

Cycling Under Economic, Environmental, and Occupational Pressure: Retention Conditions in Three LMIC Cities

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Abstract

Bicycling is usually advocated as a low-carbon and health-supporting means of transport, yet in many low- and middle-income cities it is also a work resource for cyclists suffering from low income, risky traffic environment and poor institutional protection. This paper asks what minimum support conditions need to be in place to retain existing cyclists in Delhi, Dhaka and Accra where comparable evidence is available only in aggregate form on income, cost of a bike, time spent cycling, occupational cycling, public-transport availability, modal share and exposure to PM_{2.5}; Chennai is included in this study as a comparison city due to incomplete comparable intercept and occupational information. The data come from Kannan et al.'s four-city bicycling evidence that includes 171 intercepts from Delhi, 50 intercepts from Dhaka and 238 intercepts from Accra, along with rider monthly household income of US\$216.2, US\$291.8 and US\$82.9, respectively [1]. By not adding any further variables in the form of the established Minimum Support Envelope (MSE), Retention-Fragility Gradient (RFG) and Envelope-Sequencing Test (EST), affordability, exposure, occupational reliance and urban friction are identified as the retention conditions. Cost of a new bicycle makes up 93.2% of monthly household income in Accra, 39.9% in Dhaka and 27.0% in Delhi, whereas second-hand bicycles cost 52.6%, 13.6% and 9.1%, correspondingly. Weekly cycling exposure reaches 9.4 hours during six days in Delhi and 204 minutes of strain relief is required to provide for six-hour protection threshold. Work anchoring in Dhaka is the most developed, with 84% cyclists commuting as part of their job and 57% undertaking multi-stop cycling trips. MSE and RFG values are largest in Accra, yet each city needs different policy sequence: Accra requires budget stabilization, Delhi requires exposure compression and Dhaka requires livelihood-continuity protection. This paper concludes that LMIC cycling policy should prioritize protection of already-cycling riders via affordability, repairability, security of parking, better crossing safety, shady spots, stopping rights and continuity of work routing before considering lane availability as evidence of support.

Keywords: bicycling; low- and middle-income countries; mobility justice; active travel; transport affordability; occupational mobility; minimum support envelope

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1. Introduction

Bicycling is a paradoxical transport choice. Its small carbon footprint, compact size and physical activity make it ideal for urban transport policy, but it remains a marginalized transport mode in many cities where its users' needs are believed to be insignificant due to the low cost of bicycles in comparison to motorised modes of transport. Climate policy identifies non-motorised transport as a part of transport-demand management and mitigation [2]. Global health policy recommends active travel as a significant way to encourage physical activity among populations [3]. European public health evidence also links active mobility with healthy and sustainable urban transport [4]. Physical-activity research demonstrates the significance of the non-communicable disease burden that results from the lack of physical activity [5]. Road safety evidence adds urgency since cyclists remain a vulnerable road user group exposed to speed, bad road design and poor enforcement [6]. Global burden of traffic injuries disproportionately falls on unprotected people [7]. Motor vehicle traffic, land-use intensity and industrial emissions add complications to air pollution in large cities; thus, protection of low-emissions modes of transport is necessary from the point of view of public health and environment [8]. These multiple reasons for the desirability of bicycling are not enough to indicate what cyclists need in low- and middle-income country (LMIC) cities.

The main problem with cycling policy is that it is aimed at future mode shift rather than current riders' retention. In transport

policy, bicycling emerges as lane kilometres, demonstration corridors, shared public bike systems, recreational greenways and aspirational vision inspired by high-income cycling cities. A systematic review and meta-analysis evidence demonstrates that interventions can help to switch people to walking and cycling [9]. Evidence about active transport intervention also highlights the benefits of well-designed interventions [10]. A systematic review confirms that the effectiveness of active transport intervention depends on its form and context [11]. Behavioural research demonstrates the influence of capability, opportunity and motivation on walking and cycling adoption [12]. Experience of high-income cycling countries also indicates the value of coordinated infrastructure, traffic calming and policy intervention [13]. Yet, a policy aimed at switching people to bicycling can ignore existing riders who already use it because cycling is linked to income generation, goods transportation, education, chores, public transport access and time management. These cyclists do not only need persuasion to keep cycling. They need conditions that will ensure that cycling will remain affordable, repairable, socially acceptable, relatively safe and compatible with work.

It is especially true for LMIC setting. Evidence from a low-income country suggests that cycling decisions are influenced by safety, social norms and local travelling conditions [14]. Recent comparative evidence about LMIC cities also indicates that the quality of infrastructure, relations with public transport, institutional environment and the politics of cycling determine whether bicycle riding is encouraged or marginalized [1]. These patterns cannot be extrapolated from European and North American cases. While a bicycle is a relatively cheap mode in relation to the citywide hierarchy of modes, it can be an expensive asset if its price is compared to the monthly income of a vendor, security guard, shop assistant, factory worker or delivery rider. While a lane can be included in municipal reporting, it can fail to protect a cyclist who has to pass dangerous junctions, make stops during his job, park near a market, repair punctures, transport some load or combine a short cycling trip with a public transport trip. These features change the focal point of analysis from a lane to a capacity of a cyclist to keep riding without excessive financial and physiological burden.

A minimum support approach is an answer to limitations of aggregate data. Most municipal agencies lack route-level exposure data, crash history by rider type, inventory of repair market and full household travel diary data. Yet, planning cannot be stalled by the availability of an ideal dataset. A table that contains information about the bicycle cost, cyclist income, six-day average riding duration, occupational distribution, public transport access, mode share and pollution pressure can reveal urgent retention challenges if it is interpreted properly. The relevant question is not whether such data can create a behavioural model. It cannot. The question is whether it can help to detect minimum support conditions already justified by the visible evidence. This paper attempts to answer this question by using the Minimum Support Envelope (MSE) method on four-city LMIC bicycling evidence of Kannan et al. [1].

The social rationale for this paper is derived from the literature on active mobility, mobility justice and infrastructure maintenance. Cross-city evidence links supportive urban environments to higher levels of physical activity [15]. New walking and cycling routes can also increase physical activity if they are usable and connected [16]. Separated cycling infrastructure is especially important for those social groups who feel extra concerns about motor-traffic exposure [17]. Evidence about safety demonstrates that objective safety of cyclists depends on more factors than just the presence of the lane [18]. A decade of research about cyclist safety also emphasizes the importance of road design, intersections, traffic conditions and coordination [19]. Route-choice evidence confirms that accident risk and subjective safety influence the usability of the cycling route [20]. Mobility justice literature shows how movement is distributed through the relations of safety, time, legitimacy and vulnerability [21]. Relational ethics of care also links mobility justice with climate and social responsibility [22]. Research about feminist cycling indicates why women and caregivers disappear from aggregate success stories [23]. Evidence from African cities also reveals socioeconomic and gender inequalities in travel behaviour [24]. Infrastructure research explains that transport systems operate as a result of social, political and material relations rather than as a set of static assets [25]. Research about South Asian cities makes repair and maintenance work central for keeping cities moving [26]. Work about cycling and urban space demonstrates how everyday cyclists navigate streets, rules and access through practices [27]. Recent work about cycling transitions emphasizes that infrastructure should be studied through diversity and care [28]. For cycling, it means that repair shops, safe parking, right to stop, affordable spare parts and access to markets are not peripheral services; they are conditions for the functioning of bicycle use.

