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Modeling Road Traffic Crash Occurrence on Toll Plaza: The Case of Addis Ababa- Adama Expressway

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Abstract

Toll plazas are essential components of road systems, generating capital funding and sustaining revenue for infrastructure maintenance. Their design—including plaza width, tangent length, gradient, number of exits, speed limits, vehicle types, and annual average daily traffic—is crucial for ensuring smooth traffic flow and minimizing congestion. This study investigates traffic crash occurrences at toll plazas along the Addis Ababa–Adama expressway using both primary and secondary data. A census sampling method was employed to capture the entire population, and data were analyzed using descriptive statistics and multi-linear regression models.The findings reveal that crash severity at toll plazas resulted in 3.34% fatalities, 4.56% serious injuries, 7.90% minor injuries, and 84.19% property damage. Average annual daily traffic increased sharply from 8,955 vehicles per day in 2007 E.C to 26,424 vehicles per day in 2015 E.C. The Tulu Dimitu toll plaza experienced the highest proportion of crashes at 51.67%, with peak crash days being weekdays—17.63% on Tuesdays and 17.93% on Wednesdays. Brake defects were identified as the leading cause, contributing to 54.41% of crashes. The study concludes that vehicle type and traffic volume significantly influence crash frequency, underscoring the need for targeted safety interventions at toll plazas.

Key Words*:* Crash Frequency, Toll Plazas, Vehicle classification, Operating speed, Average annual daily traffic

1. Introduction

1.1. Background of the Study

Traffic accidents are among the leading causes of social mortality, disabilities, public health issues, and challenges to economic development worldwide. They represent a significant concern for individuals, governments, nations, and organizations. In particular, traffic accidents are a critical factor affecting a country's socioeconomic status, especially in developing nations where they lead to substantial losses in both financial and human resources (Chaudhry K. and Iqbal, 2018).

Toll plazas are vital components of road systems, providing essential funding for capital projects and ongoing infrastructure maintenance. These plazas are designed to facilitate traffic flow and reduce congestion. However, after being exposed to a wealth of information, drivers often have limited time to decide their speed, tollbooth lane, and exit ramp. This situation may correlate directly with an increased risk of accidents and the frequency of near misses. One effective approach to enhancing road safety is to analyze and improve the consistency of the factors contributing to traffic accidents at toll plazas.

Globally, the scale of the issue is profound. According to the World Health Organization (WHO, 2023), road traffic incidents cause approximately 1.19 million fatalities annually, establishing them as the foremost cause of death and serious injury worldwide. The burden is disproportionately borne by low- and middle-income countries, where fatality rates are more than double those of high-income nations. Consequently, road traffic injuries now rank as the third leading contributor to the global disease burden. Their economic impact is estimated at around 1% of GDP in low-income countries—a figure consistent with the 1-2% of GDP observed across many emerging economies.

The national context of Ethiopia reflects this alarming global trend. Data from the Ethiopian Ministry of Transport and Logistics, covering a 24-year period (1996/97 to 2019/20 E.C.), reveal a distribution of 9.95% fatal crashes, 12.76% serious crashes, 12.10% minor crashes, and 65.19% property-damage-only incidents. Cumulatively, these crashes resulted in 66,218 fatalities, 107,588 serious injuries, and 120,840 minor injuries, underscoring a severe public safety crisis.

This study focuses specifically on the Addis Ababa–Adama Expressway in Ethiopia. As summarized in Table 1, based on data from the Ethiopian Toll Roads Enterprise (2015 E.C), the analysis aims to examine and model road traffic crashes occurring at toll plaza exits along this critical transport corridor.

Table 1:- The nine years of traffic crash data on Addis Ababa – Adama Expressway

Fiscal Budget Year E.C	Total No. of Crash	Total No. of Vehicles Involved	No. of Human Injury			Type of Crash			
			Fatal Injury	Serious Injury	Light Injury	Fatal Crash	Serious Crash	Light Crash	Property Damage
2007	164	188	21	33	74	9	11	27	117
2008	307	385	28	74	166	17	24	56	210
2009	310	357	20	33	75	11	25	56	218
2010	391	481	26	64	125	20	18	48	305
2011	469	578	25	87	197	16	33	78	342
2012	448	522	11	42	151	10	30	63	345
2013	447	527	16	52	164	13	19	80	335
2014	497	587	24	67	135	17	26	58	396
2015	453	589	28	95	291	21	38	85	309
Sum	**3,486**	**4,214**	**199**	**547**	**1,378**	**134**	**224**	**551**	**2,577**

Source: Ethiopian Toll Roads Enterprise recording data

1.2. Statement of the Problem

Toll plazas represent a unique operational environment within highway systems, functioning as service bottlenecks rather than continuous traffic lanes. This fundamental distinction makes them analytically different from regular road segments. Unlike conventional road sections where traffic flows freely and delays are primarily attributable to congestion, toll plazas introduce distinctive operational complexities including lane-choice effects, upstream queue formation, and artificial bottlenecks—phenomena that do not occur on regular road segments. These characteristics create unique safety challenges that warrant specialized investigation.

Traffic crashes have emerged as a pressing national concern in Ethiopia, with the Addis Ababa–Adama Expressway corridor representing a particularly critical area of concern. According to data obtained from the Toll Road Enterprise Safety Department, traffic crashes along this route have demonstrated alarming increases in both frequency and severity. During the nine-year period from 2007 E.C. to 2015 E.C., the expressway recorded a total of 3,486 road traffic crashes. During this same period, average daily traffic flow rose dramatically from 8,955 vehicles per day in 2007 E.C. to 26,424 vehicles per day in 2015 E.C.—a nearly threefold increase that has intensified exposure to crash risks.

This surge in crashes is compounded by significant safety deficits in the current infrastructure and management systems. The expressway lacks effective speed control mechanisms, and its existing safety provisions remain inadequate for the growing traffic volume. Furthermore, there is no systematic testing for drunk driving, nor is a radio communication system in place for incident management and coordination. These gaps in safety infrastructure exacerbate the risks already inherent in high-speed, high-volume expressway travel.

As one of Ethiopia's most prominent and heavily trafficked highways, the Addis Ababa–Adama Expressway accommodates substantial vehicle volumes passing through its toll plazas daily. The marked increase in crashes underscores an urgent need to identify and mitigate high-risk areas along

this vital transport corridor. Understanding the specific crash patterns, contributing factors, and safety deficiencies at toll plazas is essential for developing targeted interventions that can reduce crash frequency and severity while maintaining the operational efficiency of this critical infrastructure.

This study investigates the occurrence and characteristics of traffic crashes at toll plazas along the Addis Ababa–Adama Expressway, with the goal of informing evidence-based safety improvements for Ethiopia's evolving expressway network.

1.3. Objective of the Study

1.3.1. General Objective

The general objective of this study is to model the occurrence of traffic crashes at toll plazas, using the Addis Ababa–Adama Expressway as a case study.

1.3.2. Specific Objectives

This study aims to achieve the following specific objectives:

- To assess trends and characteristics of road traffic crashes at toll plazas.
- To investigate traffic flow characteristics and their relationship with crash occurrence at toll plazas.
- To identify the main contributing factors to traffic crashes at toll plazas.

