eq. (18) is imposed as strict positivity in the numerical implementation. Let $g_{c,s,r}$ represent the geometric mean of the individual Round 1 BWM persona-influence weights assigned to persona r for solution s in city c:

$$g_{c,s,r} = \left(\prod_{e \in E_{c,s}} \beta_{e,c,s,r}^{(1)} \right)^{1/|E_{c,s}|} \qquad \text{Eq. (20)}$$

The final normalised ICB-derived persona-influence weight used in the SOMI calculation is:

$$\beta_{c,s,r} = \frac{g_{c,s,r}}{\sum_{r' \in R_c} g_{c,s,r'}} \qquad \text{Eq. (21)}$$

Eq. (21) ensures that the final persona-influence weights sum to one for each city and solution. The resulting $\beta_{c,s,r}$values are then used in the SOMI aggregation as solution-specific persona-influence weights.

Let $SOMI_{c,s}$ represent the solution-level SOMI score of solution s in city c. It is calculated by aggregating the persona-level SOMI scores using the ICB-derived solution-specific persona-influence weights:

$$SOMI_{c,s} = \sum_{r \in R_c} \beta_{c,s,r} \, SOMI_{c,s,r} \quad \text{Eq. (22)}$$

Substituting Eq. (8) into Eq. (22), the solution-level SOMI score can be written as:

$$SOMI_{c,s} = \sum_{r \in R_c} \beta_{c,s,r} \left(\sum_{p \in P} \lambda_{c,r,p} \, R_{c,s,r,p} \right) \quad \text{Eq. (23)}$$

Substituting Eq. (3) into Eq. (23), the solution-level SOMI score can be expressed directly from the normalised KPI values:

$$SOMI_{c,s} = \sum_{r \in R_c} \beta_{c,s,r} \left[\sum_{p \in P} \lambda_{c,r,p} \left(\frac{1}{|K_{c,s,p}|} \sum_{k \in K_{c,s,p}} z_{c,s,r,p,k} \right) \right] \quad \text{Eq. (24)}$$

Let $\omega_{c,s}$ represent the solution weight assigned to solution s in city c for the city-level SOMI aggregation. In this study, the examined solutions are assumed to have equal significance at city level. Therefore, the solution weight is defined as:

$$\omega_{c,s} = \frac{1}{|S_c|}, \quad \forall s \in S_c \quad \text{Eq. (25)}$$

where $|S_c|$ denotes the number of examined solutions in city c. Let $SOMI_c$ represent the city-level SOMI score of city c. It is calculated as the equal-weighted average of the solution-level SOMI scores:

$$SOMI_c = \sum_{s \in S_c} \omega_{c,s} \, SOMI_{c,s} \quad \text{Eq. (26)}$$

Substituting Eq. (23) into Eq. (26), the city-level SOMI score can be written as:

$$SOMI_c = \sum_{s \in S_c} \omega_{c,s} \sum_{r \in R_c} \beta_{c,s,r} \left(\sum_{p \in P} \lambda_{c,r,p} \, R_{c,s,r,p} \right) \quad \text{Eq. (27)}$$

Substituting Eq. (3) into Eq. (27), the fully expanded city-level SOMI function is:

$$SOMI_c = \sum_{s \in S_c} \omega_{c,s} \sum_{r \in R_c} \beta_{c,s,r} \left[\sum_{p \in P} \lambda_{c,r,p} \left(\frac{1}{|K_{c,s,p}|} \sum_{k \in K_{c,s,p}} z_{c,s,r,p,k} \right) \right] \quad \text{Eq. (28)}$$

Eq. (28) is the fully integrated SOMI function. It shows that the final city-level score is derived from normalised KPI values, pillar scores, Mentimeter-derived persona-pillar significance weights, ICB-derived solution-specific persona-influence weights and equal solution-level aggregation.

Table 3: Nomenclature of Model Parameters and Variables

Parameter	Description
C	Set of all cities included in the analysis.
c	Generic city.
S_c	Set of mobility solutions or policy packages evaluated in city c.
s	Generic mobility solution or policy package.

Parameter	Description
R_c	Set of representative mobility personas considered in city c.
r	Generic persona.
P	Common set of SOMI pillars.
p	Generic SOMI pillar.
$K_{c,s,p}$	Set of KPIs assigned to pillar p for solution s in city c.
k	Generic KPI.
$x_{c,s,r,p,k}$	Observed or estimated raw KPI value.
$L_{c,r,p,k}$	Lower reference limit for KPI k.
$U_{c,r,p,k}$	Upper reference limit for KPI k.
$z_{c,s,r,p,k}$	Normalised KPI value on the 0-1 scale.
$R_{c,s,r,p}$	Pillar score for city c, solution s, persona r and pillar p.
i	Individual Mentimeter respondent.
$n_{c,r,p}$	Number of valid Mentimeter responses for city c, persona r and pillar p.
$x_{i,c,r,p}$	Mentimeter score assigned by respondent i to pillar p, for persona r, in city c.
$\bar{x}_{c,r,p}$	Mean Mentimeter relevance score for pillar p, persona r and city c.
$q_{c,r,p}$	Rescaled 0-1 relevance score for pillar p, persona r and city c.
$\lambda_{c,r,p}$	Mentimeter-derived persona-pillar significance weight for pillar p, persona r and city c.
$SOMI_{c,s,r}$	Persona-level SOMI score for persona r, solution s and city c.
$\beta_{c,s,r}$	ICB-derived solution-specific persona-influence weight.
$E_{c,s}$	Set of valid expert inputs for solution s in city c.
e	Generic expert input.
$\lvert E_{c,s} \rvert$	Number of valid expert inputs for solution s in city c.
$a_{e,c,s,r}^{(0)}$	Round 0 points allocated by expert e to persona r.
$\beta_{e,c,s,r}^{(0)}$	Individual Round 0 persona-influence weight.
$\beta_{c,s,r}^{(0)}$	Aggregated Round 0 persona-influence weight.
$B_{e,c,s}$	Best, or most influential, persona selected by expert e.
$W_{e,c,s}$	Worst, or least influential, persona selected by expert e.
$a_{Br}^{e,c,s}$	Best-to-Others comparison value.
$a_{rW}^{e,c,s}$	Others-to-Worst comparison value.
$b_{e,c,s,r}$	BWM-derived weight assigned by expert e to persona r.
$\xi_{e,c,s}$	BWM deviation or consistency indicator.
$\beta_{e,c,s,r}^{(1)}$	Individual Round 1 BWM persona-influence weight.
$g_{c,s,r}$	Geometric mean of individual Round 1 BWM persona-influence weights.
$SOMI_{c,s}$	Solution-level SOMI score.
$\omega_{c,s}$	Equal city-level solution weight.
$SOMI_c$	City-level SOMI score.

5. Numerical implementation and Results

The applicability of the proposed Social Optimum Mobility Index (SOMI) methodology is examined through its application in the urban mobility setting of Florence. Florence's economy is characterized by a strong manufacturing base and a large tertiary sector, with tourism representing one of the city's

most important sources of income (Camera di Commercio di Firenze, 2023; Comune di Firenze, 2023). The city receives a high number of daily users, particularly tourists, whose average stay is slightly above three days (Comune di Firenze, 2023). Mobility policies are coordinated between the Municipality of Florence and the Metropolitan City through metropolitan mobility planning, and Florence is recognised as an urban node on the TEN-T Scandinavian–Mediterranean Corridor (Città Metropolitana di Firenze, 2021). Florence's urban mobility landscape consists of nine personas and three main urban mobility solutions as summarised in Table 4.

Table 4: Selected personas and mobility solutions in Florence

Selected personas	Selected mobility solutions
1. City-centre resident. 2. Urban family. 3. Older / less mobile resident. 4. Business in the city centre. 5. Student living away from home to study in Florence. 6. Culture visitor. 7. Commuter. 8. Logistics operator, meaning companies carrying out deliveries. 9. Single or couple with no children.	**SOL1: 30 km/h zones and traffic calming**. This solution reflects Florence's road-safety and traffic-moderation priorities, including measures aimed at reducing vehicle speeds and improving conditions for pedestrians, cyclists, older residents, families, and other vulnerable road users (Città Metropolitana di Firenze, 2021; Comune di Firenze, 2023). **SOL2: Urban logistics micro-hubs / proximity logistics spaces.** This solution reflects Florence's need to manage last-mile logistics in a dense historic centre, where freight movements, delivery access, congestion, emissions, and conflicts with pedestrians and cyclists are central mobility-management concerns (Città Metropolitana di Firenze, 2021; Comune di Firenze, 2023). **SOL3: Road-space redistribution toward safer, more sustainable and people-centred mobility**. This solution reflects Florence's policy direction toward reallocating street space to walking, cycling, public transport, shared mobility, and public-space functions, particularly in areas affected by congestion, tourism pressure, and competing street uses (Città Metropolitana di Firenze, 2021; Comune di Firenze, 2023).

