STUDENT MOBILITY AFTER TERMINAL RELOCATION: EVIDENCE WITH SYSTEMS DYNAMICS AND POLICY EVALUATION IN AN INTERMEDIARY CITY

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Summary
The relocation of the transport center from the urban center to the far north increased the effective distance to the university area, reconfiguring times, costs and modal choice of student travel. With a mixed sequential design and abductive approach, probabilistic surveys, interviews and focus groups were integrated with a Systems Dynamics model to simulate intervention scenarios. The findings show low adoption of the new terminal (≈47%), high participation of motorcycles (≈44%) and persistence of motorcycle taxis (≈7%), associated with penalized transfers and double payments. In the simulation, the direct route to the university area reduces travel time ≈23% and the daily cost ≈34% compared to the trend; A high-capacity corridor with tariff integration achieves greater reductions in time and cost and increases satisfaction (≈4.4/5). It is concluded that tariff integration, dedicated service (frequencies ≤10 min) and inter-institutional governance are levers to correct access inequities. The work provides a replicable framework based on accessibility and causal simulation to evaluate infrastructural decisions in intermediary cities.

Keywords: forced mobility; accessibility; shuttles; fare integration; Systems Dynamics; intermediate cities.

1. Introduction

Transport infrastructure and operation decisions shape accessibility to public goods such as education and, therefore, mediate territorial equity. The literature has consistently shown that the transfer penalty, walking and waiting times, uncertainty, discomfort and, in particular, double payment reduces the perceived utility of public transport when there is no operational and fare integration (Guo & Wilson, 2011; Sharaby & Shiftan, 2012). This penalty is accentuated in systems with irregular frequencies and poor connectivity, where the travel experience is highly sensitive to intermodal coordination and service reliability (TRB, 2013; Eboli & Mazzulla, 2007). In Latin America, weak institutional arrangements and fragmented networks have favored individual motorization and the persistence of informal modes when the formal supply is not competitive in time and cost (Hagen, Pardo & Valente, 2016; Paget-Seekins & Tironi, 2016; Venter, Jennings, Hidalgo & Pineda, 2020).
In this framework, the analysis of intermediate cities becomes relevant, where decisions such as the relocation of an intermunicipal terminal from the urban center to a perimeter (north) can increase the effective distance to the university area, introduce mandatory transfers and

reconfigure the pattern of student travel. Although there is a robust tradition in metropolitan studies on accessibility, equity, and performance of trunk systems (Hidalgo & Gutiérrez, 2013; Hidalgo, Pereira, Estupiñán & Jiménez, 2013; Lucas, 2012; Martens, 2016), a gap persists for intermediary cities in the global south. In Colombia, for example, evidence of spatial inequalities in access to transport and urban services has been documented for major cities such as Cali and Bogotá (Jaramillo, Lizárraga & Grindlay, 2012; Guzmán, Oviedo & Rivera, 2017), but little is known about the ex-post effects of infrastructure relocations in intermediary cities, where institutional capacity and interjurisdictional coordination are often more limited (Oviedo & Titheridge, 2016; Pereira, Schwanen & Banister, 2017).

From a public policy perspective, the literature identifies at least three levers with evidence of impact: (i) tariff integration and operational coordination to reduce transfer penalties (Sharaby & Shiftan, 2012; TRB, 2013); (ii) frequencies and operational prioritization that shorten waits and improve reliability (TCRP 95, 2004; Eboli & Mazzulla, 2007); and (iii) passports or student passes that reduce economic barriers to access to transportation (Lachapelle, Dugas, Schepper, & El-Geneidy, 2022; Brown, Hess & Shoup, 2003). In parallel, international standards for BRT systematize design elements: central alignment, off-vehicle charging, at-grade boarding, intersection management that, combined, are associated with improvements in performance and perception (ITDP, 2016; Hidalgo & Gutiérrez, 2013; Hensher & Golob, 2008). The convergence between fare rules, network design, and access point quality (stops, recommended walking radii of 400–800 m) is a critical component of effective accessibility (El-Geneidy, Grimsrud, Wasfi, Tétreault & Surprenant-Legault, 2014; TRB, 2013; Martens, 2016).

