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Research article

Impact of the revised Unified Federal Traffic Law on crash casualties in Abu Dhabi Emirate: Interrupted time series analysis

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ABSTRACT

In recent years, different developing countries have shown growing interest in enacting road safety policies. However, research on their effectiveness in reducing crashes, injuries, and deaths is limited. This study evaluated the impact of traffic safety measures introduced in the revised Unified Federal Traffic Law in the Emirates of Abu Dhabi (AD) and the United Arab Emirates (UAE) on crash and casualty reductions. In particular, it examines the 2009 enactment of the black-point system. To the best of our knowledge, this is the first study to consider this topic in a desert or UAE context. Box–Tiao intervention analysis was used to examine monthly AD police data from January 2007 to December 2013. The analysis utilized a dynamic programming approach to test for structural changes in the AD casualty data and empirically confirm the presence and exact location of breakpoints (intervention time). The interrupted time-series analysis results indicated a significant drop in casualty rates post-intervention. Since the intervention, the AD has witnessed a slow downward trend in the crash casualty rate. These findings confirm the effectiveness of the implemented safety measures. They provide quality information to authorities regarding implementing and adopting life-saving interventions and road safety management.

1. Introduction

Road crashes represent a burden on resources and a continuing challenge to safety and economic sustainability worldwide (World Health Organization WHO [1]). Governments continually introduce numerous strategies to reduce crash and casualty rates, injury severity, and related costs. Road crashes account for 3% of the gross domestic product of most countries, and 90% of the world's recorded road fatalities occur in low- and middle-income countries, although these countries account for approximately 48% of the world's vehicles [1].

This study focuses on the United Arab Emirates (UAE), a high-income, oil-producing country. The country has a higher rate of road accidents and casualties than many other developed countries. The country's road safety situation is comparable to that of its Gulf Cooperation Council (GCC) neighbors, who share a similar socio-economic and cultural background. The GCC region has been significantly affected by excessive road traffic crashes and injuries and still faces road safety problems [2,3]. Among GCC countries, the UAE had the second-lowest rate of 10.9 road traffic fatalities per 100,000 residents. However, it is still far behind industrialized countries, such as the UK, which had a rate of 2.9 fatalities per 100,000 residents [4].

Many developed countries have implemented safety measures to minimize road-related deaths, economic losses, and social burdens. Recently, the UAE invested heavily in bringing its road and highway networks to the highest international standards. In 2018, the

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UAE ranked first among 137 countries in terms of road infrastructure quality [5]. In 2007, the UAE introduced new regulations to control road crashes, including speed limits and prohibiting cell phone use while driving. However, road crashes continue to be the second leading cause of death and healthy life-years lost in the Emirate of Abu Dhabi (AD), accounting for 47.2% of all injury-related deaths [6].

While road safety progress is mainly measured by the decline in crash and casualty rates over time, insights into the effectiveness of the introduced measures and policies are contingent on a detailed empirical assessment of the factors influencing these rates. Various methodological techniques and statistical models have proven pivotal in understanding and assessing the influence of safety measures. It is critical to distinguish between the two types of statistical models when assessing road safety performance and examining crash frequency and casualty data. Road crash prediction models are commonly used to predict the occurrence and frequency of road crashes [7]. These models analyze various variables to identify the risk factors related to road crashes. The aim is to understand the likelihood of crashes occurring at specific locations or under certain conditions. Poisson and negative binomial models are popular for count crash data, as are random forest machine-learning models, which identify the most influential variables and predict the severity of road crashes. Crash intervention models, on the other hand, focus on identifying and implementing measures to prevent or mitigate the severity of road crashes [8]. These models analyze the effectiveness of various interventions and strategies to improve road safety. The before-and-after approach, which compares the crash data before and after the deployment of an intervention to measure success, is popular in this domain. Interrupted time-series analysis (ITSA) is a valuable approach for assessing the impacts of interventions or policy changes on road safety. It has several advantages over other accessible intervention approaches, such as pre-post assessments, control group studies, and regression-based models [8]. Intervention models, particularly the ITS, were utilized in this study to evaluate the impact of road safety interventions in the Emirate of Abu Dhabi (AD).

In this context, it is worth noting that no systematic evaluation of the effectiveness of measures to mitigate crashes and casualty rates has been conducted in the AD or the UAE. This is particularly relevant following new regulations and safety measures, including the revised 2008 Unified Federal Traffic Law (UFTL) and the enactment of the black point system [9,10]. As noted by Grivna et al. [10], many AD interventions focus on increasing awareness without evaluating the impact and outcomes of the intervention, and some actions are merely reactions to fatal incidents. Traffic laws in the UAE mainly target driving behavior and implement penalties for serious traffic offenses, along with a recent black point system for driving licenses. In addition to heavy fines, drivers face vehicle and/or license confiscation for limited periods, depending on the severity of the offense. Preceded by extensive awareness and publicity campaigns, the revised UFTL law entails the use of smart technology for traffic surveillance and instant notification of involved drivers about the details of offenses.