1.4. Significance of the Study

The significance of this study lies in its analysis of road traffic accidents on the Addis Ababa - Adama Expressway toll plazas. From a rational standpoint, the impact of traffic accidents on a country's economy is substantial, highlighting the importance of researching these effects for both governmental bodies and organizations addressing traffic accident issues. The findings will benefit key stakeholders, including government agencies, toll plaza operators, and road users. Furthermore, this research will contribute to the existing body of knowledge on road safety. The study's specific significance lies in its focused analysis of crash patterns on the Addis Ababa–Adama Expressway toll plazas.

2. Literature Review

2.1. Introduction

This chapter presents a theoretical and empirical review of literature concerning road traffic crashes (RTCs), including their severity, trends, and consequences. RTCs result in significant loss of life and exert profound—though often under-recognized—economic, health, and social impacts. While developed nations often see a decline in traffic fatalities with rising GDP, Ethiopia faces a substantial and growing burden, particularly in its major cities. Current interventions are frequently reactive and uncoordinated, underscoring the need for a holistic, planned approach. This chapter reviews the global rise of RTCs, identifies existing research gaps, and connects these themes to the specific objectives of the present study.

2.2. Definition of Road Traffic Crash

A road traffic crash (RTC) is defined as a collision occurring on a public road involving at least one moving vehicle, which results in fatal or non-fatal injuries (Faizal, 2021). This term encompasses incidents involving multiple vehicles—counted as a single crash if collisions occur in rapid succession—as well as collisions with pedestrians, animals, or fixed objects, and single-vehicle incidents (Mekti, 2019).

2.3. General Trends of Traffic Crashes

2.3.1. The Context of Ethiopia

As a low-income, rapidly developing nation, Ethiopia experiences a high rate of traffic crashes. Over a recent five-year period, the number of crashes increased by more than 1,000 incidents (Oluma, 2016). In 2013 E.C, an estimated 31,564 deaths in Ethiopia were attributed to RTCs, representing 5.6% of all deaths and a mortality rate of 42.41 per 100,000 people—ranking the country 19th globally (Deme, 2019). The economic impact is also significant, with RTCs costing an estimated 0.8% to 0.9% of the nation's GDP in recent years (Deme, 2019).

Despite this historical trend, recent data indicates a decline. The 2020/21 period saw a 13% reduction in fatal crashes and a 14% reduction in fatalities compared to prior year (Team, 2021). In Addis Ababa specifically, the 2013-14 E.C period recorded 389 traffic fatalities, 1,824 serious injuries, 994 minor injuries, and 27,882 instances of property damage. Young adults aged 18-30 represent the most affected demographic, and the associated damage to road infrastructure was estimated at 9.1 million Birr.

2.4. Contributing Factors to Crashes

Identifying risk factors is essential for developing effective road safety interventions. These factors range from issues requiring immediate action to longer-term structural challenges (Alebachew, 2019). Human error is consistently identified as the primary contributor. Research in Ethiopia attributes the majority of RTCs to driver behavior, particularly:

- **Speeding** (19–32% of crashes)
- **Careless or unethical driving** (22–39%)
- **Improper overtaking** (16%)

Collectively, driver-related factors account for 53.4% to 62% of all RTCs (Abera, 2019; Debela, 2019). This aligns with global findings; Agarwal et al. (2020) note that human factors are implicated in 78% of crashes, with drivers directly at fault in 57% of cases, primarily due to excessive speed (49.8%) and inattention (30.8%). Vehicle-related factors, such as brake or steering failure (14.2%) and tire defects (8.5%), are less common.

2.5. Expressway Toll Plazas and Safety

While toll roads offer substantial transportation benefits, the toll plaza areas themselves present distinct safety challenges. Despite their widespread use—particularly in the United States—their safety implications remain understudied (Muamer & Mohamed, 2018). Recent research indicates that zones surrounding toll plazas can be more hazardous than other road segments, experiencing a higher frequency of crashes (Saad, 2016).

A primary safety hazard is driver confusion induced by complex lane configurations (e.g. cash, electronic toll collection, and high-speed lanes). The decision-making process for lane choice, coupled with the necessity to decelerate or stop, creates significant conflict points. Consequently, the geometric and operational design of toll plazas is a critical factor for enhancing safety in these high-risk zones (Saad, 2016; Suryo, 2019).

2.6. Traffic Volume & Flow Characteristics

Traffic flow is a complex system whose characteristics directly impact safety. Microscopic traffic flow theory examines the behavior of individual vehicles and their interactions to understand the statistical properties of the overall system (Zeng et al., 2017).

At toll plazas, driver behavior—including speed reduction, lane selection, and lane-changing maneuvers—significantly influences the quality of traffic flow. Congestion often occurs unevenly, with extended queues forming at specific lanes while others remain underutilized. Enhanced driver information systems and intelligent traffic management applications present a significant opportunity to reduce travel delays and improve operational efficiency at these critical bottlenecks (Neuhold et al., 2018).

2.7. The Role of Road Geometry

Unsafe or inadequate road infrastructure is a major contributor to traffic crashes. The geometric design of a road—encompassing its cross-section, profile, and alignment—has a significant impact on crash frequency (Sipos, 2022). Key design elements include lane width & number, shoulder dimensions, median presence, and horizontal and vertical curvature (Tesema, 2020). The primary goal of geometric design is to optimize safety and operational efficiency while minimizing construction costs & environmental impact.

3. Methodology and Data

3.1. Research Design

This study employed a cross-sectional research design, integrating both descriptive and empirical approaches. The descriptive component characterized the existing traffic crash scenario at the toll plazas, while the empirical component facilitated the analysis of relationships between key variables. Data were collected for a specific point in time, consistent with cross-sectional framework.

3.2. Data Sources and Collection

Both primary and secondary data sources were utilized to address the research objectives.

- **Primary Data:** Field observations and photographic documentation were conducted at each toll plaza to capture site-specific physical characteristics and prevailing operational conditions.
- **Secondary Data:** Historical data on road traffic crashes, traffic flow, and geometric design were obtained from the Ethiopian Toll Road Enterprise (ETRE). Additional secondary sources included annual reports, published journals, relevant institutional websites, academic modules, and textbooks.

The core dataset comprised complete crash frequency and severity records from the ETRE for a nine-year period (September 4, 2007 E.C, to June 30, 2015 E.C). Of the 329 reported traffic incidents at the expressway toll plazas, 52 resulted in injuries, with the remainder causing property damage only. A mixed-methods approach, integrating quantitative and qualitative analytical techniques, was applied to this data.

3.3. Variable Description

3.3.1. Independent Variables

The following independent variables were used in the analysis:

- **Annual Average Daily Traffic (AADT):** The yearly AADT value for each of the six toll plazas on the expressway.
- **Road Geometric Characteristics:** Data collected for each toll plaza included:
  - ✓ Number of exit lanes
  - ✓ Exit width (meters)
  - ✓ Road gradient (percentage)
  - ✓ Tangent length (meters)
  - ✓ Operating speed (km/h)

- **Vehicle Type:** Vehicles were classified according to the Ethiopian Toll Road Enterprise's (ETRE) axle-based system (V1–V7). For modeling purposes, these were consolidated into four behavioral categories:
  - ✓ **Category 1:** V1 (Car & 4WD) & V2 (Minibus)
  - ✓ **Category 2:** V3 (Bus & Small Truck – 2 Axles)
  - ✓ **Category 3:** V4 (Heavy Truck – 3 Axles)
  - ✓ **Category 4:** V5 (Heavy Truck – 4 Axles), V6 (Heavy Truck – 5 Axles), & V7 (Truck & Trailer – 6 Axles)

3.3.2. Dependent Variable

The dependent variable for this study is the **annual number of crashes**. In the subsequent multiple linear regression analysis, this constitutes the known response variable (Y), which is modeled as a function of the independent predictor variables (X). Establishing a relationship between a variable that is known to react to changes in two or more other variables is the issue at hand. The other variable influencing the known-to-respond variable, Y, is referred to as the dependent variable and the known-to-respond variable is the independent variable i.e. X variable.