At the conceptual level, the link between mobility and social exclusion has been articulated by approaches that place accessibility at the center of distributive justice (Kenyon, Lyons, & Rafferty, 2002; Lucas, 2012; Martens, 2016). Kenyon et al. (2002) showed that mobility impairments not only reflect inequality, but reproduce it; In operational terms, this implies that small frictions (e.g., an additional transfer or a larger access radius than the standard) can have large effects on the modal decision of students with forced mobility. On the other hand, Currie (2010) proposes measuring "spatial gaps" between transport provision and social needs, a useful approach for intermediary cities where the distribution of the service is usually less synchronized with the origins/destinations of demand. In university settings, evidence of "Unlimited Access" (college passes) shows substantial increases in public transportation use and reduced parking pressure when first-mover price barriers are removed (Brown, Hess, & Shoup, 2003). In summary, the literature converges that the "quality of access", integration, frequency, safety, and walkability to the whereabouts matter as much as the geometric distance (TRB, 2013; El-Geneidy et al., 2014; Eboli & Mazzulla, 2007).

For Latin America, several recent studies delve into equity in accessibility to employment and study, highlighting distributional effects by income level and location (Guzmán et al., 2017; Jaramillo et al., 2012; Welch, 2013; Pereira et al., 2017). Jaramillo et al. (2012) show disparities between social needs and transportation provision in Santiago de Cali, while Guzmán et al. (2017) show accessibility gradients in the Bogotá region when comparing employment and education opportunities by mode and income. In practice, trunk-feeder designs and integration can improve average accessibility, but without adequate tariff and governance instruments, the distribution of benefits may continue to be inequitable (Hidalgo & Gutiérrez, 2013; Venter et al., 2020; ITDP, 2016). This reinforces the need to evaluate policy packages that combine fare integration, frequency adjustments, and direct routes to areas with concentrated educational demand.

In the specific case of Tuluá (Valle del Cauca), the relocation of the intermunicipal terminal from the center to the north increased the effective distance to the university area and, with it, the need for transfer to urban services, introducing a penalty that could discourage the use of the formal terminal. This type of spatial shock, sudden increase in terminal-campus friction, is an ideal setting for ex-post research that combines empirical measurement and dynamic modeling to: i) identify causal mechanisms (e.g., non-integrated transshipment, reduced utility, reduced adoption of the formal system); ii) compare alternatives (direct route vs. fare integration with operational prioritization); and iii) estimating adjustment trajectories under realistic budgetary and institutional constraints (Shepherd, 2014; Sterman, 2000; Forrester, 1961).

From the methodological point of view, opting for System Dynamics (DS) is consistent with three features of the phenomenon: endogenous feedbacks between demand and frequency, delays in operational adjustments, and second-order effects when interventions are combined (Forrester, 1961; Sterman, 2000; Shepherd, 2014). In addition, DS allows ex-ante evaluation of packages not only isolated measurements under transparent assumptions and with structural, behavioral and sensitivity validation (Barlas, 1996). In terms of comparative policy, the literature on BRT and quality standards offers a catalog of components that are often associated with robust performance improvements when implemented together (ITDP, 2016; Hensher & Golob, 2008; Hidalgo & Gutiérrez, 2013). This is relevant for intermediary cities, where fiscal feasibility and technical capacity condition the implementation time: incremental solutions (e.g., direct terminal route–university zone with integrated fare) can prepare for a subsequent transition to dedicated infrastructure (TCRP 95, 2004; TRB, 2013). Finally, the fair accessibility approach proposes that the evaluation of transport policies should not be limited to aggregate averages, but should incorporate the distribution of opportunities between groups and territories (Martens, 2016; Lucas, 2012; Welch, 2013; Pereira et al., 2017). In this sense, a case of relocation that increases distance and transfers to the university area puts the effective right to education in tension and requires instruments that guarantee accessibility at reasonable costs for students who depend on combined intermunicipal and urban transport.

