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Trend and Causative Factors of Road Traffic Crashes in Nigeria: A Six Sigma (DMAIC) Approach

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Abstract

In Nigeria, Road Traffic Crashes (RTC) are a major health problem that result in numerous deaths and financial losses. Thus, it is important to monitor the existing road safety policies and continue further steps to prevent RTC. This study used the Define, Measure, Analyse, Improve, and Control (DMAIC) approach of Six Sigma to investigate the trends and causative factors of RTC in south-south and southeast regions in Nigeria between 2020 and 2023. The findings reveal that the south-south region experienced a higher number of total RTC including a higher proportion of crashes resulting in death (17.5%) compared to the southeast region (14.4%). The majority of crashes in both regions resulted in a serious injury outcome (south-south region, n=6,281, 82.5%; southeast region, n=6,529, 85.6%). Study findings indicated that the mortality, human damage, and case fatality rates were statistically significant between the two regions, with the south-south region facing more severe consequences of each. Overall, the causative-effects analysis showed that speeding violations was the primary contributors to RTC in both the regions. Short and long-term measures for improvement to prevent RTC are included.

Key Findings

- The south-south region of Nigeria experienced a higher number of Road Traffic Crashes (RTC) than the southeast region
- Serious crashes make up over half of the RTC in both regions
- Differences in mortality, human injury and case fatality rates were statistically significant between the two regions, with more severe consequences in the south-south region
- Speed Violation were the primary contributors to RTC with share of 56.3% and 37.50% in both regions

Glossary

CFR Case Fatality Rate

DMAIC Define, Measure, Analyse, Improve, and Control

FRSC Federal Road Safety Corps

HD Human Damage

MRP Mortality Rate per Population

RTC Road Traffic Crashes

Introduction

Road Traffic Crashes (RTC) remain a leading cause of mortality and a direct economic burden worldwide (WHO, 2023). Accordingly, it is projected that if sustained actions are not taken, RTC will become the seventh leading cause of death by 2030, particularly affecting developing countries and causing substantial socioeconomic burden (WHO, 2023). Alarming, 90 percent of road crashes occur in low- and middle-income countries, (WHO, 2018) that have not yet benefited from the stricter vehicle standards and effec-

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tive traffic safety laws established in high-income countries (Ning et al., 2016; Pal et al., 2018).

In Nigeria, the road serves as the most practical mode of transportation for a larger percentage of its citizens. However, the roads are not safe with approximately 5,500 deaths and 39,000 injuries are recorded on Nigerian roads annually (FRSC, 2021; Modobi, 2021). Given the overwhelming challenges affecting road transportation in Nigeria, road safety research has recently attracted government and scholarly attention. The Federal Government of Nigeria (FGN) is dedicated to reducing RTC while also ensuring a secure transportation system for all types of road users. Nevertheless, even with the commendable initiatives taken by the government, RTC remain notably high, indicating that the country has not yet achieved an effective solution (Atubi, 2022; Siyan et al., 2019).

In Nigeria, crash statistics analysis literature (Liu et al., 2021; Song et al., 2019) including the usefulness of analysing spatial and temporal information of road crashes have determined the severity index of crashes and identify locations most prone to crashes. For instance, Lawan et al. (2018) explored the spatial and temporal patterns of RTC between Kano-Wudil on Kano Maiduguri road utilising monthly data and multiple linear regressions, descriptive tools, and geographic information system (GIS) to demonstrate the result of the findings.

Road crash analysis involves identifying and investigating individual crashes focusing on immediate causes like driver error or vehicle malfunction. However, this approach often neglects the underlying systemic factors contributing to the problem. To close this gap, the inclusion of the Six Sigma (DMAIC) cycle in RTC analysis has recently attracted scholarly attention due to the expansion of the research scope (Umit & Ali, 2017), which is the novelty of the current study. Six Sigma methodology has been adopted in many industries as a business management tool to improve operational capabilities and reduce defects in any process. The technique improves existing business processes through regular review and fine-tuning (Ankesh et al., 2023). Six Sigma employs a five-step approach: Define, Measure, Analyse, Improve, and Control (DMAIC). DMAIC methodology of the Six Sigma initiative is the roadmap for continuous improvement (V. Gupta et al., 2018). Numerous effective Six Sigma studies are documented in manufacturing and other industries (N. Gupta & Bharti, 2013; Mamatha & Vasuki, 2014).

Therefore, incorporating Six Sigma (DMAIC) approach offers a structured framework for analysing complex systems like road traffic crashes. This forms the study's contribution and remains novel. The study's results are significant and will assist policymakers within Nigeria and other developing countries to develop and keep track of existing road safety policies and take further actions to reduce RTC in the future.

Methods

Data source

The data on RTC and causative factors for this study were obtained from the quarterly reports of the Federal Road Safety Corps (FRSC) of Nigeria, published by the National Bureau of Statistics of Nigeria from 2020, Quarter 4 to 2023, Quarter 1 (NBS, 2023). The RTC data were divided into three severity categories: fatal crash, serious crash, and minor crash. A fatal crash is defined as a collision that directly results in the death of at least one individual, either at the scene or within 30 days post-crash due to injuries sustained or direct complications (WHO, 2023). A serious crash is defined as an event that results in injury to any of the parties involved and requires medical attention. A minor crash is defined as an event where no one needs medical attention but an injured person may sustain some bruising and superficial cuts (Shakil et al., 2023).

