ANALYZING ACCIDENT RISK THROUGH HAZARDOUS MANOEUVRES IN VARIOUS TRAFFIC CLUSTERS - A CASE STUDY OF NATIONAL ROAD NO.1 (EN1) IN NAMPULA CITY, MOZAMBIQUE

CL FERNANDO[1] and **DV FIJAMO**[2]

[1]Faculdade de Arquitectura e Planeamento Físico, Universidade Lúrio, Marrere Campus, Road 2.3 Km, Nampula, Mozambique; Cell: +258-870066777;
Email: cfernando@unilurio.ac.mz
[2]Departamento de Engenharia, Faculdade de Ciências Tecnológicas, Universidade de Coimbra, Portugal; Email: dorivalvictorino@gmail.com

ABSTRACT

In the present day, road accidents within the urban network of Nampula are emerging as a significant concern. Quite literally, traffic accidents are reported by road users on a daily basis; however, only those with a certain degree of severity are officially documented by the police. In reality, the number of traffic accidents recorded by the police, though substantial, falls significantly short of the total accidents occurring each day. The absence of traffic monitoring devices in the urban network of Nampula poses a hindrance to the collection of accident data, which serves as the primary source for accident risk analysis. This manuscript takes a novel approach by employing hazardous driving/maneuvering events to estimate the associated accident risk in different traffic conditions, defined by the penetration levels of various transport modes. The analysis results reveal that when the traffic flow in Nampula City is dominated by motorcycles, the risk of accidents tends to increase. The research demonstrates that alternative methodologies can be employed to improve traffic safety in contexts characterized by a deficiency in accident data.

1. INTRODUCTION

Every day, a substantial number of individuals worldwide fall victim to road accidents. As reported by the World Health Organization (WHO), an estimated 1.35 million people die to these causes annually, with an additional 20 to 50 million sustaining injuries. Human behaviour is identified as the most important factor contributing to road accidents. Notably, statistics reveal that 90% of all road traffic fatalities occurred in low and middle-income countries, particularly in Africa, despite these regions having a relatively lower percentage of the world's vehicles. In such countries, the efficacy of traffic safety policies is weakened, and monitoring systems for traffic are nearly non-existent, leading to a disregard for safety measures by drivers and motorcycle riders, (Malta, et al. 2007; Ahmed, S. et al. 2023).

To enhance traffic safety, a comprehensive understanding of the root causes of accidents is imperative, alongside the proposition of tailored measures to reinforce traffic policies. It is crucial to recognize that these measures cannot be universally applied, as each site or location may exhibit distinct characteristics, necessitating specific and targeted interventions.

A methodology employed by experts in both academic and industrial settings to assess the risk of accidents involves normalizing the number of occurred accidents in a specific traffic condition by the exposure level (Tsubota et al., 2019). However, the applicability of this approach is contingent upon well-monitored traffic conditions and the availability of representative accident data. Conversely, in situations where accident data are inexistent, implementing the aforementioned approach becomes considerably challenging.

An alternative methodology, proposed in this context, involves utilizing hazard manoeuvres rather than the absolute number of accident events to evaluate associated risk. This alternative approach assumes paramount significance in instances where accident data are unavailable, but still, it is essential to communicate to drivers and motorcycle riders the safety implications associated with their driving behaviours.

In the present study, hazard manoeuvres on a road segment are defined as any manifestation of unsafe operation by drivers and motorcycle riders within the road system.

2. AIM OF PAPER

2.1 Problem Statement

Currently, the escalation of road accidents within the urban network of Nampula City has become a notable cause for concern. While road users report daily traffic incidents, only those characterized by a certain severity level, such as severe injuries, fatalities, or major property damage, are officially documented by the police. This discrepancy results in the official accident records significantly deviating from the actual frequency of occurrences, highlighting a considerable gap between reported incidents and reality. The absence of traffic monitoring devices in Nampula's urban network further hinders the systematic collection of accident data and traffic monitoring, which is essential for conducting a comprehensive analysis of accident risk. Conducting such an analysis requires an extended and thorough period of accident data collection.