4. Results and Discussion

This chapter presents the analysis of the primary and secondary data collected for the research. The crash database, sourced from the Ethiopian Toll Roads Enterprise, spans an eight-year period from September 4, 2007 E.C, to June 30, 2015 E.C.

4.1. Characteristics of Road Traffic Crashes on the Expressway

The crash records for the Addis Ababa–Adama Expressway, as shown in Table 2, encompass all incidents reported by the Road and Traffic Safety Management Department from September 4, 2007 E.C, to June 30, 2015 E.C.

During this period, 3,486 traffic crashes were recorded on the expressway, resulting in 199 fatalities, 547 serious injuries, and 1,378 minor injuries. An analysis of crash outcomes reveals that 5.71% of crashes resulted in fatalities, 15.69% led to serious injuries, and 39.52% caused minor injuries. Due to incidents involving multiple outcomes (e.g., a single crash causing both injury and property damage), the total proportion exceeds 100%; the data indicates that 73.92% of crashes resulted in some form of property damage.

Table 2: ETRE road traffic crash data for the past nine (9) years

Fiscal Budget Year (E.C)	Total No. of Crash	Total No. of Vehicles Involved	No. of Human Injury			Type of Crash				AADT
			Fatal Injury	Serious Injury	Light Injury	Fatal Crash	Serious Crash	Light Crash	Property Damage	
2007	164	188	21	33	74	9	11	27	117	8,955
2008	307	385	28	74	166	17	24	56	210	12,935
2009	310	357	20	33	75	11	25	56	218	18,301
2010	391	481	26	64	125	20	18	48	305	21,197
2011	469	578	25	87	197	16	33	78	342	23,225
2012	448	522	11	42	151	10	30	63	345	22,860
2013	447	527	16	52	164	13	19	80	335	24,505
2014	497	587	24	67	135	17	26	58	396	26,928
2015	453	589	28	95	291	21	38	85	309	26,424
Sum	**3,486**	**4,214**	**199**	**547**	**1,378**	**134**	**224**	**551**	**2,577**	

Source: ETRE, Road and Traffic Safety Management Department database

4.1.1 Road traffic crash on Toll Plazas

Data encompassing the entire nine-year service life of the expressway, including all reported crashes, was collected and analyzed using both qualitative and quantitative methodologies.

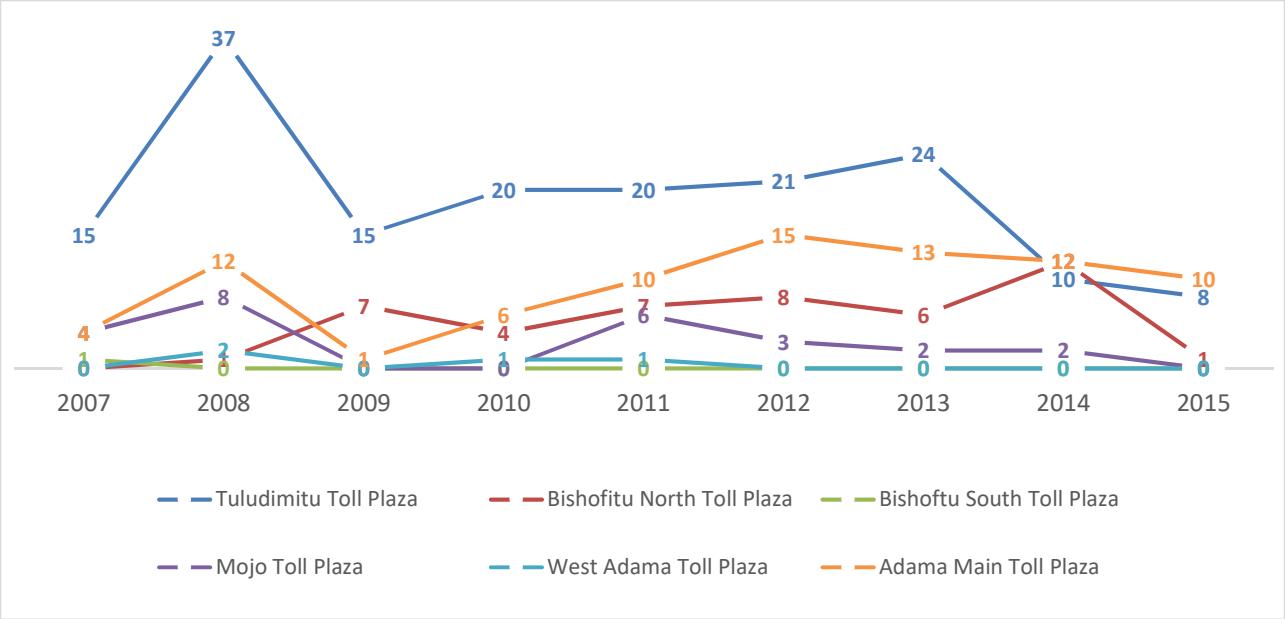


Figure 1: Crash yearly on each Plaza over the analysis
Source: ETRE road traffic crash database

The analysis of 329 recorded traffic accidents (RTA) at toll plazas reveals specific temporal and spatial patterns. As shown in Figure 1, the fiscal years 2008 and 2012 had the highest incidence, with 60 and 47 crashes respectively. Spatially, over half of all incidents (51.67%) occurred at the Tulu Dimitu Plaza (Figure 2). Temporally, crashes were distributed relatively evenly throughout the week, with a slight mid-week peak on Wednesday (17.93%) and Tuesday (17.63%), as illustrated in Figure 3. This pattern suggests that consistent factors like traffic volume and driver behavior, rather than weekend-specific activities, are primary influencers of crash frequency.

Table 3: ETRE road traffic crash causality data on each plaza in the past nine (9) years

Name Plazas	Fatal Crash	Serious Crash	Slight Crash	Property Damage	Total
Tulu Dimitu	4	9	10	147	**170**
Bishofitu North	1	2	0	43	**46**
Bishoftu South	0	0	0	1	**1**
Mojo	0	0	3	22	**25**
West Adama	0	0	0	4	**4**
Adama Main	6	4	13	60	**83**
Total	**11**	**15**	**26**	**277**	**329**

Source: ETRE road traffic crash database

Further analysis of crash severity, detailed in Table 3, identifies the Main Adama Plaza as

the location with the highest number of fatalities, accounting for 25.26% of all crash-related deaths. The most prevalent cause of crashes across all locations was brake failure, responsible for 54.41% of incidents. The most hazardous specific location on record was the main gate at Tulu Dimitu, situated at the 2+600 km road section.