Equity research in recent years also confirms the same transition from visible provision to practical usability. Equity research in cycling warns that funding, street space and maintenance can be allocated unequally if policy is concentrated on politically visible areas and users who have the confidence, money and social legitimacy to cycle [29]. Transport poverty research also shows that affordability, access and vulnerability should be interpreted as a whole rather than separate welfare issues [30]. Informal urbanism research further shows that vending, transport and settlement are interdependent in many Global South cities; mobility and street work often reinforce each other rather than belong to different policy domains [31]. These arguments make the bicycle a transport, livelihood and maintenance object at once. Thus, a city can support bicycling by providing lanes, but at the same time weaken it by making repairs unaffordable, penalizing stopping, providing insecure parking or restricting market access.

The research question is: what minimum support conditions are needed to retain existing everyday cyclists in Delhi, Dhaka and Accra when the available evidence is aggregated values about bicycle cost, income of cyclists, cycling duration, occupational distribution, public transport access, mode share and PM_{2.5} exposure? The paper answers this question without proposing a new method. It uses the known MSE score to measure the support magnitude, RFG to differentiate the pathway through which cycling becomes fragile and EST to prioritize practical interventions. The contribution is therefore interpretive and organizational; it converts limited but policy-relevant data into a city-specific retention diagnosis. The expected result is not a universal cycling policy blueprint, but a defensible sequence of support priorities that differentiate affordability problems of Accra, exposure burden of Delhi and livelihood continuity requirements of Dhaka.

City portraits in Figure 1 provide the organizing contrast before the numerical tables. Delhi appears as an exposure compression case, Dhaka as a livelihood continuity case and Accra as a budget stabilization case. This initial visual separation helps to prevent a reading of numerical scores as a simple ranking.



Figure 1. City retention portraits.

It is intended as an entry into the concepts, rather than as street-level data in itself, which links each city to the pressure defined subsequently in quantitative terms: extended exposure cycling in Delhi; work cycling in Dhaka and cost of asset cycling in Accra. It indicates why no single policy design will suffice. The full analysis is to determine the support condition that is first missing in each city.

2. Materials and methods

2.1 City evidence and input variables

The analysis depends on the tabular and supplementary evidence on bicycling in Delhi, Dhaka, Accra and Chennai provided by Kannan et al. [1]. The inputs consist of the published intercept-survey counts, monthly rider household income, proportion of city household income, new-bicycle cost burden, second-hand bicycle cost burden, six-day cycling duration, occupational categories, use characteristics, bicycle mode share, convenient access to public transport, annual average PM_{2.5} and city context. Delhi, Dhaka and Accra have complete input because the necessary intercept and occupation rows exist. Chennai retains its role as an urban profile comparator because the public-transport access, bicycle mode share and PM_{2.5} figures are available, but is not scored for MSE, RFG or EST because of an incomplete intercept-survey row.

The data is aggregate, not individual-level. It does not contain the individual raw trip records, income distribution, geocoded routes, crash history or transcripts of interviews. This limitation arises directly from the scope of the present work. In many LMIC cities, there is enough information to see that the current cyclists are under financial and spatial pressure, but not enough to fit individual behavioral models. Hence the approach assumes that each table entry is a decision support observation. Its objective is to identify the minimum priorities indicated by the evident figures without making prevalence claims supported by the evidence.

2.2 Minimum Support Envelope variables

Let c be a city. The affordability envelope examines the acquisition cost burden of new and second-hand bicycles. The new-bicycle burden is

$$B_c^{new} = 100 \times \frac{P_c^{new}}{I_c}, \quad (1)$$

where P_c^{new} is the mean cost of a newly bought bicycle and I_c is mean monthly household income among surveyed riders. The second-hand burden is

$$B_c^{used} = 100 \times \frac{P_c^{used}}{I_c}. \quad (2)$$

This is done because replacement and maintenance are considered part of the value of affordability. A used bike will lower the cost of acquisition, but at the same time, it may lead to high costs associated with maintenance and even stolen bikes. The affordability envelope evaluates whether a bike can be a reliable means of transport and does not just focus on whether there is an affordable acquisition price.

The income-position variable compares rider household income with city-average household income:

$$Q_c = 100 \times \frac{I_c}{\bar{I}_c}, \quad (3)$$

where $\bar{I}_c$ represents average city monthly household income. The smaller the Q_c , the more differentiated the sampled cyclist is from the average urban household. The value of Q_c is critical in that the same price level of bicycle will be trivial for recreational biking but very serious for those whose monthly income is well below city average.

The exposure envelope takes six-day weekly riding time W_c . Weekly minutes are converted into hours as

$$H_c = \frac{W_c}{60}. \quad (4)$$

A six hour per week protection level is used in determining the strain reduction that will make the weekly exposure conservative service target. The protection level is not an indication that livelihood journeys are supposed to be reduced. Rather, it shows the amount of exposure that needs to be provided by safer crossing, good surface conditions, shaded waiting areas, secure parking areas, and reliable repairs. The required time relief is determined as

$$R_c^{time} = \max(0, W_c - 360), \quad (5)$$

and proportional relief is

$$\rho_c^{time} = 100 \times \frac{R_c^{time}}{W_c}. \quad (6)$$

The occupational envelope is formed based on occupation and use-characteristic indicators. The cycling-as-work indicator, C_c^{work} , is the sum of all categories where the bicycle is directly related to remunerated work, services, deliveries, vending, domestic tasks, shop help, trade work, or unpaid work/apprenticeship. The multi-stop indicator, C_c^{multi} , is the sum of all categories with the use-characteristics that relate to trip-chaining or multiple stops. The occupational dependence indicator is

$$O_c = \frac{C_c^{work} + C_c^{multi}}{200}. \quad (7)$$

The urban friction envelope identifies three factors contributing to the greater urgency for bicycle support: income marginality, pollution pressure, and weak positioning of bicycles/public transportation. Income marginality is measured using $V_c = 1 - Q_c/100$, truncated at zero. Pollution pressure is calculated as annual mean PM_{2.5} divided by maximum of the survey cities' values. The MSE score is defined as

$$MSE_c = 100 \times (0.30A_c + 0.25E_c + 0.25O_c + 0.10V_c + 0.10U_c), \quad (8)$$

where A_c is the normalized measure of affordability, E_c is normalized exposure per week, O_c is occupational dependence, V_c is marginal income and U_c is normalized pollution pressure. More weight is assigned to affordability, exposure and occupation because these factors are more immediately relevant for retention of existing cyclists. This is not an absolute measure of the quality of urban cycling; it is rather a diagnostic measure of the first level of support for existing cyclists.

