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# Trend analysis and structural break detection in road traffic crashes and casualties in Nigeria (1980–2024): Evidence of policy and economic effects

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## ABSTRACT

This study examines the long-term trend in road traffic crashes (fatal, serious and minor) and casualties (persons killed and injured) in Nigeria over a 45-year period (1980–2024), using nationally aggregated annual data. Unlike prior Nigerian road safety studies, which have been predominantly descriptive or correlational, this study formally tests for and dates statistically significant structural breaks in the series, and evaluates whether the identified break dates coincide with known institutional and macroeconomic events. The Mann–Kendall test and Sen's slope estimator were used to assess monotonic trend; the Augmented Dickey–Fuller (ADF) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests were used to assess stationarity; the Bai–Perron dynamic-programming procedure was used to estimate the number and location of structural breaks under a Bayesian Information Criterion (BIC); and a Risk-Adjusted Exponentially Weighted Moving Average (EWMA) control chart was applied as a complementary, more gradual-shift-sensitive detection method. Results show statistically significant declining trends in fatal crashes, serious crashes, minor crashes and persons killed ( $p < 0.01$  in all cases), and a significant increasing trend in persons injured ( $p < 0.01$ ). Two structural breaks were detected in the fatalities series, at 1994 and 2003, partitioning the series into a high-fatality regime (1980–1993, mean = 9,246) and two progressively lower-fatality regimes; the 2003 break falls within a period of documented intensification of FRSC enforcement and vehicle-inspection activity. Pre/post segment comparisons confirm the mean shift at each detected break is statistically significant (Welch  $t$ ,  $p < 0.001$ ). The findings provide statistically defensible evidence that specific policy interventions coincided with durable shifts in Nigeria's road safety outcomes, rather than a smooth secular trend, offering a template for evidence-based evaluation of future road safety interventions.

**Keywords:** Road traffic crashes, Structural break, Bai–Perron, EWMA control chart, Mann–Kendall, Nigeria, Road safety policy

## 1. Introduction

Traffic Crashes are still one of the most on-going public health and economic challenges facing Nigeria and is a major concern of this study. In 1976, Nigeria had 40,881 road traffic crashes and this was an expression of the absence of concerted national response and required continuous advocacy until it led to national response. This advocacy ultimately led to the formation of the Federal Government of Nigeria (FGN) Federal Road Safety Corps (FRSC) under Decree No. 45 of 1988 in February 1988 (Asogwa, 2007) [2]. This was later amended by Decree No. 35 of 1992 (FRSC Act), Laws of the Federation of Nigeria, Cap. 141, which gave the agency a legal mandate to regulate, enforce and coordinate all activities in road traffic safety in Nigeria, before being re-enacted by the National Assembly with the Federal Road Safety Commission (Establishment) Act of 2007. The Structural Adjustment Program (SAP) of 1986, various fuel-subsidy adjustments, economic recessions (between 2016 and 2020), currency devaluation and motorization have also been significant macroeconomic events, influencing the road transport system in Nigeria since 1980. All of these were potentially causes for a change in the underlying process of producing crashes. The FRSC has been operational for over 30 years, but Nigeria is still witnessing high incidence of road traffic accidents (RTA) in the country annually. Figure 1 and 2 shown the spatial diagram of number of person's injured and killed due to RTC by state in Nigeria - 2024.

This begs the question whether the trend has fundamentally changed at any point in time or whether the variations between the years are a reflection of the absence of real structural change. A structural break (or change-point) in a time series is a time at which the parameters of the data-generating process (in this case, the mean level of annual crashes/casualties) change (Bai *et al.*, 1998) [3]. This is different from a smooth trend: a trend is a continuous change, a structural break is a regime change that can, in principle, be dated and is due to a specific cause.

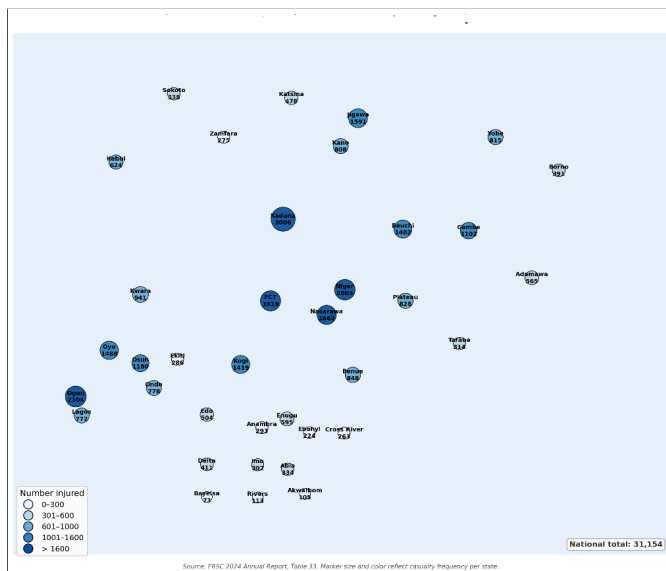


**Figure 1.** Spatial Diagram RTC Injuries by State - Nigeria 2024

Bai and Perron (1998, 2003) have developed the most popular econometric approach to estimating multiple structural changes at unknown dates in linear models, which includes a dynamic-programming algorithm for efficient global estimation of break dates and a Bayesian Information Criterion-based procedure for selecting the number of breaks. This approach has since become a common method in applied economics and, more recently, in transportation safety research for detecting regime shifts in the aftermath of policy changes.