2. Methodology

2.1. Design

A mixed sequential explanatory design was used: first the quantitative phase, followed by a qualitative phase and culminating with the simulation in System Dynamics. This strategy allows estimating patterns and magnitudes, understanding the mechanisms that generate them and evaluating ex-ante intervention packages under explicit assumptions. The approach is abductive: empirical findings guide provisional theorizing, which in turn guides new iterations of analysis and modeling (Creswell & Plano Clark, 2018; Stake, 1995; Sterman, 2000).

The integration between methods was carried out at three levels. At the design level, the qualitative phase was derived from survey results to explain regularities and outliers linked to transfer penalties, double payment, and pedestrian accessibility. At the method level, quantitative and qualitative evidence fed the causal structure of the Forrester-type model and the parameterization of key variables (e.g., waiting times and transfer conditions), maintaining the supply-demand endogeneity characteristic of transport systems (Forrester, 1961; Sterman, 2000). At the interpretative level, meta-inferences were generated by contrasting the simulated trajectories with the observed patterns, under formal criteria of structural, behavioral, and sensitivity validity (Barlas, 1996; Shepherd, 2014). The choice of a mixed sequential and abductive design is consistent with the methodological literature that recommends combining statistical explanation, contextual understanding, and dynamic modeling when the phenomenon presents feedbacks, delays, and second-order effects (Johnson, Onwuegbuzie & Turner, 2007; Tashakkori & Teddlie, 2010; Timmermans & Tavory, 2012; Dubois & Gadde, 2002).

2.2. Study area

The study is being carried out in Tuluá (Valle del Cauca), where the intermunicipal power plant was relocated from the urban center to the far north in 2020, a decision foreseen by the municipal POT and formalized in local administrative acts. The new location increased the effective distance between the terminal and the university area, making it mandatory to transfer to urban services to conclude the trip. In the technical inputs consulted, the terminal-university zone link from the new terminal registers ≈8.2 km and 13 min on the route evaluated as faster (taxi mode, "route 1"), and ≈9.6 km for an alternate route used in the simulations (motorcycle/taxi), reflecting longer routes dependent on the northern corridor (both values support the calibration of the model).

The T-20 urban route operationally connects the new terminal with the university area (north), in accordance with Resolution No. 340-59-3633-11-2020 of the Administrative Department of Mobility and Road Safety.

For the old terminal (located in the center and supported by "switchboards" on Carrera 40), the documents reviewed do not report a measured distance from the terminal to the university zone; They do note that this configuration reduced routes and avoided transfers compared to the current scheme.

In terms of implications, international evidence shows that each transfer imposes a temporal and perceptual penalty that diminishes the usefulness of public transport (Guo & Wilson, 2011), and that reasonable pedestrian access to stops is typically between 400–800 m (TRB, 2013; El-Geneidy et al., 2014). In the absence of fare integration and with longer distances/transfers, the adoption of the formal system tends to fall and private or informal solutions tend to grow, a pattern documented in Latin American cities with fragmented supply. (Lucas, 2012; Oviedo & Titheridge, 2016).

2.3. Sample, instruments and quality

Target population: students enrolled in the university area (N≈4,789). Sample: n=356 (error ≤5%, 95% confidence). Response rate: 89.2%. Instrument validated by expert and pilot judgment (n=30); reliability of scales using Cronbach's α.

Table A1. Instrument reliability.