5.1 Persona–pillar weighting assessment

The Mentimeter scoring process was conducted during the first General Assembly meeting in Brussels in January 2026. It took the form of an in-person consortium workshop. A total of nine experts participated in the Mentimeter scoring exercise consisting of project experts and consortium partners involved in pilot-city implementation, urban mobility planning, stakeholder engagement, persona development and SOMI methodology. For each persona, experts were asked to assess which SOMI pillars, namely Acceptability (ACP), Accessibility (ACS), Affordability (AFB), Agency (AGE), Availability (AVL), Legal Recognition (LER), Participation (PAR), and Safety & Security (SS) were most suitable or relevant for each persona. Table 5 summarises the derived persona–pillar normalised significance weights of the Mentimeter process employed. The weights are reported to two decimal places for readability; all SOMI calculations use the unrounded values, which satisfy Eq. (7) exactly.

Table 5: Persona–pillar significance weights

Personas	ACP	ACS	AFB	AGE	AVL	LER	PAR	SS
City-centre resident	0.12	0.15	0.09	0.09	0.12	0.10	0.16	0.18
Urban family	0.13	0.15	0.16	0.09	0.13	0.08	0.09	0.17
Older / less mobile resident	0.14	0.14	0.13	0.09	0.15	0.11	0.09	0.16
Business in the city centre	0.13	0.13	0.14	0.13	0.15	0.10	0.10	0.11
Student living away from home	0.08	0.12	0.19	0.11	0.15	0.10	0.10	0.15
Culture visitor	0.13	0.19	0.12	0.08	0.20	0.06	0.02	0.21
Commuter	0.13	0.13	0.14	0.14	0.14	0.08	0.11	0.14
Logistics operator	0.13	0.13	0.14	0.13	0.15	0.10	0.10	0.11
Single or couple with no children	0.12	0.15	0.09	0.09	0.12	0.10	0.16	0.18

The highest-weighted SOMI pillars show that Florence personas attach different levels of importance to the eight SOMI dimensions. For the city-centre resident, Safety & Security, Participation and Accessibility are the dominant pillars. This reflects the relevance of safe streets, involvement in mobility planning and access to everyday destinations in the dense urban core. For the urban family, Safety & Security, Affordability and Accessibility are the most important pillars, which are consistent with household mobility needs, school-related trips, exposure to traffic risks and the cost of daily mobility. For the older / less mobile residents, Safety & Security, Availability and Accessibility receive the highest weights, showing the importance of usable, safe and available mobility options for people with reduced mobility or higher vulnerability in public space. For business in the city centre, the most important pillars are Availability, Affordability and Agency. This reflects the practical need for reliable access, economically viable mobility and logistics arrangements, and sufficient operational choice. The same logic applies to the logistics operator, whose mobility needs are closely linked to delivery access, loading/unloading conditions, final-mile options and operational flexibility. For the student living away from home to study in Florence, Affordability is the dominant pillar, followed by Availability and Safety & Security. This profile is consistent with the cost sensitivity of students and their dependence on affordable and available mobility options for education, services and social activities.

For the culture visitor, Safety & Security, Availability and Accessibility receive the highest weights. This is coherent with the visitor profile, because visitors need safe, legible and available access to cultural destinations, especially in a historic and tourism-intensive city such as Florence. For the commuter, Agency and Availability are the most important pillars, followed by Affordability and Safety & Security. This shows that commuters are particularly affected by the availability of practical travel options, the ability to choose between modes and routes, the cost of repeated travel and the reliability and safety of everyday trips. Finally, the single or couple with no children has the same weighting profile as the city-centre resident, indicating that this persona is mainly shaped by safe, accessible and participatory urban mobility conditions.

5.2 Persona-influence weighting assessment

Regarding the ICB expert questionnaire, a second weighting layer was used to estimate the solution-specific persona-influence weights. The ICB questionnaire was conducted remotely and asynchronously in May 2026 through structured Excel-based expert-elicitation workbooks. Seven ICB organisations contributed valid input. These organisations provided complementary expertise in public transport, logistics, urban mobility policy, parking and curbside management, shared mobility, transport innovation, stakeholder engagement and city implementation. For each Florence mobility solution, the experts assessed the relative influence of the nine Florence personas. Table 6 presents the ICB-derived solution-specific persona-influence weights used for the Florence SOMI calculation. As for Table 5, the weights are reported to three decimal places, while the calculations use the unrounded values, which satisfy Eq. (11) exactly.

Table 6. ICB-derived solution-specific persona-influence weights for Florence

Persona	30 km/h zones	Micro-hubs	Road-space red.
City-centre resident	0.122	0.081	0.154
Urban family	0.251	0.110	0.179
Older / less mobile resident	0.149	0.078	0.129
Business in the city centre	0.137	0.168	0.141
Student living away from home	0.058	0.066	0.070
Culture visitor	0.058	0.042	0.053
Commuter	0.075	0.070	0.049
Logistics operator	0.097	0.351	0.159
Single or couple with no children	0.052	0.035	0.066

The results in Table 6 show that each Florence solution has a distinct implementation-influence profile. For SOL1 - 30 km/h zones and traffic calming, the highest weight is assigned to the urban family (0.251). This is consistent with the road-safety and liveability focus of the solution, because urban families are directly affected by vehicle speeds, school-related mobility, pedestrian safety, cycling conditions and the quality of everyday streets. The older / less mobile resident also receives a relatively high weight (0.149), reflecting the importance of traffic calming for vulnerable road users. The business in the city centre (0.137) and the city-centre resident (0.122) also remain relevant because changes in speed limits, traffic circulation and street design can influence local accessibility, commercial activity and everyday movement in dense urban areas.

For SOL2 - urban logistics micro-hubs, the dominant implementation persona is the logistics operator, with a weight of 0.351. This is expected because the success of a micro-hub depends strongly on the participation, acceptance and operational adaptation of delivery companies and logistics service providers. The business in the city centre receives the second-highest weight (0.168), because businesses are directly affected by delivery reliability, loading and unloading conditions, ZTL access rules and final-mile logistics arrangements. The urban family also receives a non-negligible weight

(0.110), indicating that the micro-hub solution can influence residential quality, pedestrian safety, local traffic intensity and the presence of freight vehicles in mixed-use areas.

For SOL3 - road-space redistribution, the highest weight is again assigned to the urban family (0.179). This reflects the broad relevance of road-space redistribution for household mobility, school trips, pedestrian safety, cycling conditions and access to everyday services. The logistics operator also receives a high weight (0.159), showing that changes in street allocation, loading areas, circulation rules and access priorities can strongly affect final-mile delivery operations. The city-centre residents receive a similarly high weight (0.154), because road-space redistribution directly changes the daily mobility environment in the dense urban core. The business in the city centre (0.141) and the older / less mobile resident (0.129) also remain relevant because the solution affects commercial access, pedestrian comfort, public-space quality and mobility conditions for more vulnerable users. Overall, the ICB results confirm that implementation influence is solution specific. The urban family is the most influential persona for 30 km/h zones and traffic calming, the logistics operator is the most influential persona for urban logistics micro-hubs, and the urban family is again the most influential persona for road-space redistribution.

Finally, since the objective is to quantify SOMI at persona, solution and city level, and given the estimated persona–pillar and persona–solution weights, the next step is to identify measurable KPIs for each SOMI pillar and each Florence mobility solution. These KPIs are selected based on existing data currently available for Florence. The evidence is mainly derived from published urban mobility reports, metropolitan mobility-planning documents, municipal monitoring material, open-data sources, stakeholder-engagement outputs and selected literature benchmarks. This ensures that the numerical SOMI implementation is not based on abstract assumptions, but on traceable indicators that can be linked to the policy context of Florence. The Florence KPI values and reference limits used below follow the Florence evidence base compiled for the SOMI implementation.

5.3 SOL1: 30 km/h zones and traffic calming solution KPIs

In February 2025, the Municipality of Florence reported that 19 Zone 30 areas were active, covering approximately 45% of the built-up area. This measure leads to safer streets around schools, hospitals and densely inhabited roads, as well as to lower traffic speeds, lower collision severity, reduced noise and lower emissions (Comune di Firenze, 2025b).

For Acceptability, the selected KPI is the share of citizen priority responses supporting Zone-30-relevant road-safety objectives. The value is 71.1%, calculated from the PUMS citizen questionnaire by summing the response share for reducing road-crash risk (44.1%) and the response share for reducing serious crashes involving vulnerable road users (27.0%) (Città Metropolitana di Firenze, 2019a). This remains an indirect acceptability proxy, because it measures support for the safety

objectives that Zone 30 measures are designed to achieve, rather than direct approval of a specific Zone 30 intervention. Regarding the acceptable upper and lower limits for the KPI normalisation, the lower limit is set at 50%, representing a minimum majority-support threshold, while the upper-performance reference is set at the Florence-specific value of 71.1%, reflecting the acceptability level of citizens for safety and security measures.

For Accessibility, the KPI measures the share of the built-up area covered by active Zone 30 areas. The Florence value is 45%, based on the municipal statement that the 19 active Zone 30 areas cover approximately 45% of the built-up area (Comune di Firenze, 2025b). The lower-performance reference is the current Florence coverage of 45% of the built-up area. The upper-performance reference is set at 70%, using Bologna "Città 30" as an Italian high-coverage benchmark, where the 30 km/h limit applies to approximately 70% of urban roads (Comune di Bologna, 2024).