2.3 Support calculations

There are three support calculations which translate the measures of the envelope variables into the amounts of policy support required. The purchase-protection support calculation determines how much policy support will be required to reduce the cost of buying a new bike to 20% of monthly income, while a used bike should cost no more than 10%. These figures represent practical affordability criteria for transport, potentially used for work. The policy support required is

$$S_c^{new} = \max(0, P_c^{new} - 0.20I_c) \quad (9)$$

and

$$S_c^{used} = \max(0, P_c^{used} - 0.10I_c). \quad (10)$$

This conversion provides a monetary figure that represents the burden level in a way that is interpretable to planners. The computation does not imply any single form of subsidy provision. It quantifies the size of the affordability issue which can be solved using verified second-hand provision, repair credits, quality assurance of components, bicycle access linked to employment, secure parking, or direct subsidies.

The time-relief calculation uses Eqs. (5) and (6) to identify the effective amount of weekly strain to be released in order to meet the six hours protection target. Occupational-targeting calculation interprets C_c^{work} and C_c^{multi} as signals for service design. Cycling as work shares larger than 60% are interpreted as livelihood-based bicycle services, while cities with extremely high multi-stop shares need to include curbside stopping and short-link continuity as well as linear routes in addition to bicycle corridors. There is no additional computation involved at this point; the same measured values are simply carried into interpretation.

2.4 Retention-Fragility Gradient and Envelope-Sequencing Test

The RFG separates the magnitude of support need from the mechanism of cycling instability. The procedure is built upon social multi-criteria evaluation, which involves the transparent combination of a number of policy relevant dimensions [32]. Multi-criteria decision methods have been extensively applied in transport planning due to necessity to compare different alternatives using heterogeneous performance measures [33]. Problem-structuring approaches further justify transparent normalization and combination of criteria [34]. Thus, the procedure combines the normalized components for policy interpretation rather than black-boxed prediction. Five components are used. Acquisition-strain component A_c^r is an average of new and second-hand purchase burden levels divided by maximum observed average. Exposure-strain component E_c^r is proportional time relief divided by the maximum observed proportional time relief. Livelihood component L_c^r is an average of cycling as work and multi-stop shares divided by 100. Connectivity-deficit component D_c^r includes the low bicycle mode share and imperfect convenient access to public transport:

$$D_c^r = 0.60 \left(1 - \frac{M_c}{M_{\max}} \right) + 0.40 \left(1 - \frac{T_c}{100} \right), \quad (11)$$

where M_c is bicycle mode share, $M_{\max}$ is the highest bicycle mode share among Delhi, Dhaka and Accra, and T_c is convenient public-transport access. Income marginality remains $V_c = 1 - Q_c/100$. The final RFG score is

$$RFG_c = 100(0.28A_c^r + 0.22E_c^r + 0.22L_c^r + 0.18D_c^r + 0.10V_c). \quad (12)$$

The RFG is preserved as an interpretive decomposition of the same city values. The method does not estimate individual mode choice probabilities or crash risk probabilities. Instead, its task is to determine which vulnerability is more serious – acquisition costs, exposure, livelihood dependence, connectivity, or income marginality. This distinction is important because even if two cities have similar support needs, they may need radically different initial interventions.

The EST produces a policy sequence. The first move is the greatest normalized pressure of acquisition, exposure, livelihood, or connectivity. The second and third moves are the following pressures, except that livelihoods are never below the second move if cycling-as-work is over 80%. The exception prevents the interpretation of a city where bicycles are deeply embedded in livelihoods based on acquisition cost or exposure alone. Thus, the output of the EST is a policy sequence.

3. Results and discussion

3.1 Affordability and exposure demonstrate that existing cycling is not residual cycling

The core values of affordability and exposure are listed in Table 1. The income of surveyed riders varies widely relative to city averages. The monthly income of Delhi riders is 46.7% of the city average, that of Dhaka riders is 93.0%, and that of Accra riders is 20.7%. This ranking is crucial for interpreting bike prices. While bikes are relatively inexpensive compared to motorized alternatives, they might remain a big investment for a person if his income is low or variable. This interpretation is

consistent with transport poverty literature, where access issues include not only the availability of services, but also reliable access [30].

The table of affordability demonstrates that the case of acquisition in Accra is the most difficult. A new bicycle costs 93.2% of monthly household income of a bike rider and even a used one is 52.6% of the monthly income. It indicates that the second-hand market cannot be considered an immediate solution for affordability. If a used bicycle costs more than half of the monthly income of household, then such issues as frame durability, tire reliability, brake condition, prevention from theft and the expenses for repair become components of transport affordability. In Dhaka, new bicycle costs 39.9% of monthly income and the used bicycle costs 13.6% of it. Price pressure is less in comparison with the situation in Accra, but it is still relevant for workers dependent on bicycles. The used-bicycle burden in Delhi is under the selected 10% affordability threshold, but the new bicycle burden is 27.0%.

Table 1. Affordability and exposure inputs.

City	Intercept <i>N</i>	Income US\$/month	Income as city average %	New cost burden %	Used cost burden %	Weekly cycling h
Delhi	171	216.2	46.7	27.0	9.1	9.4
Dhaka	50	291.8	93.0	39.9	13.6	6.2
Accra	238	82.9	20.7	93.2	52.6	8.2

Notes: Cost burdens equal bicycle acquisition cost divided by monthly rider household income. Weekly hours equal six-day cycling minutes divided by 60. The Accra income row uses the informal-sector income value.

The panels of acquisition burden in Figure 2 visualize the same values using the income envelope principle. The used-bicycle burden in Delhi stays within the selected affordability threshold; in Dhaka, there is a moderate but real support need; the purchase burden in Accra nearly takes all the place of a monthly income envelope. The visual logic reinforces the need to interpret affordability as asset security, not simply as the presence of cheaper second-hand bicycles.

