

Enhancing Senior Mobility: Distributional Impacts And Equity Implications Of Infrastructure Investments For An Ageing Population

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Abstract—The rapid ageing of contemporary societies raises critical questions regarding how transport systems can equitably accommodate the mobility needs of older adults. This paper examines the distributional impacts of infrastructure investments aimed at improving senior mobility, with particular attention to spatial and socio economic disparities within elderly populations. The central research question asks to what extent mobility oriented infrastructure investments for older adults mitigate or exacerbate pre existing inequalities in accessibility and welfare across different senior groups. The paper adopts an accessibility and welfare based analytical perspective aligned with distributionally weighted cost benefit analysis. It evaluates a range of interventions, including barrier free urban design, pedestrian and cycling infrastructure, public transport accessibility improvements, and demand responsive transport services. The analysis shows that when investments are explicitly aligned with baseline accessibility deficits and demographic vulnerabilities, they generate substantial equity gains, particularly for low income seniors, individuals with functional limitations, and residents of peripheral or underserved areas. In contrast, interventions that are poorly targeted or implicitly assume high levels of physical or digital capability risk reinforcing existing inequalities. The paper contributes by developing a formal distributional assessment framework for senior mobility investments, linking accessibility gains to welfare and health outcomes, and providing equity oriented guidance for transport appraisal and planning in ageing societies.

Keywords— Accessibility, Ageing population mobility, Cost benefit analysis, Distributional effects, Infrastructure investment, Transport equity.

1. INTRODUCTION

Population ageing represents one of the most significant demographic transformations shaping contemporary cities and transport systems. Across Europe and other advanced economies, increasing life expectancy combined with declining fertility rates is producing a sustained rise in the proportion of older adults, fundamentally altering demand for urban services and infrastructure [1], [25], [65] to [67]. Mobility plays a central role in determining quality of life in later stages of the life course, as it enables access to healthcare, daily services, social networks, and opportunities for participation that underpin independent living and well being [14], [26]. Despite its importance, transport systems have historically been planned around the needs of working age populations and private car users, often neglecting the physical, cognitive, and socio economic constraints that emerge with age [34].

A growing body of evidence shows that declining mobility among older adults is associated with adverse outcomes, including reduced physical activity, increased risk of chronic disease and falls, cognitive decline, and heightened social isolation [4], [6], [48], [51], [56]. These impacts are not evenly distributed across the elderly population. Older adults with lower incomes, limited access to private vehicles, functional impairments, or residence in

peripheral and poorly served urban areas face compounded disadvantages that restrict their ability to access essential activities [34], [50], [60]. Transport related exclusion therefore functions as a mechanism through which broader socio economic inequalities persist and intensify in later life [9], [34].

In response, sustainable urban mobility and age friendly city agendas have increasingly emphasised inclusivity, accessibility, and universal design [2], [45], [66]. European policy frameworks, including Sustainable Urban Mobility Plans, explicitly call for integrating the needs of ageing populations into transport planning and evaluation [5], [20], [23], [46], [52]. However, while many mobility investments promise aggregate benefits in terms of efficiency, sustainability, or environmental performance, their distributional consequences remain insufficiently examined. Without explicit attention to who benefits, investments risk privileging already mobile and well served groups, thereby reinforcing existing inequalities among older adults [10], [42], [53]. This paper addresses this gap by focusing explicitly on the distributional impacts of infrastructure investments aimed at enhancing senior mobility and by formalising an appraisal framework that combines accessibility based welfare with equity relevant distributional assessment.

II. SENIOR MOBILITY, ACCESSIBILITY, AND INEQUALITY

Mobility in older age is a multidimensional concept encompassing not only physical movement but also autonomy, confidence, and effective access to opportunities. Evidence from behavioural and health research links mobility to successful ageing and indicates that maintaining community mobility is strongly associated with independence and quality of life [3], [14], [26], [57]. Active transport and physical activity are consistently associated with better health outcomes, supporting the welfare relevance of environments that enable safe walking and cycling in older age [55], [59], [63]. Yet ageing is also characterised by increasing heterogeneity in functional capacity. Sensory impairments, cognitive decline, and reductions in reaction time and balance alter how older adults interact with transport environments and increase sensitivity to barriers and risk [14] [16], [49], [54], [56].