For Affordability, the selected KPI is the expected fuel-consumption reduction from lower urban speeds. The value is a 7% reduction benchmark from European 30 km/h literature (Yannis and Michelaraki, 2024). Regarding KPI Limits, we employ the European 30 km/h literature range, where 3.4% is the lower-performance reference reduction, while 11% is the upper-performance reference reduction (Yannis and Michelaraki, 2024).

For Agency, the KPI is the share of trips made on the integrated public transport network. The value is 17%, derived from the official PUMS monitoring indicator A.2.B, "% di spostamenti sulla rete integrata del TPL" (Città Metropolitana di Firenze, 2025). The Agency Limits have a lower-performance reference of 16.9% and an upper-performance reference of 21.2%, both taken from the official PUMS monitoring indicator (Città Metropolitana di Firenze, 2025).

For Availability, the KPI is the number of active Zone 30 areas, reported together with the corresponding built-up-area coverage. The current value is 19 active areas (Comune di Firenze, 2025b). The lower-performance reference is the current documented supply of 19 active Zone 30 areas covering approximately 45% of the built-up area. The upper-performance reference is estimated considering a 100% full built-up-area coverage which corresponds to approximately 42 active areas.

For Legal Recognition, the KPI is the number of formally approved Zone 30 regulatory changes. The value is 6, calculated as five newly approved Zone 30 areas in Coverciano, Campo di Marte, San Bartolo a Cintoia, Soffiano and Statuto, plus one expansion of the existing Via di Ripoli Zone 30 area (Comune di Firenze, 2023). The lower-performance reference is 0 formally approved regulatory changes and the upper-performance reference is the baseline KPI value of 6.

For Participation, the KPI is the number of questionnaire participation inputs in the Florence metropolitan mobility-planning process. The value is 5,100 inputs, calculated as 4,824 citizen questionnaire responses plus 276 stakeholder questionnaire responses (Città Metropolitana di Firenze,

2019a; Città Metropolitana di Firenze, 2019b). The lower-performance reference is 0 inputs, and the upper-performance reference is 5,100 inputs, matching the documented Florence metropolitan mobility-planning participation base.

Finally, for the Safety & Security pillar, the baseline value is 2,275 injury crashes (Comune di Firenze, 2025b). Lower values indicate better safety performance, so a reduction relative to this baseline indicates improvement while an increase indicates deterioration. Because the KPI is lower-is-better, the lower reference limit is set at approximately 2,070 injury crashes, obtained by applying Florence's most recent approximate 9% injury-crash reduction to the baseline, and represents the best reference performance. The upper reference limit is set at 2,275 injury crashes, corresponding to the current baseline, and represents the worst reference performance. Movement from 2,275 toward 2,070 injury crashes therefore indicates improved safety performance. Since the observed value coincides with the upper reference limit, Eq. (2) returns a normalised value of zero for this pillar. Table 7 summarises the derived KPI values per pillar for the 30 km/h traffic-calmed areas solution, along with the KPIs upper and lower acceptable limits.

Table 7: Summary of KPI values and reference limits for SOL1

Pillar	KPI	Direction	$x_{c,s,r,p,k}$	$L_{c,r,p,k}$	$U_{c,r,p,k}$
ACP	Citizen priority responses supporting Zone-30-relevant road-safety objectives	Higher better	71.1%	50%	71.1%
ACS	Built-up area covered by active Zone 30 areas	Higher better	45%	45%	70%
AFB	Expected fuel-consumption reduction from lower and smoother speeds	Higher better	7%	3.4%	11%
AGE	Trips on the integrated public-transport network	Higher better	17%	16.9%	21.2%
AVL	Active Zone 30 areas	Higher better	19	19	42
LER	Formally approved Zone 30 regulatory changes	Higher better	6	0	6
PAR	Mobility-planning participation inputs	Higher better	5,100	0	5,100
SS	Number of injury crashes	Lower better	2,275	2,070	2,275

5.4 SOL2: Urban logistics micro-hubs / proximity logistics spaces solution KPIs

The selected KPIs in this solution are designed to capture how proximity logistics infrastructure can improve last-mile freight operations, reduce the negative impacts of delivery vehicles in the city centre, and support more sustainable urban logistics. In the municipal planning framework, this solution is presented as a laboratory for managing access and delivery-vehicle operations, particularly during peak hours, while creating a trial micro-consolidation centre and related digital services (Comune di Firenze, 2024). This direction is reinforced in the Documento Unico di Programmazione (DUP) 2026–2028, which refers to the realisation of micro-centres of consolidation and loading/unloading bays as part of Florence's urban logistics strategy (Comune di Firenze, 2025a).

For Acceptability, the selected KPI is the number of documented stakeholder-engagement sources reporting positive appraisal of the shared micro-hub concept. The current value is 1, because the Firenze per il Clima stakeholder report records that the idea of a shared space close to the centre, with a dedicated area for each operator, was considered "molto interessante" by participating companies and associations (Firenze per il Clima, 2024). This remains a planning-stage acceptability proxy, because it reflects positive stakeholder appraisal of the concept rather than a large-scale public-acceptance measurement. Regarding the selected upper and lower limits for KPI normalisation, the lower-performance reference is set at 0 documented sources, representing the absence of documented positive appraisal. The upper-performance reference is set at 3 documented sources, reflecting the main evidence categories needed for a robust shared micro-hub solution, namely, logistics operators and delivery companies, municipality or public authority responsible for mobility and ZTL management, and local businesses or receivers affected by freight deliveries. This categorisation is consistent with urban freight and city-logistics literature, which identifies freight operators, public authorities, and receivers or local businesses as key stakeholder groups whose participation is necessary for the planning and implementation of urban consolidation and micro-logistics schemes (Ballantyne et al., 2013; Lindholm and Browne, 2013).

For Accessibility, the selected KPI is the share of ZTL loading/unloading bays equipped with real-time availability sensors. The Florence value is 29.6%, calculated as 80 smart sensor-equipped loading/unloading bays out of approximately 270 ZTL freight bays (Comune di Firenze, 2026b; Città Metropolitana di Firenze, 2019b). This KPI captures the extent to which logistics access points become digitally visible and manageable for delivery operations. The lower-performance reference is set at 0%, representing no digitally visible ZTL loading/unloading bays. The upper-performance reference is set at 100%, representing full sensor coverage of the relevant ZTL loading/unloading bay stock.

For Affordability, the selected KPI is the number of documented affordability-supporting mechanisms for the micro-hub/proximity-logistics pilot in Florence. The first mechanism is external public funding support. The micro-hub/proximity-logistics solution's 2025–2028 action sheets, identify "Soluzioni di prossimità" as a municipal action involving urban micro-hubs and connect the pilot living lab to the European micro-hub/proximity-logistics solution, with Horizon Europe funding reported for the Comune di Firenze (Comune di Firenze, 2026a). The second mechanism is an operational cost-sharing arrangement. The stakeholder report describes a possible model in which each logistics operator rents part of the shared hub space, while an entrusted managing body operates the hub to support economic sustainability (Firenze per il Clima, 2024). The baseline KPI is therefore equal to 2 and interpreted as a planning-stage affordability proxy that captures whether the pilot includes documented mechanisms to reduce, distribute, or structure implementation and operating costs.

For Agency, the selected KPI is the number of operator-facing delivery-management options available to logistics providers during the pilot. The value is 3. These options include sensor-equipped loading/unloading bays with booking and check-in/check-out services, a cargo-bike routing application allowing flexible and dynamic route selection, and a micro-hub-based final-mile delivery option using smaller ecological vehicles such as cargo bikes (Comune di Firenze, 2026a). This KPI captures the degree to which the solution increases the operational choices available to logistics operators. The lower-performance reference is set at 0 operator-facing delivery-management options, representing a condition in which the pilot provides no additional operational choice. The upper-performance reference is set at 3 documented options, corresponding to the three operator-facing options identified in the Florence evidence base.

For Availability, the selected KPI is the number of pilot micro-hub sites to be tested. The value is 1, because the 2025-2028 micro-hub/proximity-logistics solution's action sheet identifies one specific temporary experimental logistics micro-hub site in Piazza Annigoni (Comune di Firenze, 2026a). This value measures pilot-stage availability only and does not, however, imply that one hub is sufficient for future citywide scale-up. The lower-performance reference is set at 0 pilot micro-hub sites, representing the absence of a physical site available for operational testing. The upper-performance reference is set at 1 pilot micro-hub site, reflecting the current documented pilot-stage scope in Florence.

For Legal Recognition, the selected KPI is the number of documented regulatory-readiness mechanisms for ZTL freight and micro-hub logistics. The value is 3. These mechanisms include the assessment of the digital system for requesting, issuing and managing ZTL access authorizations for freight distribution and collection services, the development of an experimental mobile-app interface for logistics operators, and the development of an experimental web app to compare the effects of possible changes to current ZTL access rules through predefined KPIs and KPAs (Comune di Firenze, 2026a). The lower-performance reference is set at 0 regulatory-readiness mechanisms, representing the absence of documented legal or administrative preparation. The upper-performance reference is set at 3 regulatory-readiness mechanisms, corresponding to the three mechanisms documented in the Florence evidence base.