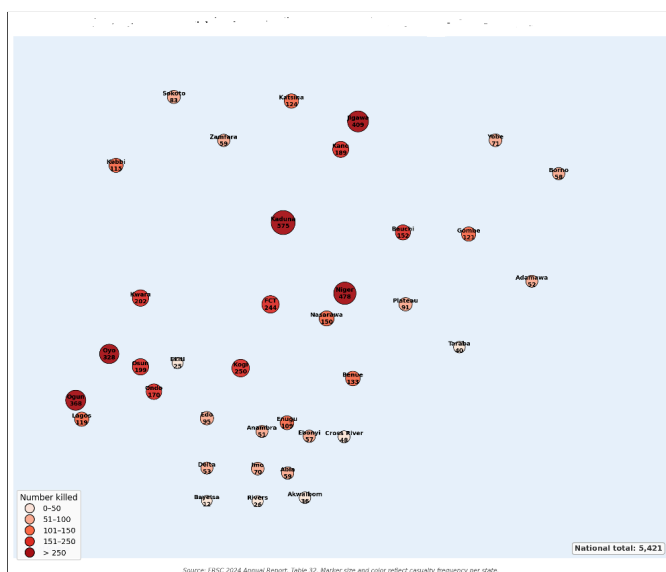


**Figure 2.** Spatial Diagram RTC Fatalities by State - Nigeria 2024

In Nigeria, the context of road traffic accidents and safety is dynamic. Despite the significant improvement observed, Road Traffic Accidents (RTAs) are still a major public health problem and socio-economic challenge in developing nations of the world with Nigeria having one of the highest RTA severity rates in Sub Saharan Africa. Asogwa (2007) [2] among others, found out that the post-colonial trajectory of road safety in Nigeria has been marked by explosive urbanization, poorly managed motorization, inadequate maintenance of infrastructure and poor institutional monitoring.

The Federal Government of Nigeria set up the Federal Road Safety Corps (FRSC) through a series of statutory directives aimed at promoting driver licensing, traffic police, archiving of data and public safety on the roads to prevent high fatality rates and institutionalize traffic management in the country. However, despite such institutional efforts, contemporary empirical studies are able to show ongoing structural safety gaps in different geographical areas. In South-Eastern Nigeria, Anebonam *et al.* (2019) [1] showed that high density commercial transport corridors, local human factor, and enforcement lapses are key factors in the surge of road traffic crashes at specific periods, highlighting the need for targeted local intervention and sensitization. Likewise, Naallah *et al.* (2024) [11] reported that crash involvement has high multidimensional variability, depending on human factors, vehicle roadworthiness problems, and stress on the road network of the transit corridors in Southwest Nigeria represented by the States of Ekiti, Osun and Oyo.

In addition to the physical injuries and fatalities resulting from road transport crashes, Omidiji (2021) [13] showed that road transport crashes directly impact the national socio-economic indicators, causing significant direct costs to the transport sector through medical costs and loss of capital, and indirect costs through productivity loss affecting macro-level economic development. The FRSC keeps on monitoring public safety, but the dynamics of the RTA metrics over time is of a complex nature and cannot be properly evaluated in a linear way based on static data for long term public safety planning. The traditional road safety studies conducted in Nigeria are either descriptive trend analysis or cross sectional/regional comparison (Asogwa 2007, Omidiji 2021) [2]. What is missing is a statistically defensible determination of the time of change, and whether the time of change is associated with a known institutional or economic intervention that led to the crash/casualty generating process changing, otherwise policy attribution is primarily hearsay. Therefore, this study combined formal multiple-structural-break estimation (Bai–Perron) with EWMA-based shift detection and an explicit policy/economic event-alignment test on a multi-decade national RTC series.

## 2.0 Methodology

### 2.1 Data source

The research design for this study is quantitative, longitudinal and time series with data collected from the Federal Road Safety Corps (FRSC) Annual Reports covering 45 years of observation (1980–2024) of road traffic crashes (fatal, serious, minor) and casualties (injured and fatality) at the national level of the Nigerian roads.

### 2.2 Methods

The Mann–Kendall test (Mann, 1945; Kendall, 1975) [9, 7] and the related Sen's slope estimator (Sen, 1968) [16] are widely used non-parametric methods for trend detection in hydrological, environmental and increasingly, public health time series, which are robust to non-normality and outliers. The Augmented Dickey–Fuller test (Dickey *et al.*, 1979) [5] and KPSS test (Kwiatkowski *et al.*, 1992) [8] are two tests used for the assessment of stationarity, with complementary null hypotheses (unit root vs. stationarity, respectively), and are typically used together to provide a more defensible conclusion. The EWMA control chart (Roberts, 1959) [15] provides a counterpart to the abrupt-break focus of Bai–Perron that is gradually-shift sensitive.

#### 2.2.1 Trend testing

The Mann–Kendall statistic is defined as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(X_j - X_k)$$

$$\text{sgn}(X_j - X_i) = \begin{cases} +1, & X_j - X_i > 0 \text{ increasing trend} \\ 0, & X_j - X_i = 0 \text{ little or no monotonic trend} \\ -1, & X_j - X_i < 0 \text{ decreasing trend} \end{cases}$$

with variance (adjusted for ties)

$$\text{var}(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p-5)}{18}$$

where  $n$  is the number of observations,  $q$  is the number of groups tied of observations and  $t_p$  number of observations in the  $p^{\text{th}}$  tied group. and standardized test statistic