This manuscript aims to estimate the associated risk of road accidents at two specific points along the EN1 (National Road Number 1) in Nampula, taking into account the hazardous driving events (HDEs) perpetrated by drivers and motorcycle riders.

Hazardous Driving Events (HDEs) inherently encapsulate risk and potential dangers, unveiling unstable interactions among motor vehicles on the road (Shimada, 1974). HDEs are defined as manifestations of unsafe traffic conditions. The collection of Traffic Surveillance Data (TSD) at designated road sections enables the use of HDEs to more reliably capture metrics related to road traffic safety.

The ability to identify and analyse HDEs represents a promising opportunity for proactively preventing traffic accidents.

2.2 Scope of Paper

This manuscript aims to estimate traffic accident risk by considering hazardous driving events (HDEs) performed by drivers and motorcycle riders under various traffic characteristics. Traffic characteristics are defined in relation to the penetration level of different transport modes in the traffic flow, including passenger cars, public transport (minibuses), trucks, and motorcycles. HDEs, in this context, represent interactions among these transport modes on the road, indicating the potential for road accidents.

The prediction of road accident associated risk through hazardous driving events becomes particularly valuable in situations where accident data are either unavailable or do not accurately reflect actual events, as observed in Nampula City. Despite the prevailing belief that the primary cause of road accidents in Nampula City is the risky manoeuvres performed by public transport operators, such as bus drivers and motorcycle-taxi riders, who often disregard traffic codes, not all accidents are officially recorded by the police for further analysis. Therefore, this manuscript utilizes traffic surveillance data (TSD) collected on site to identify dangerous manoeuvres in traffic, subsequently employed for the analysis of road accident associated risk.

The independent variables, in this analysis, include the traffic flow of different transport modes (passenger cars, public transport, trucks, motorcycles, and heavy machinery) at each 5-minute time interval, while the dependent variable is the number of HDEs detected during each 5-minute period.

3. METHODOLOGY

3.1 The Study Area

The study was conducted in two sections along the EN1 national road in Nampula City, namely Muako-Wanvela and Nampako.

Muako-Wanvela is distinguished as a permanent roadside marketplace predominantly occupied by informal vendors, with some fixed kiosks also present. It serves as a stopping point for minibuses to embark and disembark passengers. Although the road was originally designed to have one lane for each direction, the persistent presence of vendors, buyers, and commuters contributes to overcrowding, resulting in a reduced road capacity. Muako-Wanvela serves as an access point to two minibuses terminals, Substação and Marrere. The road surface leading to the Marrere terminal, where is located one of the two major hospitals of the city and a well know university in the region, is in suboptimal condition; primarily contributing to the reduction in the number minibuses' traffic towards this terminal, however, increasing the number of motorcycles operating as taxi.

In contrast, Nampako represents a straight-line road segment along the EN1 with one lane for each direction. The road surface is well-maintained, and no specific activities are conducted along the roadside. However, like Muako-Wanvela, Nampako segment leads to a new residential area.

3.2 Data Collection and Cleaning

3.2.1 Data Collection

In both road sections, Muako-Wanvela and Nampako, traffic surveillance data (TSD) were systematically gathered. Vehicle classification was conducted based on their dimensions and activities, resulting in the identification of five categories: i) motorcycles, ii) passenger cars, iii) minibuses (limited to those operating as public transport), iv) trucks (vehicles with a weight exceeding 2,000 tons), and v) heavy machines (including agricultural and construction machinery). At each 5-minute time interval, the flow of vehicles in each category was recorded separately, specifying the trajectory as either "in" or "out", indicating movement toward or away from the city centre, respectively.