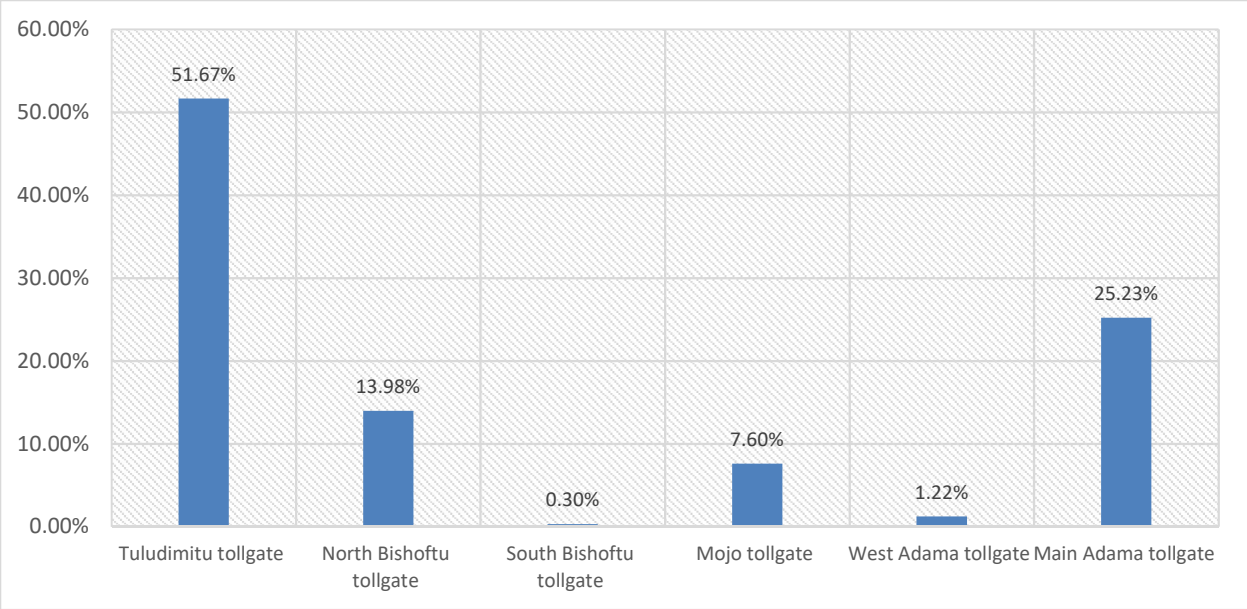


Figure 2: Crash on each Plaza over the analysis
Source: ETRE traffic crash database

According to nine years of traffic crash data on the expressway toll plazas, Tulu Dimitu plaza is the most dangerous tollgate because it accounts for 51.67% of all crash. Mojo Plaza accounts for 7.60% of crash while Main Adama Plaza comes in second with 25.23%. West Adama Plaza records 1.22% while North Bishoftu Plaza has 13.98%. With just 0.30%, South Bishoftu Plaza has the smallest proportion. While the lower crash rates at other plazas may imply comparatively better circumstances or lower traffic volumes the high percentage of incidents at Tulu Dimitu and Main Adama plazas implies that these areas may demand particular attention for safety improvements.

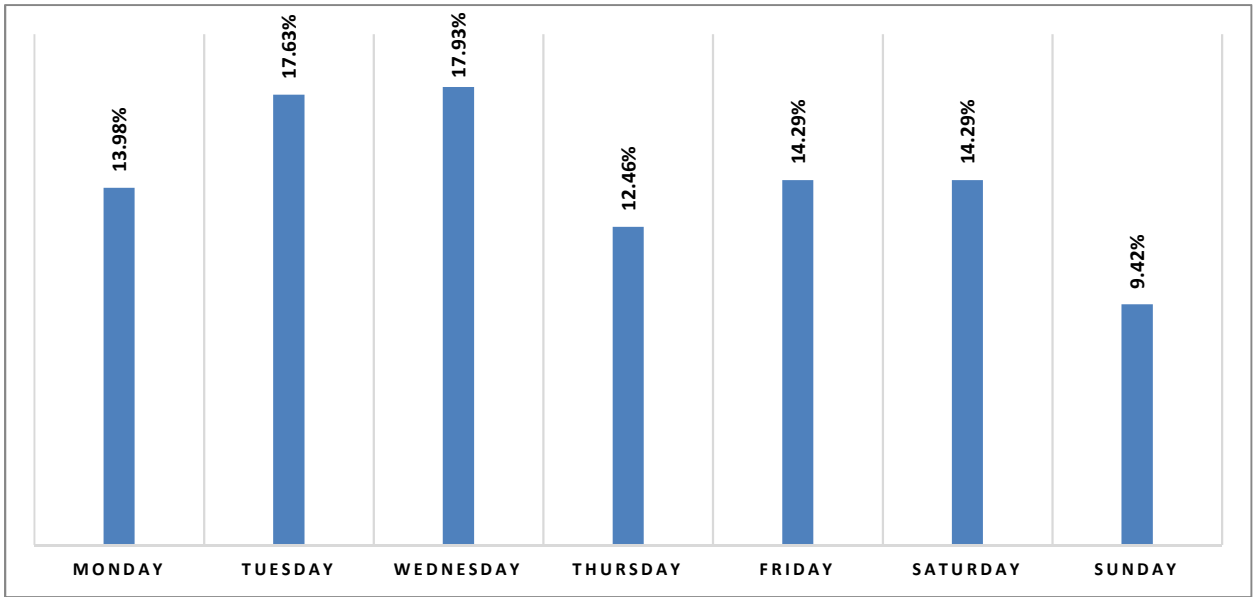


Figure 3: Crash distribution of weekdays over the analysis period
Source: ETRE traffic crash database