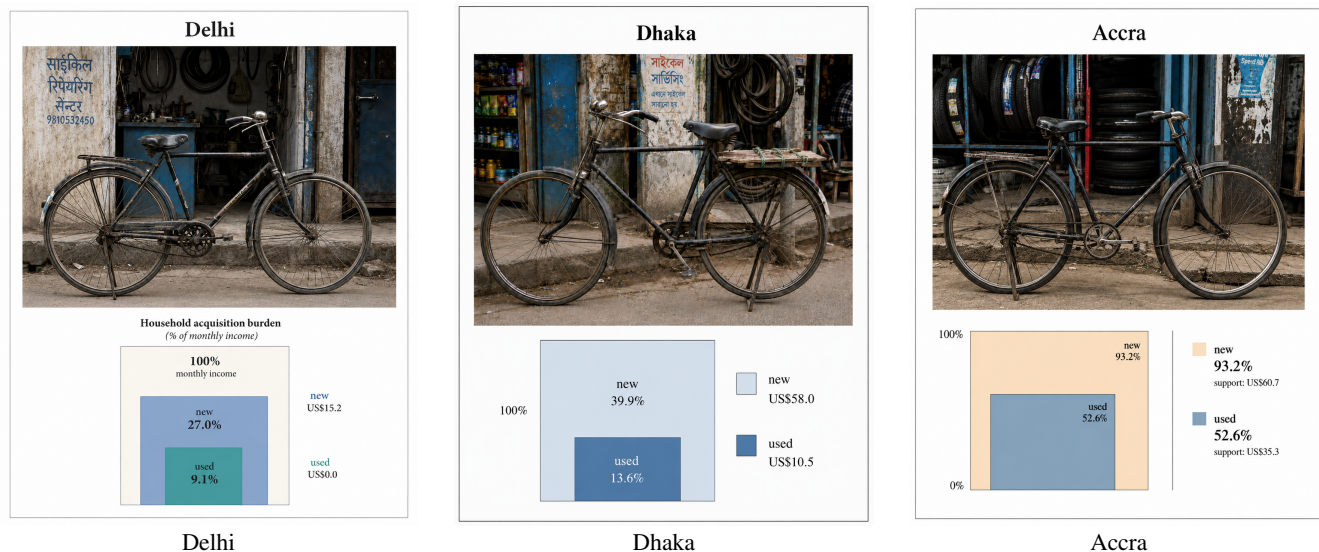


Figure 2. Acquisition burden by city.

Weekly exposure generates a distinct ranking. Delhi commuters cycle for 9.4 hours across six days, while Accra commuters for 8.2 hours and Dhaka commuters for 6.2 hours. Such numbers cannot be understood as indicators of an active lifestyle alone. Active transportation can generate positive health impacts provided it is integrated into daily routine [35]. In mixed traffic and intermittent cycling environments, however, high exposure levels may imply exposure to heat, particulates, noise, traffic hazards, road quality issues, theft danger, and fatigue. It is demonstrated by interventions that the impact of active transport depends on the conditions of its performance [9]. The objective-safety approach demonstrates that infrastructure and traffic conditions determine whether exposure translates into harm that needs to be avoided [18]. A retention analysis thus requires checking whether the city reduces the risks associated with the cycling performed by low-income people.

The six-day exposure panels shown in Figure 3 compare the observed exposure with the six-hour safety threshold. The most distant from the safety threshold is Delhi, which needs 204 minutes of weekly strain reduction. Accra requires 133 minutes of such relief. The level of exposure in Dhaka is close to the threshold; however, the low relief need is to be considered in conjunction with the occupational analysis results.

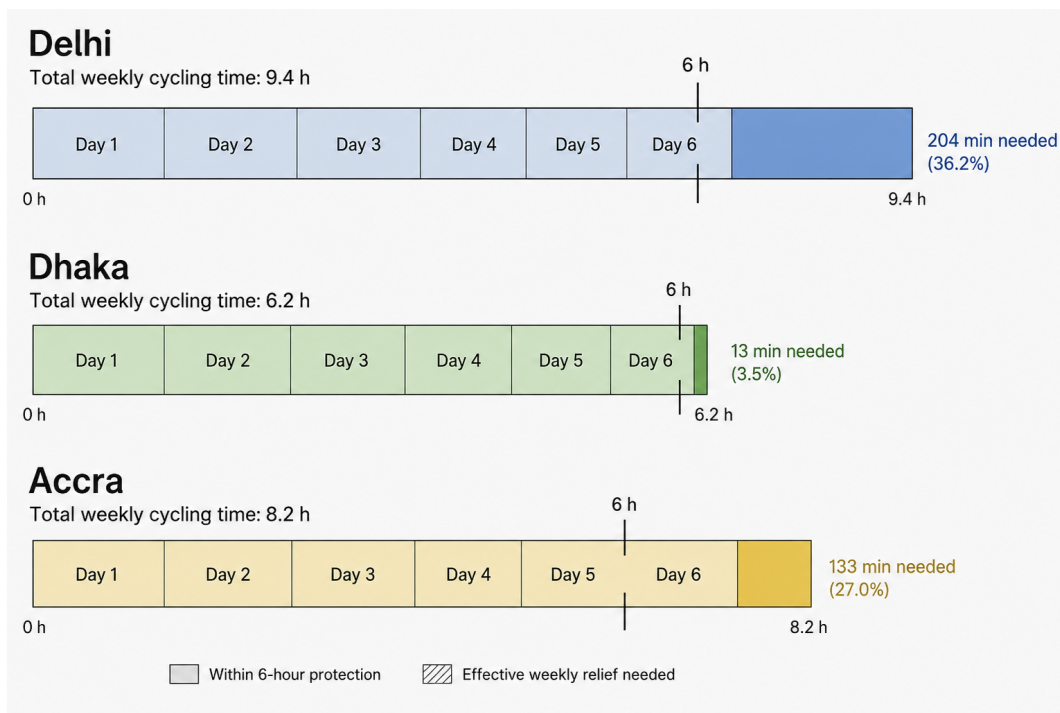


Figure 3. Weekly cycling exposure.

Affordability and exposure results together show the first key result: daily cycling in the three surveyed cities is both non-negligible and not universally affordable. The relevant burden varies depending on the city. Accra needs purchase and repair stabilisation, Delhi needs exposure reduction and Dhaka needs analysis of work dependence. A policy which calculates lane kilometres without accounting for those burdens will increase visibility without retaining the cyclists who are already providing low-carbon transportation. As the investment guidance indicates, benefits from cycling depend on the infrastructure quality [36]. The review literature similarly underscores the importance of matching active transport interventions with local circumstances and safety needs [10]. Research on barriers to fair bicycle policy implementation reveals how infrastructure can fail to serve current cyclists [29].

3.2 Occupational structure means that bicycle policy must account for work route services

The occupation distribution in Table 2 clearly shows that bicycle is used heavily in the context of work. Bicycle-for-work accounts for 84% of trips in Dhaka, 66% in Delhi and 64% in Accra. Multistop cycling stands at 57% in Dhaka and 64% in Delhi. In both Delhi and Dhaka load, market and service cycling are very common. These values show that the bicycle is not just a mode of transportation to work but also a means of transportation of work and goods as well as movement.

Table 2. Occupational cycling envelope.

City	Cycling- as-work %	Multi-stop cycling %	Load/market/ service %	Long fixed- schedule %	Dominant occupational signal
Dhaka	84	57	84	16	Vendors, trade and service providers: 41%; shop assistants: 27%.
Accra	64	58	49	34	Vendors, trade and service providers: 40%; security guards and peons: 20%.
Delhi	66	64	60	34	Vendors, trade and service providers: 49%; factory workers and laborers: 19%.