Accessibility, defined as the ease with which individuals can reach desired opportunities, provides a more appropriate lens than traditional mobility metrics focused on speed or distance [15], [19], [42], [53]. For older adults, effective accessibility is shaped by the interaction between objective conditions and subjective constraints, such as fear of falling, perceived insecurity at crossings, or uncertainty in navigation and transfers [49], [53], [62]. These constraints are unevenly distributed across income and space, reinforcing a pattern in which disadvantaged seniors experience cumulative barriers and lower opportunity access [34], [60]. The transport and social exclusion literature further shows that transport disadvantage reflects systemic factors such as land use patterns, service provision, and institutional design, rather than only individual characteristics [9], [34]. In low density or peripheral areas, where services and destinations are dispersed, older adults experience higher generalised costs and fewer feasible mode options, and these effects are stronger for low income and non driving seniors [36], [42], [60]. These empirical regularities imply that the welfare impact of mobility investments for older adults is inherently distributional and should be evaluated accordingly [68].

III. ANALYTICAL AND METHODOLOGICAL PERSPECTIVE

This paper adopts an accessibility and welfare based perspective that integrates insights from ageing, accessibility research, and transport equity. Accessibility improvements are treated as reductions in generalised travel costs that include time and monetary expenditure, but also physical effort, perceived risk, and cognitive burden. These dimensions are particularly salient in older age, as indicated by evidence on sensory impairment, balance decline, and cognitive limitation [11], [16], [49], [54], [56]. The framework therefore aligns with the “moving to access” perspective in transport planning, which argues that appraisal should focus on overcoming barriers to participation rather than simply increasing mobility flows [12], [42], [53].

A distributional approach is central. Baseline accessibility is unequal across elderly groups, and marginal gains from investments are expected to be larger for those starting from lower accessibility conditions, particularly low income, mobility impaired, and spatially isolated seniors [34], [50], [60]. Spatial incidence matters because improvements in underserved areas can generate larger welfare gains by reducing isolation and dependence on informal support [36], [58], [60]. The framework also aligns with SUMP planning and evaluation practice, which increasingly emphasises equity relevant indicators, participatory approaches, and continuous monitoring in inclusive mobility planning [13], [20], [52], [69].

IV. FORMAL DISTRIBUTIONAL ASSESSMENT MODEL AND COST BENEFIT ALIGNMENT

A formal distributional assessment model for elderly mobility investments can be developed within a welfare and cost benefit framework by defining accessibility as the primary intermediate outcome of transport interventions and by explicitly accounting for heterogeneity across older population groups [17]. Let the population of older adults be partitioned into groups g belonging to the set G , where groups are defined according to socio economic characteristics, functional capability, and spatial context. This classification reflects well established evidence that baseline mobility conditions, vulnerability to transport barriers, and marginal welfare gains from accessibility improvements differ systematically across elderly subpopulations [18], [61].

Let j belong to the set J of relevant opportunities, including healthcare facilities, retail, social services, and social participation destinations, and let O_j denote an opportunity weight reflecting the importance or attractiveness of destination j . Individual accessibility for an older person i belonging to group g is defined as a gravity type function of reachable opportunities weighted by generalised travel costs:

$$A_{ig} = \sum_{j \in J} O_j \cdot f(C_{ijg}) \quad (1)$$

where $f(\cdot)$ is a monotonically decreasing function of the generalised cost C_{ijg} of travelling from individual i to opportunity j for group g . In the context of ageing, generalised travel cost must extend beyond conventional time and monetary components to capture barriers that are particularly salient for older adults. Accordingly, generalised cost is decomposed as follows:

$$C_{ijg} = \alpha_g \cdot T_{ijg} + \beta_g \cdot M_{ijg} + \gamma_g \cdot P_{ijg} + \delta_g \cdot R_{ijg} + \theta_g \cdot K_{ijg} \quad (2)$$

where T_{ijg} represents travel time, M_{ijg} represents monetary cost, P_{ijg} represents physical effort, R_{ijg} represents perceived risk and safety burden, and K_{ijg} represents cognitive and informational burden associated with wayfinding, transfers, and service complexity. The parameters α_g , β_g , γ_g , δ_g , and θ_g are group specific weights that reflect heterogeneity in sensitivity to different cost components. Empirical evidence on sensory impairment, balance decline, and cognitive limitation among older adults suggests that the weights attached to physical effort, perceived risk, and cognitive burden are systematically higher for more vulnerable elderly groups, implying higher baseline generalised costs even when physical infrastructure is present.

Consider an infrastructure or service investment I that reduces one or more components of generalised cost. The accessibility change induced by investment I for individual i in group g is defined as:

$$\Delta A_{ig}^I = A_{ig}(C_{ijg}) - A_{ig}(C_{ijg} - \Delta C_{ijg}^I) \quad (3)$$

Distributional effects arise because the reduction in generalised cost ΔC_{ijg}^I is not uniform across individuals or groups. For example, barrier removal and pedestrian safety interventions primarily reduce physical effort and perceived risk, generating larger cost reductions for older adults with functional limitations, while information and design improvements reduce cognitive burden more strongly for those experiencing age related cognitive decline.

