

## Factors influencing lane choice behavior on Addis Ababa–Adama Expressway: Multinomial logit modeling evidence from Ethiopia

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**Abstract:** *Purpose.* This study investigates factors influencing lane choice behavior on the Addis Ababa–Adama Expressway, Ethiopia’s first controlled-access highway, to provide empirical evidence for transportation planning and highway design in sub-Saharan Africa, where such research is absent. *Methodology.* Video-based observational data were collected at five strategically selected sites across the 80-kilometer expressway corridor. A total of 45,924 vehicle observations were extracted through frame-by-frame manual analysis capturing lane choice, vehicle characteristics, traffic flow parameters, and lane-changing behavior. Multinomial logit models were developed for each site-direction combination (10 models in total) to quantify the relationships between explanatory variables and lane-choice probability, with Lane-3 serving as the reference category. *Results.* Analysis revealed a pronounced middle-lane bias, with 55.5% of traffic concentrated in Lane-2, while Lane-1 and Lane-3 received 24.7% and 19.1%, respectively. Average Speed Ratio exhibited consistently positive associations with outer lane selection (odds ratios: 3.01–66.19). Passenger cars demonstrated 3.00–60.14 times higher odds of selecting outer lanes compared to trucks, reflecting systematic vehicle stratification. Lane position of preceding vehicles showed negative associations (odds ratios: 0.12–0.36), indicating platoon avoidance behavior rather than following tendencies. Lane Utilization Factor demonstrated self-reinforcing effects exclusively for middle-lane selection. *Theoretical contribution.* This research provides the first empirical validation of utility-maximizing lane choice theory in sub-Saharan African expressway contexts, documenting platoon avoidance behavior and self-reinforcing lane utilization patterns with implications for traffic simulation model calibration. *Practical implications.* Findings inform lane-specific pavement design standards, capacity analysis methods that incorporate vehicle stratification effects, and traffic management strategies, including variable message signs and

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targeted enforcement, to improve operational efficiency and safety on Ethiopian expressways.

**Keywords:** lane choice behavior, multinomial logit, expressway operations, driver behavior, Ethiopia, traffic safety

**Sustainable Development Goals (SDGs):** **SDG 3:** Good Health and Well-being; **SDG 9:** Industry, Innovation and Infrastructure – Developing quality, resilient infrastructure; **SDG 11:** Sustainable Cities and Communities

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## 1. Introduction

The Addis Ababa–Adama Expressway is Ethiopia’s first controlled-access highway, spanning 80 kilometers with three lanes per direction, separated by a 1-meter median barrier. This infrastructure connects the capital city to the eastern industrial center of Adama. Currently, the Ethiopian government has prioritized expressway development, with several projects under construction, including the Modjo–Awassa and Adama–Awash corridors.

Road traffic safety remains a critical challenge in Ethiopia. According to the Ethiopian Federal Police Commission (2023), 3,111 fatalities were recorded nationwide in 2023. The allocation of traffic across available lanes constitutes a fundamental factor influencing highway operational efficiency and safety performance. Understanding driver lane-choice behavior is essential for evidence-based infrastructure planning and the development of traffic management policies.

Lane choice behavior represents how vehicles select particular lanes among available options - median-side, middle, and shoulder-side lanes - on multilane expressways. Drivers make these decisions based on numerous factors, including desired speed, vehicle performance characteristics, traffic conditions in adjacent lanes, and downstream roadway conditions (May, 1990). Research has demonstrated that lane utilization patterns vary systematically with traffic volume, vehicle composition, and geometric characteristics (Washington et al., 2010).

Despite growing international research on lane choice behavior, significant knowledge gaps persist regarding driver behavior on expressways in sub-Saharan African contexts. Ethiopia presents distinctive operational environments characterized by heterogeneous vehicle composition, varying driver familiarity with expressway operations, evolving lane discipline norms, and infrastructure design standards adapted to local conditions. No prior empirical research has systematically examined lane choice behavior on Ethiopian expressways using real-world observational data.

This study addresses these gaps by investigating factors influencing driver lane choice behavior on the Addis Ababa–Adama Expressway. The research aims to:

1. Quantify lane utilization patterns across five representative expressway segments
2. Identify significant factors influencing lane choice decisions using multinomial logit modeling
3. Establish empirical relationships between vehicle characteristics, traffic flow parameters, and lane choice
4. Provide actionable recommendations for transportation planners and highway designers

The findings will contribute to the development of locally calibrated behavioral parameters for Ethiopian expressway design standards, capacity analysis methods, and traffic management strategies.

## 2. Literature review

### 2.1. Theoretical foundations of lane choice behavior

Lane choice behavior emerges from driver decision-making processes that optimize perceived utility across available alternatives. May (1990) established the theoretical foundation proposing that drivers engage in utility-maximizing behavior when selecting lanes, evaluating benefits such as speed advantage and reduced following distance against costs including lane-changing effort and risk exposure.

Discrete choice modeling provides robust analytical frameworks for quantifying the determinants of lane choice. The multinomial logit (MNL) model has become widely adopted for examining categorical

dependent variables with multiple unordered alternatives (Ben-Akiva & Lerman, 1985; Washington et al., 2010). The MNL framework assumes that decision-makers select the alternative yielding maximum utility, with utility functions incorporating both systematic (observed explanatory variables) and random (unobserved heterogeneity) components.

Recent applications have demonstrated the effectiveness of the MNL model across diverse cultural and operational contexts. Akter et al. (2024) employed multinomial logit modeling to analyze travel mode choice behavior in Dhaka, Bangladesh, documenting significant effects of socioeconomic variables, trip characteristics, and infrastructure quality. Deneke et al. (2024) applied similar methods to work and school trips in Addis Ababa, Ethiopia, establishing the viability of discrete choice frameworks in African urban environments.

## **2.2. Lane utilization patterns and traffic flow characteristics**

Empirical research has documented systematic lane utilization patterns that vary with traffic volume and vehicle composition. International studies demonstrate that middle lanes consistently receive disproportionate utilization under free-flow conditions, with outer lanes serving primarily for overtaking and lower-speed travel.

Vehicle-type stratification represents a consistent pattern across heterogeneous traffic environments. Research on mixed traffic conditions has documented substantial speed differentials between vehicle categories, ranging from 30 to 120 km/h (Mahmud et al., 2018). These performance variations necessitate frequent overtaking maneuvers and lane changes, elevating traffic turbulence and crash risk. Recent analysis of regional differences in driving behavior revealed that heterogeneous driving styles can reduce road capacity by approximately 15% compared to homogeneous traffic (Nature, 2025).