Notes: Cycling-as-work sums domestic/service, delivery, shop-assistant, vendor/trade/service and unpaid/apprentice categories. Multi-stop cycling sums categories whose use characteristics include multiple stops or trip chaining. Long fixed-schedule cycling sums security/peon, factory/labor and desk-job categories.

The interpretation of the table will need a work-route approach. A vendor or courier needs a safe stopover, short links, space for loading and protection close to markets and repairs close to market zones. A security guard or factory worker needs safety at dawn and dusk, lighting, safe storage and crossings. A retail shop employee or domestic worker needs continuity of the area more than a long route. In other words, the occupational values shift the discussion from route supply to service

continuity. There is evidence showing that movement in LMIC contexts does not always amount to free will exercise [37]. There is also evidence showing that travel inequalities linked to socio-economic status and gender imply that the very same movement can have health benefits but be constrained by livelihood pressure [24].

The image of work route in Figure 4 offers a condensed visual summary of the occupational envelope. It specifically illustrates bike usage close to markets, cargos, repairs and repeated stops rather than the long arterial route. This figure clarifies why a supposedly transport-oriented solution would fail because of disruption of curbs, repair and trade routes.

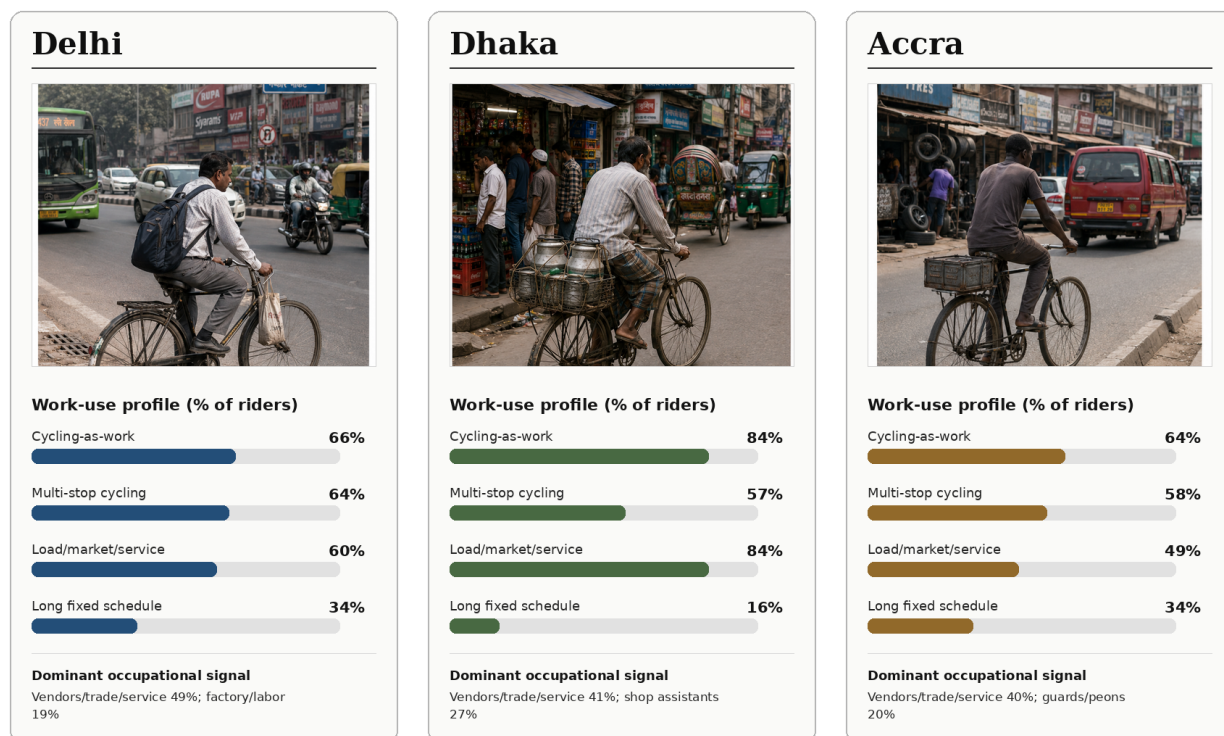


Figure 4. Occupational cycling profile.

The Dhaka values are particularly telling. Since 84% cycle for work purposes and 84% load/market/service use is observed, there is no way to analyze the city through the lens of a cleaner commute. Even though the city has a smaller MSE score compared to Accra, the importance of bicycle provision is still high since the major retention challenge faced here is livelihood continuity as opposed to affordability or excessive weekly exposure. In Delhi, the large percentage of occupation cycling paired with the highest exposure time indicates the need for stopping and crossing protection under the burden of lengthy exposures. In Accra, the share of work-related commuting makes it important to integrate affordability support into work access and reparability instead of offering a purchase subsidy.

The larger point is the need to design bicycle support into the street economy. While street vendors, repairers, parking attendants, delivery riders and market users are typically viewed as informal users of public space, the occupational values indicate the role of these users in the cycling system. Studies related to the topic of informal urbanism have proven that vending, transport and settlement usually depend on each other in Global South cities [31]. Therefore, displacement of repair shops, criminalization of market stops or lack of secure parking facilities near public transport can undermine cycling in the city despite the infrastructure investment.

3.3 Minimum Support Envelope calculations identify different first-order pressures

The purchase-protection, weekly-relief and MSE scores are provided in Table 3. Accra comes in first with the score of 70.9, followed by Delhi with 62.0 and Dhaka with 51.4. Although the score ranking is quite revealing, the key finding here is pathway differentiation as each city achieves its score via a unique combination of pressures.

The first-order issue of Accra is acquisition and maintenance affordability. To reach the 20% threshold using a new bicycle, an offset of US\$60.7, which represents 78.6% of the cost of the new bicycle, is needed. To reach the 10% threshold using a second-hand bicycle, an offset of US\$35.3, or 81.0% of the cost of the used-bicycle, is needed. A standard policy measure

looking at only lane supply will not pick up this barrier. For cyclists in this income bracket, a secure availability of second-hand bicycles, repair credits, component affordability, employer-related purchasing assistance and safe storage are likely to be more crucial than a corridor that does not address the ownership and repair issue.

Table 3. MSE support calculations.

City	New-bicycle support to 20% income	Used-bicycle support to 10% income	Weekly relief to six hours	MSE score
Delhi	US\$15.2 (26.0%)	US\$0.0 (0.0%)	204 min (36.2%)	62.0
Dhaka	US\$58.0 (49.9%)	US\$10.5 (26.5%)	13 min (3.5%)	51.4
Accra	US\$60.7 (78.6%)	US\$35.3 (81.0%)	133 min (27.0%)	70.9

Notes: Price-support percentages are expressed as the share of the bicycle purchase price that would need to be offset. Weekly relief is the reduction in effective weekly strain required to reach a six-hour protection threshold.