The Black Point system campaign was formally launched in the UAE in 2009 [10]. The main objective of a black-point system is to promote safer driving and strict adherence to traffic rules and regulations [11]. The maximum number of points was 24. For severe violations, the court can order a license suspension for three or six months if the same driver accumulates 24 points a second time. If this accumulation occurs a third time, the license will be confiscated for one year. It will not be returned until the driver passes a training course from an institute authorized by the traffic department. The license will also be impounded for drivers under 21 years of age, who will collect 24 black points and return only if the driver passes a driving course. Drivers who collect 24 points within six months of license issuance will have their licenses canceled and must wait one year to apply for a new license. The law can also mandate vehicle confiscation for periods ranging from seven to 60 days, depending on the severity of the offense.

Other countries use comparable intervention systems, such as the demerit point system (DPS). The DPS aims to prevent unsafe driving behavior by imposing penalty points, detecting repeat offenders, and correcting unsafe behaviors through driver education courses [12–14]. It also acts as a deterrent and encourages responsible driving, improving road safety. It is important to note that the demerit point system's specific rules and thresholds differ across countries [14].

Therefore, this study aimed to evaluate the impact of the revised UFTL measures and implementation of the black point system on reducing crash injury rates using road traffic injury data obtained from the AD Police Database from January 2007 to December 2013. Road crash and casualty rates in AD are believed to have decreased since the black point system was officially launched in 2009. This study employs interrupted time-series analysis (ITSA) to quantify the impact of the revised UFTL and black point system by comparing changes following the intervention with the expected trend in the absence of intervention (the counterfactual).

2. Literature review

Martinez and Contreras [15] studied how Chile's 2005 traffic law reform (TLR) and socioeconomic inequalities affected road traffic deaths (RTD) among 0–14-year-olds using interrupted time-series analysis (ITSA) comparing road traffic mortality before and post-TLR. After the law was enacted, the TLR trend lowered RTD growth by 20%. Their study indicated that traffic rule modifications affected urban and low-income children more. This study uses biannual and triennial survey data. Interpolation was used to estimate the lost observations that may have affected the analysis.

Using an interrupted time-series analysis, Fei et al. [16] investigated the impact of China's 2011 drinking and driving regulations on crashes, injuries, and deaths. According to police data, drinking and driving laws have reduced the average annual number of crashes, fatalities, and injuries. Aside from failing to account for regional and economic confounders, the study's definition of road traffic crash fatalities addresses all traffic-related deaths within seven days of the crash, as opposed to 30 days in many other countries. This may have led to an underestimation of road deaths in China.

Nazif-Munoz and Nikolic [17] used ITS to assess the short- and long-term impacts of Serbia's 2009 child restraint and seatbelt legislation on motor vehicle injuries. The data from a traffic safety agency were used in this study. The study included four exposure variables: health risk (child population) and traffic risk (registered vehicles, passenger kilometers traveled, and passengers transported). In the short term, the child restraint law reduced injuries among 0-3-year-olds. For children aged 4–12 years, the law was effective in both the short and long terms. The authors attributed the negligible long-term decline among 0-3-year-olds to poor child restraint use and insufficient police enforcement.

Abegaz et al. [18] used ITSA to estimate the impact of an improved road safety strategy on a major Ethiopian road using monthly data from 2002 to 2011. According to this study, the number of non-injury crashes and fatalities has decreased dramatically. One year after the implementation of the road safety policy, the fatality rate dropped 12.4% to 156 per 10,000 cars from 178. The new road safety strategy did not significantly reduce nonfatal injuries. Data exclusion and underreporting of low-severity instances may have biased the results. The authors attributed the poor road safety performance of low-income countries to a lack of advanced traffic control devices and effective traffic enforcement.

Song and Noyce [19] examined transit signal priority (TSP) and traffic safety using ITSA and monthly property damage-only crash data from 1995 to 2010. The TSP in Portland, Oregon, reduced all crashes by 4.5% after the intervention (2003–2010). Post-intervention, pedestrian and bike crashes increased, whereas fatal-injury crashes did not change. The analysis by Song and Noyce [19] was limited by the lack of an appropriate crash risk exposure measure and the assumption of linearity of the crash data over time. This study examined the TSP at only a few Portland crossings. Thus, the results may not be applicable to other locations or a larger number of intersections.

Foroutaghe et al. [20] used ITSA and Iranian monthly data from 2009 to 2016 to examine the impact of law enforcement and increasing fines on road traffic fatalities and injuries across urban, rural, and gender divisions. Traffic interventions reduce fatalities and road accidents. Urban roadways are the most affected. Rural roads remained unchanged. Men suffered fewer injuries than women.