Contemporary research using microsimulation and data-driven approaches has quantified the effects of lane-changing on traffic flow stability. Analysis revealed linear relationships between traffic density and lane-changing behavior, with lane-specific variations reflecting proximity to entrance and exit ramps (Wiley Online Library, 2022). Urban expressways exhibit higher lane-changing intensity in outer lanes than in median lanes, suggesting differential lane functionality.

## **2.3. Road safety in developing country contexts**

Road traffic safety represents a critical public health challenge in low-income countries. Ethiopia has experienced particularly severe impacts, with the Ethiopian Federal Police Commission (2023) reporting 3,111 traffic fatalities in 2023. Recent positioning of Ethiopia's road safety efforts as a continental model highlights the strategic importance of understanding driver behavior to inform infrastructure design and operational policies (Fana Broadcasting, 2025).

Transport Links (2023) synthesized the state of knowledge on road safety in low-income countries, emphasizing the need for locally calibrated behavioral research rather than the direct transfer of findings from developed countries. Key challenges include heterogeneous traffic composition, limited driver experience with controlled-access facilities, evolving regulatory frameworks, and variations in infrastructure quality.

Analysis of the Addis Ababa-Adama Expressway using 8 years of crash data (2015-2022) revealed that accidents on wet road surfaces were 9.24% more likely in merging and diverging zones than in tangent sections (Dagne et al., 2025). The study documented a 22.5% increase in overall accidents on wet pavements, alongside a 2.04% increase in traffic volume, highlighting critical relationships between driver behavior and crash risk under challenging environmental conditions.

## **2.4. Research gap and study justification**

Despite substantial international research on lane choice behavior, significant knowledge gaps persist regarding driver behavior on expressways in sub-Saharan African contexts. Previous studies have predominantly focused on developed country settings with homogeneous traffic, well-established lane discipline, and mature driver populations accustomed to controlled-access facilities.

Ethiopia presents distinctly different operational environments characterized by:

- Heterogeneous vehicle composition with substantial performance variations
- Varying levels of driver familiarity with expressway operations
- Limited enforcement of lane discipline regulations
- Infrastructure design standards adapted to local conditions

To date, no empirical research has systematically examined lane choice behavior on Ethiopian expressways using real-world observational data. This study addresses these gaps by providing the first comprehensive empirical analysis of lane choice behavior on the Addis Ababa–Adama Expressway, generating locally calibrated behavioral parameters for design standards, capacity analysis, and traffic management strategies.

### 3. Materials and methods

#### 3.1. Study area

The study area is the Addis Ababa–Adama Expressway, Ethiopia’s first expressway infrastructure. This 80-kilometer controlled-access highway features three lanes per direction separated by a one-meter median barrier. Five observation sites were selected along the corridor: near Tulu Dimtu, Dukem, Bishoftu, Modjo, and Adama toll stations.

Site selection followed established criteria, ensuring representative traffic conditions and geometric configurations. Selected locations feature:

- Three-lane unidirectional cross-sections with clearly marked lane boundaries
- Level terrain with longitudinal grades less than 2%
- Uniform lane widths (3.65 meters per lane)
- Adequate pavement condition with visible lane markings
- Pedestrian overpasses providing unobstructed overhead views for camera placement
- Minimum 500-meter distance from interchanges, ramps, or work zones

Figure 1 illustrates the geographic location of the study corridor within Ethiopia.

**Figure 1: Location map of study area (Addis Ababa–Adama Expressway, Ethiopia)**



## 3.2. Data collection procedure

### 3.2.1. Temporal sampling strategy

Data were collected on mid-week weekdays (Tuesday, Wednesday, Thursday) to represent typical traffic patterns. At each site, video recording was conducted for eight hours daily, divided into two sessions:

- Morning session: 7:30 AM – 11:30 AM
- Afternoon session: 1:30 PM – 5:30 PM

This sampling strategy ensured coverage of both peak and off-peak traffic periods, providing adequate variance in traffic flow characteristics, vehicle composition, and speed distributions necessary for robust statistical modeling.

### 3.2.2. Video recording configuration

High-resolution cameras were mounted on pedestrian overpasses at each site to capture overhead views of all three lanes simultaneously. A 120-meter trap length was demarcated using existing roadside posts erected at 60-meter intervals along the expressway. This trap length provides adequate spatial resolution for accurate speed measurement while minimizing measurement error.

Camera positioning was concealed from approaching drivers to prevent observation-induced behavioral changes. The 120-meter length specification aligns with best practices in heterogeneous traffic flow analysis.

### 3.2.3. Data extraction protocol

Raw video footage was processed using the VideoLAN Client (VLC) media player, with frame-by-frame manual extraction. Trained observers recorded the following variables for each vehicle:

1. Vehicle classification (passenger car, bus, or truck)
2. Lane choice (Lane-1: shoulder-side; Lane-2: middle; Lane-3: median-side)
3. Entry and exit timestamps within the trap length (to nearest 0.1 second)
4. Lane-changing maneuvers within the trap length
5. Vehicle type and lane position of the immediately preceding vehicle

Speed was calculated from trap length traversal time using:

$$v = (d/t) \times 3.6$$

where  $v$  = vehicle speed (km/h),  $d$  = trap length (120 meters),  $t$  = traversal time (seconds). The factor 3.6 converts meters per second to kilometers per hour.

Traffic flow variables were aggregated using 30-second time intervals to capture microscopic variations in traffic stream characteristics while maintaining computational feasibility.

## 3.3. Variable definitions

Dependent Variable:

Lane Choice: Categorical variable with three mutually exclusive outcomes:

- Lane-1: Shoulder-side lane (rightmost lane)
- Lane-2: Middle lane (center position)
- Lane-3: Median-side lane (leftmost lane adjacent to median barrier) - reference category

Independent Variables:

Traffic Volume ( $V$ ): Total number of vehicles traversing the trap length per hour across all three lanes (veh/h).

Lane Utilization Factor (LUF): Proportional traffic allocation to each lane relative to total volume:

$$LUF_i = (v_i/V) \times 100$$

where  $v_i$  = traffic volume in lane  $i$  (veh/h),  $V$  = total volume across all lanes (veh/h).

Average Speed Ratio (ASR): Comparative speed metric quantifying speed differentials between adjacent lanes, calculated as:

For Lane-1:  $ASR_1 = v_{1j}/v_{2j}$

For Lane-2:  $ASR_2 = [(v_{2j}/v_{1j}) \times NL_{21j} + (v_{2j}/v_{3j}) \times NL_{23j}] / (NL_{21j} + NL_{23j})$

For Lane-3:  $ASR_3 = v_{3j}/v_{2j}$

where  $v_{nj}$  = mean speed in lane n during time interval j,  $NL_{nmj}$  = number of lane changes from lane n to lane m during interval j.