Simultaneously, during the same time intervals, the occurrence of hazardous manoeuvres in the traffic flow was counted. In this study, a hazard manoeuvre represents any of the following: abrupt lane changes, sudden turns, zigzag driving behaviour, overtaking on the left side or simultaneously on both sides, and sudden braking.

Data collection spanned from 6:00 AM to 12:00 PM over five days, from February 1st to 5th, 2022. A total of 913 collected samples were obtained, being 233 from Muako-Wanvela and 680 from Nampako. Due to technical issues with the video camera during the survey at Muako-wanvela led to the corruption of three data samples; thus, explaining the disparity in the dataset sizes between Muako-Wanvela and Nampako.

3.2.2 Data Cleaning

As mentioned in the preceding subsection, the unequal number of samples at both sites stems from the corruption of data for three days at Muako-Wanvela. To mitigate the impact of this unbalanced data distribution, only the samples corresponding to the dates available at both sites were included in the analysis. Given that Muako-Wanvela has samples from two days, only those two days were considered for Nampako, with the remaining days excluded from the analysis. This approach yielded a total of 493 observations, distributed as follows: 233 from Muako-Wanvela and 260 from Nampako.

3.2.3 Distribution of the Vehicles' Categories at the Sites

The penetration rates of each vehicle category in the traffic flow, given by the average (μ) and standard deviation (σ), are exhibited for both sites as shown in the Table 1.

Table 1: Penetration level of vehicles category at the sites

Vehicle categories	**Muako-wanvela (μ, σ):**	**Nampako (μ, σ):**
Heavy Machines	(0, 0)	(0, 0)
Minibuses	(6, 2)	(10, 3)
Motorcycles	(23, 5)	(14, 5)
Passenger Cars	(13, 5)	(12, 5)
Trucks	(5, 3)	(6, 3)

The data reveals that the penetration rates of heavy machines, passenger cars, and trucks in the traffic flow are nearly comparable between the two sites.

In Nampako, the traffic flow for passenger cars, minibuses, and motorcycles tends to be more evenly distributed, while in Muako-Wanvela, noteworthy differences are observed in these categories.

<u>3.3 Data Analysis</u>

Four analytical steps have been taken to analyse the associated risk of accident on the traffic flow.

3.3.1 Cluster of the Traffic Flow (first step)

The clustering analysis aimed to identify existing patterns in traffic flow, employing vehicle categories (passenger cars, minibuses, trucks, heavy machinery, and motorcycles) as clustering factors. Categorical variables such as the direction of movement (in and out) and the location (Muako-Wanvela and Nampako) were excluded to prevent these variables from overshadowing the primary clustering factors, acting as potential "swamping variables."

The K-means clustering analysis was selected to profile the existing homogeneity in traffic flow characteristics. Using the elbow method, three optimal patterns were identified:

Pattern (1): Higher traffic flow of minibuses and passenger car; Pattern (2): Characterized by a higher motorcycle traffic flow and lower minibuses traffic flow; and, Pattern (3): Lower traffic flow of passenger cars and motorcycles, as shown in Figure 1.

The outcomes of the clustering analysis define the traffic flow conditions, playing a pivotal role in determining exposure to the associated risk of a road accident. Understanding these patterns can guide the development of targeted strategies for accident risk mitigation in specific traffic conditions.