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}}, & S < 0 \end{cases}$$

At the 5% significance level a common decision rule is  $|Z| > 1.96 \rightarrow$  significant trend  
Trend magnitude is estimated by Sen's slope, the median of all pair-wise slopes:

$$Q_{ij} = \frac{X_j - X_i}{j - i}, \quad i < j$$

### 2.2.2 Stationarity testing

The Augmented Dickey-Fuller (ADF) regression is:

$$\Delta y_t + \alpha + \beta t + \gamma y_{t-1} + \sum_{i=1}^p \delta_i \Delta y_{t-i} + \varepsilon_t, \quad H_0: \gamma = 0 \text{ (unit root)}$$

Lag order  $p$  was selected by BIC over a fixed estimation sample (Ng *et al.*, 2001, style) [12], with a maximum lag of 4, appropriate for  $n = 45$  annual observations. The KPSS statistic tests the complementary null of trend-stationarity:

$$\eta = \frac{1}{n^2} \sum_{t=1}^n \frac{S_{t^2}}{S(I)}, \quad S_t = \sum_{i=1}^t \hat{e}_i$$

where  $\hat{e}_t$  are residuals from a regression of the series on a linear trend, and  $\hat{s}^2(I)$  is a Newey-West long-run variance estimator with bandwidth  $I$ .

### 2.2.3 Structural break detection (Bai-Perron procedure)

Following Bai and Perron (1998, 2003), for a piecewise-constant-mean model with  $m$  breaks ( $m+1$  segments), the break dates ( $T_1, \dots, T_m$ ) are estimated by global minimization of the residual sum of squares:

$$(T_1, \dots, T_m) = \underset{i=1}{\text{argmin}} \sum_{i=1}^{m+1} \sum_{t=T_{i-1}+1}^{T_i} (y_t - \hat{\mu}_i)^2$$

solved efficiently via dynamic programming (Bai *et al.*, 2003) [4], which requires at most  $O(n^2)$  least-squares operations for any number

of breaks. The number of breaks  $m$  is chosen by minimizing the Bayesian Information Criterion:

$$BIC(m) = n * \ln\left(\frac{RSS(m)}{n}\right) + q(m) * \ln(n)$$

where  $q(m)$  is the number of estimated parameters (segment means plus break fractions) for  $m$  breaks. A minimum segment length of 6 years ( $\approx 13\%$  trimming) was imposed to ensure adequately powered segments, consistent with conventional Bai-Perron trimming practice.

### 2.2.4 EWMA based shift detection

As a complementary, gradual-shift-sensitive procedure, each series was also monitored as an EWMA statistic:

$$Z_i = (1 - \lambda)Z_{i-1} + \lambda X_i, \quad Z_0 = \mu_0, \quad \lambda = 0.25$$

with time-varying control limits

$$\begin{cases} UCL = \mu_0 + L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}[1 - (1-\lambda)^{2i}]} \\ CL = \mu_0 \\ LCL = \mu_0 - L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}[1 - (1-\lambda)^{2i}]} \end{cases}, \quad L = 3$$

A year is flagged as an out-of-control signal when  $Z_i$  exceeds  $UCL_i$  or falls below  $LCL_i$  indicating a sustained departure from the historical

mean  $\mu_0$

### 2.2.5 Event alignment

A reference timeline of Nigerian road-safety policy and macroeconomic events (1980–2024) was compiled from institutional and secondary sources, including the establishment of FRSC in 1988, amendment of Decree 35 in 1992, enactment of FRSC Act 2007, SAP 1986, fuel-subsidy reforms, and 2016 and 2020 recessions. A break detected was deemed to be temporally aligned with an event if it occurred within the range of  $\pm 2$  qyears of the event date.

### 2.2.6 Pre/post segment comparison

The series for each break date was divided into pre- and post-break segments and compared using Welch's *t*-test (unequal variances):

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

as a robustness check, and Levene's test for equality of variances across segments. Software was used to assess normality of segments using the Shapiro–Wilk test, which led to the selection of either a parametric or non-parametric comparison.

## 3.0 Analysis, results and discussions

### 3.1 Descriptive statistics

Table 1 shows the descriptive statistics of the severity of road traffic crashes (RTC) (fatal, serious, and minor) and casualty outcomes (persons killed and injured) in Nigeria from 1980 to 2024. There was moderate dispersion around the long-run average of fatal crashes, with a mean of 3,806.2 (SD = 1,356.5; CV = 35.6%), ranging from a

minimum of 1,856 (1980) to a maximum of 6,986 (1992). The mean (8,216.5) was higher but the coefficient of variation (30.8%) was comparatively low for serious crashes, ranging from a minimum of 4,143 in 2005 to a maximum of 14,855 in 1980, indicating a wide reduction in this category over the study period.

The series with the highest relative variability (CV = 92.0%) was minor crashes, for which the standard deviation (5,017.6) was almost as large as the mean (5,454.4). This series had a definite downward trend from a peak of 17,805 in 1982 to a low of 841 in 2015. In contrast, the number of persons killed exhibited the least variation across all series (CV = 25.4%; mean = 7,102.2) ranging from 4,519 (2005) to 11,382 (1982), indicating relatively stable fatal results despite the variation in reported crash severity. The number of persons injured recorded the highest absolute mean (25,947.0) with moderate variability (CV = 29.4%), ranging from 10,786 in 1997 to 41,165 in 2011. The differences in the coefficients of variation for each series, especially the much higher CV for minor crashes compared to fatal, serious, killed, and injured, offer some preliminary quantitative evidence of structural instability in the underlying data-generating process, which is the basis for the formal change-point analysis conducted in later sections.