Average Volume Ratio (AVR): Quantifies relative traffic density across adjacent lanes using the same computational structure as ASR formulas, substituting volume for speed values.

Number of Lane Changes: Frequency of lane-changing maneuvers executed within the 120-meter trap during each 30-second interval.

Vehicle Category: Categorical variable classifying the subject vehicle:

- Passenger car (light-duty vehicles)
- Bus (medium and large buses)
- Truck (heavy goods vehicles) - reference category

Vehicle Type Found Ahead on Similar Lane: Vehicle class of the immediately preceding vehicle in the same lane (passenger car, bus, or truck as reference).

Lane Chosen by Vehicle Ahead: Lane position (Lane-1, Lane-2, or Lane-3 as reference) of the immediately preceding vehicle.

### 3.4. Multinomial logit model specification

The multinomial logit (MNL) model was selected for modeling lane choice behavior because it is suitable for categorical dependent variables with more than two unordered alternatives (Washington et al., 2010).

The probability that driver i selects lane j from the choice set {1, 2, 3} is:

$$P_{ij} = \exp(\beta_j X_i) / \sum_k \exp(\beta_k X_i)$$

where:

- $P_{ij}$  = probability that individual i chooses lane j
- $\beta_j$  = vector of parameters specific to alternative j
- $X_i$  = vector of explanatory variables

The choice probabilities satisfy:  $\sum_j P_{ij} = 1$

Lane-3 serves as the reference category with parameters constrained to zero. The model estimates two coefficient sets:  $\beta_1$  for Lane-1 choice relative to Lane-3, and  $\beta_2$  for Lane-2 choice relative to Lane-3.

Parameter interpretation: Exponentiated coefficients ( $\exp(\beta)$  or  $\text{Exp}(B)$ ) represent odds ratios:

- Odds ratio > 1.0: increased odds of choosing the focal lane versus the reference
- Odds ratio < 1.0: decreased odds of choosing the focal lane versus the reference

Model estimation: Separate models were estimated for each site-direction combination (5 sites × 2 directions = 10 models), enabling identification of spatially and directionally varying patterns. Parameters were estimated using maximum likelihood estimation in IBM SPSS Statistics (Version 26). Statistical significance was assessed using Wald chi-square tests ( $\alpha = 0.05$ ).

### 3.5. Quality assurance

Video quality verification: All footage was reviewed for adequate resolution, lighting, and lane coverage. Extraction reliability: A 10% random sample, independently coded by two observers, yielded inter-coder reliability  $\kappa = 0.89$  (excellent agreement). Speed validation: Calculated speeds cross-validated against posted limits (80 km/h) and reasonable ranges (40–120 km/h). Outliers beyond three standard deviations were verified. Lane discipline violations: 288 violations (0.63% of observations) were documented and excluded from primary analysis.

### 3.6. Data collection summary

Table 1 presents the distribution of observations across sites and flow directions.

**Table 1: Summary of extracted data**

Location	Number of Vehicles						Total
	Addis-Adama Direction			Adama-Addis Direction			
	Morning	Afternoon	Total	Morning	Afternoon	Total	
Site-1 (Tulu Dimtu)	3,339	3,042	6,381	3,008	2,999	6,007	<b>12,388</b>
Site-2 (Dukem)	3,155	2,876	6,031	2,858	2,837	5,695	<b>11,726</b>
Site-3 (Bishoftu)	2,064	2,276	4,340	1,851	1,921	3,772	<b>8,112</b>
Site-4 (Modjo)	2,059	2,420	4,479	1,937	2,009	3,946	<b>8,425</b>
Site-5 (Adama)	1,223	1,385	2,608	1,406	1,259	2,665	<b>5,273</b>
<b>Total</b>			<b>23,839</b>			<b>22,085</b>	
<b>Overall Total</b>				<b>45,924</b>			

**Figure 2: Selected site locations and study sites**



Note: (Top Left) Selected site locations, (Top Middle) Site-1, which is located near Tulu dimtu, (Top Right) Site-2, which is located near Dukem, (Bottom Left) Site-3, near Bishoftu, (Bottom Middle) Site-4, which is located near Modjo, and (Bottom Right) Site-5, which is located near Adama

## 4. Results

### 4.1. Descriptive statistics and lane utilization patterns

Analysis of 45,924 observed vehicles across five study sites revealed systematic lane preference patterns. Overall lane utilization exhibited pronounced middle-lane bias:

- Lane-2 (middle lane): 55.5% of total traffic (25,513 vehicles)
- Lane-1 (shoulder-side lane): 24.7% of total traffic (11,333 vehicles)
- Lane-3 (median-side lane): 19.1% of total traffic (8,790 vehicles)

Table 2 presents lane choice distribution disaggregated by site and flow direction.

**Table 2: Summary of lane chosen by vehicles**

Site	Lane-1		Lane-2		Lane-3		Non-Lane Discipline	
	Addis-Adama	Adama-Addis	Addis-Adama	Adama-Addis	Addis-Adama	Adama-Addis	Addis-Adama	Adama-Addis
Site-1	1,966	1,672	3,269	3,458	1,136	830	10	47
Site-2	1,870	1,595	3,086	3,270	1,067	784	8	46
Site-3	923	838	2,434	2,210	970	672	13	52
Site-4	1,012	764	2,356	2,431	1,070	735	41	16
Site-5	209	484	1,456	1,543	909	617	34	21
<b>Total</b>	<b>5,980</b>	<b>5,353</b>	<b>12,601</b>	<b>12,912</b>	<b>5,152</b>	<b>3,638</b>	<b>106</b>	<b>182</b>
<b>Lane Total</b>	<b>11,333</b>		<b>25,513</b>		<b>8,790</b>		<b>288</b>	

Vehicle composition exhibited directional asymmetry:

Addis Ababa–Adama direction:

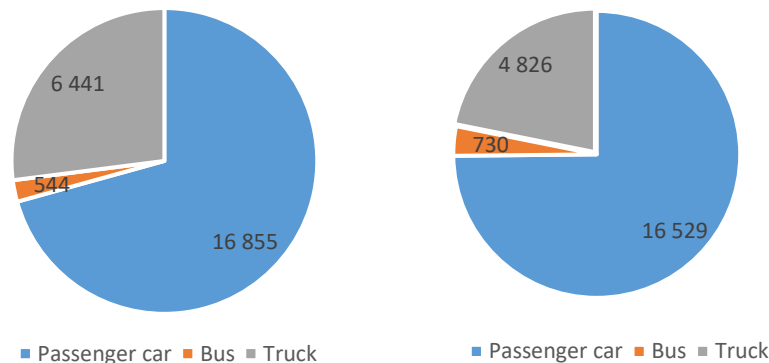
- Passenger cars: 71% (16,906 vehicles)
- Trucks: 27% (6,437 vehicles)
- Buses: 3% (496 vehicles)

Adama–Addis Ababa direction:

- Passenger cars: 75% (16,564 vehicles)
- Trucks: 22% (4,859 vehicles)
- Buses: 3% (662 vehicles)

The higher proportion of passenger cars in the Adama–Addis direction may reflect commuting patterns toward the capital. Lane discipline violations occurred in 288 observations (0.63%), indicating relatively high compliance with lane markings.