The first-order issue for Delhi is exposure. The city needs 204 minutes of effective strain relief per week to compensate for the road exposure to make up the threshold of six hours. The offset of the new bicycle that is needed in Delhi is only US\$15.2, and the burden of the used-bicycle is already below the chosen threshold. The policy priority, therefore, is not a universal purchase subsidy but protection from road and time strain: safer crossings, better surfaces, shading waiting areas, parking facilities near public transport and workplace, traffic calming where necessary, and maintenance where cyclists have no option but take a hazardous maneuver. Evidence of separated cycling provision indicates that protection from motor traffic influences cyclists' willingness to use bicycles [17]. Route-choice evidence confirms that accident risk and perceived safety influence riders' decision-making process [20]. A review of cyclist safety literature emphasizes the role of road and intersection conditions [19]. An objective safety review confirms that visibility and infrastructure should be measured based on its protective effect [18].

The score of Dhaka is lower, but the need of the city is not small. The city needs US\$58.0 for a new bicycle to reach the 20% threshold, and US\$10.5 for a used-bicycle to reach the 10% threshold. The weekly strain relief value of Dhaka is only 13 minutes because the time spent cycling six days a week is close to the threshold. However, the low time-relief value should not be confused with low vulnerability. In Dhaka, the occupational envelope reveals that bicycles play a significant role in work life, and the relevant policy tools in this regard are route continuity, legal stopping, repair proximity and durable used bicycle acquisition. When bicycle becomes a work tool, poor bicycle quality may cause repetitive repairs and income interruption.



Figure 5. MSE component envelope.

The envelope visualization in Figure 5 makes the same point. Accra has the highest support requirement, but the figure is especially meaningful because of the connection between the score and component pressure. For Delhi, the interpretation is

conditioned by the exposure component, for Dhaka, by the occupational component and for Accra by affordability and income strain.

The score should therefore be interpreted as a triage instrument and not as a performance ranking. Accra is not just the poorest city for cycling but the city where the possibility of bicycle retention may be undermined first by household budget pressure. Delhi is not an easy case in terms of affordability but a hard exposure case. Dhaka is not a low-need city but a work continuity city. This interpretation answers the key question of the paper by revealing the first support condition that should be addressed in each city.

3.4 The Retention-Fragility Gradient distinguishes support magnitude from failure pathway

The RFG components in Table 4 reveal retention risk. Again, Accra has the highest score at 77.8, but the components reveal why: acquisition strain is normalized at 1.000, exposure strain is 0.746, connectivity deficit is 0.670 and income marginality is 0.793. There is a wide retention risk here. Cycling is financially fragile, exposure is significant, and the bicycle is poorly positioned in the transport system.

Table 4. RFG component values.

City	Acquisition strain	Exposure strain	Livelihood anchoring	Connectivity deficit	Income marginality	RFG score
Delhi	0.248	1.000	0.650	0.073	0.533	49.9
Dhaka	0.367	0.097	0.705	0.632	0.070	40.0
Accra	1.000	0.746	0.610	0.670	0.793	77.8

Notes: Acquisition strain normalizes the average of new and second-hand bicycle burdens by the maximum observed value. Exposure strain normalizes proportional weekly relief. Connectivity deficit combines low bicycle mode share and imperfect access to public transport.

However, the RFG value for Delhi is 49.9 and the two strains are quite different. The acquisition strain is 0.248 but the exposure strain is normalized to 1.000. Therefore, Delhi cannot be considered a case of weak support just because the acquisition strain is lower compared to Accra. Its vulnerability stems from accumulated exposure in dangerous urban settings, enhanced by high PM_{2.5} levels, high cycling duration per week and multi-stop cycling. The cyclist continues riding the bike because he has no choice but the cost of such behavior is significant.

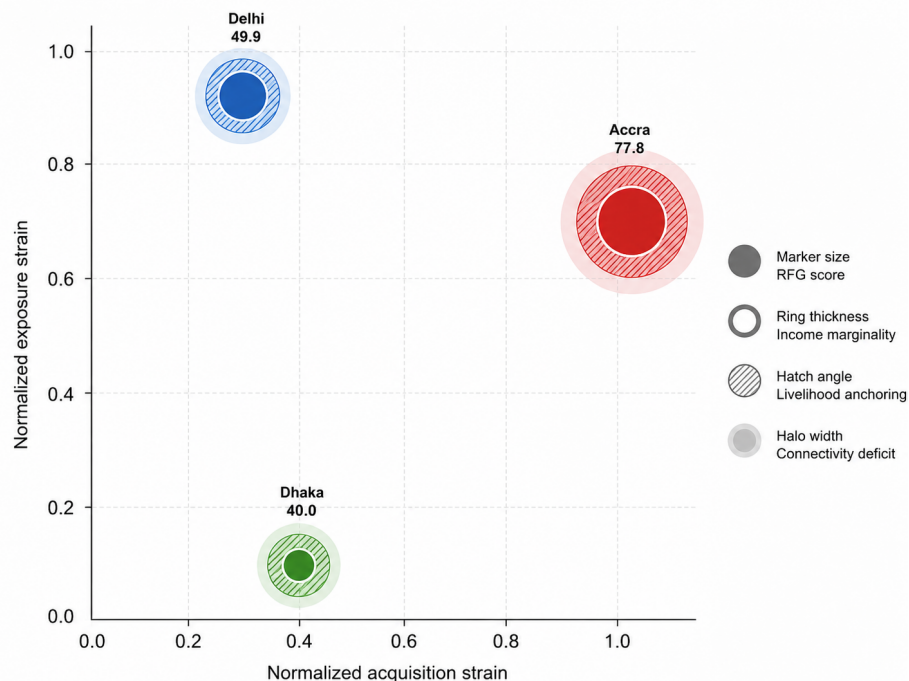


Figure 6. Retention-fragility field.

Dhaka is the weakest of the three cities in terms of RFG, with the value of 40.0 but its livelihood anchoring is the highest of the three at 0.705. This means that the policy package should focus on work route protection and multimodal access.

Connectivity deficit is also high, meaning that bicycle-public transport integration should not be overlooked. Recent studies in the field of bicycle-transit integration show that bicycle access can expand public transport catchment if certain parking, transfer and continuation conditions are met [38]. This point is important for Dhaka because work-route continuity and multimodal access may support each other.

The field plot in Figure 6 separates the two strains: acquisition strain and exposure strain. Accra occupies the area of high acquisition strain and high exposure strain, Delhi is in the area of high exposure strain and lower acquisition strain while Dhaka occupies the area of lower exposure strain and high livelihood anchoring. The picture clearly shows why a single index of vulnerability is not enough since support magnitude and support type have to be analyzed jointly.

The analysis of retention-fragility graph enhances the conclusions of the research while retaining the method. It provides a clear explanation of the mechanisms of creation of cycling unsustainability even if the cyclist still rides a bike. In Accra, fragility is caused by the costs of obtaining and maintaining the bicycle. In Delhi, fragility is generated by the amount of time the cyclist spends in the dangerous road environment. In Dhaka, fragility is caused by the dependency of work routes continuity on cycling. The mechanisms require different municipal actions and different evaluation indices.