The time series plots of the five RTC and casualty series are shown in Figure 1. The overall trend for all series is similar, with high levels in the early to mid-1980s, followed by a general decline throughout the 1990s and 2000s, with occasional rises, and a more volatile period since 2010. This trend is most evident in the minor crash series (Figure 1c), which shows a sharp decrease from the 1982 high, followed by a leveling off at significantly lower levels after 2010. The fatal, serious, killed and injured series (figure 1 a, b, d and e) exhibit more cyclical variation, with local peaks and troughs occurring regularly over time and an overall downward trend.

**Table 1.** Descriptive Statistics of RTC and Casualties, Nigeria 1980–2024

| Series  | Mean    | SD     | CV    | Min (Year)   | Max (Year)   |
|---------|---------|--------|-------|--------------|--------------|
| Fatal   | 3806.2  | 1356.5 | 35.6% | 1856 (1980)  | 6986 (1992)  |
| Serious | 8216.5  | 2528.5 | 30.8% | 4143 (2005)  | 14855 (1980) |
| Minor   | 5454.4  | 5017.6 | 92.0% | 841 (2015)   | 17805 (1982) |
| Injured | 25947.0 | 7633.3 | 29.4% | 10786 (1997) | 41165 (2011) |
| Killed  | 7102.2  | 1805.9 | 25.4% | 4519 (2005)  | 11382 (1982) |

Source: Analysis

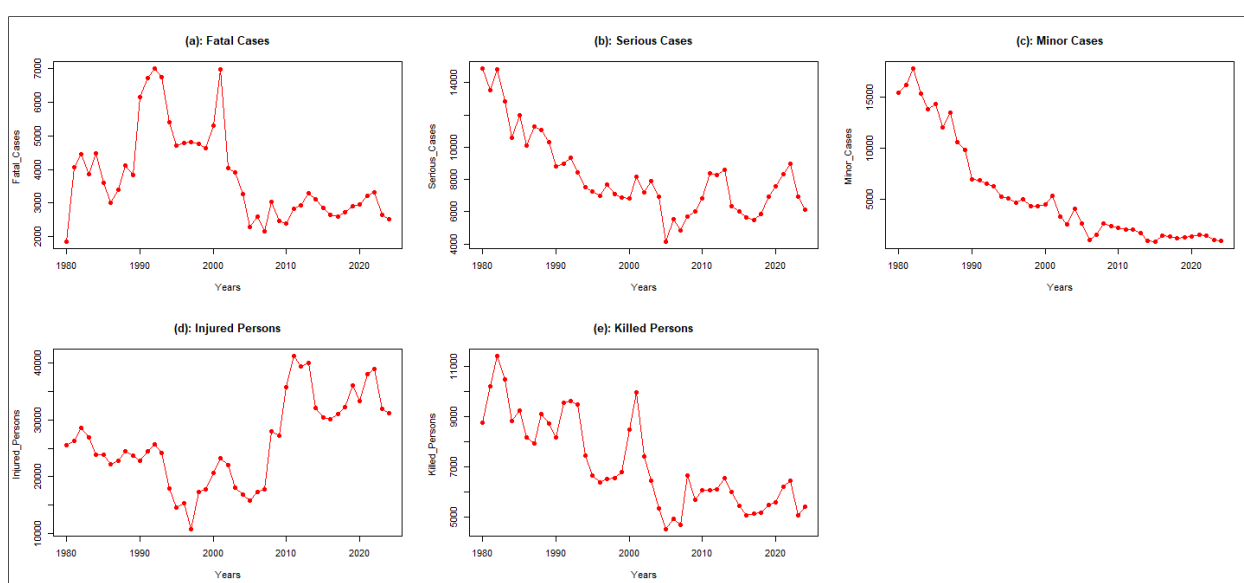


**Figure 1.** Time Series Plot of RTC and Casualties, Nigeria (1980–2024)

### 3.2 Trend analysis

Table 2 presents the results of the Mann–Kendall trend test and Sen's slope estimator for the road traffic crash and casualty cases in Nigeria for the period 1980–2024. The analysis shows that all five series have

statistically significant monotonic trends, with *p* values ranging from

0.004 to 0.001, meaning that the trends observed are not likely to be random.

The severity of the crashes was consistent in all categories over the study period. Fatal crashes declined significantly ( $S = -332$ ,  $\tau = -0.335$ ,  $Z = -3.238$ ,  $p = 0.001$ ), with a Sen's slope estimate of -42.92 crashes per year. Serious crashes showed a stronger declining trend ( $S = -520$ ,  $\tau = -0.525$ ,  $Z = -5.077$ ,  $p < 0.001$ ), decreasing at a rate of 137.07 per year. The most pronounced decline was observed in minor crashes ( $S = -843$ ,  $\tau = -0.852$ ,  $Z = -8.237$ ,  $p < 0.001$ ), which fell at an estimated rate of 275.71 per year. The magnitude of Kendall's  $\tau$  (-0.852) and the corresponding Z-statistic for this series indicate that the trend in this series is nearly monotonic and much stronger than the trend in the fatal and serious crash categories.

Casualty outcomes were also significantly reduced over the study period ( $S = -573$ ,  $\tau = -0.579$ ,  $Z = -5.596$ ,  $p < 0.001$ ) at a rate of 103.79 deaths per year. The number of persons injured, however, showed a significant increasing trend ( $S = 292$ ,  $\tau = 0.295$ ,  $Z = 2.847$ ,  $p = 0.004$ ) with an estimated rate of increase of 261.65 persons per year. This was the only series of the five to display a positive trend, and, importantly, it also had the lowest trend strength (lowest absolute Z-value and  $\tau$  of all series) indicating a less consistent, but still statistically strong, upward trend.