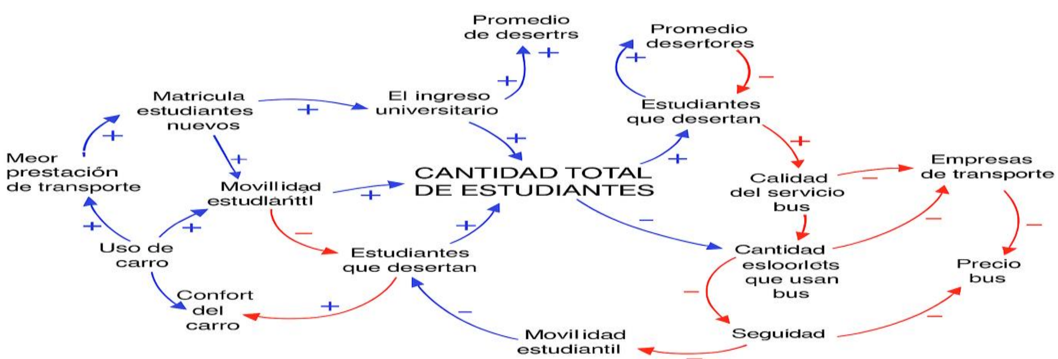
Scale	Items	α of Cronbach
Satisfaction with the trip	6	0,84–0,86
Transfer quality	5	0,80–0,83

Source: Own elaboration

2.4. System Dynamics Model

The dynamics observed after the transfer of the terminal from the centre to the north are characterised by endogenous interdependencies between demand, frequency and satisfaction, by delays in operational adjustments and modal adoption, and by the need to evaluate ex-ante policy combinations not yet implemented. These three conditions justify the use of System Dynamics (DS): it allows representing feedbacks through levels and flows, incorporating explicit delays, and testing scenarios with transparent and traceable assumptions, following standards of structural, behavioral, and sensitivity validity (Forrester, 1961; Sterman, 2000; Barlas, 1996; Shepherd, 2014). The model is aligned with sectoral evidence: the transfer penalty and the absence of fare integration reduce the perceived usefulness of public transport (Guo & Wilson, 2011), while frequency and reliability, together with acceptable pedestrian access conditions and safe stops, are determinants of user satisfaction and retention (TRB, 2013; TCRP 95, 2004; Eboli & Mazzulla, 2007; El-Geneidy et al., 2014; Martens, 2016; Lucas, 2012). In Latin American cities, institutional and operational fragmentation can favor the persistence of informal modes when the formal system is not competitive in terms of time and cost, which reinforces the relevance of integrated intervention packages (Oviedo & Titheridge, 2016; Paget-Seekins & Tironi, 2016; Venter et al., 2020).

Figure 1. Simplified causal diagram of student mobility after terminal relocation



Source: Authors' elaboration based on surveys, interviews and workshops; conceptual formalization in Vensim. In the original Spanish language.

Notes: The full diagram and equations of the model are included in the Appendix and supplementary material; the notation identifies relationships between perceived utility, demand, frequency, transfers, satisfaction, and pedestrian access according to DS standards (Forrester, 1961; Sterman, 2000).

The diagram synthesizes **three guiding mechanisms** that structure the behavior of the system and that are consistent with empirical diagnosis and literature:

1. **Impairment due to non-integrated transshipment.** When the trip requires transfers with double payment and long waits, the generalized cost increases; the perceived utility decreases; formal demand contracts; the scheduled frequency is reduced and, with it, the waits increase again. The result is a low-quality equilibrium, widely documented in systems with transfer penalties (Guo & Wilson, 2011; TRB, 2013).

2. **Improvement due to tariff and operational integration.** The elimination of double payment and the coordination of services increase the perceived utility, attract demand and make it possible to sustain greater frequency and shorter waits, consolidating a more favorable balance for the user (TCRP 95, 2004; TRB, 2013; Eboli & Mazzulla, 2007).
3. **Improvement by direct connection to the university area.** Reduced transfers and access time increases service satisfaction and adoption, especially when walking radii to the bus stop remain within the recommended 400–800 m (El-Geneidy et al., 2014; Martens, 2016).