Mehmood [9] denoted the UAE's black point system as a demerit point system and collected spot speed data from randomly selected vehicles using speed guns on three major arterial urban roads in Al-Ain, UAE, to evaluate the impact of the demerit point system on excessive speeding. The data were obtained three months prior to and three months following the introduction of the system. The study indicated that the demerit point system did not significantly affect the drivers' speeding behavior in Al Ain. According to the author, the lack of effective enforcement may be one reason for the absence of a significant impact. An independent samples *t*-test was used to analyze the data. However, without a control group, it is difficult to verify whether the observed outcome was primarily attributable to the intervention or whether other factors, such as traffic volume and weather conditions, influenced the results [21]. In addition, the study was constrained to a short period before and after the intervention in a less-populated city in the UAE. As a result, the findings lack generalizability.

In their study, Gitelman et al. [14] employed a before-and-after design featuring a comparison group, which is a commonly utilized method in safety evaluations, to assess the impact of a demerit point system (DPS) on driver involvement in road crashes and traffic law violations in Israel. Using data from the National Licensing Authority and complementary accident files, they assessed the impact of DPS corrective measures on the rates of violations and road crashes among drivers. The results suggest that driver involvement in road crashes and the number of violations committed decreased significantly, providing further support for the continued use of the DPS to improve road safety. Pulido et al. [12] used seasonality and a trend-adjusted autoregressive integrated moving average (ARIMA) model to assess the effect of a demerit point system (DPS) of intervention on traffic fatality reduction. They reported a 14.5% drop in road traffic deaths 18 months after the introduction of the scheme.

TavaKKoli et al. [22] conducted a systematic review of the effectiveness of interventions in low- and middle-income countries (LMIC) from 2011 to 2020. According to the authors, previous research on road safety measures in low- and middle-income countries has been limited to specific interventions, primarily in legislation and law enforcement. The systematic review comprised 33 studies from 17 LMICs. The intervention categories with the most supporting evidence were enforcement and traffic laws, speed management, and leadership. The ITS approach was used in 13 of the 18 studies that evaluated enforcement and traffic laws as interventions. Most of this research used crash, injury, or fatality rates as primary indicators to compare pre- and post-intervention.

3. Methods

3.1. Study data

This study extracted monthly road traffic data from January 2007 to December 2013, representing injuries of all types, from minor to fatal, from the AD Police Database. To capture exposure to road traffic hazards, casualty counts are generally converted into rates, using a denominator that amounts to passenger-kilometer or vehicle-kilometer traveled. However, reliable estimates of these measures are currently unavailable for AD data. Instead, we used rates based on the population at risk, that is, the number of casualties per 100,000 residents. These rates were calculated by dividing monthly casualties by mid-year population estimates for 2007–2013, obtained online from the Statistical Center of the Emirate of Abu Dhabi (SCAD). Limiting the analysis to 2007–2013 data guarantees that there are sufficient observations before and after the intervention to model the trend and assess the intervention effect. The pre- and post-intervention series must be long enough to capture both the trend and any seasonal or cyclical variations in casualty rates and the immediate and long-term impacts of the intervention.

3.2. ITSA

ITSA is a robust quantitative approach used to measure the effect of an intervention relative to a counterfactual, using routine data collected before and after the intervention. Researchers have used ITSA to assess the impact of various policy issues in several fields, including public health, traffic safety, marketing, finance, and economics [23–25]. In the case of road traffic crashes, the ITSA can be used to examine whether a policy intervention, such as a road safety policy, a demerit or black point system, or the improvement of infrastructure, affects road traffic crashes and causality.

Despite its simplicity and common use in evaluating intervention effects, segmented regression for the ITSA is flawed. This approach is inadequate when the data trend is nonlinear, irregular, or exhibits complex seasonality [8]. Lagarde [26] noted that the expected result bias when longitudinal data analysis does not account for the specific properties of time-series data, including non-stationarity, autocorrelation, and seasonality. Moreover, the use of simplistic methods, such as Student's t-test, to evaluate before and after a policy change is irrelevant in the case of time-series data and could be misleading. Alternatively, the autoregressive integrated moving average (ARIMA) for the ITSA can adequately identify the underlying data trend, account for autocorrelation and seasonality, and flexibly model different intervention effects.