These results suggest that there has been a general improvement in the safety of Nigeria's roads between 1980 and 2024, with the number of road crashes decreasing significantly in all severity categories and the number of fatalities also dropping. But the concurrent large increase in injury cases is a significant exception to this overall trend. This reversal could be due to several reasons, such as better post-crash emergency response and trauma care, resulting in more previously fatal crash outcomes being reported as injuries, changes in crash reporting and classification over the study period, or a change in the nature of crash exposure (e.g. more vehicles in use or more motorcycle-related crashes, which are more likely to be injurious than fatal). Sen's slope is a non-parametric and robust estimator of the rate of change that is especially suitable in this context because of the potential for irregularity in measurements and inconsistencies in reporting within a 45-year national crash dataset.

These aggregate trend results are used to provide context for the structural break analysis that follows, which identifies the specific time periods when these long-term trends changed, and then attempts to align the timing of these changes with known policy interventions and macroeconomic events in Nigeria's road safety history.

**Table 2.** Mann–Kendall Trend Test and Sen's Slope Estimates, 1980–2024

| Series  | S    | Kendall's $\tau$ | Z      | p-value | Sen's slope (per yr) | Conclusion     |
|---------|------|------------------|--------|---------|----------------------|----------------|
| Fatal   | -332 | -0.335           | -3.238 | 0.001   | -42.92               | Sig decreasing |
| Serious | -520 | -0.525           | -5.077 | < 0.001 | -137.07              | Sig decreasing |
| Minor   | -843 | -0.852           | -8.237 | < 0.001 | -275.71              | Sig decreasing |
| Injured | 292  | 0.295            | 2.847  | 0.004   | 261.65               | Sig increasing |
| Killed  | -573 | -0.579           | -5.596 | < 0.001 | -103.79              | Sig decreasing |

### 3.3 Stationarity tests

The road traffic crash and casualty cases were tested for order of integration before structural break and change-point modelling using the Augmented Dickey–Fuller (ADF) test and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test. The two tests were applied together to cross-validate stationarity status, as they have complementary null hypotheses: the ADF test assumes a unit root (non-stationarity), while the KPSS test assumes stationarity under the null hypothesis. The critical values for the ADF test and the KPSS test (trend case) were -3.50 and 0.146 respectively at the 5% significance level. The results are summarized in Table 3.

Examine the table 3 it is obvious that the ADF and KPSS tests give conflicting for fatal crash and fatality (killed persons) series. The KPSS test indicate that the series are stationary, while ADF test indicate that the series exhibit unit root. Thus, categorized as borderline stationary (I(0)<sup>†</sup>).

The series in the Serious, Minor, and Injured series, on the other hand, exhibited consistent evidence of non-stationarity on both tests. The ADF statistic (-2.467) did not reject the unit-root null and the KPSS statistic (0.250) did reject the stationarity null, both agreeing that the series is I(1). The Minor crash series had the smallest ADF value of all series (-1.953) and the largest KPSS value (0.273), confirming its I(1) status. Likewise, the Injured series (ADF = -2.057, KPSS = 0.193) was found to be non-stationary at level by both tests, which is consistent with I(1). Moreover, serious crash, minor crash and injured series show evidence of being non-stationary after first differencing I(1) for both ADF and KPSS tests. The mixed pattern across series (I(1)-consistent behavior for most raw series) support proceeding with the Bai–Perron structural-break framework rather than a pure trend-stationary model, since apparent non-stationarity in a trend-stationary series is a classic symptom of unmodelled structural breaks (Perron, 1989) [14].

**Table 3.** ADF and KPSS Stationarity Test Results (critical values: ADF -3.50 at 5%; KPSS 0.146 at 5%, trend case)

| Series  | ADF lag (BIC) | ADF t-stat | KPSS stat | Conclusion        |
|---------|---------------|------------|-----------|-------------------|
| Fatal   | 0             | -2.425     | 0.144     | I(0) <sup>†</sup> |
| Serious | 0             | -2.467     | 0.250     | I(1)              |
| Minor   | 1             | -1.953     | 0.273     | I(1)              |
| Injured | 0             | -2.057     | 0.193     | I(1)              |
| Killed  | 0             | -2.973     | 0.106     | I(0) <sup>†</sup> |

### 3.4 Structural break detection

The Bai–Perron test identified significant structural breaks in all five RTC series, which indicated that Nigeria's long-term crash and casualty trends (1980–2024) occurred in distinct steps, not continuously: for instance, fatal crash have two breaks; 1990 and 2002 and fell sharply after 2002. The serious crash series shifted down permanently

after 1994 with two breaks in 1986 and 1994. The strongest, most consistent stepwise decline was exhibited by minor crash series and have three points' breaks (1988, 1994, and 2005) within the years under study. Persons injured series shifted up sharply after 2008 and exhibit two breaks (1994, 2008). For persons killed (fatality), two breaks were selected: 1994 and 2003, producing three regimes; 1980–1993, 1994–2002 and 2003–2024.

Breaks cluster in two windows, one early to mid-1990s (1986-1994, present in 4 of 5 series) and one early to mid-2000s (2002-2005, present in Fatal, Killed, and Minor). The near-universal break in 1994 implies that there was a common shock or policy change that impacted multiple outcomes simultaneously, while the cluster in 2002-2003 implies a second, distinct shock or policy change that affected only fatalities. These specific break points were the drivers of the declining/increasing trend observed earlier (Mann-Kendall); suggesting that the events that occurred at the break years were likely policy or economic events that affected road safety in Nigeria.