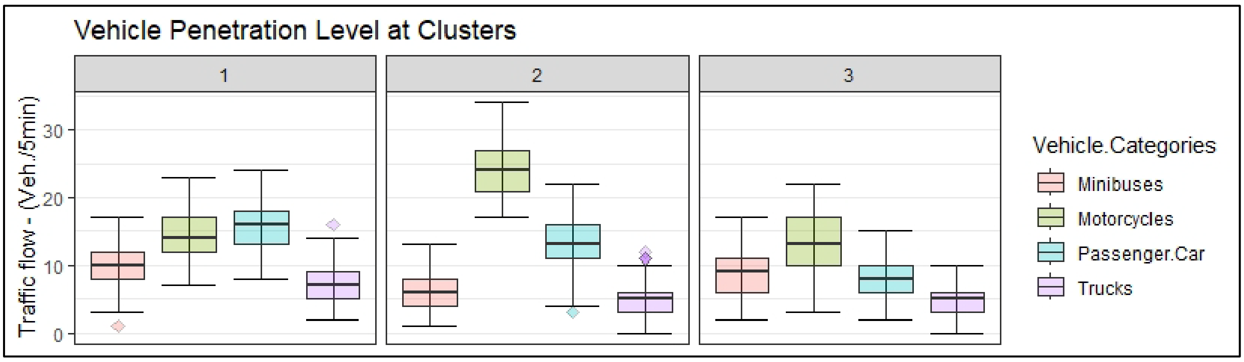

Figure 1: Vehicle penetration level at each cluster group

3.3.2 Driving Exposure Determination (second step)

Driving exposure was initially defined by Phillip Carroll in 1971 as "the frequency of traffic events which create a risk of an accident." Roger Chapman, in 1973, offered an alternative definition, characterizing it as "a measure of the opportunities for an accident to occur" (Wolfe, 1982). Despite acceptance, these definitions have faced criticism for their limited consideration of exposure as an active process involving motor vehicles only. A more comprehensive concept was proposed by Wolfe in 1982, defining exposure as any "situation that has some risk of involvement in a road traffic accident." The utility of exposure lies in determining the degree of risk in various road traffic situations, enabling the comparison of accident rates that cannot be achieved through absolute accident frequencies. However, meaningful comparisons require a common measure of exposure.

In this study, each traffic pattern resulting from the cluster analysis is employed to define the traffic condition from which the associated risk of an accident is estimated. Exposure is calculated based on the time spent in each traffic pattern, expressed as vehicle hours travelled (VHT).

As the patterns consist of vehicles from different categories, the traffic unit for all vehicle categories is converted to Passenger Car Units (PCU), and exposure is calculated as shown in Equation (1).

$$VHT_i = t_i \, x(Minibuses_i + Motorcycle_i * 0.75 + Passenger.car_i + Truck_i * 2) \qquad (1)$$

Where:

$i - is\ the\ traffic\ condition\ which\ includes\ the\ traffic\ patterns,$

$t_i - time\ spent\ travelling\ in\ "i"\ condition,$

$VHT_i - Vehicle\ Hour\ Travelled\ in\ "i"\ condition\ (exposure),$

$Minibuses_i - Traffic\ volume\ of\ the\ minibus\ in\ "i"\ condition,$

$Motorcycle_i - Traffic\ volume\ of\ themotorcycle\ in\ "i"\ condition,$

$Passenger.car_i - Traffic\ volume\ of\ the\ passenger - car\ in\ "i"\ condition,$

$Truck_i - Traffic\ volume\ of\ the\ truck - car\ in\ "i"\ condition,$

0.75 and 2 – Passenger Car Units factors (PCU) for motorcycle and trucks, respectively, (Highway Capacity Manual)

3.3.3 Accident Risk Definition (third step)

The primary objective of transportation safety planning is to enhance safety by supporting initiatives that formulate policies, programs, and projects encompassing all transportation infrastructures (Sirwan Ahmed, 2023). Despite the majority of studies emphasizing human behaviour as the most crucial factor contributing to observed road accidents, most existing accident risk studies concentrate on the number of reported accidents to assess the safety of specific traffic conditions (Celso Ferando et al., 2019; Tsubota et al., 2018).

To the best of the author's knowledge, there is, currently, no study advocating the use of hazard manoeuvres in predicting road accident associated risk, despite acknowledging that inattentive and careless driving behaviour significantly influences crash occurrences (Cheol Oh et al., 2013).