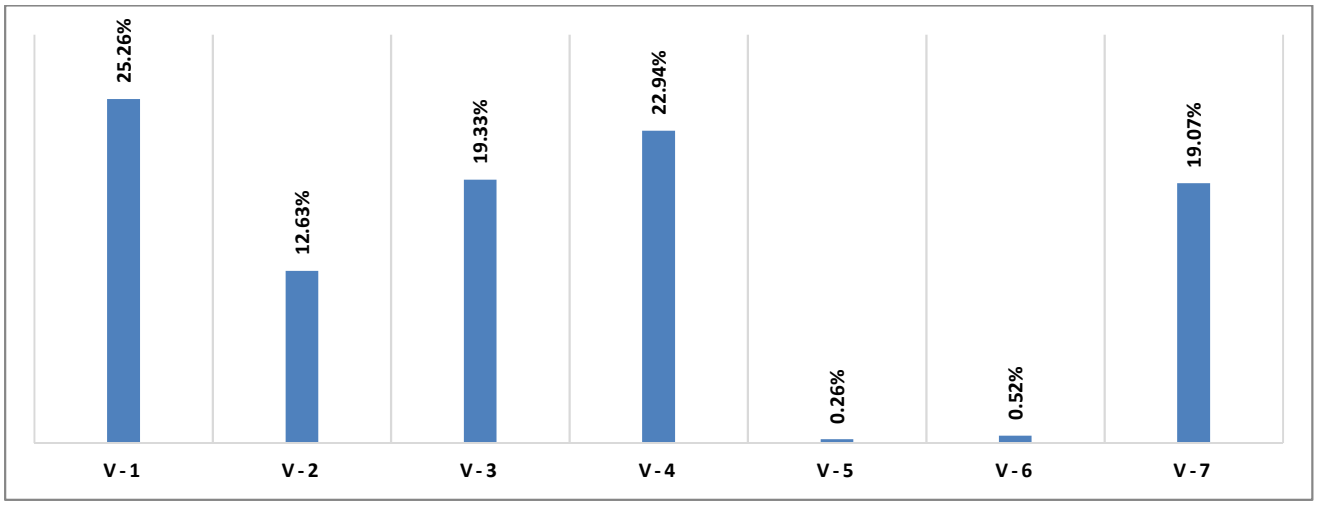


Figure 4: Crash distribution of vehicle type over the analysis period
Car & 4WD, V2= minibus, V3= bus & small truck (2 Axle), V4= heavy truck (3 Axle), V5 = heavy truck with (4 Axle), V6 = different axle confirmation of heavy truck (5 Axle) and V7= Truck & Trailer/Articulated Truck (6 Axle)
Source: ETRE traffic crash database

As shown in Figure 4, V-1 is the most involved in occurrences up to 25.26% of the total followed by V-4 which makes up 22.94%. V-3 and V-7 make up 19.33% and 19.07% of the total respectively. V-5 and V-6 contribute very little 0.26% and 0.52%, respectively. However, V-2 counts 12.63% while the nearly zero involvement of V-5 and V-6 discloses their relatively lower crash rates the large percentage of occurrences involving V-1, V-4, and V-3 recommends that these vehicle types may face unique dangers.

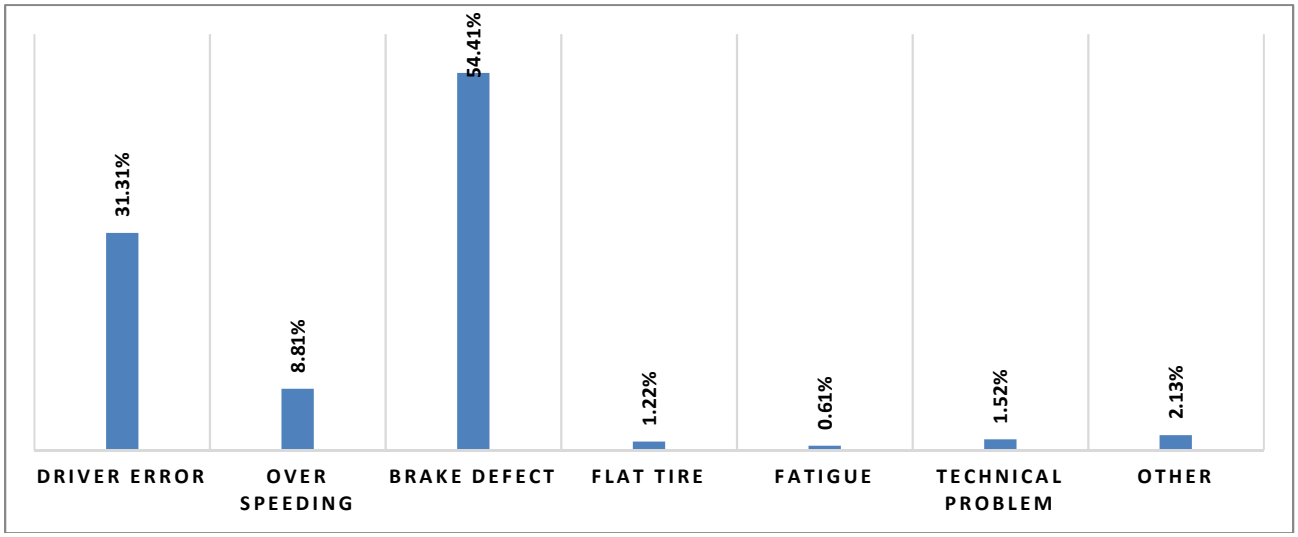


Figure 5: Crash distribution of Tollgate over the analysis period
Source: ETRE traffic crash database

As summarized in Figure 5, brake failure is the leading cause of crashes, accounting for 54.41% of all incidents. Driver error is the second most significant factor, responsible for 31.31% of occurrences. Speeding contributes to 8.81% of crashes, while other factors like flat tires (1.22%), mechanical problems (1.52%), and driver exhaustion (0.61%) are less common.

This distribution underscores two critical safety issues: the high prevalence of brake faults highlights a pressing need for improved vehicle maintenance and inspections, while the substantial role of human error emphasizes the importance of enhanced driver education and the promotion of safer driving habits. On the expressway, traffic police and road safety officers determine the official cause of a crash at the scene. Under this classification, "driver error" is the primary cause. This category encompasses a range of dangerous behaviors, including:

- Exceeding the speed limit.
- Tailgating (following too closely).
- Improper signaling.
- Making unsafe lane changes.
- Disobeying traffic control devices (e.g., stop signs, yield signs, and traffic signals).

In more extreme cases, aggressive driving practices—such as intentionally pursuing another vehicle to intimidate its driver or cause damage—have also been identified as contributing factors.

These findings highlight an urgent need for strengthened traffic law enforcement and targeted safety initiatives. Comprehensive driver education programs and public awareness campaigns are essential to curb the aggressive and negligent driving behaviors that lead to collisions.

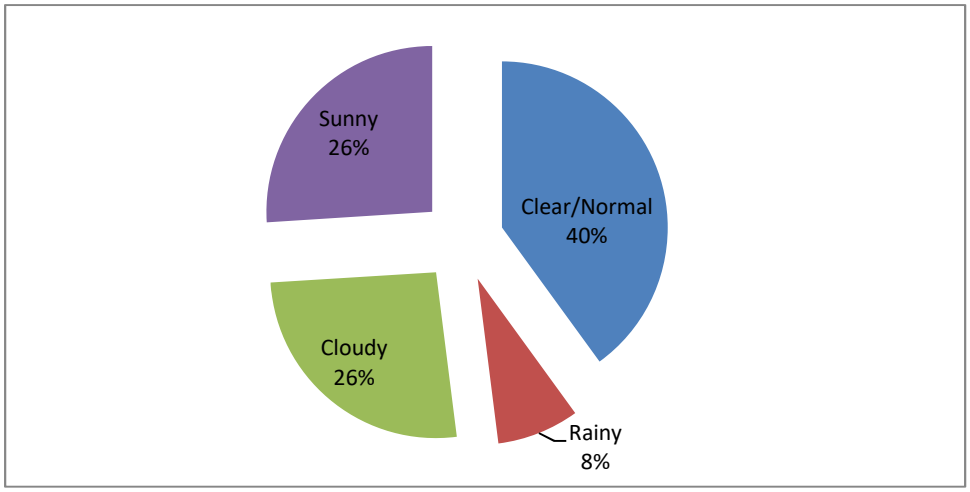


Figure 6: Crash distribution of climate conditions in the analysis period
Source: ETRE traffic crash database

As illustrated in Figure 6, the majority of crashes occurred during clear or normal weather (40.14%), followed by cloudy conditions (26.30%). Sunny weather accounted for 25.95% of incidents, while rainy conditions were the least common, responsible for only 7.61%. This distribution suggests that crashes are more frequently associated with clear and cloudy conditions. This may be due to higher traffic volumes or altered driving behaviors, such as increased speed or reduced vigilance, during these prevalent weather states. Conversely, the lower incidence of crashes during rainy weather could result from either reduced traffic volume or increased driver caution in adverse conditions.