Variable definition and metrics classification of crash incidence and severity

Using Equations (1), (2) and (3), RTC were analysed based on three different epidemiology metrics to evaluate the severity of traffic crashes.

$$\begin{aligned} & \text{Mortality Rate per Population (MRP)} \\ &= \frac{\text{Number of people killed (NK)}}{\text{Population of region (P)}} \times 100 \end{aligned} \quad (1)$$

$$\begin{aligned} & \text{Human Damage (HD)} \\ &= \frac{\text{Number people seriously injured (NI)}}{\text{Population of region (P)}} \times 100 \end{aligned} \quad (2)$$

$$\begin{aligned} & \text{Case Fatality Rate (CFR)} \\ &= \frac{\text{Number of people killed (NK)}}{\text{Total Number of people killed or seriously injured (Casualties) (TC)}} \times 100 \end{aligned} \quad (3)$$

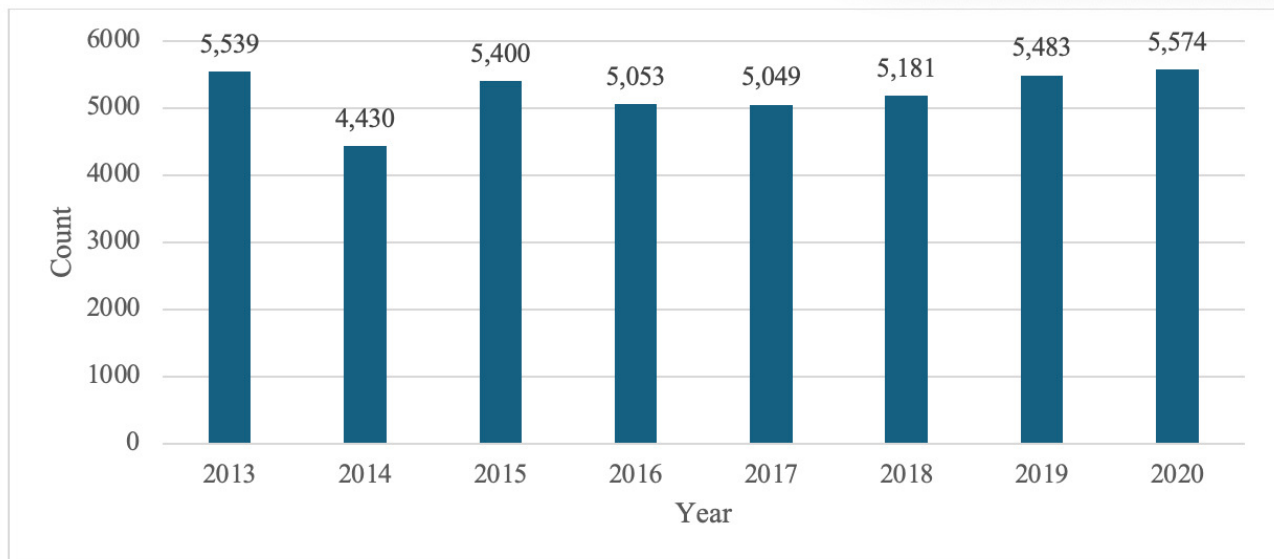
NK denotes the total number of people killed, NI denotes the total number of people seriously injured, P denotes the population of each region and TC denotes the total casualties, that is the number of people killed or seriously injured. While MRP denotes mortality rate per population, case fatality rates (CFR), and HD denotes human damage. As indicated by its name, the HD describes the average human damage per crash. The CFR index describes the proportion of deaths within a designated population of crash cases (Hayakawa et al., 2000).

Case study on Sigma DMAIC implementation on RTC Analysis

The study used a conceptual framework developed with a qualitative and quantitative approach, creating an in-depth case study of RTC analysis records. The case study allowed the possibility of implementing the Six Sigma technique for crash prevention to be examined. The DMAIC methodology framework used in this research is categorised into the following five basic phases (Table 1). The outcome of the analysis will enable road safety regulators to develop evidence-based rules or policies on road safety and uncover the causes of crashes to prevent future crashes.

Table 1. Six Sigma Define–Measure–Analyse–Improve–Control roadmap for RTC analysis

1. Define	2. Measure	3. Analyse	4. Improve	5. Control
Clearly define the goals of road safety improvement. The research focused on reducing fatalities and injuries in the south-south and southeast regions of Nigeria using the DMAIC framework.	Gather and analyse historical data on road transport crashes, including frequency, severity, and contributing factors.	Apply statistical methods to analyse crash data and identify trends.	Develop and implement targeted improvements based on the analysis of root causes.	Establish control measures to monitor and sustain the implemented improvements.
Identify baseline metrics to assess the current state of transport safety.	Develop baseline metrics to assess the current state of road safety.	Utilise root cause analysis tools to identify the primary factors contributing to road crashes.	Implement preventive measures, such as improved signage, flow optimisation, or public awareness campaigns.	Develop a proactive system for continuous, feedback, and intervention.

**Figure 1. Number of people killed by road crashes in Nigeria (2013 to 2020)**

Source: FRSC, 2021

Define phase

The RTC in Nigeria have increased annually since 2017 ([Figure 1](#)). While acknowledging the overall RTC trend in Nigeria, the specific objective of the current study is to address the road safety challenges inherent in the south-south and southeast regions of Nigeria between 2020 (Quarter 4) and 2023 (Quarter 1). This involves exploring the regional trends and key drivers that contributed to fatalities and injuries and suggesting improvement measures, based on the research outcomes.

Measure phase

The measure phase involved two major steps, 1) the collection of historical data on road traffic crashes, including the frequency, severity, temporal changes, and contributing

factors and, 2) developing baseline metrics to assess the current state of road safety. The number of RTC that occurred in the two regions are presented in [Figure 2](#). The south-south region recorded the highest number of crash cases during the study period (2,013, 50.4%). The quarter with the highest number of crashes was Q1, 2022. While in the southeast region, 1,980 crashes occurred and Q3, 2021 had the highest number of crashes.