These mechanisms explain the hierarchy of simulated results in this study: scenarios with integration and/or direct route improve times and costs and increase satisfaction, while the trend scenario reproduces the observed penalties. The formalization was carried out in a model of levels and flows, maintaining the endogeneity between demand, frequency and satisfaction, and incorporating operational delays. The validity of the model was established by: a) structural tests (coherence of signs and dependencies); b) qualitative comparison of the simulated behavior with the observed times and costs; and c) sensitivity analysis with variations of ±20–30% in critical parameters, without alteration of the hierarchy of scenarios (Barlas, 1996; Sterman, 2000; Shepherd, 2014). In Latin American contexts, combinations of operational integration, coherent tariff rules, and service prioritization have shown consistent improvements in performance and perception, which supports the intervention logic used (Hidalgo & Gutiérrez, 2013; Hidalgo, Pereira, Estupiñán & Jiménez, 2013; Venter et al., 2020; Oviedo & Titheridge, 2016; Paget-Seekins & Tironi, 2016).

2.5. Intervention scenarios and assumptions

Three scenarios (2021–2030) were simulated: (S0) trend; (S1) direct route to the university area; (S2) high-capacity corridor with tariff integration and feeder services.

Table 1. Scenario Operating Assumptions

Parameter	S0 Trend	S1 Direct Route	S2 Corridor + Integration
Frequency at peak time (min)	18–20	≤10	8–10 (trunk)
Terminal transfers – university area	1–2	0–1	0–1
Fare integration	No	Partial (subscription)	Full (season ticket + transfers)
Distance of access to whereabouts (m)	600–900	400–600	400–600
Information/Standby Management	Basic	Stocking	Loud

Source: Own elaboration

2.6. Evaluation metrics

Door-to-door time (min), daily cost (COP), number of transfers, satisfaction (Likert 1–5), and accessibility (% with whereabouts at ≤400–800 m), according to standards (TRB, 2013; TCRP 95, 2004; El-Geneidy et al., 2014; Martens, 2016).

3. Results

3.1. Empirical diagnosis after transfer

It is evidenced: ≈53% of intermunicipal origin; ≈44% of motorcycle use as primary mode; ≈47% utilization of the new terminal; ≈7% of motorcycle taxis as a link. Increases of 25–40% in times and costs are reported compared to the previous situation, attributable to double payment, long waits and absence of direct terminal-university zone connection.

3.2. Comparison of scenarios (simulation)

Table 2. Comparative synthesis by scenario (reference year 2025)

Indicator	Trend (S0)	Direct Route (S1)	Corridor + Integration (S2)
Average Time (min)	≈49	≈38 (−23%)	≈32 (−35%)
Cost of Diary (COP)	≈10,600	≈7,000 (−34%)	≈6,950 (−34%)
Transfers	1–2	0–1	0–1
Satisfaction (1–5)	≈2.8	≈3.9	≈4.4

Source: Own elaboration

3.3. Qualitative evidence

Three emerging categories: (i) amplified transfer penalty for double payment; (ii) technical feasibility of a direct route with co-financing; (iii) conditional modal transition: without a competitive formal alternative, the motorcycle taxi persists.

3.4. Sensitivity analysis

Reductions in time and cost remain robust in the face of ±20–30% variations in frequency and transfer times; the sensitivity is higher in S0 due to the cumulative effect of waiting and transfers.

4. Discussion

The transfer of the terminal from the center to the north increased the effective distance to the university area and, without fare integration or direct connection, raised the generalized cost of the trip. The transfer penalty and double payment explain the low adoption of the new terminal and the high participation of motorcycles, in line with evidence on transfer costs and their deterrent effect (Guo & Wilson, 2011; Sharaby & Shiftan, 2012). In Latin American contexts with fragmented networks, these frictions enhance informality (Hagen, Pardo & Valente, 2016; Paget-Seekins & Tironi, 2016).