For Participation, the selected KPI is the number of dedicated participatory tables or processes on urban logistics linked to the micro-hub/proximity-logistics solution of Florence. The value is 1, corresponding to the dedicated logistics-operator roundtable documented during the second Firenze per il Clima meeting (Firenze per il Clima, 2024). The lower-performance reference is set at 0 public events or participatory processes on urban logistics, representing the absence of documented stakeholder involvement in the design, testing or refinement of the solution. The upper-performance

reference is set at two participatory events or processes per year, representing a basic annual engagement cycle composed of one consultation or co-design moment and one follow-up, validation, or refinement moment. This threshold is defined as a methodological benchmark, consistent with participatory planning and co-design literature that emphasises iterative stakeholder engagement, feedback, and refinement over one-off consultation (Innes and Booher, 2004; Reed, 2008; Sanders and Stappers, 2008).

Finally, for the Safety & Security pillar, the selected KPI is the number of injury crashes. The value is 2,275 injury crashes, corresponding to the municipal road-safety baseline (Comune di Firenze, 2025b). In the case of the micro-hub solution, this is used as a city-wide safety monitoring proxy and does not represent an observed safety effect of the pilot. Since the KPI is lower-is-better, the lower reference limit is set at approximately 2,070 injury crashes, obtained by applying Florence's most recent approximate 9% injury-crash reduction to the baseline, while the upper reference limit is set at 2,275 injury crashes, corresponding to the current baseline. Movement from 2,275 toward 2,070 injury crashes therefore indicates improved safety performance. As the observed value coincides with the upper reference limit, the normalised value for this pillar is zero. Table 8 summarises the derived KPI values per pillar for the Urban logistics micro-hubs / proximity logistics spaces solution along with the selected lower and upper limits for KPI normalisation.

Table 8: Summary of KPI values and reference limits for SOL2

Pillar	KPI	Direction	$x_{c,s,r,p,k}$	$L_{c,r,p,k}$	$U_{c,r,p,k}$
ACP	Stakeholder-engagement sources reporting positive appraisal of shared micro-hub concept	Higher better	1	0	3
ACS	ZTL loading/unloading bays equipped with real-time availability sensors	Higher better	29.6%	0%	100%
AFB	Affordability-supporting mechanisms for the micro-hub / proximity-logistics pilot	Higher better	2	0	2
AGE	Operator-facing delivery-management options	Higher better	3	0	3
AVL	Pilot micro-hub sites to be tested	Higher better	1	0	1
LER	Regulatory-readiness mechanisms for ZTL micro-hub logistics	Higher better	3	0	3
PAR	Participatory tables or processes on urban logistics	Higher better	1	0	2
SS	Number of injury crashes	Lower better	2,275	2,070	2,275

5.5 SOL3: Road space redistribution solution KPIs

The selected KPIs of SOL3 are designed to capture how the redistribution of urban space can support walking, cycling, public transport, shared mobility and social use. The solution is consistent with international road-space redistribution and Complete Streets principles, which frame streets as public

spaces that should support safe access for all users, including pedestrians, cyclists, public transport users and motor-vehicle users, rather than allocating most space primarily to private cars (International Transport Forum, 2022).

For Acceptability, the selected KPI is the share of citizen priority responses supporting road-space redistribution toward sustainable modes and better public space. The value is 35.8%, calculated by summing 28.0% of citizen responses supporting the reduction of private-car use in favour of more sustainable alternatives and 7.8% supporting the improvement of the physical quality, usability and pedestrian safety of streets and squares (Città Metropolitana di Firenze, 2019a). This KPI captures documented citizen-priority support for the objectives that road-space redistribution is designed to address. Regarding the upper and lower limits, the lower-performance reference is set at 0%, representing the absence of documented citizen-priority support for road-space redistribution objectives. The upper-performance reference is set at 35.8%, matching the Florence-specific value calculated from the PUMS citizen-priority items.

For Accessibility, the selected KPI is the length of the cycle network available in Florence. The value is 113 km. The Florence mobility portal reports that the city's cycle network extends for 113 km and identifies 120 km as the municipal objective (Comune di Firenze, 2026c). This KPI measures the extent to which cycling infrastructure supports access across the city. The lower-performance reference is set at 0 km, representing the absence of documented cycle-network provision. The upper-performance reference is set at 120 km, corresponding to the official municipal cycle-network objective.

For Affordability, the selected KPI is the share of citizen priority responses supporting lower private-vehicle costs through more convenient shared, bicycle and pedestrian mobility. The value is 13.8%. This is a citizen-priority affordability proxy, not a direct household-cost measure, but it is linked to reduced dependence on private-car use and improved affordability of alternative mobility options (Città Metropolitana di Firenze, 2019a). The lower-performance reference is set at 0%, representing no documented citizen priority for reducing private-vehicle costs through more convenient shared, bicycle and pedestrian mobility. The upper-performance reference is set at 13.8%, corresponding to the official PUMS questionnaire result used for this KPI.

For Agency, the selected KPI is the share of PUMS citizen respondents who use the bicycle. The value is 42%, based on the PUMS citizen questionnaire (Città Metropolitana di Firenze, 2019a). This KPI measures baseline mobility agency because it captures the proportion of respondents who already use cycling as a practical mobility option. Road-space redistribution can strengthen this agency by making cycling safer, more continuous and more attractive. The lower-performance reference is set at 0%, representing a condition in which no surveyed citizens report using the bicycle as a mobility option.

The upper-performance reference is set at 42%, corresponding to the documented PUMS citizen questionnaire value.

For Availability, the selected KPI is the pedestrianised circulation area in Florence's historic centre. The value is 420,000 m². This KPI measures the amount of road and public space already made available primarily for pedestrians rather than general motor traffic. It is directly relevant to road-space redistribution because it captures the physical availability of pedestrian-priority space. The City of Florence document on new pedestrian areas reports 420,000 m² of pedestrian areas in the historic centre, equivalent to 1.14 m² per inhabitant (Comune di Firenze, 2020). The lower-performance reference is set at 0 m², while the upper-performance reference is set at 420,000 m², corresponding to the documented pedestrianised circulation area in Florence's historic centre.

For Legal Recognition, the selected KPI is the number of formal pedestrian-area regulatory typologies. The value is 6 typologies. This KPI measures the extent to which redistributed pedestrian space is legally and administratively recognised. Florence Open Data states that pedestrianised urban circulation areas are mapped as polygons and divided by type according to municipal ordinances. The same dataset classifies pedestrian areas into six typologies, identified by the letters A, B, C, D, E and F (Comune di Firenze Open Data, 2026). The lower-performance reference is set at 0 typologies, representing no formal typological or regulatory classification of pedestrian areas. The upper-performance reference is set at 6 typologies, matching the documented Florence classification.

For Participation, the selected KPI is the number of participation inputs in the Florence metropolitan mobility-planning process. The value is 5,100 inputs, calculated as 4,824 citizen questionnaire responses plus 276 stakeholder questionnaire responses (Città Metropolitana di Firenze, 2019a; Città Metropolitana di Firenze, 2019b). This KPI measures the participation base behind mobility and road-space planning decisions. The lower-performance reference is set at 0 inputs, representing the absence of documented public or stakeholder input. The upper-performance reference is set at 5,100 inputs, matching the documented Florence metropolitan mobility-planning participation base.

Finally, for the Safety & Security pillar, the selected KPI is the number of injury crashes. The value is 2,275 injury crashes, corresponding to the municipal road-safety baseline (Comune di Firenze, 2025b). This is used as a city-wide monitoring proxy for the safety context within which future road-space redistribution impacts can be assessed. Since the KPI is lower-is-better, the lower reference limit is set at approximately 2,070 injury crashes, corresponding to the level that would be reached if the recent approximate 9% improvement rate were reproduced from the baseline, while the upper reference limit is set at 2,275 injury crashes, corresponding to the current baseline. As the observed value coincides with the upper reference limit, the normalised value for this pillar is zero. Table 9 summarises the

derived KPI values per pillar for the road space redistribution solution KPIs along with the selected lower and upper limits for KPI normalisation.

Table 9: Summary of KPI values and reference limits for SOL3

Pillar	KPI	Direction	$x_{c,s,r,p,k}$	$L_{c,r,p,k}$	$U_{c,r,p,k}$
ACP	Citizen priority responses supporting road-space redistribution toward sustainable modes and better public space	Higher better	35.8%	0%	35.8%
ACS	Length of cycle network available in Florence	Higher better	113 km	0 km	120 km
AFB	Citizen priority responses supporting lower private-vehicle costs and more convenient shared / cycle-pedestrian mobility	Higher better	13.8%	0%	13.8%
AGE	PUMS citizen respondents who use the bicycle	Higher better	42%	0%	42%
AVL	Pedestrianised circulation area in Florence's historic centre	Higher better	420,000 m²	0 m²	420,000 m²
LER	Formal pedestrian-area regulatory typologies	Higher better	6	0	6
PAR	Mobility-planning participation inputs	Higher better	5,100	0	5,100
SS	Number of injury crashes	Lower better	2,275	2,070	2,275

5.6 SOMI Evaluation

Following the definition of the KPI values and reference limits, the next step is to estimate the SOMI values at persona, solution and city level. The persona-level SOMI values were calculated through a sum-product of the normalised pillar scores of each solution with the persona-specific SOMI pillar weights derived from the Mentimeter exercise of Table 5. The resulting value ranges from 0 to 1, where higher values indicate stronger performance from the perspective of that persona.