A comparison of crash categories shows that serious cases were the most common crash outcome in both regions (south-south: 55.6%; southeast: 56.9%). However, the time of these peaks varied (south-south, Q1 2022, 57.5%; southeast Q1 2021, 59.1%).

Data presented in [Table 2](#) show the south-south region experienced a total of 6,281 serious casualties from Quarter 4 2020 to Quarter 1 2023; of these, 5,179 were injury-related (82.5%) and 1,102 were death-related (17.5%). Quar-

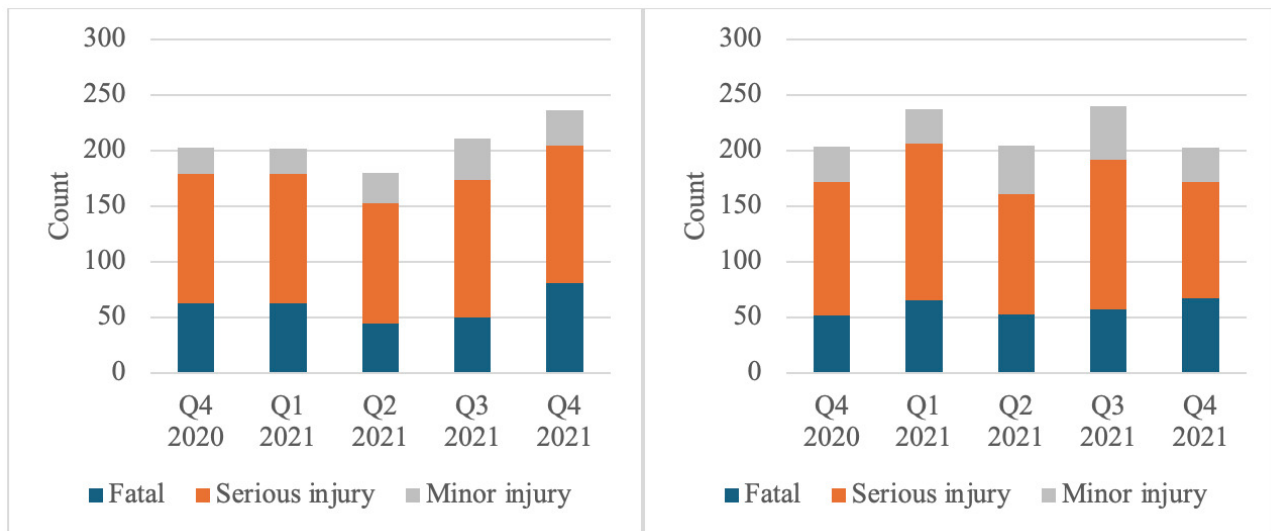


Figure 2. Number of crash cases per quarter in Nigeria: South-South (left) and Southeast Region (right) (Q4 2020-2021)

terly data reveal a complex trend following a 12.9% increase in Quarter 1 2021, serious casualties in Quarter 2 2021 declined by 13.2 percent. This was succeeded by an increase of 18.4 percent and 20.1 percent in Quarter 3 2021 and Quarter 4 2021, respectively. In subsequent quarters, serious casualties fell sharply by 2.54 percent, 10.2 percent, 24.6 percent, and 27.3 percent in Quarter 1 2022, Quarter 2 2022, Quarter 3 2022, and Quarter 1 2023, although there was a notable increase of 22.7 percent in Quarter 4 2022.

In contrast, the southeast region recorded 6,529 serious casualties between Quarter 4 2020 and Quarter 1 2023, with 5,590 being injury-related (85.6%) and 939 being death-related (14.4%). Here, the quarterly patterns showed a significant 25.7 percent decrease in Quarter 2 2021 following a 16 percent increase in Quarter 1 2021, with a recovery of 25.3 percent in Quarter 3 2021. This decline persisted in subsequent periods, culminating in a considerable 28.4 percent drop in Quarter 1 2023.

Severity of crash casualties

Using Equations (1) to (3), the comparison of MRP, HD, and CFR between Quarter 4, 2020 and Quarter 1, 2023 is shown in [Figure 3](#) and [Figure 4](#). The regional and time dimension comparison of road traffic crash severity indicators illustrates the temporal changes in traffic metrics within these regions.

To further compare the differences in crash severity between the two regions for the period from 2020 to 2023, the model metrics: MRP, HD, and CFR were analysed using one-way ANOVA as shown in [Table 3](#).

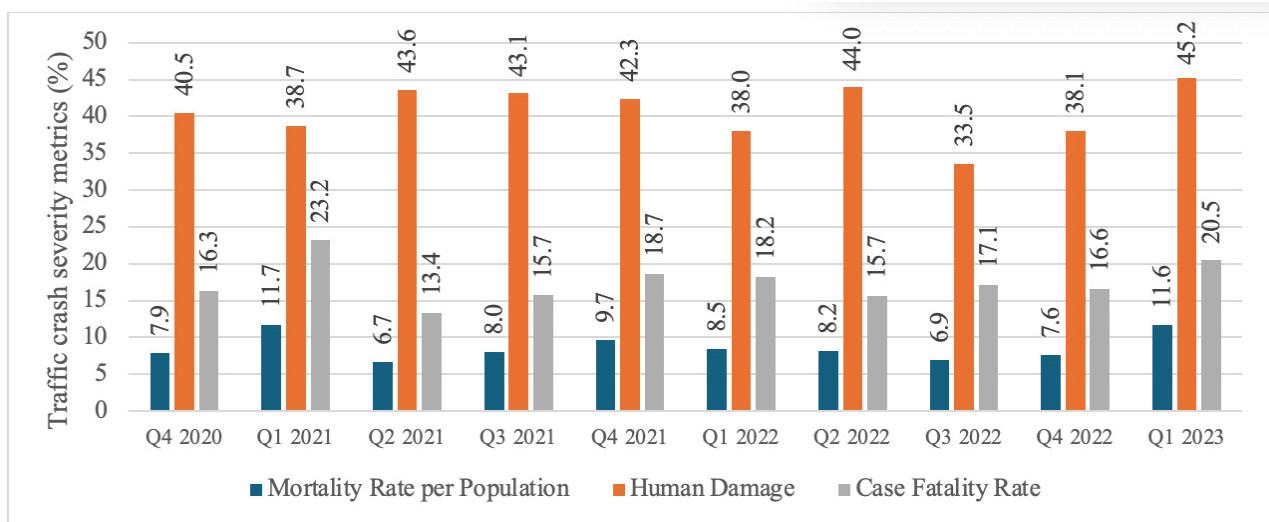
The south-south region experienced more severe effects in terms of mortality (MRP), human damage (HD), and case fatality rates (CFR) compared to the southeast region. The differences between the two regions were statistically significant. However, in terms of time distribution, in the south-south region there was considerable variation in the mortality rate (Q1, 2021: 11.7%; Q2, 2021: 6.7%; Q1, 2023:

11.6%). This variability reflects substantial alterations in safety compliance and the severity of traffic incidents (Inah & Nwankwojike, 2018).

In contrast, the human damage metric in the south-south region varies considerably, however, general trend was relatively stable from Q4, 2020 (40.5%) to Q1, 2023 (45.2%). The case fatality rate also demonstrates notable fluctuations, as the maximum (23.2%, Q1, 2021) and minimum (13.3%, Q2, 2021) occurred in the same year. On the other hand, the southeast region maintains a generally lower mortality rate than the south-south region, starting at 6.6%, in Quarter 4 of 2020 and peaking at 7.50 percent in Quarter 4 of 2021. The rates are more stable, ranging from 4.94 percent to 7.50 percent which suggests a consistently lower level of mortality. Human damage in the southeast region initiates at 36.2 percent in Quarter 4 2020 and reaches a peak of 42.9 percent in Quarter 2 2022. While fluctuations are present, the overall trend is less pronounced than that observed in the south-south region, indicating a more stable pattern. Finally, the case fatality rate in the southeast region is generally lower and more consistent, starting at 15.4 percent in Quarter 4 2020, peaking at 17.5 percent in Quarter 4 2021, and decreasing to 13.7 percent by Quarter 1 2023, reflecting a more stable yet lower level of fatality per case compared to the south-south Region. The research outcome infers that a combination of greater RTC involvement and possibly more severe crash circumstances can be blamed for the higher death rates in the south-south region. The high number of people involved is associated with greater casualty rates, particularly in Quarter 1 2021 when a high mortality rate (11.7%) is accompanied by a notable number of serious casualties (148). Perhaps stronger emergency response systems, less severe crash conditions, or more effective road safety measures may have accounted for the southeast region's lower death rates. For instance, even though 1,759 individuals got

Table 2. Crash statistics injury outcome by region

Region	Year	Quarter	Injured		Killed		Total Casualties	Total people involved
			n	%	n	%		
South-South	2020	Q4	473	83.7%	92	16.3%	565	1168
	2021	Q1	490	76.8%	148	23.2%	638	1267
		Q2	480	86.6%	74	13.4%	554	1101
		Q3	553	84.3%	103	15.7%	656	1282
		Q4	641	81.3%	147	18.7%	788	1514
	2022	Q1	628	81.8%	140	18.2%	768	1653
		Q2	582	84.3%	108	15.7%	690	1324
		Q3	431	82.9%	89	17.1%	520	1285
		Q4	532	83.4%	106	16.6%	638	1397
	2023	Q1	369	79.5%	95	20.5%	464	816
South-South		Total	5179	82.5%	1102	17.5%	6281	12807
	2020	Q4	587	84.6%	107	15.4%	694	1622
	2021	Q1	680	84.5%	125	15.5%	805	1759
		Q2	510	85.3%	88	14.7%	598	1378
		Q3	659	88.0%	90	12.0%	749	1822
		Q4	564	82.5%	120	17.5%	684	1601
	2022	Q1	599	84.2%	112	15.8%	711	1587
		Q2	489	85.3%	84	14.7%	573	1140
		Q3	511	88.3%	68	11.7%	579	1385
		Q4	582	87.9%	80	12.1%	662	1637
	2023	Q1	409	86.3%	65	13.7%	474	968
		Total	5590	85.6%	939	14.4%	6529	14899

**Figure 3. Quarterly distribution of Road traffic crash severity indicators, South-South region**

involved in RTC in Quarter 1 2021, their death rates were relatively lower (7.1%).

Analyse Phase

It is important to identify factors that contributed to RTC design improvement and subsequent control. Thus, in this phase, the cause-and-effect diagram, otherwise known as the Ishikawa (Fishbone) diagram (Figure 5) was used to un-