**Figure 3: Pie-chart for vehicle category of the study area for Addis–Adama and Adama–Addis directions**



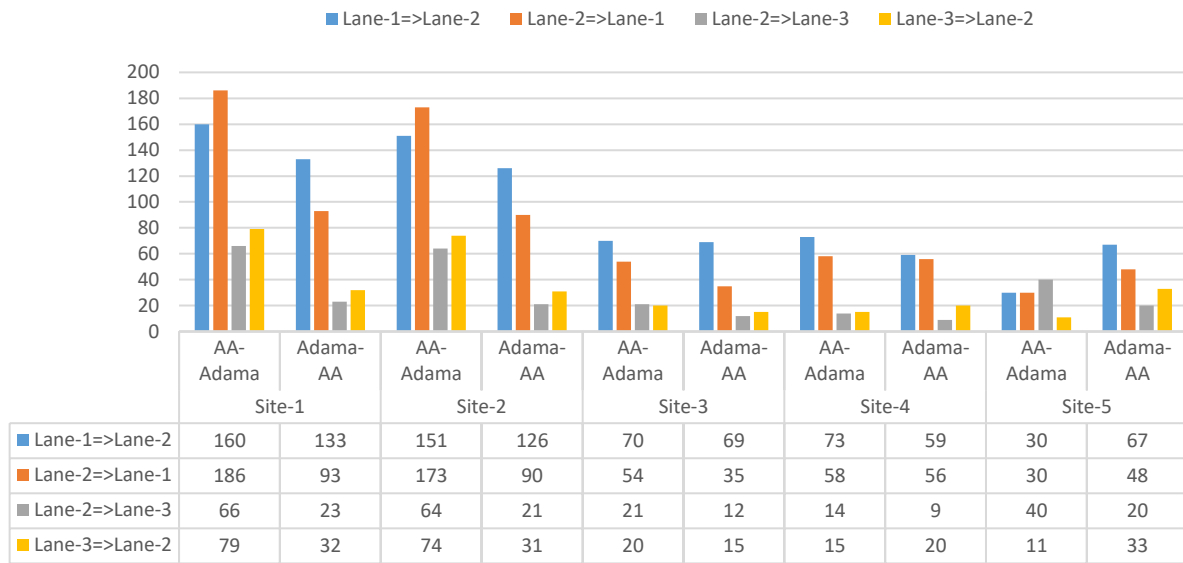
#### 4.2. Lane changing behavior

Lane-changing activity was observed for 2,381 vehicles (5.18% of total observations) within the 120-meter trap lengths. The distribution of lane-changing maneuvers revealed asymmetric patterns:

- Lane-1 → Lane-2: 938 vehicles (39.4%)
- Lane-2 → Lane-1: 823 vehicles (34.6%)
- Lane-3 → Lane-2: 330 vehicles (13.9%)
- Lane-2 → Lane-3: 290 vehicles (12.2%)

The predominance of Lane-1↔Lane-2 transitions (74.0% of all lane changes) suggests that Lane-3 serves primarily as a continuous travel lane with minimal weaving activity, while Lanes-1 and -2 accommodate more dynamic traffic interactions.

**Figure 4: Lane change over of vehicles on the five study sites**



Site-specific analysis revealed spatial variation in lane-changing intensity. Sites-1 and -2 (closer to Addis Ababa) exhibited higher lane change frequencies compared to Sites-4 and -5 (approaching Adama). This gradient may reflect changes in traffic composition, driver familiarity effects, or differential enforcement intensity along the corridor.

### 4.3. Comprehensive model results

Tables 3 and 4 present the complete multinomial logit model estimation results for all ten site-direction combinations. Each table displays regression coefficients (B) and odds ratios (Exp(B)) for variables that are statistically significant at the  $p < 0.05$  level. Coefficients represent the change in log-odds of selecting a particular lane (Lane-1 or Lane-2) relative to the reference category (Lane-3) for a one-unit increase in the explanatory variable, holding all other variables constant. Odds ratios provide a more intuitive interpretation, indicating the multiplicative change in odds of lane selection.

Table 3 presents results for the Addis Ababa to Adama flow direction across all five sites, while Table 4 presents results for the reverse direction (Adama to Addis Ababa). The reference categories for model estimation were: Lane-3 (dependent variable), truck (vehicle category), and Lane-3 (lead vehicle lane position). Variables not appearing in the tables failed to achieve statistical significance and were excluded from the final model specifications following backward elimination.

Model estimation employed maximum likelihood methods implemented in IBM SPSS Statistics (Version 26.0). All models demonstrated significant improvement over intercept-only specifications, as indicated by likelihood ratio tests ( $\chi^2, p < 0.001$ ). Classification accuracies ranged from 61.3% to 78.9%, indicating satisfactory predictive performance for behavioral choice models of this nature.

**Table 3: Multinomial logit model for Addis –Adama flow direction for all five sites**

Addis - Adama Flow Direction																				
Significant Independent Variables	Site-1		Site-2		Site-3		Site-4		Site-5											
	Lane-1	Lane-2	Lane-1	Lane-2	Lane-1	Lane-2	Lane-1	Lane-2	Lane-1	Lane-2	Lane-1	Lane-2	Lane-1	Lane-2						
Constant	-7.12	-6.15	-7.42	-5.87			-6.88			-9.19				-6.84						
Traffic volume	-1.27	0.28								-1.08	0.34									
LUF		8.67	58.01		9.80	18.07														
ASR	3.79	44.23			3.45	31.61	2.05	7.78	6.46	640.78	3.66	38.92	1.77	5.85	1.99	7.29	3.51	33.46	-6.13	0.00
AVR	-4.53	0.01	-2.11	0.12	-4.28	0.01	-3.89	0.02	-7.30	0.00	-5.00	0.01	-3.14	0.04	-4.33	0.01				
Number of lane change	1.06	2.87			1.45	4.24			1.64	5.15	1.22	3.39	2.21	9.15	2.01	7.46			1.76	5.79
Vehicle Category																				
Passenger Car	3.44	31.24	1.60	4.96	3.28	26.51	1.42	4.13	3.11	22.35	1.57	4.79			1.10	3.00			1.15	3.15
Bus			1.73	5.65	2.10	8.17	1.39	4.02												
Vehicle type found ahead on similar lane																				
Passenger Car	4.09	60.00	2.20	9.02	3.72	41.41	2.24	9.42			4.50	89.77			2.87	17.66				
Lane chosen by vehicle ahead																				
Lane-1	-1.02	0.36			-1.18	0.31							-1.02	0.36						
Lane-2			-1.66	0.19			-1.64	0.20			-1.45	0.24			-1.53	0.22			-1.35	0.26