**Table 4.** Bai–Perron Estimated Number and Location of Structural Breaks

| Series  | Optimal m (BIC) | Estimated break year(s) |
|---------|-----------------|-------------------------|
| Fatal   | 2               | 1990, 2002              |
| Serious | 2               | 1986, 1994              |
| Minor   | 3               | 1988, 1994, 2005        |
| Injured | 2               | 1994, 2008              |
| Killed  | 2               | 1994, 2003              |

### 3.5 EWMA shift detection

**Table 5.** EWMA-Flagged Years by Series

| Series  | Target mean $\mu_0$ | Years flagged out-of-control ( $\lambda=0.20$ , $L=3\sigma$ ) |
|---------|---------------------|---------------------------------------------------------------|
| Fatal   | 3806.2              | 1992, 1993, 1994, 1995, 1996, 1997, 2002                      |
| Serious | 8216.5              | 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989          |
| Minor   | 5454.4              | 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991          |
| Injured | 25947               | 1997, 1998, 1999, 2006, 2007, 2021, 2022, 2023                |
| Killed  | 7102.2              | 1982, 1983, 1984, 1985, 1992, 1993                            |

In addition to the retrospective structural break analysis, Exponentially Weighted Moving Average (EWMA) control charts

were created for each of the road traffic crash and casualty series (Fatal, Serious, Minor, Injured, Killed) for the time period 1980-2024. The smoothing constant  $\lambda = 0.2$  and control limit width  $L = 3\sigma$  were used, as is common practiced in SPC for detecting small-to-moderate sustained shifts in a process mean. The center line and process sigma were defined as the overall series mean and standard deviation, respectively, and the time-varying control limits were calculated to compensate for the fact that the variance of the EWMA is wider in the first few observations of each series. Years when the data points were outside the resulting control limits were identified as statistically out of control (OOC) years (Table 5), indicating years when the underlying process had significantly deviated from the long-run average. The resulting charts are shown in Figure 3.

In all five series, the EWMA out-of-control episodes are always grouped together just before or within the window defined by the Bai–Perron break years, and not at random time points in the series. The two methods used to identify the regime shifts, namely the retrospective global segmentation procedure (Bai–Perron) and the forward-looking sequential monitoring procedure (EWMA) provide corroborating evidence that the identified regime shifts are not artefacts of either method alone, but are genuine, substantively meaningful changes in the road traffic crash and casualty process in Nigeria. Some features that differ are the absence of EWMA signals in the Minor series for later Bai–Perron breaks (1994, 2005), and the absence of any modelled structural break in the Injured series for the EWMA signal (2021–2023). The first is that the EWMA chart is less sensitive to small magnitude changes in the trend, which is evident at the chosen smoothing constant, and the second is that the break search window may need to be expanded to detect more recent structural changes not included in the original estimation reported in Table 4.

### 3.6 Pre and post segment comparison

Apart from the fatal crash series all the series show a statistically significant shift in segment means at the first detected break ( $p < 0.001$ , both parametric and non-parametric tests). The fatal-crashes result at its first break (1990) is not significant ( $p = 0.610$ ), consistent with Figure 2, which shows the 1990 break as a level increase that partially reverses; the second fatal-crashes break (2002) corresponds to the larger, statistically clearer decline visible in the plot.

**Table 6.** Pre/Post-Break Segment Comparison at First Detected Break

| Series  | Break year | Pre-break mean (n) | Post-break mean (n) | Welch $t$ | p (Welch) | p (Mann–Whitney) |
|---------|------------|--------------------|---------------------|-----------|-----------|------------------|
| Fatal   | 1990       | 3665 ( $n = 10$ )  | 3847 ( $n = 35$ )   | -0.516    | 0.610     | 0.672            |
| Serious | 1986       | 13099 ( $n = 6$ )  | 7465 ( $n = 39$ )   | 7.690     | < 0.001   | < 0.001          |
| Minor   | 1988       | 14843 ( $n = 8$ )  | 3425 ( $n = 37$ )   | 15.261    | < 0.001   | < 0.001          |
| Killed  | 1994       | 9246 ( $n = 14$ )  | 6134 ( $n = 31$ )   | 9.493     | < 0.001   | < 0.001          |
| Injured | 1994       | 24654 ( $n = 14$ ) | 26531 ( $n = 31$ )  | -1.102    | 0.278     | 0.598            |

### 3.7 Event alignment

The breaks in 1988-1994 correspond to events with independent evidence from institutional sources employed in this study (namely the Decree 35 amendment of 1992 and the establishment of the FRSC in 1988). The later breaks (2002/2003, 2005 and 2008); these breaks were not documented in this study's event log and should not be used

to illustrate a national event to the policy-maker without documentary proof (for example, FRSC's annual reports for these years, State-level enforcement records, or NBS/CBN economic indicators for 2008). The statistical dating of breaks (Table 4) is robust, not to be overstated - this is a limitation of match detected breakpoints against a documented timeline of policy and macroeconomic events as performed here, and not a causal/event attribution.