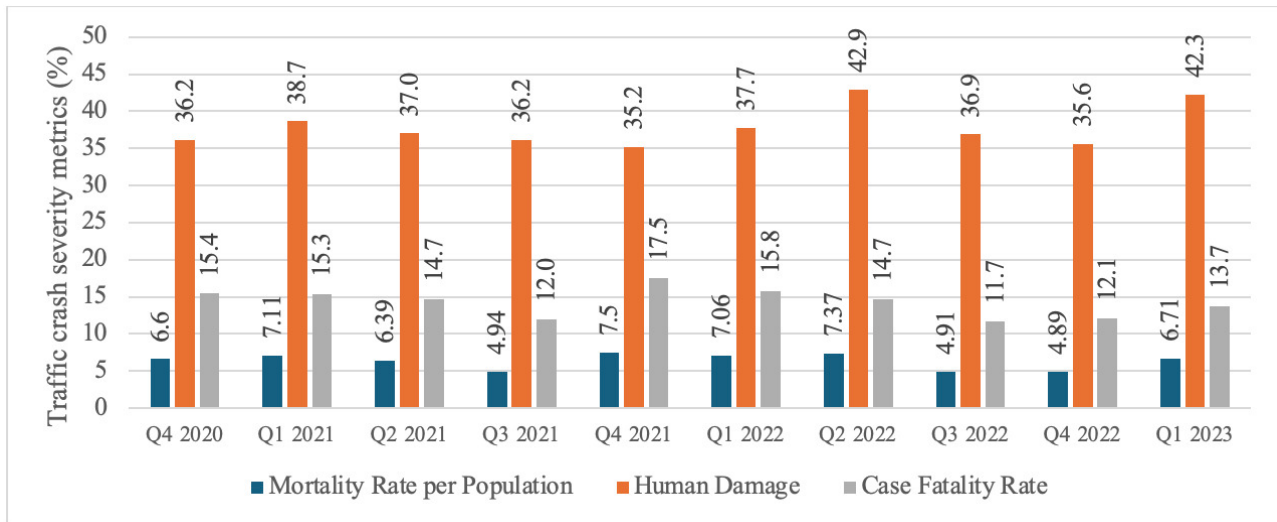


Figure 4. Quarterly distribution of Road traffic crash severity indicators, SouthEast Region

Table 3. One-way ANOVA results

Metrics	South-south		Southeast	
	Mean	Std. Dev.	Mean	Std. Dev.
Mortality Rate	8.681	1.773	6.348	1.0452
Human Damage	40.704	3.617	37.859	2.6826
Case Fatality Rate	17.527	2.7766	14.317	1.9061
F-Statistic	342.768	-	675.492	-
P-value	0.00*	-	0.00*	-

*Refer to the differences are statistical significance with $p < 0.05$

cover the root causes of RTC across the two regions. This involved interviews and brainstorming sessions between the research team and selected personnel of the Federal Road Safety (FRSC) of Nigeria in the two regions. Based on the responses of the FRSC officials, the causative factors of RTC were classified (human, environment, machine and other). After determining these factors, a detailed analysis was conducted using statistical comparisons across the two regions to verify the root cause and the degree of causative factor of RTC occurrence as summarised in Table 4.

Overall, the classification of these factors is in accordance with the Federal Road Safety Cooperation of Nigeria (FRSCN) and National Bureau of Statistics (NBS) classification. During the study period, a total of 17 causative factors were identified in the RTC data including some factors with similar, but distinct definitions including:

- Wrongful Overtaking: specifically rule violations during overtaking
- Dangerous Driving: encompassed a broad range of behaviours (e.g., pulling of stunts)
- Dangerous Overtaking: action during overtaking that directly endangered the safety of the driver and passenger
- Road Obstruction Violation: blocking or hindering traffic flow.

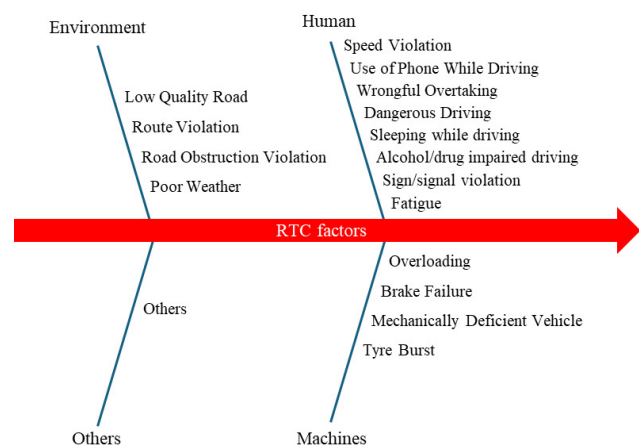


Figure 5. Cause and effect diagram of Road Traffic Crashes (RTC)

- Mechanically deficient vehicle: A mechanically deficient vehicle risks the driver and road users due to defects from poor maintenance, wear, or manufacturing faults. Such defects compromise road standards, reliability, and safety.
 - Brake failure: failure refers to a vehicle's braking system's inability to adequately stop or decel-

Table 4. The frequency of RTC causative factors

Causative Factors	South-south Region		Southeast region		Total	
	Count	%	Count	%	Count	%
Speed Violation (SPV)	1545	56.3%	882	37.5%	2427	47.6%
Brake Failure (BFL)	191	7.0%	348	14.8%	539	10.6%
Traffic Sign/Signal Violation (SLV)	239	8.7%	291	12.4%	530	10.4%
Wrongful Overtaking (WOT)	171	6.2%	165	7.0%	336	6.6%
Tyre Burst (TBT)	159	5.8%	175	7.4%	334	6.6%
Others	99	3.6%	155	6.6%	254	5.0%
Route Violation (RTV)	93	3.4%	101	4.3%	194	3.8%
Dangerous Driving (DGD)	96	3.5%	89	3.8%	185	3.6%
Mechanically Deficient Vehicle (MDV)	72	2.6%	44	1.9%	116	2.3%
Road Obstruction Violation (OBS)	12	0.4%	69	2.9%	81	1.6%
Overloading (OVL)	21	0.8%	8	0.3%	29	0.6%
Low quality road (BRD)	10	0.4%	7	0.3%	17	0.3%
Alcohol/Drug impaired driving (DAD)	3	0.1%	11	0.5%	14	0.3%
Sleeping while driving (SOS)	11	0.4%	1	0.0%	12	0.2%
Fatigue (FTQ)	8	0.3%	4	0.2%	12	0.2%
Dangerous Overtaking (DOT)	9	0.3%	0	0.0%	9	0.2%
Illegal mobile phone Use While Driving (UPWD)	4	0.1%	2	0.1%	6	0.1%
Poor Weather (PWR)	1	0.0%	0	0.0%	1	0.0%
Total	2744	100.0%	2352	100.0%	5096	100.0%

erate the vehicle. This failure typically arises from issues such as worn brake pads, brake fluid leaks, or overheating. Common warning signs include reduced braking effectiveness, which can create difficulty in stopping the vehicle