To objectively assess road safety, the crash rate is a key metric. It is calculated to standardize crash frequency relative to exposure, providing a clearer picture of risk. The crash rate for a specific road segment over a given period is determined by dividing the total number of crashes by the total vehicle distance traveled (often expressed in million vehicle kilometers, or MVK).

$\mathbf{AR} = (\mathbf{Accidents} * \mathbf{10}\text{^}8)/ (\mathbf{AADT} * \mathbf{365} * \mathbf{T})$

AR is Crash rate (Million vehicle kilometer travel), $\mathbf{10}\text{^}8$ shows 100,000,000 kilometer travel, AADT means Average annual daily traffic, T is the length of the investigated period (in years), and 365 means number of days per year.

Table 4 Total toll plazas crash rates were computed with a mean AADT of 100,000,000 travel kilometers.

No	Plaza	Total Crashes	Average annual daily traffic	Days in year	year of Analysis	Crash rate (AR)
1.	**Adama Main Plaza**	83	19,003	365	9	133
2.	**Adama West Plaza**	4	33,338	365	9	4
3.	**Bishoftu North Plaza**	46	34,484	365	9	41
4.	**Bishoftu South Plaza**	1	8,976	365	9	3
5.	**Mojo Plaza**	25	22,781	365	9	33
6.	**Tulu Dimitu Plaza**	170	83,136	365	9	62

Source: ETRE traffic crash database

Table 4 shows the noticeable difference in the crash rates (AR) between the different plazas. With 133 crash per 100 million vehicle kilometers, Adama Main Plaza has the highest crash rate signifying that crashes occur more frequently than traffic volume. With an AR of 62, Tulu Dimitu Plaza comes next indicating a significant safety issue as well. Mojo Plaza and Adama West Plaza have comparatively lower crash rates with rates of 33 and 4 respectively. Comparing Bishoftu North Plaza's moderate crash rate of 41 and only 3 crash, Bishoftu South Plaza has the lowest crash rate of any of the plazas on the list making it the safest.

4.1.2 Description of the characteristics of traffic flow on toll plazas

In the Addis Ababa - Adama expressway on six toll plazas in the study period there was 67,063,549 traffic flow counted. As shown in Figure 5, the highest traffic flow count was 41.21% at Tulu Dimitu Plaza and the 48.10% vehicle type was V1 (automobile and similar vehicles) as shown in Table 5 below, the study mentioned the traffic flow and the crash relationship by using the collected data.

Table 5: ETRE traffic flow data for the past nine (9) years

Toll Plaza	V-1	V-2	V-3	V-4	V-5	V-6	V-7	Total	AADT
Adama West	2,732,284	1,644,107	1,301,945	266,596	106,519	38,549	346,052	6,436,052	17,892
Adma Main	4,216,099	2,029,974	2,045,617	1,134,224	222,327	87,560	1,172,174	10,907,975	30,052
Bishoftu North	6,657,946	2,065,850	1,434,775	766,156	43,531	23,378	308,048	11,299,684	31,148
Bishoftu South	1,344,957	821,947	486,265	189,575	10,960	7,011	109,503	2,970,218	8,216
Mojo	3,037,045	1,227,754	1,858,846	822,082	194,694	158,512	600,730	7,899,663	21,889
Tulu Dimitu	14,097,881	5,630,087	4,891,770	1,455,615	249,028	140,404	1,085,172	27,549,957	76,133
Total	**32,086,212**	**13,419,719**	**12,019,218**	**4,634,248**	**827,059**	**455,414**	**3,621,679**	**67,063,549**	

Source: ETRE, Road and Traffic Safety Management Department database

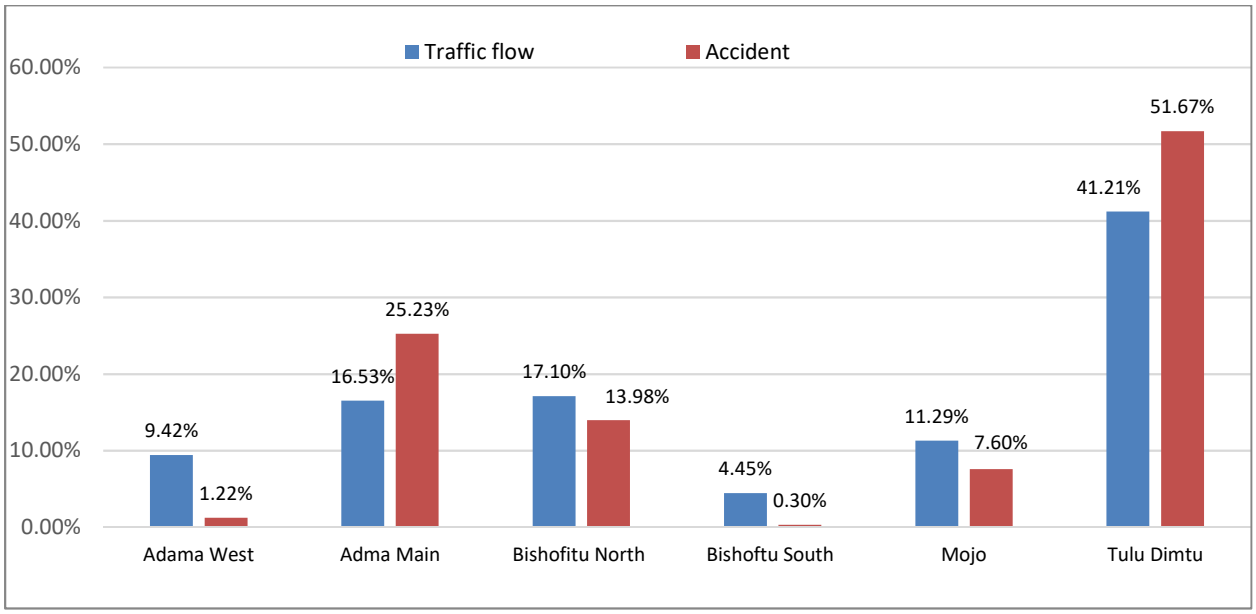


Figure 7: The relationship of traffic flow with traffic crashes over the analysis period
Source: ETRE traffic crash database

As shown in Figure 7, there are important differences in safety performance amongst plazas when comparing traffic flow and crash rates. With the greatest crash rate of 51.67% and the largest traffic flow of 41.21% Tulu Dimitu Plaza shows an excessively high crash rate to its traffic volume. Similar to this, Adama Main Plaza has a high crash rate of 25.23% with 16.53% of traffic flow indicating possible safety issues. With 17.10% of the traffic and a lower crash rate of 13.98% at Bishoftu North Plaza shows a better correlation between traffic volume and crash frequency.