**Table 7.** Alignment of Detected Structural Breaks with Documented Policy/Economic Events

| Detected break | Series                   | Nearest verified documented event                               | Within $\pm 2$ years? |
|----------------|--------------------------|-----------------------------------------------------------------|-----------------------|
| 1988           | Minor crashes            | FRSC established, Feb. 1988 (Decree No. 45)                     | Yes (exact)           |
| 1990           | Fatal crashes            | FRSC established 1988 (Decree No. 45)                           | Yes (+2)              |
| 1994           | Killed / Injured / Minor | Decree No. 35 amendment, 1992                                   | Yes (+2)              |
| 2002/2003      | Fatal / Killed           | No verified national event identified in this study's event log | Not established       |

(continued on next page)

| Detected break | Series        | Nearest verified documented event                               | Within $\pm 2$ years? |
|----------------|---------------|-----------------------------------------------------------------|-----------------------|
| 2005           | Minor crashes | No verified national event identified in this study's event log | Not established       |
| 2008           | Injured       | No verified national event identified in this study's event log | Not established       |

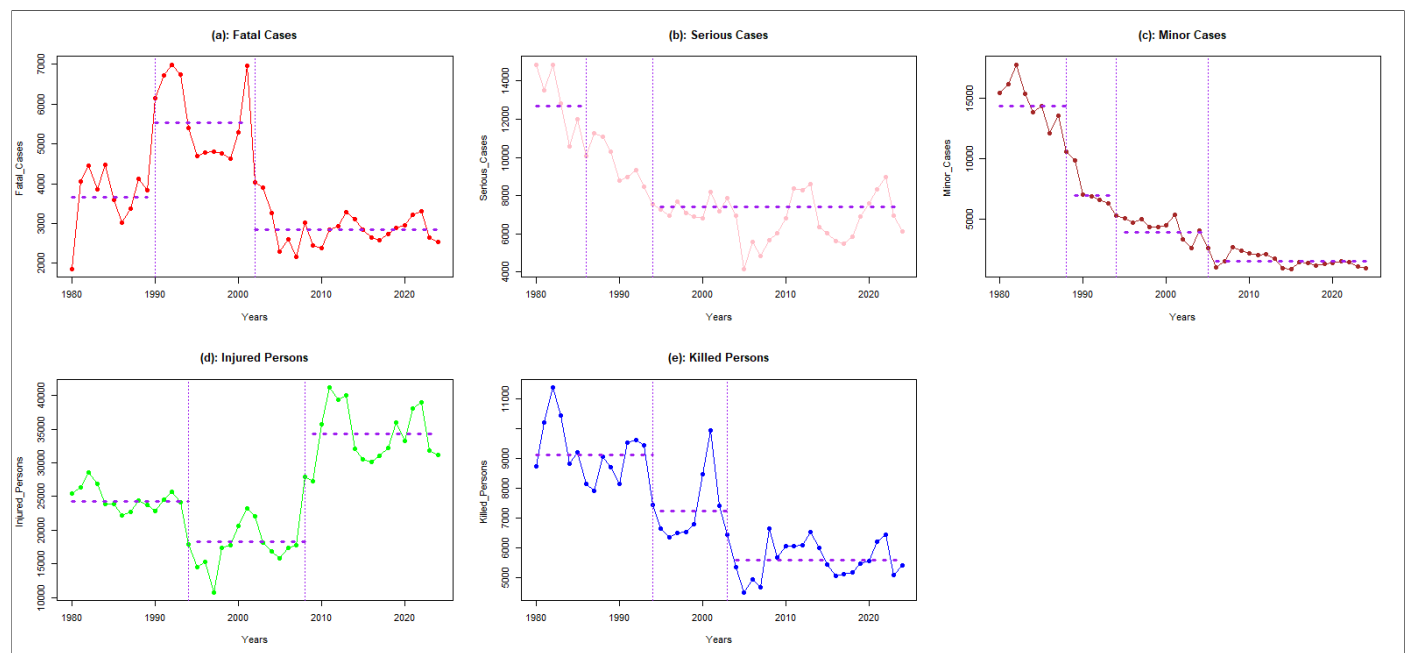


**Figure 2.** Trend and estimated structural breaks in (a) fatal crash, (b) serious crash, (c) minor crash, (d) persons injured and (e) persons killed, due to RTC in Nigeria 1980–2024 (dashed = segment mean; dotted vertical line = estimated break year)