- Tyre burst: Is characterised by a sudden loss of air pressure in a tire, often resulting from inadequate inflation, wear, or excessive heat. This phenomenon can impair steering and lead to a loss of vehicle control, particularly at elevated speeds
- Route violation: unauthorised use of roads

The top three factors were speed violation, brake failure and traffic sign/signal violation. These three causative factors accounted for the majority (68.6%) of all reported crashes in the two study regions. The most frequent of the three was speed violations, reported in over half the crashes in the south-south region (56.3%) and over a third in the south-east region (37.5%), highlighting the need for public awareness campaigns to promote responsible driving and long-term traffic calming measures such as lower speed limits and improved road designs in high-risk areas. The next two causative factors were Brake Failure and Traffic Sign/Signal Violation. Greater attention the roadworthiness of motor vehicles in Nigeria is needed as Brake Failure was the second most frequently reported causative factor in total and in the southeast region (14.8%), although the third most frequent in south-south (7.0%), emphasising the need for regular brake inspections and the adoption of advanced braking technologies such as ABS to improve ve-

hicle safety. Traffic Sign/Signal Violation was the second most frequent causative factor in south-south region (8.7%) and third in southeast (12.4%), calling for enhanced traffic signal visibility and placement and automated enforcement systems such as red-light cameras.

The other factors were reported for a third of the total crashes (31.3%), with slightly more in the southeast region (35.3%) than the south-south region (28.0%). Again, the roadworthiness of motor vehicles in Nigeria is highlighted with the frequency of burst tyres reported as a causative factors in crashes in both the south-south (5.8%) and the southeast region (7.4%). This suggests a lack of awareness of the dangers of worn tyres and the need for community education. Further, regulatory responses could include routine tyre inspections that specify minimum requirements for tyre quality and tread depth. Route violations were reported as a causative factor in almost 100 crashes in each region (south-south: 93, 3.4%; southeast: 101, 4.3%). This is likely to be due to drivers making wrong turns or confusion about permitted access and needs to be addressed with improved road signage and advanced traffic management systems. While dangerous driving was relatively infrequent compared to other behaviours (south-south: 3.5%; southeast: 3.8%), it indicates that there may be a need for penalties for reckless overtaking and driver training programs focusing on hazard recognition and risk assessment. The roadworthiness of motor vehicles is reported again with Mechanically Deficient Vehicles a causative factor in the south-south (2.6%) and southeast region (1.9%), reinforcing

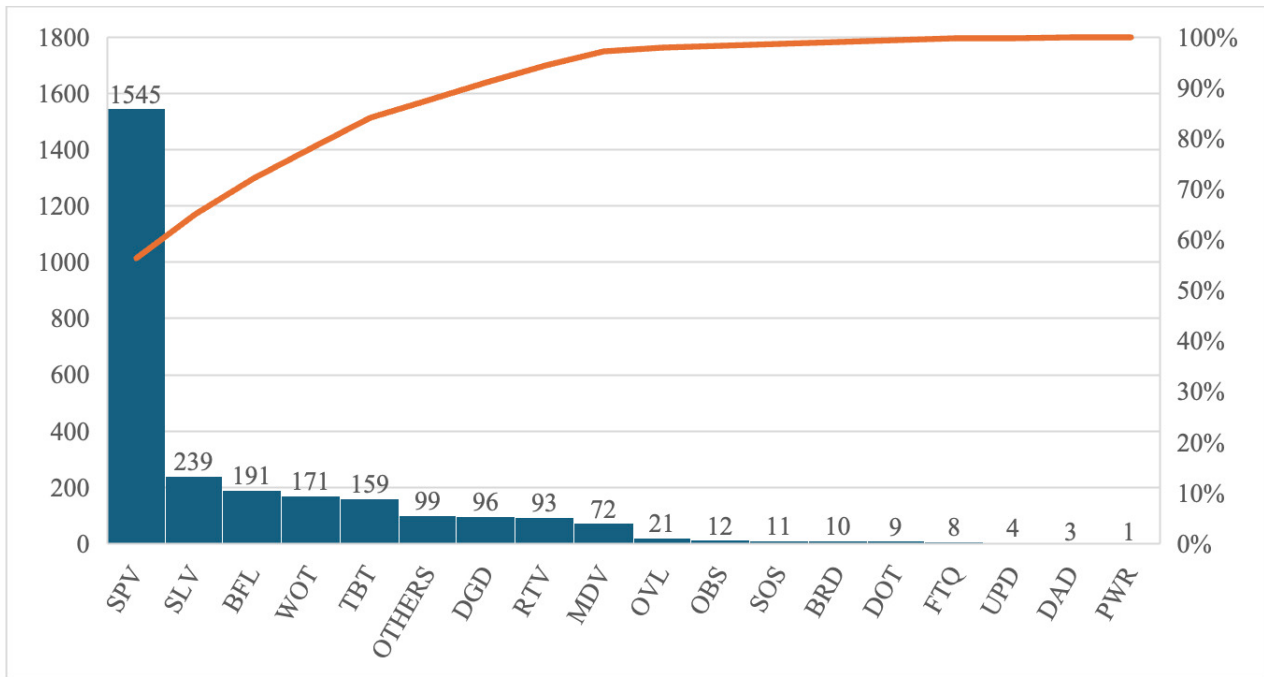


Figure 6. Pareto diagram of causative factors of road traffic crashes (RTC) for the south-south

ing the need for mandatory vehicle inspections and maintenance awareness programs to ensure vehicles are safe.

