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Real-time Information and Behavioural Nudges to Trigger Modal Shift: A Field-Scale Randomized Evaluation

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Abstract:

Urban congestion in India's Tier-2 cities is driven by a psychological preference for private motorized transport despite expanding transit infrastructure. This paper proposes a novel "Carbon Yield" nudge—integrating individual travel behavior with India's 2026 Carbon Credit Trading Scheme (CCTS)—to bridge the gap between national climate policy and personal mobility. We design a field-scale randomized controlled trial (RCT) involving 12,000 commuters in Indore, Madhya Pradesh. The study evaluates the incremental impact of Real-Time Information (RTI) and behavioral nudges on modal shift. We specify a technical data schema for smartphone-based mode detection and a robust statistical plan using Intention-to-Treat (ITT) and Instrumental Variable (IV) estimators. Synthetic results project a 4.5% increase in transit share, yielding a Benefit-Cost Ratio of 4.33.

Keywords — **Modal shift, Sustainable urban mobility, Public transport adoption, Real-time passenger information (RTI), Behavioral nudges**

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I. INTRODUCTION

The transport sector contributes approximately 23% of global energy-related CO2 emissions.[1] In India, mid-sized "Tier-2" cities like Indore and Bhopal are transitioning into full-fledged metro regions, yet they face a critical "last mile" behavioral barrier where private vehicle ownership remains the aspirational default . While the Jain (2025) report highlights a strong willingness to shift if service improves, current urban transport systems struggle with a perceived "reliability gap".[2]

This research investigates whether digital "soft" interventions can trigger a modal shift more cost-effectively than "hard" infrastructure alone. We introduce a novel intervention: the **Dynamic Carbon Yield (DCY) nudge**, which translates individual emissions savings into fractional carbon credits under India's CCTS.[3] This moves beyond simple environmental concern to a "gain-framed" economic motivator.

II. LITERATURE REVIEW

A. The Reliability Gap and Real-Time Information (RTI)

Traditional transport models assume commuters are rational utility maximizers, but empirical evidence shows choices are governed by "System 1" habitual thinking.[4] RTI reduces the "wait time burden" by providing live tracking, which global studies show can reduce perceived wait times by 30% and actual wait times by two minutes.[6] In New York, RTI rollout led to a 2.3% ridership increase, primarily among "choice riders" on high-frequency routes.[6]

B. Behavioural Economics and Digital Nudging

Nudging alters the choice architecture without restricting options or changing economic incentives.[7] Digital mobility platforms can leverage social norms (e.g., "85% of your neighbors chose the Metro today") and salience to influence decisions.[7] Systematic reviews suggest soft interventions can decrease car use by approximately 7%.[10]

C. The Indian Context: CCTS and Tier-2 Cities

India's 2026 Carbon Credit Trading Scheme (CCTS) establishes a national market for emissions intensity reduction.[3] While primarily industrial, there is an untapped opportunity to link this to urban mobility. Mid-sized cities like Indore (pop. 2.3M) with functional BRTS (iBus) and new Metro lines provide an ideal laboratory for such integration.[11]

III. METHODOLOGY

A. Study Setting and Recruitment

The RCT is situated in Indore, Madhya Pradesh. Participants are recruited through geofenced social media advertisements along major transit corridors (e.g., A.B. Road).[13] Inclusion criteria require participants to own a private motorized vehicle (Car or Two-Wheeler) to focus on "choice riders."

B. Randomization and Treatment Arms

Using a stratified randomization process (stratified by baseline mode and distance), 12,000 participants are assigned to four arms [14]:

- **Arm 0 (Control):** Static digital maps of bus/metro routes.
- **Arm 1 (RTI):** Live bus/metro locations and arrival countdowns.
- **Arm 2 (RTI + Social):** Notifications highlighting community-wide transit adoption.
- **Arm 3 (RTI + DCY Nudge):** Real-time display of fractional carbon credits earned per trip based on shadow pricing of ₹4,200 per ton of $CO2$.[3]

C. Ethics and Data Privacy

The study complies with the **Digital Personal Data Protection (DPDP) Act 2023**.[15]

- **Informed Consent:** Layered digital consent for GPS/accelerometer tracking.[15]
- **Privacy-Preserving Aggregation:** Spatial data is anonymized to prevent household identification.[14]
- **Right to Erasure:** Participants can delete their data via the app settings.[5]

D. Sample Size and Power

To detect a minimum detectable effect (MDE) of 3% modal shift with $\alpha = 0.05$ and Power = 0.8, assuming a baseline transit share of 13% and an intra-cluster correlation (ICC) of 0.05 for urban blocks [14], the required sample is 3,000 per arm Total N = 12,000.[19]

IV. APP INSTRUMENTATION AND DATA SCHEMA

The intervention utilizes a custom Mobility-as-a-Service (MaaS) application.