In developing countries, the number of accidents recorded by the police often fails to reach the actual count, and even the registered accidents frequently fail to comprehensively describe the conditions and environment in which they occurred. This limitation hinders the utilization of accident data for safety analysis.

Acknowledging the substantial role of HDEs in traffic safety, this study employs dangerous manoeuvres such as sudden braking, abrupt lane changes, and overtaking on both sides performed on the roadway to estimate the associated risk of a road accident. The number of HDEs observed in each traffic condition is normalized by the exposure variable, Vehicle Hours Travelled (VHT), as in Equation (2).

$$R_i = \left({}^{HDE_i}/_{VHT_i} \right) * 100^6 \tag{2}$$

Where:

$i - is\ the\ traffic\ condition\ which\ includes\ the\ traffic\ patterns,$
$R_i - associated\ risk\ of\ road\ accident\ in\ "i"\ condition,$
$HDE_i - hazardous\ driving\ events\ in\ "i"\ condition,$

3.3.4 Associated Accident Risk Estimation Model (fourth step)

The hazardous manoeuvres are deemed as random events, and their frequency of occurrence within a specific time interval and on a particular road segment is presumed to follow the Poisson distribution. Assuming that the number of hazardous manoeuvres performed in each traffic pattern is proportional to the exposure in that specific traffic pattern, the rate of hazardous manoeuvres on the traffic pattern is formulated as the product of traffic flow and exposure, as illustrated in Equations (3) and (4).

$$P(Y = y_i | \lambda_i t_i) = \frac{e^{-\lambda_i t_i (\lambda_i t_i)^{y_i}}}{y_i!}, \tag{3}$$

$$\lambda_i t_i = exp\ (a + b_1 x_1 + \cdots + b_n x_n) t_i, \tag{4}$$

Where

$Let, t_i\ represent\ the$ exposure (VHT_i),
$P(Y = y_i|\lambda_i t_i)$: Probability of observing y_i hazard maneuver in the traffic pattern i,
λ_i: Expected number of hazard manoeuvre per unit VHT in traffic pattern i,
x_k: The flow of each transport modes (k=1~n),
a, b_k: Unknown parameters (k=1~n).

4. DISCUSSION OF RESULTS

4.1 Relationship Between Traffic Patterns and Accident Associated Risk

As per the definition of accident associated risk in this study, a risky traffic pattern is identified when the traffic condition is characterized by a high volume of motorcycles and a low volume of minibuses, specifically in pattern 2; this phenomenon may be associated with the fact that most motorcycles operating in the city provide taxi services, and in situations where minibuses operate on a smaller scale, motorcycle taxis stand out as the primary means of transportation. In this contexts, where motorcycle taxis predominate, there is an intensification of competition among the riders, leading them to engage in high-speed maneuvers, often disregarding traffic regulations, in order to quickly drop off their passengers and seek new clients. Conversely, when the traffic flow is marked by a low volume of motorcycles and passenger cars, Pattern 3, it tends to be less risky, this scenario may indicate an off-peak period, during which the absence of passengers prompts motorcycle taxi operators to park their vehicles, consequently reducing their activity, as shown in Figure 2.

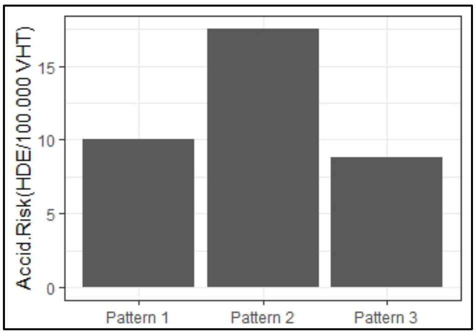

Figure 2: Associated accident risk at each traffic condition

4.2 Accident Risk Estimation Model Considering the Hazard Manoeuvres

The statistical tests based on the Poisson regression model, as elucidated in equations (3) and (4), validate the observation in subsection 3.1. Specifically, the number of hazardous manoeuvres in pattern 2 is found to significantly differ from that in pattern 1, which serves as the baseline in the Poisson regression model.