The remaining factors were reported in fewer than 2 percent of crashes. However, countermeasures for some of the factors are well-established. In particular, strengthening DUI laws, imposing stricter penalties, and increasing public education campaigns on the risks of impaired driving remain crucial. While implementing mandatory rest breaks for long-distance drivers and fatigue detection systems in commercial vehicles can help reduce fatigue-related crashes.

Overall, the findings emphasize the necessity for region-specific interventions, including stricter law enforcement, enhanced vehicle inspection programs, and targeted public education campaigns, ensuring a data-driven approach to mitigating RTC risks effectively (see [Figure 6](#) and [Figure 7](#)).

Improve Phase

The goal of the improve phase in the DMAIC principle is to detail the action needed to reduce the occurrence of each causative factor identified as contributing to the RTC. Following the crash analysis above, [Table 5](#) presents improvement measures, both short term and long term, for the causative factors in the RTC during the study period.

Control Phase

The control phase is intended to implement long-term improvements. Implementing the improvement measures outlined in the studied regions is likely to result in a significant reduction in RTC. Furthermore, as previously mentioned by Umit and Ali (2017), monitoring the implemented improvements and conducting regular meetings to analyse

the likely causes of the increase in the number of crashes, as well as adopting the required preventive measures is important.

Discussion and Conclusions

The continuous economic progression of Nigeria has brought about significant transformations, in both transportation modes and lifestyles. Private motor vehicle ownership has dramatically increased with a concurrent increase in road traffic crashes and casualties. This calls for the implementation of stricter vehicle standards and effective traffic safety laws that will address these challenges.

The results of this study showed that the south-south region experienced a higher number of crashes than the southeast region, with serious cases making up more than half the RTC in both regions. However, while both regions experienced peaks in serious cases, the times these peaks occurred varied. These differing peak intervals may be attributed to economic inequality which could lead to varying investments in road designs, and traffic infrastructures across each region. The above analysis suggests that there is a statistically significant difference in the severity of MRP, HD, and CFR between the two regions. The south-south region consistently showed higher values for all variables than the southeast region. To further reduce the incidence and mortality of RTC in the regions, collaboration efforts are needed to improve the quality of roads, increase enforcement, modernise the motor vehicle fleet and increase education for drivers across all social strata on the importance of safe driving behaviours.

Further analysis on the root causes of RTC using the Ishikawa diagram ([Figure 5](#)), revealed speed violation was a significant factor across the two regions. High-risk behav-

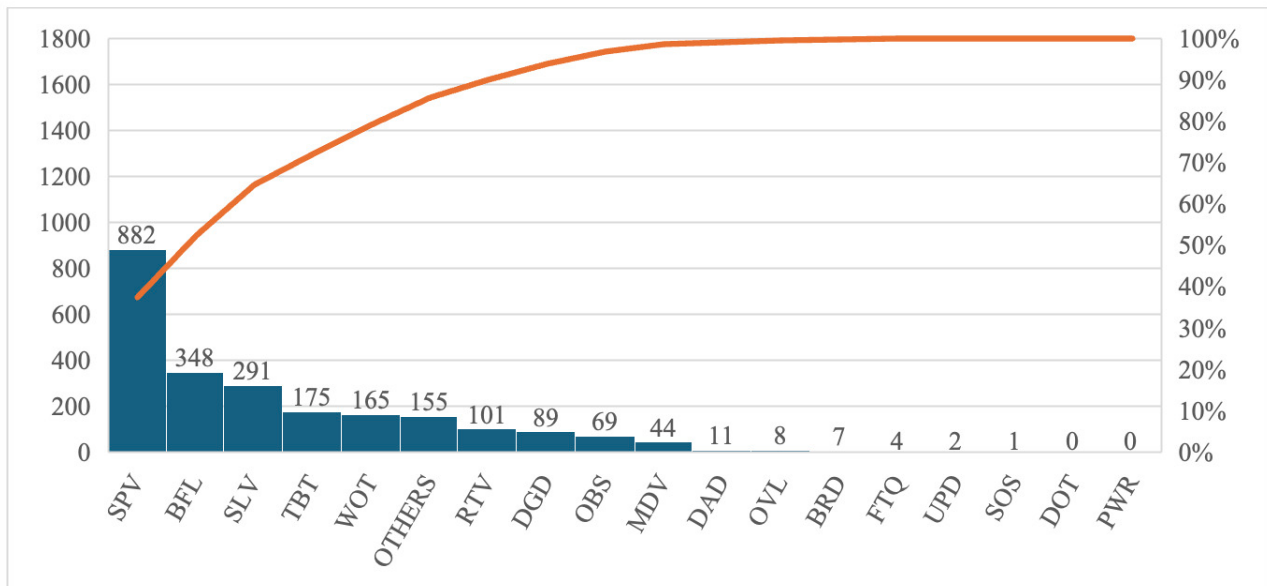


Figure 7. Pareto diagram of causative factors of road traffic crashes (RTC) for the southeast

ious such as exceeding the speed limit is often associated with greater severity of casualties in the event of RTC (Sae-Tae et al., 2020). Also, our findings, reveal lower values for incidences of drink driving (e.g., southeast region) relative to other traffic violations, this is because drink driving has been criminalised in Nigeria as in many other countries (Gaoqiang et al., 2020) and driving with a blood alcohol content above 0.05 is a criminal offence. However, greater enforcement is needed to continue to gain the benefits that are possible through the BAC restriction. Further, stricter traffic laws targeting drug prohibition and unsafe behaviours need to be further strengthened to curb drugged driving.