Table 10: Persona-level SOMI estimates for Florence

Persona	30 km/h zones	micro-hubs	Road-space red.
City-centre resident	0.421	0.559	0.813
Urban family	0.378	0.593	0.821
Older / less mobile resident	0.400	0.607	0.833
Business in the city centre	0.403	0.658	0.881
Student living away from home	0.373	0.662	0.843
Culture visitor	0.266	0.564	0.781
Commuter	0.386	0.631	0.854
Logistics operator	0.403	0.658	0.881
Single or couple with no children	0.421	0.559	0.813

The persona-level SOMI estimates show that SOL3, road-space redistribution, achieves the highest score for every Florence persona. The strongest SOMI values are observed for the business in the city centre and the logistics operator, both at 0.881, followed by the commuter at 0.854 and the student

living away from home at 0.843. The older / less mobile resident records 0.833 and the urban family 0.821, while the city-centre resident and the single or couple with no children both record 0.813. The lowest value is observed for the culture visitor at 0.781. SOL3 reaches full performance in Acceptability, Affordability, Agency, Availability, Legal Recognition and Participation, and performs strongly in Accessibility, because the current cycle-network length of 113 km is close to the official municipal objective of 120 km. The differences among personas are therefore explained by the weights they attach to the two pillars that are not at full performance, namely Safety & Security, which remains at its worst reference value, and Accessibility. The business in the city centre and the logistics operator assign the lowest weight to Safety & Security and consequently record the highest SOL3 scores, whereas the culture visitor assigns the highest weight to both Safety & Security and Accessibility and records the lowest, although still high, SOL3 score.

SOL2, urban logistics micro-hubs, produces the second-highest SOMI values. The highest value is recorded for the student living away from home at 0.662, followed by the business in the city centre and the logistics operator, both at 0.658, and the commuter at 0.631. The older / less mobile resident and the urban family record 0.607 and 0.593 respectively, the culture visitor records 0.564, and the city-centre resident and the single or couple with no children both record 0.559. This reflects the strong performance of SOL2 in Affordability, Agency, Availability and Legal Recognition, each of which reaches its best reference value. However, its overall score remains below SOL3 because Acceptability, Accessibility and Participation are only partially fulfilled at the current pilot stage, and Safety & Security remains at its worst reference value.

SOL1, 30 km/h zones and traffic calming, records the lowest SOMI values among the three Florence solutions. The highest values are observed for the city-centre resident and the single or couple with no children, both at 0.421, followed by the business in the city centre and the logistics operator, both at 0.403, and the older / less mobile resident at 0.400. The commuter records 0.386, the urban family 0.378 and the student living away from home 0.373. The lowest value is observed for the culture visitor at 0.266. The lower performance of SOL1 is mainly explained by the fact that the current Zone 30 coverage, the number of active Zone 30 areas, the public-transport agency indicator and the injury-crash baseline all remain at or close to their worst reference values. However, SOL1 performs strongly in Acceptability, Legal Recognition and Participation, while Affordability shows an intermediate level of performance.

To obtain the Florence city-level SOMI, the three assessed solution-level SOMI values were aggregated using equal solution weights. Equal weighting is used because the three Florence solutions are treated as parallel assessed interventions within the same use case, and no alternative strategic, budgetary, territorial-impact or stakeholder-defined solution weighting is introduced at this stage.

Table 11. City-level SOMI estimate for Florence

Aggregation level	SOMI estimate
Solution-level SOMI — 30 km/h zones	0.388
Solution-level SOMI — Micro-hubs	0.630
Solution-level SOMI — Road-space redistribution	0.840
Equal-weighted city-level SOMI	0.619

The estimated Florence city-level SOMI is 0.619. This value represents the combined social-optimum mobility performance of the three Florence solutions assessed in the use case. It should be interpreted as a synthetic evaluation of the current evidence base rather than as a permanent city score. The value is mainly shaped by the high performance of road-space redistribution (SOL3 = 0.840), the moderate performance of the urban logistics micro-hub solution (SOL2 = 0.630), and the lower performance of the Zone 30 / traffic-calming solution (SOL1 = 0.388). The city-level result also shows the usefulness of the SOMI structure. It does not only provide a single score but also allows the analysis to identify where performance is strong and where further improvement is needed.

In Florence, the strongest contribution comes from road-space redistribution, which performs at or very close to its best reference level across six of the eight SOMI pillars. The micro-hub solution also shows strong potential, especially for logistics, business-related and cost-sensitive personas, but remains partly constrained by its pilot-stage status, partial sensor coverage, limited participatory evidence and incomplete scale-up. The Zone 30 solution has strong acceptability, legal-recognition and participation performance, but its overall SOMI score remains lower because the current Zone 30 coverage, the number of active traffic-calmed areas and the public-transport agency indicator remain close to their worst reference values. Across all three solutions, Safety & Security is scored at its worst reference value, because the only available indicator is the city-wide injury-crash baseline, which has not yet moved from the reference year and does not capture solution-specific safety effects. This pillar therefore contributes a constant to all three solution scores and does not differentiate between them.

Hence, the Florence SOMI result provides a structured basis for comparing the three selected solutions and for identifying which pillars and personas should be prioritised in future monitoring and policy refinement. For SOL1, future monitoring should focus especially on expanded Zone 30 coverage, increased availability of traffic-calmed areas, stronger integration with public-transport and active-mobility options, and continued verification of safety outcomes. For SOL2, future monitoring should focus on scaling micro-hub availability, increasing sensor coverage of freight loading/unloading bays, expanding logistics stakeholder participation and capturing direct operational and safety outcomes. For SOL3, future monitoring should preserve the very strong performance observed across most pillars while tracking whether road-space redistribution continues to deliver high accessibility, public-space, governance, participation and safety-related benefits over time.

5.7 Sensitivity Analysis of SOMI Weights

The purpose of this section is to provide a sensitivity analysis of the derived Mentimeter and ICB weights to examine whether the SOMI results are robust to alternative weighting assumptions. This is necessary because the SOMI model includes two judgement-based weighting layers. The first layer is the Mentimeter-derived persona–pillar significance weight $\lambda_{c,r,p}$, which expresses the relative importance of SOMI pillar $p$for persona $r$in city c. The second layer is the ICB-derived solution-specific persona-influence weight $\beta_{c,s,r}$, which expresses the relative implementation influence of persona $r$for solution $s$in city c. The sensitivity analysis therefore examines whether changes in these two weighting layers affect the persona-level and solution-level SOMI results.

The sensitivity analysis is conducted through a progressive perturbation approach. A sensitivity parameter $\alpha$is introduced, where:

$$0 \leq \alpha \leq 1$$

When $\alpha = 0$, the original stakeholder- or expert-derived weights are used. When $\alpha = 1$, the original weights are fully replaced by equal weights. Intermediate values of α represent gradual movement from the original weighting structure toward an equal-weighting structure. In this way, the analysis does not simply compare two extreme cases but shows the full behaviour of SOMI scores across the complete perturbation interval. Regarding the Mentimeter weights, the analysis examines how the persona-level SOMI values change when the original Mentimeter-derived persona–pillar significance weights $\lambda_{c,r,p}$ are progressively replaced by equal pillar weights. Since the SOMI framework includes eight pillars, the equal pillar weight is defined as:

$$\lambda_p^{EQ} = \frac{1}{|P|} = \frac{1}{8} = 0.125, \qquad \text{Eq. (29)}$$

The perturbed Mentimeter weight is then calculated as:

$$\lambda_{c,r,p}^{(\alpha)} = (1-\alpha)\lambda_{c,r,p} + \alpha\lambda_p^{EQ}, \qquad \text{Eq. (30)}$$

where $\lambda_{c,r,p}^{(\alpha)}$ is the perturbed persona-pillar significance weight, $\lambda_{c,r,p}$ is the original Mentimeter-derived weight, and λ_p^{EQ} is the equal pillar weight. For every value of α, the persona-level SOMI score is recalculated as:

$$\mathrm{SOMI}_{c,s,r}^{(\alpha)} = \sum_{p \in P} \lambda_{c,r,p}^{(\alpha)} R_{c,s,r,p}, \qquad \text{Eq. (31)}$$