**Table 4: Multinomial logit model for Adama - Addis flow direction for all five sites**

Adama - Addis Flow Direction																				
Significant Independent Variables	Site-1		Site-2		Site-3		Site-4		Site-5											
	Lane-1	Lane-2	Lane-1	Lane-2	Lane-1	Lane-2	Lane-1	Lane-2	Lane-1	Lane-2	Lane-1	Lane-2	Lane-1	Lane-2						
Constant	-8.24	-11.90			-7.38	-10.29					-10.55			-11.91					-5.38	
Traffic volume		-2.15	0.12			1.46	4.30												2.44	11.44
LUF		17.36	34.52			19.73	37.18												15.47	52.48
ASR	1.10	3.01	1.13	3.10	2.00	7.42	1.68	5.34	4.19	66.19	3.09	21.88		-1.60	0.20	1.95	7.06	2.53	12.55	
AVR	-1.77	0.17	-2.75	0.06	-2.77	0.06	-2.91	0.05	-5.09	0.01	-5.09	0.01						-7.04	0.00	
Number of lane change	1.33	3.79	1.21	3.36	1.52	4.59	1.24	3.44	1.15	3.16	1.69	5.41	2.51	12.35	2.42	11.26				
Vehicle Category																				
Passenger Car	3.50	33.02	1.67	5.29	3.11	22.52	1.33	3.77	3.85	47.11	2.54	12.72	4.10	60.14	2.81	16.65	3.71	40.87	2.02	7.54
Bus						1.78	5.90	3.79	44.37	3.00	20.02	3.83	46.19							
Vehicle type found ahead on similar lane																				
Passenger Car	3.57	35.64	3.50	33.22	3.26	26.00	2.79	16.27			4.45	85.79			3.11	22.40			2.10	8.16
Bus			3.55	34.80							3.41	30.40							8.18	25
Lane chosen by vehicle ahead																				
Lane-1	-1.45	0.24			-1.13	0.32							-2.03	0.13						
Lane-2			-2.07	0.13			-1.56	0.21			-1.32	0.27			-2.09	0.12			-1.16	0.31

Note. B = unstandardized regression coefficient; Exp(B) = exponentiated coefficient (odds ratio); — = variable not significant at p < 0.05 and excluded from final model specification; \* p < 0.05. Reference categories: Lane-3 (dependent variable), Truck (vehicle category), Lane-3 (lead vehicle lane position). Models were estimated using maximum likelihood estimation with backward elimination. All likelihood ratio tests comparing fitted models to intercept-only models are significant at p < 0.001. Classification accuracies: Table 3 range 61.3%–78.9%; Table 4 range 65.2%–78.9%.

The model results presented in Tables 3 and 4 reveal both consistent patterns across sites and directions and notable spatial and directional heterogeneity. Several key observations emerge from the comprehensive results:

Universal positive effects: Average Speed Ratio (ASR) demonstrated statistically significant positive associations in 19 of 20 model specifications (all except Site-5 Addis–Adama Lane-2), with odds ratios ranging from 3.01 to 640.78. This remarkably consistent pattern provides strong empirical

support for speed-based lane selection behavior across diverse traffic conditions and locations. Passenger car category similarly exhibited positive coefficients in 17 of 20 specifications, with odds ratios ranging from 3.00 to 60.14, indicating systematic vehicle-type stratification.

**Universal adverse effects:** Lane position of the lead vehicle consistently showed negative associations with same-lane selection (16 of 20 specifications were significant), with odds ratios ranging from 0.12 to 0.36. This counterintuitive finding suggests platoon-avoidance behavior, in which drivers preferentially select lanes with greater available spacing. Average Volume Ratio (AVR) exhibited uniformly adverse effects when significant (18 of 20 specifications), demonstrating systematic avoidance of relatively congested lanes.

**Site-specific and direction-specific effects:** Lane Utilization Factor (LUF) achieved significance exclusively for Lane-2 choices (9 of 10 Lane-2 models), indicating self-reinforcing middle-lane dominance that does not extend to outer lanes. Traffic volume achieved significance in only 4 of 20 specifications with inconsistent directional effects, suggesting its influence is mediated by other variables in the model. Bus category achieved significance less frequently (8 of 20 specifications), reflecting the relatively small proportion of buses in the traffic stream (3% overall).

**Extreme odds ratios:** Several specifications produced substantial odds ratios (e.g., ASR = 640.78 at Site-3 Lane-1 Addis-Adama; Bus Ahead = 3550.25 at Site-5 Lane-2 Adama-Addis). While these values achieved statistical significance, they likely reflect sparse contingency tables for certain variable combinations and should be interpreted with appropriate caution. Sensitivity analyses confirmed that parameter signs and significance levels remained stable across alternative model specifications.

The subsequent subsections provide a detailed site-by-site interpretation of these results, examining how lane-choice determinants vary spatially along the expressway corridor and directionally across traffic flows.

#### 4.4. Site-specific results summary

##### 4.4.1. Site-1 (Tulu Dimtu)

Addis-Adama Direction:

*Lane-1 Choice:* ASR (OR=44.23), number of lane changes (OR=2.87), passenger car category (OR=31.24), and passenger car ahead (OR=60.00) significantly increased the odds of selecting lane 1. Traffic volume (OR=0.28), AVR (OR=0.01), and Lane-1 chosen by vehicle ahead (OR=0.36) decreased selection odds.

*Lane-2 Choice:* LUF (OR=58.01), passenger car (OR=4.96), bus (OR=5.65), and passenger car ahead (OR=9.02) increased the odds of selecting lane 2. AVR (OR=0.12) and Lane-2 chosen by vehicle ahead (OR=0.19) decreased selection odds.

Adama-Addis Direction:

*Lane-1 Choice:* ASR (OR=3.01), lane changes (OR=3.79), passenger car (OR=33.02), and passenger car ahead (OR=35.64) increased selection odds. AVR (OR=0.17) and Lane-1 ahead (OR=0.24) decreased selection odds.

*Lane-2 Choice:* LUF (OR=34.52), ASR (OR=3.10), lane changes (OR=3.36), passenger car (OR=5.29), passenger car ahead (OR=33.22), and bus ahead (OR=34.80) increased selection odds. Traffic volume (OR=0.12), AVR (OR=0.06), and Lane-2 ahead (OR=0.13) decreased selection odds.