The results of the Poisson regression indicate that as the traffic condition shifts to a state where the volume of motorcycles tends to increase, and the volume of minibuses tends to decrease while the volume of passenger cars remains at a considerably high level (i.e., transitioning from Pattern 1 to Pattern 2), the number of hazardous manoeuvres increases; this shows that passenger cars do not have a significant influence on HDEs, but the number of motorcycles and minibuses do, as shown in Table 2. Thought, altering the volume of motorcycles and passenger cars in traffic will significantly influence the safety measures of traffic flow.

Table 2: The statistical test (p-value) of the HDEs profile relationship among traffic patterns

	Pattern 1	Pattern 2
Pattern 1		**0.0307 ***
Pattern 3	0.3292	0.2420

5. CONCLUSIONS

This study delved into the utilization of hazardous manoeuvres as a means to estimate road accident associated risk on urban networks. This approach serves as an alternative in situations where data on road accident events are either unavailable or do not accurately depict the actual scenario, thereby impeding their use in safety studies, as is the case in Nampula City, Mozambique.

From the model for estimating accident associated risk, it was observed that motorcycle and minibuses are the primary sources of traffic safety concerns, while passenger cars do not significantly contribute to this issue. The results indicate that an increase in the number of motorcycles in traffic, coupled with a steady flow of passenger cars and a decrease in the number of minibuses, leads to unsafe traffic conditions.

Motorcycles in Nampula are predominantly operated by individuals lacking proper traffic code training, and many operate informally as taxis, known as "taxi-mota." Despite the increasing number of “taxi-mota” operators, there is insufficient control over their activities. Frequently, they can be observed disregarding traffic signals, even in the presence of traffic police. The operators of “taxi-mota” are known for their careless riding behaviours.

From this, it can be inferred that, given the acknowledged disparities, unreliability and overall lack of data, especially in developing economies, it is imperative to explore “alternative” approaches or tools towards improving traffic safety.

6. ACKNOWLEDGEMENTS

The author is grateful to *“Faculdade de Arquitectura e Planeamento Fisico da Universidade Lurio – FAPF-UniLúrio”* for support the data collection of this research.

7. REFERENCES

Ahmed S et al. 2023 Road traffic accident injuries and deaths: A neglected global health issues. Wiley.

Ahmed, S, Hossain, A, Kumar, S & Islam, M. 2023. Transportation Research Inter-disciplinary Perspectives A study on road accident prediction and contributing factors using explainable machine learning models: analysis and performance. *Transportation Research Interdisciplinary Perspectives,* 19:100814. April. Available at: https://doi.org/10.1016/j.trip.2023.100814.

Bella, F. 2011. How Traffic Conditions Affect Driver Behavior in Passing Maneuver, 1-17.

Bella, F & Gulisano, F. 2020. A hazard-based model of the motorcyclists' overtaking duration. Accident Analysis and Prevention, 141:105522. January. Available at: https://doi.org/10.1016/j.aap.2020.105522.

Fernando, C et al. 2019. Analysis of Safety Performance of Drainage Pavement focusing on Pavement Age. *Journal of the Eastern Asia Society for Transportation Studies*, Vol.13.

Malta L et al. 2007. Analysis of drivers' responses under Hazardous Situation in Vehicles Traffic. IEEE Intelligent Vehicles Symposium, Proceedings.

Shimada, JK. 1974. Measures of Site Hazard - Hazardous Maneuvers. *Accid. Anal. & Prev. Pergamon Press*, 6(7):309-315.

Tsubota, T et al. 2018. Effect of Road Pavement types and Ages on Traffic Accident Risk. *Transport Research Procedia,* 34:211-218.

Wolfe, AC. 1982. Accident Analysis & Prevention, 14(5):337-340.