where $R_{c,s,r,p}$ is the normalised SOMI pillar score for city c, solution s, persona r, and pillar p. This analysis tests whether the persona-level SOMI values are strongly dependent on the Mentimeter-derived pillar-priority profiles. The KPI and pillar scores are not changed in this test; only the persona-pillar weights are perturbed. The second sensitivity test concerns the ICB-derived solution-specific persona-influence weights $\beta_{c,s,r}$. These weights are used to aggregate the persona-level SOMI values $\mathrm{SOMI}_{c,s,r}$ into the solution-level SOMI value $\mathrm{SOMI}_{c,s}$. The purpose of this test is to examine whether the solution-level SOMI results are sensitive to changes in the relative implementation influence assigned to each persona. For the Florence case, there are nine personas. Therefore, the equal persona-influence weight is defined as:

$$\beta_r^{EQ} = \frac{1}{|R_c|} = \frac{1}{9} = 0.111, \qquad \text{Eq. (32)}$$

The perturbed ICB weight is calculated as:

$$\beta_{c,s,r}^{(\alpha)} = (1-\alpha)\beta_{c,s,r} + \alpha\beta_r^{EQ}, \qquad \text{Eq. (33)}$$

where $\beta_{c,s,r}^{(\alpha)}$ is the perturbed persona-influence weight, $\beta_{c,s,r}$ is the original ICB-derived solution-specific persona-influence weight, and β_r^{EQ} is the equal persona-influence weight. For each value of α, the solution-level SOMI score is recalculated as:

$$\mathrm{SOMI}_{c,s}^{(\alpha)} = \sum_{r \in R_c} \beta_{c,s,r}^{(\alpha)}\, \mathrm{SOMI}_{c,s,r}, \qquad \text{Eq. (34)}$$

where $\mathrm{SOMI}_{c,s,r}$ is the persona-level SOMI score calculated using the original Mentimeter persona-pillar weights. In this test, the persona-level SOMI values remain fixed, while only the ICB persona-influence weights are perturbed.

In the numerical implementation, α is evaluated at eleven equally spaced values between 0 and 1, using a step size of 0.10:

$$\alpha \in \{0.00,\ 0.10,\ 0.20,\ 0.30,\ 0.40,\ 0.50,\ 0.60,\ 0.70,\ 0.80,\ 0.90,\ 1.00\}$$

Operationally, this corresponds to replacing the original judgement-derived weights with equal weights in 10% increments. For example, when $\alpha = 0.00$, the original Mentimeter or ICB weights are fully retained. When $\alpha = 0.50$, the perturbed weights are calculated as 50% original weights and 50% equal weights. When $\alpha = 1.00$, the original weights are fully replaced by the equal-weight alternative.

For instance, at $\alpha = 0.30$, 70% of the original judgement-derived weight is retained, while 30% is replaced by the corresponding equal weight. In the case of Mentimeter persona–pillar weights, this can be expressed as:

$$\lambda_{c,r,p}^{(0.30)} = 0.70\lambda_{c,r,p} + 0.30\lambda_p^{EQ}, \qquad \text{Eq. (35)}$$

Similarly, in the case of ICB persona-influence weights, the same perturbation logic is applied as:

$$\beta_{c,s,r}^{(0.30)} = 0.70\beta_{c,s,r} + 0.30\beta_r^{EQ}, \qquad \text{Eq. (36)}$$

Thus, each sensitivity curve shows how the SOMI value changes as the model moves gradually from the original stakeholder- or expert-derived weighting structure toward an equal-weighting structure.

Figures 2 to 4 present the Mentimeter sensitivity results separately for the three Florence mobility solutions. Each figure shows the behaviour of persona-level SOMI scores as α increases from 0 to 1. Therefore, the left-hand side of each figure represents the original Mentimeter-weighted SOMI result, while the right-hand side represents the equal pillar-weight SOMI result.

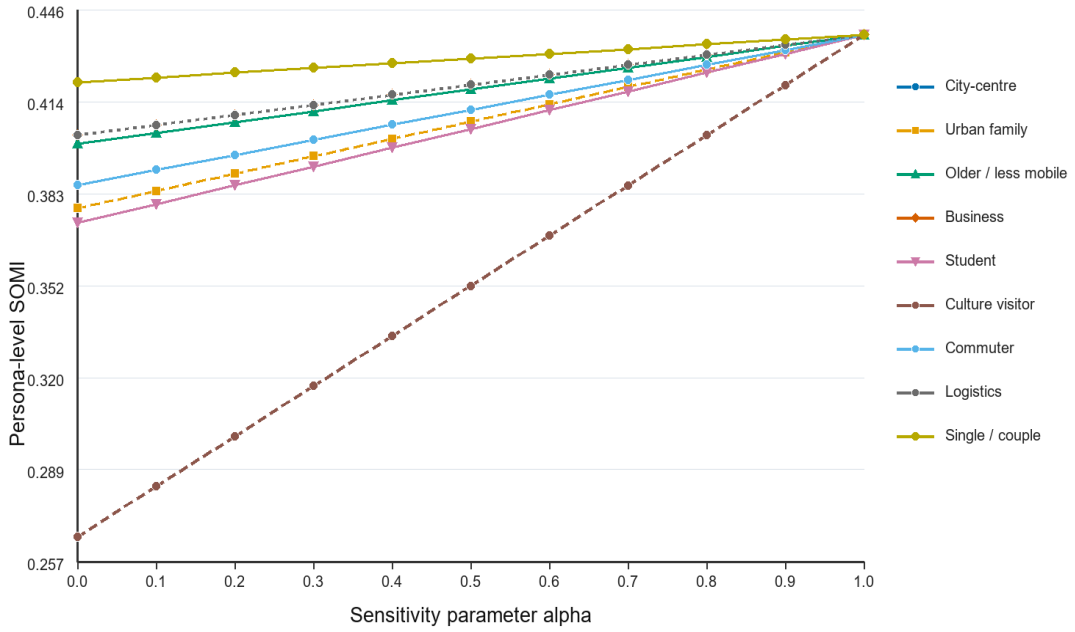


Figure 2: Mentimeter sensitivity results for SOL1-30 km/h zones and traffic calming

Figure 2 shows the Mentimeter sensitivity results for SOL1, namely 30 km/h zones and traffic calming, including all nine Florence personas. All nine persona-level SOMI curves increase as α moves from 0 to 1, and all converge on the equal pillar-weight value of 0.437, because at α = 1 every persona applies the same weight vector to the same solution. The strongest increase is observed for the culture visitor persona, which starts from the lowest baseline value of 0.266 and rises sharply toward the common

equal-weight value. This indicates that the culture visitor assigns relatively high importance to pillars where SOL1 performs weakly, especially Availability and Accessibility, which both score zero because the observed value coincides with the worst reference limit, and Safety & Security, which is also at its worst reference value. As the weighting structure moves toward equal pillar weights, the effect of these weaker-performing pillars becomes less dominant, and the culture visitor SOMI value increases substantially. The student, urban family and commuter personas also show clear increases, although less pronounced than the culture visitor. The older / less mobile resident, business in the city centre and logistics operator personas start from intermediate baseline values and move upward as α increases. The city-centre resident and the single or couple with no children record the highest baseline values, at 0.421, and show only limited increases, suggesting that their original weighting profiles are already more aligned with the stronger SOL1 pillars, particularly Participation, Acceptability and Legal Recognition.

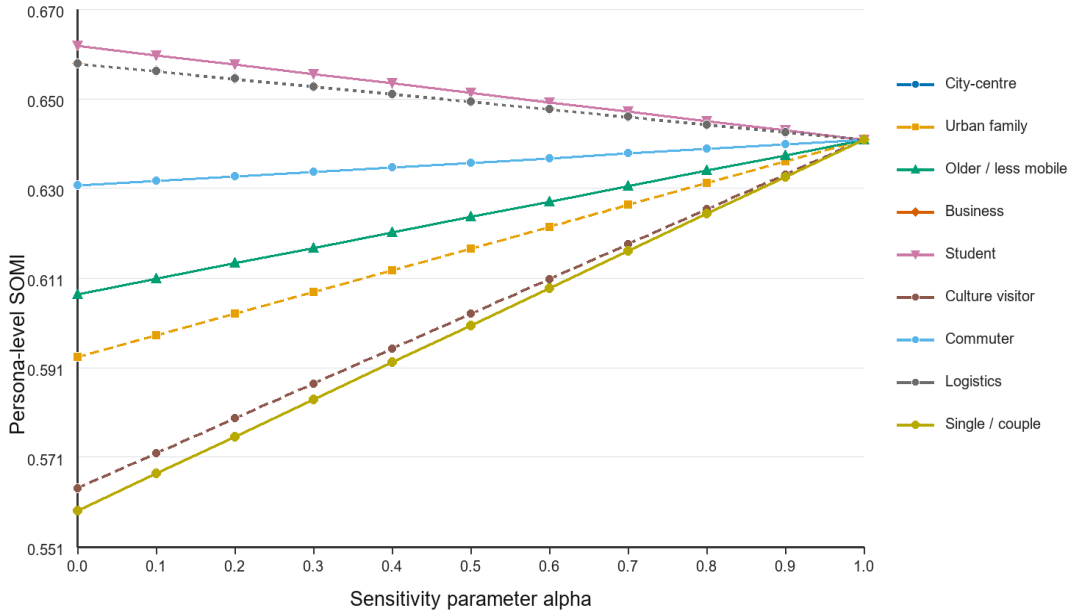


Figure 3: Mentimeter sensitivity results for SOL2- urban logistics micro-hubs

Figure 3 shows the Mentimeter sensitivity results for SOL2, namely the urban logistics micro-hubs / proximity logistics spaces solution, including all nine Florence personas. In contrast to SOL1, the curves are more compact, indicating that SOL2 is less sensitive to changes in the Mentimeter persona–pillar weighting structure. All persona-level SOMI values converge toward the same equal pillar-weight value of 0.641 as α approaches 1, because all personas then use the same equal pillar-weight vector for the same solution. Two distinct sensitivity patterns are observed. The student living away from home, the business in the city centre and the logistics operator start from the highest baseline