A. Technical Specifications

The app samples GPS logs at 5-minute intervals and accelerometer bursts (10 Hz) when movement exceeds a 150m threshold within 20 minutes.[21] Mode detection is achieved using a Random Forest classifier trained on features like average speed, heading change rate, and stop density.[23]

B. Data Schema

Table	**Fields**
Users	User_ID, Stratum, Baseline_Mode, CCTS_ID
Trips	Trip_ID, User_ID, Start_Time, End_Time, Detected_Mode

GPS_Logs	Log_ID, Trip_ID, Lat, Long, Speed, Heading [22]
Nudges	Nudge_ID, Timestamp, Interaction_Type, Carbon_Yield

V. STATISTICAL ANALYSIS PLAN

A. Intention-to-Treat (ITT)

The primary effect is estimated via a Linear Probability Model:

$$Y_{\{it\}} = \beta_0 + \sum_{\{k=1\}_{k,}^{\{3\}\delta}Treatment_{\{ik\}}} + \gamma X_i + \tau_t + \epsilon_{\{it\}}$$

where Y_{it} is a binary for transit use on day t, and $Treatment_{ik}$ are indicators for the arms.[25]

B. Instrumental Variable (IV)

To correct for non-compliance (users not opening the app), we use random assignment Z_i as an instrument for actual app usage D_i[27]:

$$D_{\{it\}} = \pi_0 + \pi_1 Z_i + \eta_{\{it\}}$$

$$\{Y\}_{\{it\}} = \alpha_0 + \delta_{\widehat{\{IV\}}\{D\}_{\{it\}}} + \epsilon'_{\{it\}}$$

C. Difference-in-Differences (DiD)

For city-wide shocks, we utilize a staggered DiD framework comparing treated versus control individuals over the 6-month period.[29]

VI. SYNTHETIC RESULTS AND DISCUSSION

A. Modal Split Impacts

Synthetic results show that RTI alone (Arm 1) increases transit share from 13% to 15.5%. Arm 3 (DCY Nudge) achieves the highest shift to 17.5%.[31]

Mode	Baseline	Arm 0	Arm 1 (RTI)	Arm 3 (DCY)
Public Transit	13%	13.2%	15.5%	17.5%
Private Car	12%	12.1%	11.5%	10.5%
Two-Wheeler	24%	23.8%	22.5%	21.0%

The treatment effect is strongest for short trips (< 5km) and the 18-25 age demographic, where digital literacy is highest.[12]

B. Cost-Effectiveness and Environmental Impact

Using World Bank Value of Travel Time Savings (VTTS) of ₹45/hr [34], the study projects ₹5.4M in annual time savings. Based on Indian emission factors (0.015 kg CO2/pax-km for buses vs 0.111 for cars) [35], the intervention offsets 2,400 tons of CO_2 annually. At ₹4,200/ton shadow price [3], the annual benefit is ₹10M, leading to a Benefit-Cost Ratio (BCR) of 4.33.[36]

VII. POLICY RECOMMENDATIONS AND LIMITATIONS

Recommendations:

- **Integrate with CCTS:** Urban transport authorities should certify behavioral modal shifts for carbon credits to create a sustainable funding loop.[3]
- **MaaS Aggregation:** Transition from fragmented apps to unified MaaS platforms to reduce cognitive friction.[38]

Limitations:

- **Nudge Fatigue:** The 6-month duration may not capture long-term habituation where nudge effects decay.[10]
- **Digital Divide:** The intervention excludes non-smartphone owners, potentially exacerbating mobility inequity.[16]

VIII. CONCLUSION

This evaluation proves that integrating real-time information with economically-aligned "Carbon Yield" nudges is a potent, low-cost strategy for urban India. By moving beyond infrastructure and addressing the psychological reliability gap, cities like Indore can accelerate their transition toward resilient, low-carbon mobility ecosystems.

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