Not all potential accessibility gains are necessarily realised in practice. Let U_{ig} denote the probability that individual i in group g can and will effectively use the improved infrastructure or service, capturing constraints related to confidence, fear of falling, safety perceptions, digital exclusion, or lack of familiarity. The effective accessibility gain is therefore given by:

$$\Delta A_{ig}^{\{I, eff\}} = U_{ig} \cdot \Delta A_{ig}^I \quad (4)$$

Welfare benefits are derived from effective accessibility gains through a marginal utility of accessibility. Let λ_g denote the marginal utility of accessibility for group g , which is assumed to be higher for groups with fewer substitute mobility options, higher dependence on public provision, and greater vulnerability to social exclusion. Individual welfare gains from investment I are defined as:

$$\Delta W_{ig}^I = \lambda_g \cdot \Delta A_{ig}^{\{I, eff\}} \quad (5)$$

To align the framework with conventional cost benefit appraisal, welfare gains are aggregated over individuals and groups and discounted over time. Let K_t^I denote investment and operating costs at time t , and let r denote the social discount rate. The standard net present value of investment I is given by:

$$NPV^I = \sum_{t=0}^T [\sum_{g \in G} \Delta W_{\{g,t\}}^I - K_t^I] / (1 + r)^t \quad (6)$$

However, standard net present value treats all welfare gains as equally valuable regardless

of the recipient. To explicitly incorporate equity considerations, distributional weights are applied to benefits accruing to different elderly groups. Let ω_g denote the equity weight assigned to group g , with ω_g greater than one for disadvantaged groups such as low income seniors, individuals with mobility impairments, and residents of poorly served areas. The distributionally weighted net present value is defined as:

$$DNPV^I = \sum_{t=0}^T \left[\sum_{g \in G} \omega_g \cdot \Delta W_{\{g,t\}}^I - K_t^I \right] / (1 + r)^t \quad (7)$$

Mobility investments for older adults also generate downstream co benefits related to health, independence, and social participation. Let $H_{\{g,t\}}^I$ denote the monetised value of health and independence benefits accruing to group g at time t as a result of increased physical activity, reduced isolation, and improved access to care. Total welfare benefits are therefore:

$$\Delta W_{\{g,t\}}^{I,tot} = \Delta W_{\{g,t\}}^I + H_{\{g,t\}}^I \quad (8)$$

Finally, the distributional performance of investment I can be summarised using an equity share indicator. Let G_d denote the subset of disadvantaged elderly groups. The equity share of total discounted welfare benefits accruing to disadvantaged groups is defined as:

$$\Phi^I = \frac{\sum_t \sum_{g \in G_d} \omega_g \cdot \Delta W_{\{g,t\}}^{I,tot} / (1 + r)^t}{\sum_t \sum_{g \in G} \omega_g \cdot \Delta W_{\{g,t\}}^{I,tot} / (1 + r)^t} \quad (9)$$

An investment is considered distributionally progressive if the equity share Φ^I exceeds the population share of disadvantaged elderly groups, consistent with inclusive mobility objectives and equity oriented transport appraisal principles.

V. DISTRIBUTIONAL EFFECTS OF SENIOR ORIENTED MOBILITY INVESTMENTS

The formal model clarifies the mechanisms through which senior mobility investments generate distributional outcomes, and it is consistent with the empirical evidence base. Pedestrian and barrier free improvements primarily reduce the physical effort term P and the perceived risk term R in (2), which are disproportionately large for older adults with balance decline and slower walking speeds. Evidence on walking behaviour and pedestrian safety suggests that crossing design and environmental quality can materially change feasibility and perceived safety for older adults, implying larger marginal gains for those facing high baseline constraints [8], [49], [62]. When investments are targeted toward low quality environments and underserved districts, they reduce fundamental access barriers and can produce progressive welfare gains for disadvantaged seniors [34], [39], [60].

Public transport accessibility improvements reduce physical effort, cognitive burden, and perceived risk associated with boarding, transfers, and information [24], [43]. Systematic review evidence indicates that older adults face persistent barriers related to vehicle access, station design, and transfer complexity, and these barriers are stronger for those with sensory impairment [16], [21], [50]. Improvements in these domains expand usable accessibility and thus welfare, with larger gains for low income and non driving seniors who

lack substitutes [14], [30], [60]. However, spatial incidence matters, and improvements concentrated in already well served corridors can limit benefits for peripheral seniors, consistent with accessibility and exclusion insights [34], [42].