3.5 The Envelope-Sequencing Test converts diagnosis into ordered interventions

The EST output is presented in Table 5. Accra is identified as the budget-stabilization case, Delhi as the exposure-compression case and Dhaka as the livelihood-continuity case. Those are not branding labels but intervention sequences determined by the pressure of each city.

Table 5. Ordered support priorities.

City	First support order	Second support order	Third support order	Retention diagnosis
Delhi	Exposure compression through safer crossings, shaded waiting space, smoother surfaces and secure parking near transit and work sites.	Livelihood continuity for vendors, trade workers and service workers using multi-stop routes.	Targeted repair and replacement assistance rather than a universal purchase subsidy.	Cycling is threatened mainly by accumulated road and time strain.
Dhaka	Livelihood continuity through market-route access, stopping rights, short-link continuity and repair near work clusters.	Acquisition protection for durable second-hand and working bicycles.	Connectivity improvement between neighbourhood links and public-transport access points.	Cycling remains economically embedded but needs work-route legitimacy.
Accra	Budget stabilization through purchase assistance, verified second-hand supply, repair credits and component affordability.	Connectivity support linking low-income housing, market areas, institutional sites and public transport.	Exposure protection at crossings and work-route bottlenecks.	Cycling is threatened by household affordability before infrastructure visibility.

Accra's sequence begins with budget stabilization. Possible actions include vouchers for target acquisition, quality second-hand supply, low-interest bicycle purchase, employer-supported bicycle acquisition, repair assistance, spare parts and secure bicycle parking to secure the asset. The key factor here is durability. Public support must not provide substandard bicycles that raise repair costs. A bicycle being a work tool implies repairability in its definition of equity.

Delhi's sequence begins with exposure compression. The 9.4 hours per week of exposure requires safe crossings, junction improvement, shading, surface repair, traffic calming, protected approach to flyover and bicycle parking in close proximity to transportation points. However, the need for repair and replacement assistance does not diminish due to increased wear, damage and crash risk resulting from high exposure, but the primary challenge for cycling in Delhi is the continuous burden on the body of riding in a hazardous street environment. The share of vendors, traders and service workers in Delhi needs protected access at the market edge rather than displacement.

Dhaka's sequence begins with livelihood continuity. The 84% share of cycling for livelihood makes legal stops, short links over severed paths, repair assistance and quality second-hand supply necessary. Continuity may be more important than speed. A minor gap or prohibition at a junction or the market edge may pose more threat to livelihood cycling than the disconnection of a long but incomplete cycle route. This follows from cycling equity work that shows importance of interventions other than bike lanes [29].

The action cards visualization in Figure 7 presents these intervention sequences without assuming that the first action is universal to all cities. The presentation focuses on policy sequencing: Delhi starts with exposure, Dhaka with livelihood, and Accra with budget. The message is that an urban context-based support sequence should come prior to claiming the equitable nature of any cycling policy.



Figure 7. Sequenced support actions.

The sequence results strengthen the paper's answer to the research question. Insufficient evidence is enough to identify the initial intervention priority based on affordability, exposure, occupation and urban friction. The results do not imply that the selected actions cover all possible actions in terms of cycling policy. They show what must not be postponed. Accra should not wait until it constructs a showcase cycle path before budget stabilization of bicycle ownership. Delhi should not assume that cycling time benefits cyclists' health before lowering exposure to hazardous environment. Dhaka should not encourage cycling before undermining the economic utility of cycle paths in terms of livelihood.

3.6 Urban context broadens the minimum support definition

The values in Table 6 bring an additional perspective. High annual concentrations of $PM_{2.5}$ pollutants are characteristic of Delhi and Dhaka (91.8 and $78.0 \mu g/m^3$), while Accra and Chennai are lower (36.3 and 26.0). In addition, bicycle mode share is low in all cities (5% in Delhi, 3% in Chennai and 1% in Accra and Dhaka). Convenient public transport access varies between 81.7% in Delhi, 62.0% in Dhaka, 52.5% in Accra and 47.6% in Chennai. The values show the inseparability of bicycle support from air-quality exposure, integration with public transport and the political marginality of low modal share.

Table 6. Urban-profile context.

City	Bicycle mode share %	Convenient public transport access %	$PM_{2.5} \mu g/m^3$	Interpretation for the support envelope
Delhi	5	81.7	91.8	Highest bicycle share among the complete survey cities, strong public-transport access and severe pollution pressure.
Dhaka	1	62.0	78.0	Low mode share but high occupational dependence, requiring work-route continuity and multimodal repair.
Accra	1	52.5	36.3	Low mode share and moderate public-transport access, combined with severe affordability pressure.
Chennai	3	47.6	26.0	Urban-profile comparator requiring comparable intercept and occupational values before scoring.

In light of the urban-profile table, one percent mode share of bicycling can be politically insignificant for planning, but critical for the workers constituting it. Mode share is a systemic proportion; retention is a personal condition. In case planning is guided by the mode share only, it will likely invest in the future riders who are visible but not in the current riders who are more exposed. Access to public transport alters the meaning of the support because the safe parking and short link continuity can decide on low income cyclists' capacity to integrate with other modes [38]. Similarly, the investment guide considers the integration with surrounding transportation systems a component of a viable bicycle infrastructure [36]. Studies conducted in the context of low cycling rates show that perceptions of users can determine the feasibility of the suggested infrastructure [39]. The institutional analysis of Lahore proves that the politics of implementation and coordination can make transport policies operational instead of symbolic [40].

As follows from the coverage summary in Figure 8, Chennai's place is clear. Chennai has the data on the bicycle mode share, public-transport access and $PM_{2.5}$ values, but it lacks the comparable intercept and occupational data for MSE, RFG and EST scoring. The open scoring status is thus interpreted as an evidence-coverage boundary, not as the lack of need.