SOMI values, at 0.662 and 0.658 respectively, and decline slightly as α increases. This suggests that their original Mentimeter weighting profiles are relatively well aligned with the stronger SOL2 pillars, especially Affordability, Agency, Availability and Legal Recognition. When these persona-specific weights are progressively replaced by equal pillar weights, the advantage created by this alignment is reduced, and their SOMI values move downward toward the common equal-weight value. By contrast, the city-centre resident, the single or couple with no children, the culture visitor, the urban family, the older / less mobile resident and the commuter start from lower baseline values and increase as α moves from 0 to 1. This indicates that these personas originally place greater relative importance on pillars where SOL2 is less strongly developed, especially Acceptability, Accessibility, Participation and Safety & Security. As the weighting structure moves toward equal pillar weights, the influence of these weaker-performing pillars becomes less dominant, and their persona-level SOMI values increase. The overall spread across personas narrows from 0.103 at α = 0 to zero at α = 1.

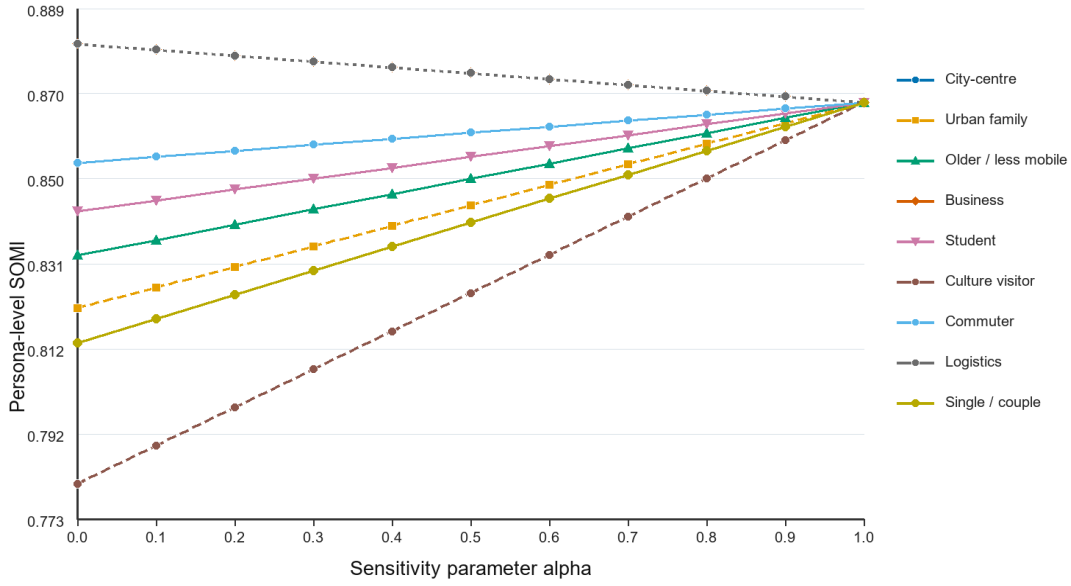


Figure 4: Mentimeter sensitivity results for SOL3- road-space redistribution

Figure 4 shows the Mentimeter sensitivity results for SOL3, namely road-space redistribution, including all nine Florence personas. The persona-level SOMI values remain high across the full perturbation interval, confirming that road-space redistribution is the strongest-performing solution under both the original Mentimeter persona–pillar weights and the equal pillar-weight scenario. As α moves from 0 to 1, all persona curves converge toward the same equal-weight SOMI value of 0.868. The figure shows that the business in the city centre and the logistics operator personas start from the highest baseline SOMI values, both at 0.881, and decline slightly as α increases. This indicates that their original Mentimeter weighting profiles are strongly aligned with the pillars where SOL3 performs

best, and that they assign the lowest weight of all personas to Safety & Security, which is the solution's weakest pillar. When these persona-specific weights are progressively replaced by equal pillar weights, this initial advantage is reduced, and their SOMI values move downward toward the common equal-weight value. By contrast, the culture visitor persona starts from the lowest baseline value of 0.781 and records the strongest increase across the perturbation interval. This suggests that the culture visitor assigns relatively higher importance to the two limiting pillars of SOL3, namely Safety & Security, which remains at its worst reference value, and Accessibility, which reaches 0.942. As the weighting structure moves toward equal pillar weights, the influence of these weaker pillars becomes less dominant, and the culture visitor SOMI value increases substantially. The city-centre resident, the single or couple with no children, the urban family, the older / less mobile resident, the student and the commuter also increase gradually as α rises, although with different slopes, because their original weighting profiles give relatively more importance to the pillars where SOL3 is not at full performance.

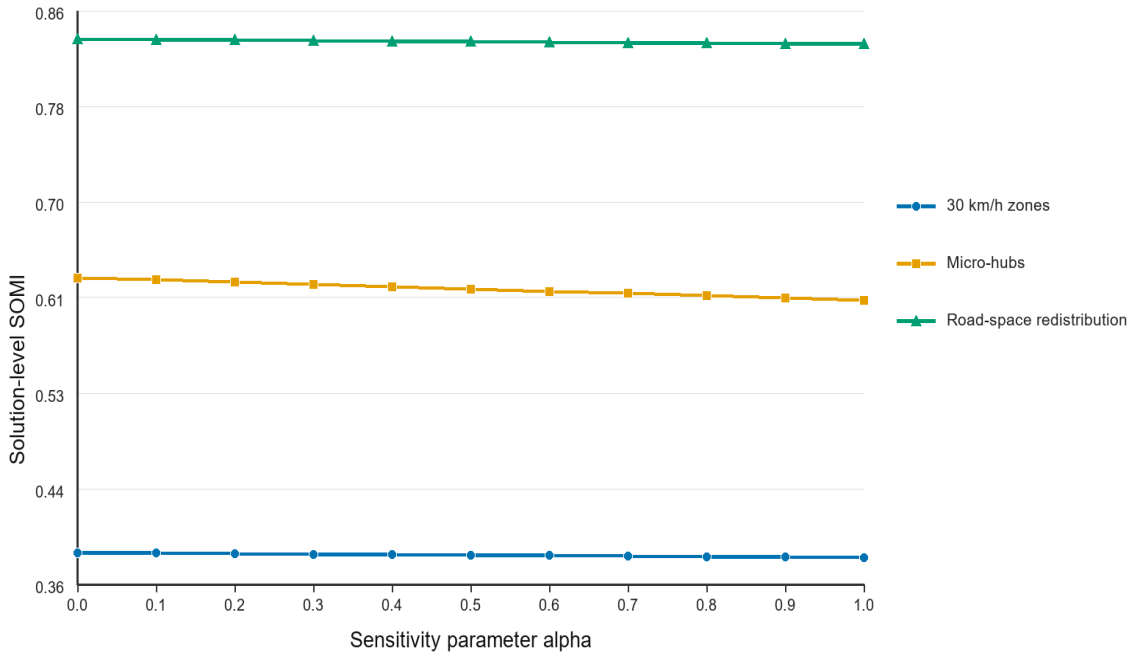


Figure 5: Solution-level SOMI sensitivity under ICB persona-influence weight perturbation.

Figure 5 shows how the solution-level SOMI values change when the ICB persona-influence weights are gradually replaced by equal persona weights. The curves are almost flat: across the full perturbation interval the solution-level values move by at most 0.005 for 30 km/h zones, 0.020 for micro-hubs and 0.004 for road-space redistribution. This indicates that the solution-level SOMI results are only weakly affected by the choice between ICB-derived persona-influence weights and equal persona weights.

This limited variation is expected because the persona-level SOMI values within each solution are relatively close to each other. When the values being aggregated are similar, changing the persona weights has only a small effect on the final weighted average.

Therefore, the analysis supports the use of equal persona weights as a robustness benchmark and shows that the solution-level ranking does not depend strongly on the exact ICB weighting structure. Road-space redistribution remains the highest-performing solution, micro-hubs remain second, and 30 km/h zones remain third across the full perturbation interval. The ICB weights remain useful for interpreting implementation influence across personas, but in this Florence application they do not materially alter the numerical solution-level SOMI results.

6. Conclusions and future research perspectives

This paper developed and applied the Social Optimum Mobility Index (SOMI), a persona-sensitive and KPI-based framework that allows different urban mobility solutions to be evaluated not only through technical or operational indicators, but also through their implications for different user groups, social priorities and implementation conditions. The framework combines normalised KPI values, persona–pillar significance weights, solution-specific persona-influence weights and multi-level aggregation to produce persona-level, solution-level and city-level SOMI results.