From the point of view of System Dynamics, the system exhibits a regressive reinforcing loop: less perceived utility, less formal demand, less frequency, longer waiting, new loss of utility. In contrast, scenarios with a direct route (S1) and an integrated corridor (S2) activate virtuous feedback: fewer transfers and waits → greater utility and satisfaction, greater demand, improved frequency. The usefulness of simulation to explore second-order effects and for validation through structure, behavior, and sensitivity tests is documented (Barlas, 1996; Sterman, 2000; Shepherd, 2014). From the perspective of accessibility, pedestrian access goals ≤400–800 m and improvements in the whereabouts environment are consistent with increases in satisfaction and retention (TRB, 2013; El-Geneidy et al., 2014; Eboli & Mazzulla, 2007; Tyrinopoulos & Antoniou, 2008; Martens, 2016).

5. Constraints and future agenda

Measurement. Time and costs come from self-reporting with specific verifications; it is recommended to expand with GPS data and systematic observation.

Model. Results dependent on operational assumptions (frequency, integration, transfer times); publish the model file and extend sensitivity analysis and validation with approach counts.

Scope. Extrapolation limited to intermediary cities with relocated terminals and fragmented networks; comparisons are required.

Variables not included. Road safety, weather, and special events were not explicitly modeled; include in future releases.

6. Public policy recommendations

1. Frequency and extension of urban routes to the university area. Programming ≤10 min during rush hour, route extensions and safe stops; the improvement in frequency and reduction of waits increase demand and satisfaction (TRB, 2013; TCRP 95, 2004).
2. Fare integration and student subscription with co-financing. Free transfers and tripartite subscriptions (municipalities, operators, commercial fees) with evidence of increased use of public transport (Sharaby & Shiftan, 2012; Guzman & Hessel, 2022; Lachapelle et al., 2022).
3. Accessibility infrastructure. Protected trails, lighting and continuous cycling infrastructure on the north terminal-university zone axis; ≤400–800 m access targets to bus stops (El-Geneidy et al., 2014; Heinen, van Wee & Maat, 2010).
4. Gradual management of informal services. Regulated transition with formal options of low capacity and effective control, consistent with regional guidelines (IDB/WRI, 2020; OECD/ITF, 2024).
5. Inter-institutional Academic Mobility Board. A decision-making body with the capacity to coordinate operation, integration, financing and continuous evaluation with KPIs: door-to-door time, % with access ≤600–800 m to stops, adoption of the subscription and satisfaction ≥4/5 (Ansell & Gash, 2008; Martens, 2016; Pereira, Schwanen & Banister, 2017).

Operational summary: attractive service (≤10 min), fair price (integrated subscription), secure access, regulated transition and polycentric governance.

7. Contributions of the study

- Integrated evidence on the effects of relocating a terminal from central to north in an intermediate city.
- Replicable framework that combines empirical measurement and Systems Dynamics to evaluate accessibility-based policy packages.
- Intervention sequence (direct route → integrated corridor) with monitoring indicators for public management.

8. Conclusions

The relocation of the terminal from the center to the north increased the effective distance to the university area and, without integration or direct connection, introduced a transfer penalty that eroded the convenience of public transportation. Empirically, low adoption of the new terminal (≈47%), high participation of motorcycles (≈44%) and persistence of motorcycle taxis (≈7%) were observed, along with increases of 25–40% in times and costs compared to the previous situation. The simulation confirmed that a direct terminal-university zone route is an effective transitional measure: ≈23% less time (≈49→≈38 min), ≈34% less cost (≈10,600→≈7,000 COP) and satisfaction of 2.8 to 3.9. A corridor with tariff integration and better operational management establishes a superior balance: ≈35% less time (≈49→≈32 min), ≈34% less cost (≈6,950 COP) and satisfaction ≈4.4; These effects are maintained under sensitivity tests ±20–30% in critical parameters. Consequently, the recommended policy sequence combines frequency ≤10 min, fare integration (subscription and transfer at no cost) and improvements in pedestrian/bicycle accessibility (radii 400–800 m), coordinated through inter-institutional governance with monitoring of door-to-door time, subscription adoption and satisfaction indicators. The mixed approach with System Dynamics provides traceability of mechanisms and a replicable framework for intermediary cities with similar constraints.

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