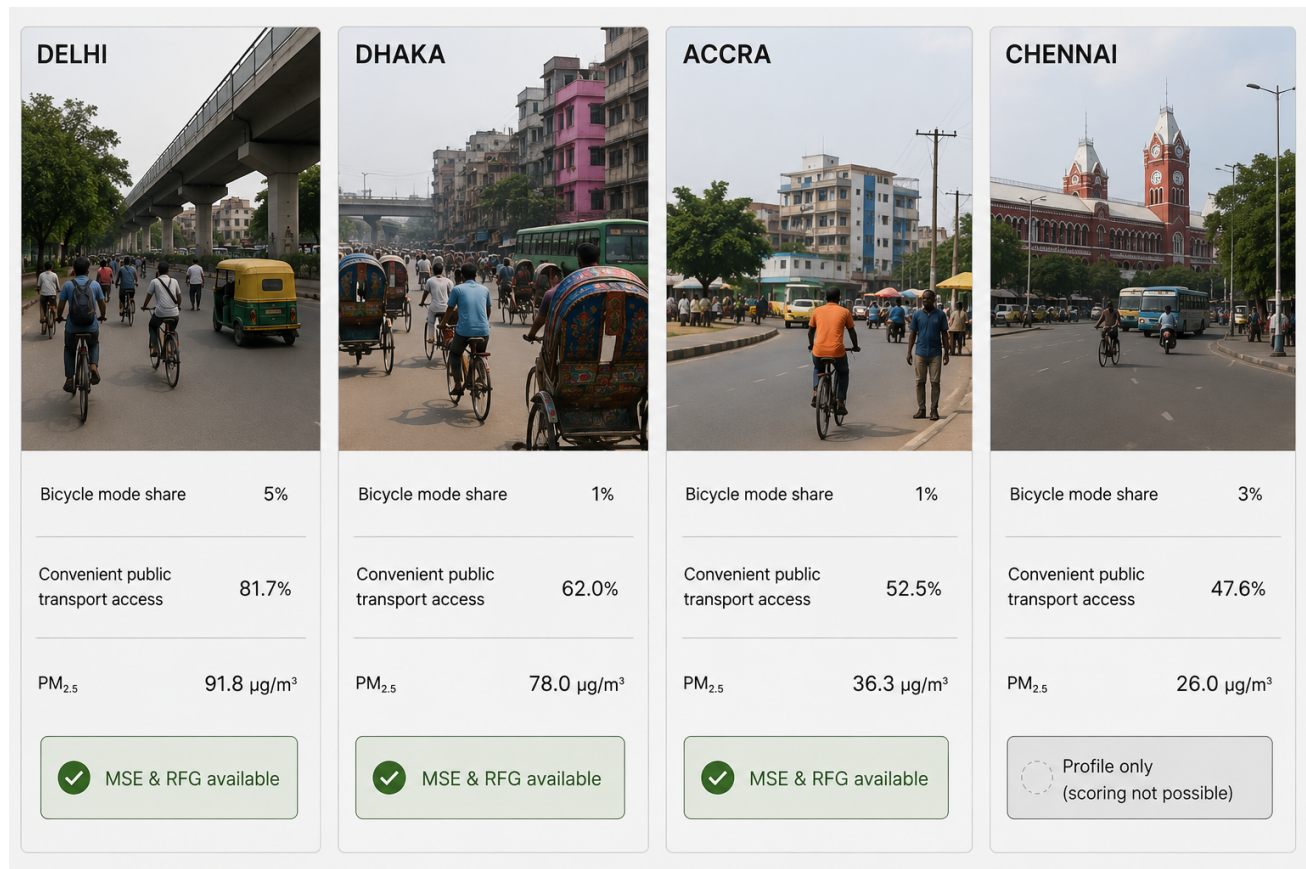


Figure 8. Urban-profile coverage.

Chennai's profile-only status is helpful because it allows to separate contextual relevance from score eligibility. The future field work in Chennai must gather the comparable intercept survey data on arterial and neighborhood streets with explicit focus on women, students, caregivers, service workers and other possibly underrepresented types of riders. Active travel research conducted globally reveals large gender disparities in walking and cycling [41]. Feminist cycling studies further help to understand how aggregated mode shares can hide inequality, care obligations and mobility constraints [23].

The results are also relevant to decarbonization. The transport strategies commonly favor the development of electric vehicles, bus networks and rail expansions. Such investments can be crucial, but they can neglect the carbon-free mobility that is currently created by bicycles. Bicycling protection will be necessary to prevent its replacement by motorcycles and cars with increasing incomes when the usage of bicycles is perceived as stigmatized, unsafe and unreliable in terms of repairs. Hence, MSE is not only the poverty-sensitive analysis of cycling, but also the motorization-preventive analysis because it targets the conditions that allow bicycles to remain part of the urban transport system.

The final implication is related to the nature of infrastructure. Protected lanes of high quality are important, but their importance depends on the rider's ability to obtain a bicycle, keep it in good condition, park it safely, cross dangerous streets,

stop working, integrate with transit and travel with reasonable exposure. The recent academic works analyzing cycling for net-zero transition emphasize care and maintenance of practical everyday infrastructures as components of sustainable bicycle usage [28]. The city-specific results confirm this point. The minimum support is not a secondary aspect of real infrastructure. It is the fundamental basis of its practical meaning for low-income and occupational cyclists.

4. Conclusion

The research question posed was what minimum support conditions are necessary to retain existing everyday bicyclists in Delhi, Dhaka and Accra based on the available aggregate evidence regarding cost, income, cycling duration, occupational use, access to public transport, mode share and PM_{2.5} exposure. The answer to this question is that different minimum support orders are necessary to achieve the same general policy objective of retaining low-carbon everyday bicycling in the three survey cities. Accra needs budget stabilization, Delhi needs exposure compression and Dhaka needs livelihood continuity protection. This answer does not involve any added methodology and does not rely on an imported cycling template.

The Accra result presents the strongest case of affordability, with a new bicycle costing 93.2% of monthly rider household income, a second-hand bicycle costing 52.6%, and an RFG score of 77.8. Therefore, the first policy priority is to protect the financial sustainability of bicycle riding and maintenance through purchasing subsidies, second-hand availability, repair credits, affordable parts and safe storage. Without this base layer, lane provision will not suffice to retain the riders whose budgets cannot accommodate the costs of replacing and repairing bicycles.

The Delhi result presents the strongest case of exposure. Bicycles are ridden for 9.4 hours across six days, requiring 204 minutes of weekly strain relief to meet the six-hour exposure protection threshold. Therefore, the first policy priority is exposure compression by providing safer crossings, better pavement, shade, traffic calming, safe parking near places of work and transit, and attention to locations where riders have to make hazardous movements. Delhi does not need to be analyzed as an acquired-bicycle problem since the burden of acquiring and owning a used bicycle is below the chosen threshold. Its critical problem is the physical and temporal burden of cycling under difficult street conditions.

The Dhaka result presents the strongest case of livelihood continuity. Its MSE score is lower than those of Accra and Delhi, but 84% bicycle employment, 57% multi-stop cycling and 84% load/market/service use mean that bicycles are integrated deeply into work routines. The first policy priority is to protect the market routes, stops, short links, repair points and durable second-hand supply. In Dhaka, a policy focused on corridor movement without protecting stopping, loading and repair opportunities would misunderstand the function of the bicycle.

The larger conclusion here is that LMIC cycling policies should start with the protection of existing riders and not be distracted by visible infrastructure. A city has failed to support bicycling when riders do not have sufficient resources to acquire, maintain and park bicycles; stop to work; cross streets safely; reach public transportation; or cycle in excessive exposure. In short, minimum support is a core transport task and not a supplementary welfare issue. The structure of MSE - RFG - EST provides a transparent means to derive policy sequences from aggregate evidence without making it rigid against recalibration as additional evidence on crashes, gender, heat, exposure and rider livelihood becomes available.

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