However, while handling 9.42% and 4.45% of the traffic respectively Adama West and Bishoftu South Plazas have comparatively low crash rates of 1.22% and 0.30% indicating that these toll plazas are relatively safer. Mojo Plaza has a moderate crash rate of 7.60% and 11.29% of the traffic flow. Traffic management or other safety benefits are demonstrated by Adama West and Bishoftu South. According to the data, the research identifies Tulu Dimitu and Adama Main Plazas as places in need of specific safety improvements because of their excessively high crash rates.

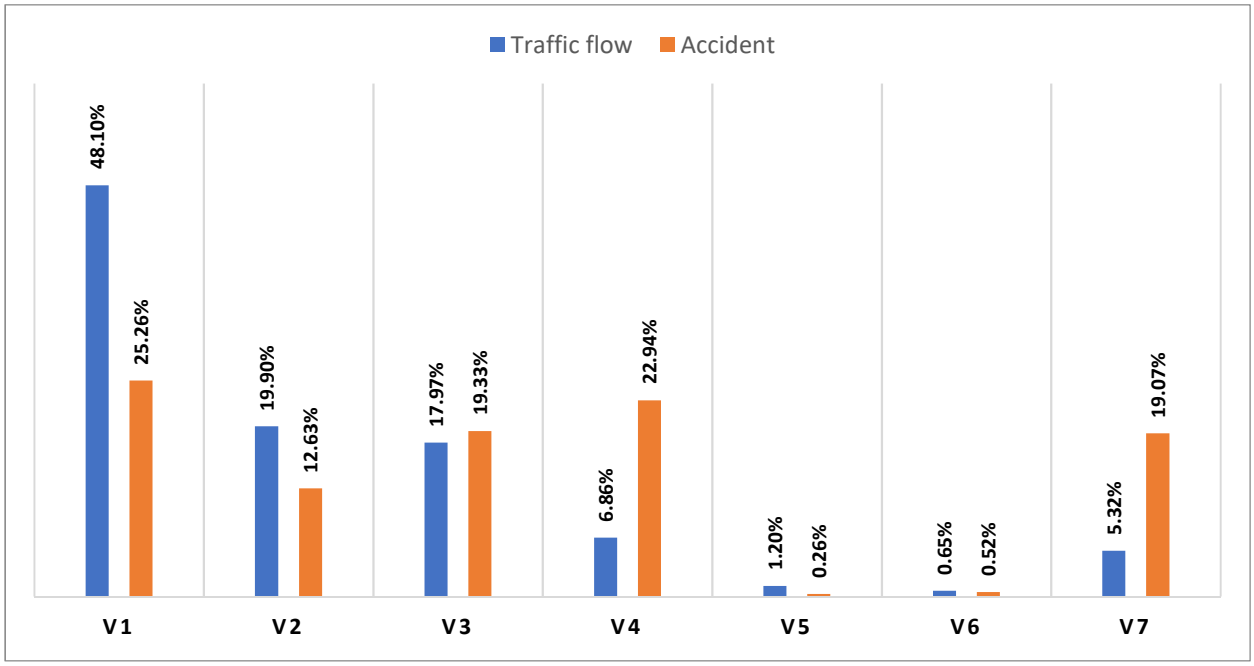


Figure 8: The relationship between vehicle-type traffic flow and traffic crashes over the analysis period
Car & 4WD, V2= minibus, V3= bus & small truck (2 Axle), V4= heavy truck (3 Axle), V5 = heavy truck with (4 Axle), V6 = different axle confirmation of heavy truck (5 Axle) and V7= Truck & Trailer/Articulated Truck (6 Axle)
Source: ETRE traffic crash database

As shown in Figure 8, some important insights were revealed when traffic flow and crash rates for various vehicle kinds were compared. Only 25.26% of crashes involve V-1 vehicles which account for 48.10% of all traffic flow indicating a comparatively low crash rate given their volume. In addition to that, representing a lower-than-expected crash rate, V-2 vehicles that make up 19.90% of traffic flow are responsible for 12.63% of crash.

In difference to the traffic flow V-3 and V-4, vehicles exhibit a higher percentage of crash. While V-4 vehicles only account for 6.86% of traffic flow they contribute to a considerable 22.94% of crash, suggesting a possibly higher risk factor connected with this type of vehicle. In addition to that, V-3 vehicles make up 17.97% of traffic but are involved in 19.33% of incidents.

V-5 and V-6 cars are involved in a few crash 0.26% and 0.52%, respectively, and have low traffic flow 1.20% and 0.65% respectively signifying little crash involvement overall. A disproportionately high crash rate proposed a 19.07% crash rate for V-7 cars that account for 5.32% of traffic flow. While V-1 and V-2 vehicles despite their dominance in traffic exhibit relatively reduced crash involvement this analysis identifies V-4 and V-7 vehicles as higher-risk categories that call for targeted safety measures or additional research.

Table 6: The expressway toll plaza operating speed

	Entrance plaza							
Exit plaza	**Adama Main**	**Adama West**	**Bishoftu North**	**Bishoftu South**	**Mojo**	**Tulu Dimitu**	**Average Operating Speed**	**Number of vehicles**
Tulu Dimitu	102	96	84	84	93	0	**76**	**15,299**
Bishoftu North	90	91	0	79	82	88	**86**	**1,737**
Bishoftu South	87	90	77	0	81	90	**85**	**1,273**
Mojo	76	71	100	85	0	95	**85**	**2,322**
Adama West	0	0	87	95	71	103	**89**	**6,683**
Adama Main	0	0	90	94	77	103	**91**	**11,840**
							Total	**39,154**

Source: Toll plazas operating speed of Expressway

4.2 Characteristics of geometric design of toll plazas

As shown in Table 6, one of the risk toll plazas is Tulu Dimitu, where 15,299 vehicles were registered. Depending on the exit destination, the average speed between Tulu Dimitu and other plazas varies, ranging from 84 km/h to 103 km/h. With 1,737 vehicles, Bishoftu North has a moderate vehicle count. Good traffic flow and road conditions are shown by the relatively high average operating speed between Bishoftu North and adjacent plazas. Compared to Tulu Dimitu and other large plazas, Bishoftu South had fewer vehicles 1,273 than other plazas. Average speeds between Bishoftu South and the other plazas are typically over 80 km/h.

4.3 Model development

4.3.1 The Effect of the Number of Crash at Toll Plaza

To examine the effect of the number of crash at toll plazas and to examine the relationship between them, three exemplary crash effect measures of the vehicle type were constituted; by adopting a multiple linear regression analysis and been shown in the table below:

Table 7: Analysis of variance (ANOVA) table

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3008.509	5	601.702	130.081	.000[b]
	Residual	222.028	48	4.626		
	Total	3230.537	53			
a. Dependent Variable: Number of crash						
b. Predictors: (Constant), Average Annual Daily Traffic, Categorical type of vehicle 3, Categorical type of vehicle 4, Categorical type of vehicle 1, Categorical type of vehicle 2						

Source: Own computation using survey data

From the above table 7, the ANOVA results show that the four vehicle types and average annual daily traffic as predictors significantly explain the variance in the number of crash. This strong correlation supports the use of these predictors in the regression model to accurately estimate crash counts and emphasizes the significance of vehicle type & average annual daily traffic in crash frequency.