The Florence case study demonstrates the practical applicability of the SOMI framework. The analysis assessed three selected mobility solutions (i) SOL1, 30 km/h zones and traffic calming, (ii) SOL2, urban logistics micro-hubs / proximity logistics spaces and (iii) SOL3, road-space redistribution toward safer, more sustainable and people-centred mobility. The results show a clear ranking among the three solutions. Road-space redistribution achieved the highest solution-level SOMI score (0.840), urban logistics micro-hubs achieved the second-highest score (0.630), and 30 km/h zones and traffic calming recorded a more moderate score (0.388). The city-level SOMI for Florence was estimated at 0.619, based on equal weighting of the three solution-level scores.

The persona-level results provide one of the most useful insights of the analysis. Road-space redistribution achieved the highest score for every Florence persona. The strongest values were observed for the business in the city centre and the logistics operator, both at 0.881, followed by the commuter (0.854) and the student living away from home (0.843). The older / less mobile resident recorded 0.833 and the urban family 0.821, while the city-centre resident and the single or couple with no children both recorded 0.813, and the culture visitor recorded 0.781. These results indicate that road-space redistribution performs strongly across most SOMI pillars. The solution reaches full performance in Acceptability, Affordability, Agency, Availability, Legal Recognition and Participation, while Accessibility also performs strongly because the current cycle-network length is

close to the official municipal objective. Safety & Security remains at its worst reference value, because the only available indicator is a city-wide injury-crash baseline rather than a solution-specific measurement. This shows the value of SOMI as a diagnostic tool, since even when a solution performs very strongly overall, the framework can identify which dimensions are already close to their best reference targets and which dimensions, such as Accessibility and Safety & Security, still offer room for further improvement.

The results for the urban logistics micro-hub solution show that SOMI can also capture the social and operational relevance of freight-related mobility interventions. SOL2 performs strongly for several personas, with the highest value recorded for the student living away from home (0.662), followed by the business in the city centre and the logistics operator, both at 0.658, and the commuter (0.631). The older / less mobile resident and the urban family recorded 0.607 and 0.593 respectively, the culture visitor recorded 0.564, and the city-centre resident and the single or couple with no children both recorded 0.559. These results reflect the strong performance of the solution in Affordability, Agency, Availability and Legal Recognition. However, the solution's overall SOMI value remains below that of road-space redistribution because Acceptability, Accessibility and Participation are only partially fulfilled at the current pilot stage. This finding highlights the importance of monitoring pilot projects beyond their technical feasibility. For micro-hubs to achieve stronger social-optimum mobility performance, future implementation should document actual use by logistics operators, effects on loading/unloading conditions, impacts on local businesses, changes in freight-vehicle circulation and wider public-space benefits.

The more moderate SOMI value for 30 km/h zones and traffic calming should not be interpreted as evidence that traffic calming is a weak policy concept. Rather, it reflects the way the current KPI values and reference limits are structured. SOL1 performs strongly in Acceptability, Legal Recognition and Participation, while Affordability shows an intermediate level of performance. However, its current spatial coverage, active-area count, public-transport agency indicator and injury-crash baseline remain at or close to their worst reference values. At persona level, the highest values are observed for the city-centre resident and the single or couple with no children, both at 0.421, followed by the business in the city centre and the logistics operator, both at 0.403, and the older / less mobile resident (0.400). The commuter records 0.386, the urban family 0.378 and the student living away from home 0.373. The lowest value is observed for the culture visitor at 0.266. The result therefore indicates clear potential for improvement. If Florence expands Zone 30 coverage, increases the availability of traffic-calmed areas and strengthens the integration of traffic calming with public transport, cycling and pedestrian-priority measures, the SOMI score of this solution is expected to improve.

The analysis also confirms that implementation influence is solution specific. In Florence, the urban family is the most influential persona for 30 km/h zones and traffic calming, the logistics operator is the most influential persona for urban logistics micro-hubs, and the urban family is again the most influential persona for road-space redistribution. These findings show that the same persona does not dominate every intervention. Instead, the relevant implementation actors change according to the logic of each solution. This supports the use of solution-specific persona-influence weights and confirms that a single citywide persona hierarchy would be insufficient for socially sensitive mobility assessment.

The sensitivity analysis further confirms the robustness of the comparative findings. The Mentimeter sensitivity test shows that persona-level SOMI values are affected differently depending on the balance of pillar performance within each solution. The 30 km/h zones and traffic calming solution is the most sensitive to persona–pillar weighting assumptions, because its performance is strong in some pillars but weaker in others. The micro-hub solution shows a more balanced sensitivity pattern, while road-space redistribution remains the strongest-performing solution across personas and across the full perturbation interval. The ICB sensitivity test shows only limited variation in solution-level SOMI values when solution-specific persona-influence weights are progressively replaced by equal persona weights. This indicates that the final ranking of the three Florence solutions does not depend strongly on the exact ICB weighting structure.

From a policy perspective, the Florence implementation suggests three main priorities. First, for 30 km/h zones and traffic calming, future monitoring should focus on expanded spatial coverage, increased availability of traffic-calmed areas and stronger integration with active-mobility and public-transport options. Second, for urban logistics micro-hubs, future monitoring should focus on scaling micro-hub availability, increasing sensor coverage of freight loading/unloading bays, expanding logistics stakeholder participation and measuring direct operational, environmental and public-space outcomes. Third, for road-space redistribution, future monitoring should preserve the very strong performance observed across most pillars while examining whether the intervention continues to deliver high accessibility, safety, governance, participation and public-space benefits over time. These priorities show how SOMI can move beyond ranking solutions and support targeted policy refinement.

Several future research directions emerge from this work. First, the SOMI methodology should be tested in additional cities and urban contexts to examine its transferability and robustness. Applying the same framework across different metropolitan structures, mobility cultures and planning systems would help assess whether the eight-pillar structure remains stable or requires context-specific adaptation. Second, future work should strengthen the empirical basis of KPI selection by incorporating more direct, regularly updated and spatially disaggregated indicators. This is particularly

important for Safety & Security, Affordability and Acceptability, where proxies are sometimes necessary when direct local measurements are unavailable.

Third, future research should further expand the sensitivity and uncertainty analysis of the SOMI framework. Although the present study tests the robustness of the results under alternative persona–pillar and persona-influence weighting assumptions, future applications could extend this by examining uncertainty in KPI values, alternative reference limits, different normalization functions, alternative aggregation rules and city-specific solution weights. This would allow SOMI results to be interpreted not only as point estimates, but also as robustness ranges under different methodological assumptions.

Fourth, citizen and local stakeholder validation should be expanded. The current weighting structure is based on expert and consortium input. Future applications could combine this with wider citizen panels, targeted interviews or participatory workshops with persona-representative groups.

Fifth, SOMI should be developed further as a longitudinal monitoring tool. The current Florence implementation is a current-state assessment based on available evidence. Future studies could use the same KPI structure to compare baseline, implementation and post-implementation conditions. This would make it possible to estimate whether a solution actually improves social-optimum mobility over time. Future longitudinal applications should also examine whether observed changes in SOMI values remain robust under alternative weighting and normalisation assumptions.

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Data availability: The datasets generated and/or analyzed during the current study are not publicly available due to ownership, access, and redistribution restrictions related to city-provided data, but are available from the corresponding author on reasonable request and with permission of the City of Florence and/or the relevant original data owners. The input data used for the SOMI calculation were compiled by the City of Florence from municipal and operational data sources in response to the data requirements defined within the GOLIA project. In line with the GOLIA Data Management and Ethics Plan, raw or external city data remain under the control of the original data owners and are not replicated or redistributed by the project. Processed indicators, methodological documentation, and supporting materials may be shared where this does not conflict with confidentiality, intellectual property, or data-protection restrictions.

Clinical trial number: not applicable.

Ethics approval: The requirement for ethics approval was waived by the Chair of the Research Ethics Committee of the Centre for Research and Technology Hellas (CERTH; Protocol No. 01-090926), as the study comprised of two internal expert-elicitation exercises involving adult consortium representatives participating voluntarily in their professional capacity. Mentimeter responses were anonymous, Impact Creation Board inputs were submitted at organizational level, and no identifiable personal data were collected. The study was conducted in accordance with the relevant ethical principles, guidelines and regulations confirmed by the Chair of the Research Ethics Committee of CERTH.

Accordance with ethical guidelines: The research was conducted under Article 14 ("Ethics and values") of Horizon Europe Grant Agreement No. 101201950, the GOLIA Consortium Agreement and the GOLIA Data Management and Ethics Plan, overseen by the project's Ethics and Data Protection Officer, and in accordance with Regulation (EU) 2016/679 and the European Code of Conduct for Research Integrity.

Consent to participate: Freely given informed consent to participate in the study was obtained from all participants before the exercises. All participants were adult representatives of consortium partner organizations acting in their professional capacity and were informed of the purpose, nature and intended use of the exercises before taking part.

Consent for publication: Not applicable. The manuscript does not contain identifiable personal information.

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