Lastly, while some improvement measures (Table 5) have been suggested to prevent crashes, to improve the health outcomes for individuals who are involved in RTC, it is important to provide effective post-crash medical care. There is an urgent need to establish a strong trauma-response system and emergency care network across regions, with trained medical staff to provide care for people injured in RTC (Tian-Jing et al., 2021). Timely, critical care at the crash location will improve an injured person's likelihood of survival until they are able to access full hospital medical care.

Study Contribution and Limitations

The strength of this study lies in its methodology. The study utilised the Define, Measure, Analyse, Improve, and Control (DMAIC) approach of Six Sigma to investigate the trends and causative factors of RTC. The integration of this approach is rare and forms the novelty of this research and offers a structured framework for analysing complex systems like road safety. Beyond the study's contribution and findings, the following key limitations should be considered while interpreting the study findings. First, despite the data size used, the rates of RTC injuries and casualties were es-

timated based on the number of crash cases and population impacted across the two regions. This is most likely to impact the precision of our estimates relative to other studies. Lastly, the study only assessed driver-related, machines, and environmental-related critical risk factors of RTC and did not explore other socio-demographic differentials. Subsequent research could extend the study to other regions in the country and the timeframe and explore the relationship between deaths and other regional performance metrics.

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Authors contributions

OII and MIO contributed to data analysis and manuscript writing, FIA and SOE contributed to the data collection and manuscript revision. OOJ contributed to data collection and preparation. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

Data used for this study are available online and can be accessed from the corresponding author.

Table 5. Improve phase

Causative Factors of RTC		Improvement measure	Prevention measures	
			Short term	Long term
A. Human Factors				
	Speed Violations	Invest in public awareness campaigns highlighting the dangers of speeding and promoting responsible driving habits	✓	
		Design roads with features like traffic calming measures and lower speed limits in high-risk areas		✓
	Use of Phone While Driving	Promote phone-free driving initiatives and encourage passengers to intervene when drivers use phones	✓	
		Greater enforcement of hands-free laws and implement automatic detection systems for phone use while driving		✓
	Wrongful Overtaking	Implement stricter penalties for reckless overtaking and enforce stricter lane discipline	✓	
		Improve road infrastructure with proper lane markings, clear overtaking zones and adequate passing lanes		✓
	Dangerous Driving	Provide comprehensive training that focuses on safe driving techniques, hazard recognition, and risk assessment	✓	
		Public awareness programs emphasising the benefits of seatbelt use and rigorous enforcement of seatbelt regulations	✓	
		Implement advanced driver assistance systems (ADAS): Technologies, like lane departure warning and automatic emergency braking, can help prevent crashes caused by distracted or reckless driving		✓
		The establishment of long-term campaigns demonstrating the life-saving benefits of seatbelt use in high-speed and low-speed crashes		✓
	Sleeping while driving	Implement mandatory breaks for long-distance drivers: Enforce regulations on driving hours and require rest periods to prevent fatigue-induced crashes	✓	
		Install fatigue detection systems in commercial vehicles: These systems can monitor driver behaviour and alertness, sending warnings when fatigue is detected		✓
	Driving Under Alcohol/ Drug Influence	Strengthen laws to prevent alcohol/drug impaired driving: Implement stricter penalties, including licence suspensions and imprisonment, for driving under the influence	✓	
		Support public education and awareness programs		✓
	Traffic Sign/ Signal Violation	Improve traffic signal visibility and placement: Ensure clear visibility of signals, especially during low-light conditions, and consider adjusting timing sequences to minimise red-light running	✓	
		Implement red-light running cameras: Capture evidence of violations and consistently enforce penalties as a deterrent		✓
	Fatigue	Introduce regulations on driver working hours and mandatory rest periods to combat fatigue-related crashes	✓	
		Implement technologies in commercial vehicles that monitor driver fatigue and alert them to potential risks		✓
B. Machines				
	Tyre Burst	Promote regular tyre maintenance and inspections to identify worn-out or damaged tyres before they fail	✓	
		Implement regulations and standards for tyre quality and minimum tread depth requirements		✓
	Mechanically Deficient Vehicle	Enforce mandatory vehicle inspection programs to ensure roadworthiness and identify potential mechanical issues	✓	
		Encourage regular vehicle maintenance and repairs to address problems before they lead to crashes		✓
	Brake Failure	Implement regular brake system inspections and maintenance schedules to identify and address potential faults	✓	
		Develop and implement advanced braking technologies such as anti-lock braking		✓

Causative Factors of RTC		Improvement measure	Prevention measures	
			Short term	Long term
		systems (ABS) as standard features		
	Overloading	Enforce weight limits and conduct regular inspections: Implement stricter monitoring of vehicle weight compliance and penalise overloading to prevent instability and crashes	√	
		Invest in weigh-in-motion (WIM) technology: Automate vehicle weight measurement at checkpoints and on highways to facilitate efficient enforcement		√
C. Environmental factors				
	Low Quality Roads	Allocate resources for proper road maintenance and repair, addressing issues like potholes, uneven surfaces, and inadequate drainage	√	
		Design new roads with safety features like improved visibility, proper signage, and crash barriers		√
	Route Violation	Improve signage and markings to guide drivers and prevent confusion or wrong turns	√	
		Utilise traffic management systems to divert or reroute traffic during road closures or disruptions		√
	Road Obstruction Violation	Improve road maintenance and infrastructure: Address issues like potholes, debris, and overgrown vegetation that can obstruct roads and create hazards	√	
		Implement clear signage and markings: Use proper warnings and instructions to guide drivers around obstructions and enforce penalties for ignoring designated detour routes	√	
	Poor Weather	Enhance weather forecasting and alert systems to promptly warn drivers about adverse weather conditions	√	
		Promote responsible driving practices in bad weather, including adjusting speed, maintaining safe distances, and avoiding unnecessary travel		√

* STM: Short-term measures and LTM: Long term measures

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