Table 8: Analysis of Coefficients table

Coefficients						
		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	.304	.479		.022	.982
	Categorical type of vehicle 1	.409	.103	.237	4.013	.000
	Categorical type of vehicle 2	1.433	.265	.348	6.543	.000
	Categorical type of vehicle 3	.747	.144	.280	5.324	.000
	Categorical type of vehicle 4	1.300	.234	.311	6.640	.000
	Average Annual Daily Traffic	.002	.000	.686	6.804	.000
a. Dependent Variable: Number of crash						

Source: Own computation using survey data

The above table 8 shows the baseline crash rate has very little predictive power because it is not statistically significant (p = 0.982). Types of vehicles among vehicle types, type of vehicle 2 (Isuzu, FSR, and similar vehicles) had the greatest impact on crash (Beta = 0.348), followed by Type 4 (Trailer vehicles like high bed, lobed, and similar trails) (Beta = 0.311), Type 3 (Sino track and similar loading track vehicles) (Beta = 0.280), and Type 1 (automobile, minibusses, and similar vehicles) (Beta = 0.237). Every type of vehicle has a significant impact on crash prediction ($p < 0.001$). The strongest significant predictor is Average Annual Daily Traffic (AADT) (Beta = 0.686), suggesting a strong correlation between greater crash rates and daily traffic volume. At $p < 0.001$, the effect is highly significant. The model emphasizes that the frequency of crash is strongly influenced by both traffic volume and vehicle type. With its emphasis on the connection between traffic exposure and crash risk, AADT has the biggest influence.

Table 9: The result of Regression of variables from SPSS

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.965[a]	0.931	0.924	2.151
a. Predictors: (Constant), Average Annual Daily Traffic, Categorical type of vehicle 3, Categorical type of vehicle 4, Categorical type of vehicle 1, Categorical type of vehicle 2				
b. Dependent Variable: Number of crash				

Source: Own computation using survey data

As shown in Table 9, the model's R-squared (R^2) value of 0.931 indicates a very strong fit. This means that 93.1% of the variance in crash frequency is explained by the four vehicle types and the Average Annual Daily Traffic (AADT) included in the model. The Adjusted R-squared value, which is also 0.931, confirms the model's robustness and suggests a minimal risk of over fitting.

Furthermore, the model demonstrates high predictive accuracy. The standard error of 2.151 indicates that the model's predictions for crash counts typically fall within approximately 2.15 units of the observed values.

Based on the coefficients presented in Table 8, a multiple linear regression equation was developed to predict the number of crashes. This model estimates the crash frequency (Y) as a function of the four classified vehicle categories. The predictive equation is as follows:

Number of crash at toll plaza = 0.304 + 0.409 (categorical type of vehicle 1) + 1.433 (categorical type of vehicle 2) + 0.747 (categorical type of vehicle 3) + 1.300 (categorical type of vehicle 4) + 0.002 (average annual daily traffic)

The number of crash varies by the coefficient value for every unit increase in the related predictor. An increasing 1.433 crash are correlated with every unit rise in Vehicle Type 2 and the number of crash rises by 0.002 for each unit of Average Annual Daily Traffic.

5 Conclusions and Recommendations

5.1 Conclusions

- Over the nine-year study period, a total of 3,486 crashes occurred, involving 4,214 vehicles. These incidents resulted in the following severity breakdown: 5.71% fatalities, 15.69% serious injuries, 39.52% minor injuries, and 73.92% property damage, the total proportion of severity breakdown exceeds 100% due to incidents involving multiple outcomes e.g., a single crash causing both injury and property damage may be counted in two groups. The overall number of crashes increased significantly, from 164 in 2007 E.C to 497 in 2014 E.C, with a minor decline in the 2015 E.C fiscal year. This upward trend corresponds with a sharp rise in traffic volume, as the Annual Average Daily Traffic (AADT) grew from 8,955 in 2007 to 26,424 by 2015 E.C.
- During this period, 67,063,549 vehicles passed through the toll plazas. Of the 329 recorded crashes specifically at the plazas, the severity distribution was 3.34% fatalities, 4.56% serious injuries, 7.90% minor injuries, and 84.19% property damage.

- An analysis of crash characteristics reveals that the majority (51.67%) occurred at the Tulu Dimitu toll plaza. Tuesday (17.63%) and Wednesday (17.93%) were the most common days for incidents. Automobiles were the vehicle type most frequently involved in crashes.
- Examination of causal factors indicates that braking failures were the leading cause, responsible for 54.41% of all crashes. Driver error was the second most significant factor, accounting for 31.31% of incidents. Speeding contributed to 8.81% of crashes, while flat tires (1.22%), mechanical problems (1.52%), and fatigue (0.61%) were less common causes. Collectively, human and vehicle factors account for 85.72% of all traffic crashes at the toll plazas.
- The research examined the relationship between traffic flow and crashes. It was found that 41.21% of the total traffic flow was observed at the Tulu Dimitu Toll Plaza, which also accounted for 51.67% of all crashes. In terms of vehicle categories, mid-level V-3 vehicles (e.g., Isuzu, FSR) represented 17.97% of the traffic flow but were involved in 19.33% of crashes. Similarly, V-7 vehicles (e.g., Trailers) were involved in 19.07% of crashes despite constituting only 5.32% of the traffic flow, indicating a disproportionately high risk.
- A multiple linear regression model was developed to analyze the correlation between vehicle types, Average Annual Daily Traffic (AADT), and crash frequency. The model demonstrates that all four vehicle categories and AADT have a statistically significant impact on crash occurrence ($p < 0.01$).
- The model's high R-squared value of 0.931 indicates that it explains 93.1% of the variance in crash numbers, showing a strong explanatory power. This confirms a robust correlation between vehicle types, traffic volume, and collision frequency.
- Based on their higher coefficients, vehicle categories 2 (Isuzu, FSR) and 4 (Sino truck and similar loading trucks) have the most substantial influence on crash rates. This finding suggests that certain vehicle models are associated with a higher risk of traffic incidents.

5.2. Recommendations

Based on the analysis of vehicle categories and their significant influence on crash rates, the following recommendations are proposed to enhance traffic safety. These measures are designed to assist the Ethiopian Toll Road Enterprise, policymakers, and road users in mitigating risks and reducing crashes.

- **Implement Targeted Public Awareness Campaigns:** Launch comprehensive campaigns to educate drivers on expressway-specific safe driving practices, with a focus on toll plaza approaches. Messaging should emphasize reducing speed, maintaining focus, and anticipating sudden stops in these high-conflict zones.
- **Focus Enforcement on High-Risk Vehicles:** The study identified that specific vehicle categories—particularly Category 2 (e.g., Isuzu, FSR) and Category 4 (e.g., Sino truck, loading trucks)—have the most substantial impact on crash rates. Furthermore, Category V-7 vehicles (Trailers) were involved in a

disproportionately high number of crashes (19.07%) relative to their traffic share (5.32%). Road safety can be significantly improved by directing targeted traffic law enforcement and inspection programs toward these high-risk vehicle types, especially at high-incident locations like the Tulu Dimitu plaza.

- **Adopt Advanced Toll Management Technologies:** The analysis confirms a direct correlation between traffic volume and crash frequency. To manage traffic density and reduce congestion-related risks, it is recommended to implement advanced toll collection systems. Solutions such as Electronic Toll Collection (ETC), dynamic toll pricing, and dedicated lanes for specific vehicle classes can streamline traffic flow, minimize stop-and-go conditions, and enhance overall safety.

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