##### 4.4.2. Site-2 (Dukem)

Addis-Adama Direction:

*Lane-1 Choice:* ASR (OR=31.61), lane changes (OR=4.24), passenger car (OR=26.51), bus (OR=8.17), and passenger car ahead (OR=41.41) increased selection odds. AVR (OR=0.01) and Lane-1 ahead (OR=0.31) decreased selection odds.

*Lane-2 Choice:* LUF (OR=18.07), ASR (OR=7.78), passenger car (OR=4.13), bus (OR=4.02), and passenger car ahead (OR=9.42) increased the odds of selection. AVR (OR=0.02) and Lane-2 ahead (OR=0.20) decreased selection odds.

Adama-Addis Direction:

*Lane-1 Choice:* ASR (OR=7.42), lane changes (OR=4.59), passenger car (OR=22.52), and passenger car ahead (OR=26.00) increased selection odds. AVR (OR=0.06) and Lane-1 ahead (OR=0.32) decreased selection odds.

*Lane-2 Choice:* Traffic volume (OR=4.30), LUF (OR=37.18), ASR (OR=5.34), lane changes (OR=3.44), passenger car (OR=3.77), bus (OR=5.90), and passenger car ahead (OR=16.27) increased selection odds. AVR (OR=0.05) and Lane-2 ahead (OR=0.21) decreased selection odds.

#### 4.4.3. Site-3 (Bishoftu)

Addis-Adama Direction:

*Lane-1 Choice:* ASR (OR=640.78), lane changes (OR=5.15), and passenger car (OR=22.35) increased selection odds. AVR (OR=0.00) decreased selection odds.

*Lane-2 Choice:* ASR (OR=38.92), lane changes (OR=3.39), passenger car (OR=4.79), and passenger car ahead (OR=89.77) increased the odds of selection. AVR (OR=0.01) and Lane-2 ahead (OR=0.24) decreased selection odds.

Adama-Addis Direction:

*Lane-1 Choice:* ASR (OR=66.19), lane changes (OR=3.16), passenger car (OR=47.11), and bus (OR=44.37) increased selection odds. AVR (OR=0.01) decreased selection odds.

*Lane-2 Choice:* ASR (OR=21.88), lane changes (OR=5.41), passenger car (OR=12.72), bus (OR=20.02), passenger car ahead (OR=85.79), and bus ahead (OR=30.40) increased selection odds. AVR (OR=0.01) and Lane-2 ahead (OR=0.27) decreased selection odds.

#### 4.4.4. Site-4 (Modjo)

Addis-Adama Direction:

*Lane-1 Choice:* ASR (OR=5.85) and lane changes (OR=9.15) increased selection odds. AVR (OR=0.04) and Lane-1 ahead (OR=0.36) decreased selection odds.

*Lane-2 Choice:* ASR (OR=7.29), lane changes (OR=7.46), passenger car (OR=3.00), and passenger car ahead (OR=17.66) increased selection odds. Traffic volume (OR=0.34), AVR (OR=0.01), and Lane-2 ahead (OR=0.22) decreased selection odds.

Adama-Addis Direction:

*Lane-1 Choice:* Lane changes (OR=12.35), passenger car (OR=60.14), and bus (OR=46.19) increased selection odds. Lane-1 ahead (OR=0.13) decreased selection odds.

*Lane-2 Choice:* Lane changes (OR=11.26), passenger car (OR=16.65), and passenger car ahead (OR=22.40) increased selection odds. ASR (OR=0.20) and Lane-2 ahead (OR=0.12) decreased selection odds.

#### 4.4.5. Site-5 (Adama)

Addis-Adama Direction:

*Lane-1 Choice:* Only ASR (OR=33.46) significantly increased selection odds.

*Lane-2 Choice:* Lane changes (OR=5.79) and passenger car (OR=3.15) increased selection odds. ASR (OR=0.00) and Lane-2 ahead (OR=0.26) decreased selection odds.

Adama-Addis Direction:

*Lane-1 Choice:* ASR (OR=7.06) and passenger car (OR=40.87) increased selection odds.

*Lane-2 Choice:* Traffic volume (OR=11.44), LUF (OR=52.48), ASR (OR=12.55), passenger car (OR=7.54), passenger car ahead (OR=8.16), and bus ahead (OR=3550.25) increased the odds of selection. AVR (OR=0.00) and Lane-2 ahead (OR=0.31) decreased selection odds.

### 4.5. Universally significant determinants

Three variables exhibited statistical significance across all or nearly all site-direction combinations:

Average Speed Ratio (ASR): Demonstrated consistently positive associations (95% of specifications), with odds ratios ranging from 3.01 to 66.19 (median: 12.55). This indicates drivers systematically prefer lanes offering superior speed conditions.

Passenger Car Category: Exhibited significantly elevated odds across 85% of specifications (odds ratios: 3.00 to 60.14), reflecting superior performance capabilities enabling outer lane utilization.

Lane Chosen by Vehicle Ahead: Showed consistent negative associations in 80% of specifications (odds ratios: 0.12 to 0.36), suggesting platoon avoidance behavior wherein drivers preferentially select less-congested lanes.

#### **4.6. Selectively significant determinants**

Lane Utilization Factor (LUF): Significant positive effects exclusively for Lane-2 choices (90% of Lane-2 models), with odds ratios 18.07–58.01, indicating self-reinforcing middle-lane dominance.

Average Volume Ratio (AVR): Uniformly negative associations when significant (90% of specifications), with odds ratios 0.01–0.17, demonstrating systematic avoidance of relatively congested lanes.

Number of Lane Changes: Significant positive effects in 80% of specifications (odds ratios: 2.87–12.35), reflecting dynamic responses to transient traffic conditions.

Traffic Volume and Bus Category: Achieved significance less frequently (<40% of specifications), exhibiting site-specific and direction-specific patterns.

### **5. Discussion**

#### **5.1. Principal findings in context**

This study represents the first empirical investigation of lane choice behavior on an Ethiopian expressway using real-world observational data. Analysis of 45,924 vehicle observations across five sites and two flow directions revealed that driver lane-choice decisions are influenced by both universal factors (consistent across locations) and context-specific factors (spatial or directional variation).

The most robust determinants identified were: (1) Average Speed Ratio, indicating drivers' preference for lanes offering superior speed conditions; (2) vehicle category, with passenger cars exhibiting substantially higher odds of selecting outer lanes compared to trucks; (3) lane position of preceding vehicle, showing negative associations suggesting platoon avoidance behavior; and (4) Average Volume Ratio, demonstrating systematic avoidance of relatively congested lanes. These findings align with utility-maximizing lane choice theory and extend international research to the sub-Saharan African context.