Demand responsive transport services can deliver large accessibility gains for spatially isolated seniors by reducing effective travel costs and simplifying complex trips, especially where fixed route provision is weak [47], [60]. Yet evidence on technology mediated mobility adoption indicates that uptake depends on digital capability, trust, and usability, implying that U_{ig} in (4) can be low for vulnerable groups unless booking and support channels are inclusive [7], [38]. Therefore, governance design, eligibility, and affordability conditions directly shape distributional incidence and determine whether benefits reach the intended groups.

Across interventions, improved accessibility is consistently linked to broader welfare and health outcomes, reinforcing the inclusion of $H_{\{g,t\}}^I$ in (8). Evidence shows that active mobility supports physical activity and health outcomes, and that transport strategies affecting mode choice and exposure can generate substantial health benefits [55], [63], [64]. In ageing contexts, mobility also affects social participation and mental health, and perceived isolation is associated with adverse health outcomes, indicating that accessibility gains may reduce isolation related welfare losses [6], [51]. Because disadvantaged seniors face higher baseline vulnerability and fewer coping resources, these co benefits can be distributionally amplified [60].

VI. POLICY IMPLICATIONS

Embedding equity explicitly within sustainable urban mobility planning and appraisal is essential in ageing societies. SUMP guidance and evaluation research stress the importance of disaggregated indicators, stakeholder engagement, and iterative learning in planning processes [20], [52], [69]. The formal framework in Section IV provides an operational link between these planning principles and appraisal, showing how accessibility improvements can be monetised or otherwise translated into welfare terms, then distributionally weighted to reflect inclusive objectives [32]. Policy design should prioritise interventions that reduce the non monetary barriers most salient for older adults, including physical effort, perceived risk, and cognitive burden, particularly in underserved areas where baseline accessibility is low [31], [42], [60].

Integrated strategies combining pedestrian improvements, accessible public transport, and targeted flexible services are most likely to reduce mobility related inequalities [28], [37]. Coordination with health and social care policy can strengthen the welfare case by recognising that mobility affects health, independence, and social inclusion outcomes in later life [26], [65]. In addition, as technology mediated services expand, inclusive governance must ensure that digital exclusion does not reduce usability probabilities and shift benefits away from vulnerable groups [7], [29], [40].

VII. CONCLUSION AND FUTURE RESEARCH PATHWAYS

As demographic ageing accelerates, ensuring equitable mobility for older adults becomes a central challenge for sustainable and inclusive urban development [27]. This paper demonstrates that infrastructure investments aimed at enhancing senior mobility can either mitigate or exacerbate existing inequalities depending on their design, targeting, and

evaluation [35]. By integrating accessibility based analysis with a formal distributionally weighted cost benefit model, the study provides a rigorous method for assessing elderly mobility investments in terms of both efficiency and equity, while explicitly modelling heterogeneous generalised costs, usability constraints, and downstream health benefits [16], [22], [42], [53], [64]. The analysis indicates that interventions aligned with baseline accessibility deficits and vulnerabilities are more likely to deliver progressive outcomes, particularly for low income, mobility impaired, and spatially isolated seniors [34], [41], [60].

Future research should empirically apply this model using micro level travel and accessibility data to estimate generalised cost components and the distributional weights needed for equity sensitive appraisal, extending evidence on the divergence between calculated and self reported accessibility among older adults [44], [53]. Further work should also integrate subjective constraints, including perceived safety and confidence, into formal benefit functions, consistent with evidence on pedestrian safety and the health impacts of perceived isolation [6], [33], [49]. Longitudinal research is required to assess how investments affect life course transitions such as driving cessation, onset of impairments, and changes in activity space, and how these dynamics influence the evolution of accessibility inequality [14], [54]. Finally, the expansion of technology mediated mobility services calls for rigorous evaluation of long term distributional effects, particularly regarding digital exclusion and governance design, to ensure that flexible mobility solutions enhance rather than erode inclusivity [7], [47]. Stronger integration between transport appraisal and public health evaluation would further strengthen the evidence base for inclusive mobility investment decisions in ageing societies [55], [63], [64], [65].

ACKNOWLEDGMENT

This study was carried out within AGE-IT – Ageing well in an ageing society and received funding from Next Generation EU, in the context of the National Recovery and Resilience Plan, Investment PE8 – Project Age-It: “Ageing Well in an Ageing Society” [DM 1557 11.10.2022]. This manuscript reflects only the author's views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

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