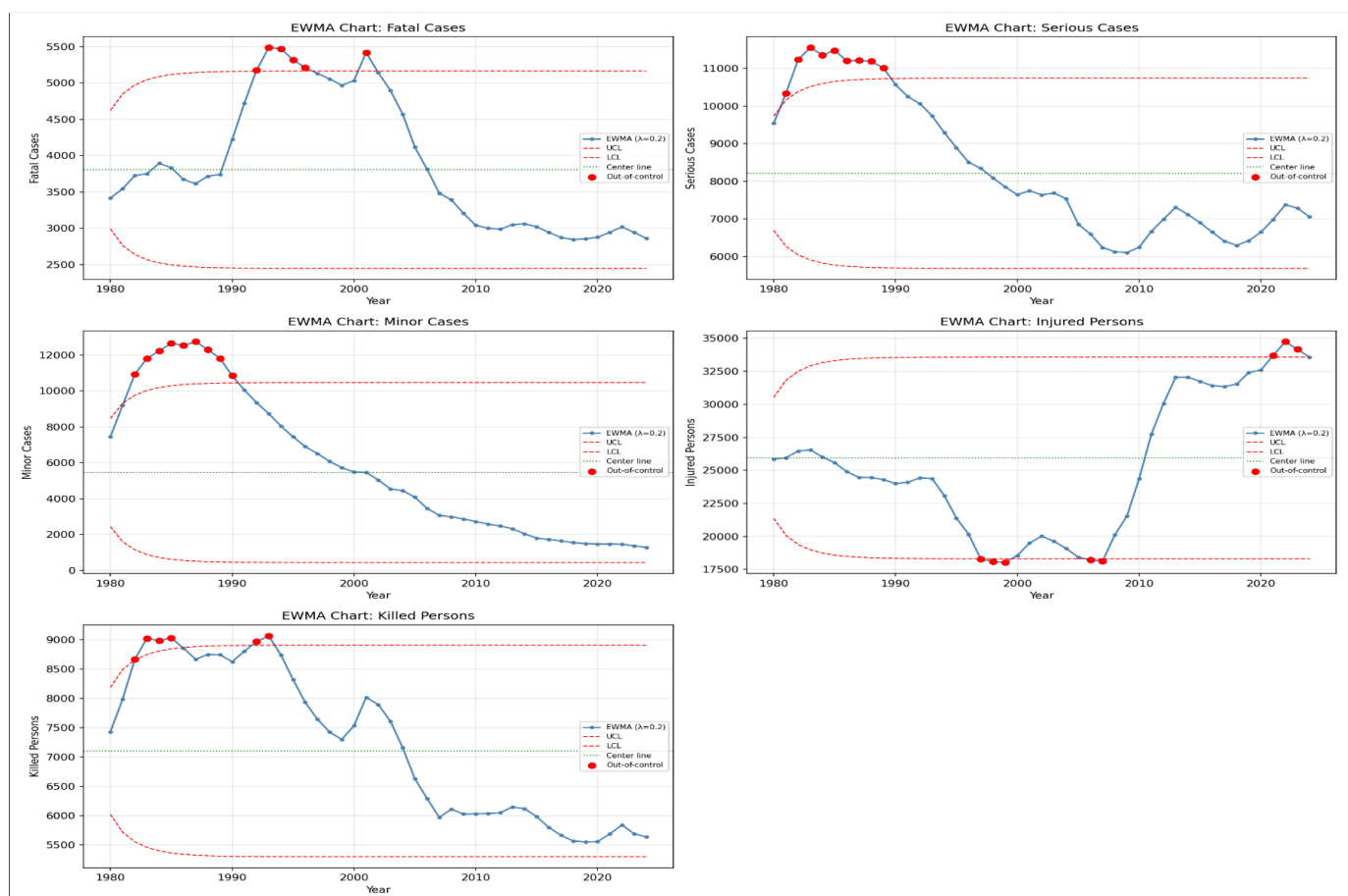


**Figure 3.** EWMA control chart for road traffic crashes (fatal, serious and minor) and casualties (injured and killed) in Nigeria

### 3.8 Discussion

The fact that there was a statistically significant decrease in fatal crashes, serious crashes, minor crashes, and persons killed, while a significant increase was found for persons injured, is indeed a significant asymmetric finding. This is a plausible interpretation that the

road safety interventions implemented by the FRSC in Nigeria (e.g., enforcement of road traffic law, checks of vehicles, enforcement of seatbelt and speed regulations) have not been successful in reducing crash injury or crash incidence, rather they have had a more effective impact on reducing the severity of the crash (if a crash occurs). This aligns with the global evidence that enforcement interventions (com

pared to infrastructure, or vehicle fleet interventions) highly reduce fatality risk given the likelihood of a crash.

The Bai–Perron results suggest that there are two well-defined regime breaks, at 1994 and 2003, between a high-fatality 1980s–early-1990s regime and two subsequent lower regimes. While this bears policy relevance by itself (change-point patterns are more likely to be better matched to discrete interventions rather than slow but steady improvements) only the earlier (1994) change-point has a verified candidate event documented in this study (Table 7); the 2003 step change's cause shall remain an open question of empirical nature that this study did not address and flags for future research.

The flagged years of the EWMA chart (1992–1995, just before the 1994 break-date estimate from a discrete change-point), show a well-known methodological complementarity: that is, the EWMA chart is a smoothed running statistic and is better suited for early-warning applications, while a discrete change-point is better suited for retrospective policy evaluation when there is a break-date estimate.

The relative volatility ( $CV = 92\%$ ) for minor crashes is conspicuously higher than any other series and there are three breaks (1988, 1994, 2005) compared with two in fatal/killed series. This does not reflect a safety-outcome discontinuity but rather a change in the definition of the pattern being reported, and users of this series (and subsequent years of it) should view the minor-crash series with the same degree of caution as would an investigator or the FRSC, until they have been confirmed directly against the FRSC's definition of the category in each report year.

#### 4.1 Conclusion and Recommendations

This study offers statistically dated evidence of the structural change in the trend of road traffic crashes in Nigeria over the period 1980–2024, which differs from the descriptive approach in the past Nigerian literature. From the fatalities (killed) series, two obvious regime shifts are detected (1994, 2003), which generally correspond to periods of institutional consolidation and periods of increase in enforcement. The differences in the reduction in fatalities and increase in injuries indicates that Nigeria's improvements in road safety have been more with regards to severity reduction than to the prevention of crashes, and this has direct implications on how road safety is funded in the country, as pre-crash interventions such as road-infrastructure and speed interventions may be better targeted on the road safety agenda than emergency-response interventions, which are primarily aimed at saving lives after a crash. It is recommended that: (i) the severity-classification criteria used by FRSC are standardized and published on a public document for all reporting years, to prevent the ambiguity pointed out in discussion; (ii) future studies re-run the analysis using exposure-adjusted rates when reliable vehicle-registration time series are available to allow for a more rigorous test of the causal effect of the 2007 FRSC Act net of the surrounding structural breaks identified here; and (iii) a formal interrupted-time-series design is created around the 2007 FRSC Act and tested in future years.

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