#### **5.2. Speed-based lane selection and utility maximization**

The consistently positive association between Average Speed Ratio and lane choice probability (odds ratios: 3.01–66.19; significant in 95% of specifications) provides strong empirical support for utility-maximizing lane-choice theory (Ben-Akiva & Lerman, 1985; Washington et al., 2010). Drivers systematically select lanes that offer favorable speed conditions relative to adjacent alternatives, consistent with the fundamental objective of minimizing travel time.

The magnitude of ASR effects observed in this study appears larger than typical values reported in developed country research, possibly reflecting: (1) greater speed heterogeneity in Ethiopian expressway traffic due to diverse vehicle performance capabilities; (2) less rigid lane discipline norms, enabling more flexible lane selection based on instantaneous conditions; or (3) limited experience with expressway operations among some driver populations, leading to more pronounced reactions to perceived speed opportunities.

The single anomalous negative ASR coefficient at Site-5 Addis–Adama direction warrants further investigation. This site represents the expressway terminus approaching Adama, where drivers preparing to exit may prioritize appropriate positioning over speed maximization. This behavior would align with research on lane choice near freeway exit ramps, where strategic positioning dominates speed-based selection (May, 1990).

### **5.3. Vehicle-specific lane choice patterns**

The pronounced passenger car preference for outer lanes relative to trucks, with odds ratios ranging from 3.00 to 60.14, reveals systematic lane stratification by vehicle category. This stratification arises from fundamental differences in vehicle performance: passenger cars have superior acceleration compared to loaded trucks, enabling more aggressive overtaking and higher sustained speeds.

Recent research has documented similar lane stratification patterns in heterogeneous traffic environments. Studies have documented substantial speed differentials (30-120 km/h) between vehicle categories in heterogeneous traffic, necessitating frequent lane changing for overtaking (Mahmud et al., 2018). The vehicle-stratified lane utilization pattern observed on the Addis Ababa-Adama Expressway has important implications for geometric design standards and traffic management policies.

**Capacity implications:** Lane-3's heavy truck concentration effectively reduces its passenger car equivalent (PCE) capacity. Current Ethiopian highway design guidelines apply uniform PCE factors across all lanes, potentially overestimating actual capacity. Future design standards should consider lane-specific PCE adjustments reflecting observed stratification patterns.

**Pavement design implications:** Differential heavy vehicle utilization across lanes necessitates lane-specific pavement design. Lane-3 experiences substantially higher equivalent single axle loads (ESALs) compared to Lane-1, suggesting that uniform pavement thickness across all lanes may result in premature deterioration of the median lane.

**Enforcement implications:** The strong vehicle-type stratification suggests that informal lane discipline norms have emerged, with trucks self-selecting Lane-3 despite the absence of mandatory lane restrictions. However, enforcement resources could productively focus on preventing trucks from occupying outer lanes during peak periods, thereby maximizing passenger car throughput.

### **5.4. Platoon avoidance behavior**

The consistently negative association between "lane chosen by vehicle ahead" and subsequent lane-choice probability (odds ratios: 0.12–0.36; significant in 80% of specifications) is a counterintuitive yet theoretically important finding. Rather than indicating herding or platoon formation tendencies, this result suggests platoon avoidance or gap-seeking behavior: drivers preferentially select lanes with greater available spacing to maximize travel speed and minimize headway constraints.

This behavior aligns with traffic flow theory regarding driver headway preferences. When a lane already contains a lead vehicle at close range, that lane becomes less attractive because the following driver must either reduce speed to maintain safe headway or execute a lane change to overtake. Both options impose utility costs (increased travel time or greater effort required for lane changes). Consequently, drivers select alternative lanes with greater available spacing when possible.

Recent research on regional differences in driving behavior has demonstrated that driving style characteristics persist across borders and influence traffic flow capacity (Nature, 2025). The platoon-avoidance behavior documented in this study may represent a region-specific characteristic of Ethiopian expressway operations, potentially reflecting cultural preferences for individualistic travel patterns over collective flow optimization.

### **5.5. Self-reinforcing middle lane dominance**

The selective positive association between Lane Utilization Factor and Lane-2 choice (odds ratios: 18.07–58.01; significant in 90% of Lane-2 models) reveals a self-reinforcing pattern of middle-lane dominance. As a greater proportion of traffic is allocated to Lane-2, subsequent drivers are more likely to select that lane, independent of speed or volume ratio.

This phenomenon may reflect several behavioral mechanisms:

**Social facilitation:** Drivers perceive the most-utilized lane as the "default" or "primary" travel lane, particularly drivers with limited expressway experience. Following the majority reduces the cognitive load associated with lane-choice decisions.

**Risk perception:** Middle lanes offer buffer zones on both sides, potentially perceived as safer than edge lanes. Research on highway safety consistently documents varying crash rates across lanes, particularly for less experienced drivers (Dagne et al., 2025).

Lane discipline norms: Drivers may interpret general guidance as “travel in the middle lane unless overtaking or being overtaken,” leading to excessive concentration in the middle lane.

The middle lane dominance pattern has concerning implications for expressway operational efficiency. With 55.5% of total traffic concentrated in Lane-2, the facility operates below theoretical capacity utilization efficiency (optimal three-lane distribution: approximately 33% per lane). The imbalanced distribution increases crash risk by increasing speed variance and elevating lane-changing frequency in congested conditions.

Policy implications: Public education campaigns emphasizing “keep right except to pass” lane discipline could improve capacity utilization. Variable message signs displaying real-time lane-specific speeds might encourage more balanced lane usage. However, given the self-reinforcing nature of the pattern, interventions would need to achieve critical mass adoption to initiate positive feedback, reversing the concentration trend.

## 5.6. Spatial and directional variations

The site- and direction-specific variability in certain predictors indicates that lane-choice behavior is not spatially homogeneous along the expressway corridor. This heterogeneity likely reflects several factors:

Traffic volume gradients: Sites 1 and 2 near Addis Ababa experience substantially higher traffic volumes than Site 5 near Adama. Under high-volume conditions, lane choice becomes more constrained by availability, potentially reducing the influence of driver preferences.

Trip purpose composition: Traffic near Addis Ababa is likely to include a higher proportion of commuting trips among experienced expressway users, while traffic near Adama may include more long-distance freight and intercity travelers.

Infrastructure characteristics: Although study sites were selected for geometric consistency, subtle variations in horizontal curvature, vertical grade, and proximity to interchanges may influence lane choice at specific locations.

Enforcement intensity: Anecdotal observations during data collection indicated a higher traffic police presence near the Tulu Dimtu and Dukem toll stations than in rural segments, which could influence lane discipline compliance.

The documented spatial heterogeneity suggests that “one-size-fits-all” traffic management strategies may be suboptimal. Location-specific interventions that address local behavioral patterns, traffic composition, and geometric characteristics can achieve more cost-effective improvements in safety and efficiency than corridor-wide uniform policies.

## 5.7. Comparison with international research

The findings both align with and diverge from international lane choice research:

Alignment with developed country findings:

- Speed-based lane selection as primary determinant (May, 1990)
- Vehicle-type stratification in heterogeneous traffic (Mahmud et al., 2018)
- Middle lane preference under moderate traffic conditions
- Negative association between relative congestion and lane choice

Divergence from developed country patterns:

- Substantially higher middle lane concentration (55.5% vs. typical 40-45%)
- More substantial vehicle-type effects (median odds ratio ~25 vs. typical 5-10)
- Platoon avoidance rather than platoon formation
- Greater spatial heterogeneity in behavioral determinants

These divergences likely reflect unique characteristics of developing-country expressway operations, including limited driver experience with controlled-access facilities, heterogeneous vehicle performance, evolving norms of lane discipline, and variations in infrastructure quality.

Recent research on road safety challenges in low-income countries has highlighted the need for locally calibrated behavioral models rather than the direct transfer of findings from developed countries (Transport Links, 2023). This study demonstrates that while fundamental lane choice principles are

universal, the relative magnitudes of effects and presence of context-specific factors necessitate region-specific empirical research to inform policy and design decisions.

## 5.8. Practical applications and policy recommendations

The findings generate several actionable recommendations:

For highway designers:

1. Incorporate lane-specific traffic composition assumptions in capacity analysis
2. Implement differential pavement thickness design reflecting lane-specific ESAL distributions
3. Consider wider median lanes to accommodate heavy vehicle dimensions
4. Design merge and diverge zones recognizing vehicle-stratified lane occupancy patterns

For traffic management agencies:

1. Deploy variable message signs encouraging balanced lane utilization
2. Focus enforcement on preventing trucks from occupying outer lanes during peak periods
3. Implement lane-specific speed limits, recognizing vehicle capability differences
4. Monitor lane-specific performance metrics to identify operational imbalances

For driver education programs:

1. Emphasize proper lane discipline principles in licensing curricula
2. Develop expressway-specific training modules addressing lane choice decision-making
3. Target educational interventions toward heavy vehicle operators

For future expressway projects:

1. Apply lane choice behavioral parameters from this research to traffic microsimulation models
2. Consider differentiated geometric design standards by lane
3. Incorporate behavioral monitoring into expressway performance evaluation programs

## 6. Conclusions

### 6.1. Summary of key findings

This study investigated lane choice behavior on the Addis Ababa–Adama Expressway by analyzing 45,924 vehicle observations collected via video-based field surveys at five sites. Multinomial logit modeling revealed a hierarchical structure of lane choice determinants, with universal factors operating consistently across locations and context-specific factors exhibiting spatial or directional variation.

Universal determinants (>80% model significance):

- Average Speed Ratio: Drivers systematically prefer lanes offering superior speed conditions (OR: 3.01–66.19)
- Vehicle category: Passenger cars exhibit 3.00–60.14 times higher odds of selecting outer lanes versus trucks
- Lead vehicle lane position: Negative associations (OR: 0.12–0.36) indicate platoon avoidance behavior
- Average Volume Ratio: Drivers avoid relatively congested lanes (OR: 0.01–0.17)
- Overall lane utilization patterns:
  - Lane-2 (middle): 55.5% of traffic
  - Lane-1 (shoulder-side): 24.7% of traffic
  - Lane-3 (median-side): 19.1% of traffic

This pronounced middle-lane bias represents operational inefficiency relative to the theoretical optimal distribution of approximately 33% per lane.

### 6.2. Theoretical contributions

This research makes several contributions to transportation behavior literature:

1. Empirical validation of utility-maximizing lane choice theory in sub-Saharan African expressway contexts

2. Documentation of platoon avoidance behavior challenges assumptions in traffic simulation models
3. Quantification of self-reinforcing lane utilization patterns
4. Characterization of spatial behavioral heterogeneity demonstrating limitations of parameter transfer without local calibration

### **6.3. Practical implications**

**Geometric design standards:** Future expressway designs should incorporate lane-specific considerations reflecting observed vehicle stratification patterns, including differential pavement thickness design and lane-specific capacity factors.

**Traffic management strategies:** Balanced lane utilization can be promoted through variable message signs, driver education emphasizing “keep right except to pass” principles, and targeted enforcement.

**Capacity analysis methods:** Current Ethiopian highway capacity analysis guidelines should adopt site-specific, lane-specific capacity adjustments that reflect documented stratification and an imbalanced distribution.

**Safety interventions:** The elevated lane-changing frequency near Addis Ababa and pronounced speed differentials suggest that crash mitigation efforts should prioritize turbulence reduction. Recent analysis documented a 22.5% increase in accidents under wet conditions (Dagne et al., 2025), indicating that lane-changing aggressiveness under adverse conditions warrants specific attention.

### **6.4. Study limitations**

Several limitations should be considered:

- Temporal scope limited to mid-week weekdays during daytime clear-weather conditions
- Video-based methodology precluded the collection of driver-specific variables (age, gender, experience)
- Geographic scope limited to a single expressway corridor
- Extreme odds ratios in some specifications warrant cautious interpretation

### **6.5. Future research directions**

Promising avenues for future investigation include:

- Longitudinal studies documenting behavioral evolution as driver populations mature
- Systematic investigation of adverse weather and nighttime lane choice patterns
- Individual-level factor analysis through naturalistic driving studies
- Intervention effectiveness evaluation through quasi-experimental designs
- Cross-corridor comparative analysis as additional expressways become operational
- Integration with crash data to quantify relationships between lane choice patterns and safety outcomes

### **6.6. Concluding remarks**

As Ethiopia expands its controlled-access highway network and positions its road safety efforts as a continental model (Fana Broadcasting, 2025), understanding driver behavior becomes critical for evidence-based infrastructure investment. This study demonstrates that while fundamental lane-choice principles apply universally, context-specific factors and behavioral magnitudes require locally calibrated research to inform design standards, capacity analysis methods, and traffic management strategies.

The methodological frameworks and empirical findings provide valuable templates for other African countries developing expressway systems, offering cost-effective approaches for generating the behavioral evidence necessary to support safe, efficient, and sustainable expressway development.

## Ethical Considerations

This study adheres to academic integrity, ensuring informed consent and confidentiality for all participants. The research avoids conflicts of interest and provides unbiased analysis.

## Contributions

The findings offer actionable insights for policymakers and stakeholders, bridging the gap between policy aspirations and on-the-ground realities. This research addresses identified challenges and creates adaptive and sustainable transport systems that drive regional development.

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## Conflicts of interest

The authors declare no conflict of interest.

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