Box and Tiao [27] introduced ITSA to evaluate the impact of population-level public health interventions. This design is more suitable for retrospective studies implemented in an entire population when randomization or identification of a control group is impractical [26,28,29]. The counterfactual trend or expected value of the outcome variable without intervention was estimated by fitting a regression model to the preintervention data. Post-intervention data were compared with counterfactual trends to estimate the effects of the intervention. To model the impact of the intervention, two components must be identified: (a) the counterfactual, by extrapolating the underlying trend of the pre-intervention series to the post-intervention period, and (b) the impact model, or the type of expected effect of the intervention on the series (AD casualty rates). The general Box and Tiao [27] intervention model is given as follows:

$$y_t = f(\boldsymbol{I}_t, \boldsymbol{x}) + n_t \tag{1}$$

where y_t is the stationary Box–Cox [30] transformation of the original time series (e.g., casualty rates), $f(\boldsymbol{I}_t, \boldsymbol{x})$ is the dynamic part of the model that contains the intervention component (I) and deterministic effects of independent potential confounding variables ($\boldsymbol{x}$), and n_t is the stochastic variation or noise component.

According to Box and Tiao [27], the random component (n_t) follows a seasonal ARIMA model, (SARIMA), denoted as the SARIMA$(p, d, q)(P, D, Q)_s$ model, where p, q, and d are the orders of the autoregressive (AR), moving average (MA), and difference in the non-seasonal components, respectively. Similarly, P, Q, and D represent the orders of the seasonal components. The subscript s denotes the length of seasonality (e.g., $s = 12$ with monthly time-series data). The SARIMA model is as follows:

$$\varphi(B)\Phi(B^s)(1-B)^D n_t = \theta(B)\Theta(B)u_t \tag{2}$$

where φ and Φ are the regular and seasonal AR operators, θ and Θ are the regular and seasonal MA operators, B and B^s are the backward shift operators and u_t is an uncorrelated random error term with zero mean and constant variance (σ^2).

Different intervention functions can be used to examine the impact of an intervention on time-series data. If the intervention has an immediate impact on the outcome variable y_t and stimulates a change in the slope of the time-series trend, two variables can be used to describe the intervention component (I): a step variable S_t which sets the initial impact of the intervention, shifting the time series immediately up or down, and a ramp variable R_t which describes the change in the slope of the trend. In this case, the intervention function $f(\boldsymbol{I}_t)$ can be defined as

$$f(\boldsymbol{I}_t) = \omega S_t + \delta R_t \tag{3}$$

$$S_t = \begin{cases} 0, t < t_0 \\ 1, t \geq t_0 \end{cases}, \qquad R_t = \begin{cases} 0, t < t_0 \\ t - t_0 + 1, t \geq t_0 \end{cases}$$

where t_0 denotes the intervention time. Therefore, the general intervention model can be written as:

$$y_t = \omega S_t + \delta R_t + \boldsymbol{\beta x} + \frac{\theta(B)\Theta(B)u_t}{\varphi(B)\Phi(B^s)(1-B)^d(1-B^s)^D} \tag{4}$$

3.3. Testing for breakpoints and structural changes

To test for structural changes in the time series data and empirically confirm the presence and exact location of breakpoints (intervention time), we used the methodology described by Zeileis et al. [31]. To test whether the mean of the series changed over time, the methodology employed a dynamic programming approach to fit an ordinary least squares regression model to data with a trend over time. Given some segment size $h \times n$ observations, the process reports m possible breakpoints that minimize the residual sum of the squares associated with a model with $m + 1$ segments. The h bandwidth parameter is chosen by the user and typically equals 0.1 to 0.15. Because the number of breakpoints m is not known in advance, the optimal breakpoints for $m = 0, 1, \dots$ breaks must be computed, and the selected model minimizes some information criteria, such as the Bayesian Information Criterion (BIC), see [31,32] for more details.

4. Results

4.1. Exploring casualty rates in AD, 2007–2013

Fig. 1 shows the rates per 100,000 residents of road crash casualties in AD from January 2007 to December 2013. Overall, the casualty rates showed a steady decrease after December 2009, following the implementation of the black point system. These rates were higher between January 2007 and December 2009. The time series in this period displayed higher volatility than that after December 2009. A seasonal pattern was also evident, with the summer months (June–August) showing lower rates, possibly owing to reduced mobility and traffic volume because of the higher summer temperatures across the region. The seasonal Mann-Kendall test [33] showed a significant increasing and then decreasing trend in the time series before and after December 2009 ($z = 2.11, -2.16$, respectively, $\mathrm{p} -$ value < 0.05). Thus, the time series showed a significant seasonal trend at the 5% significance level.

Fig. 2 displays a subseries plot of the monthly casualty rates from 2007 to 2013. The resulting plot depicts the distribution of the casualty rates throughout the year. The data showed a clear seasonal pattern, with the lowest average casualty rates in the summer months (June–August), the lowest in July, the warmest month of the year in the UAE, and higher average rates in the winter months. Based on the plot, the Abu Dhabi Emirates road traffic casualty rates were strongly influenced by seasonality, with winter showing a considerable increase in mobility. Moreover, winter rates appeared to be more variable than summer rates.

A stable time series with constant variability across time is a prerequisite for building an ARIMA model. Modeling a stable series with consistent properties involves less uncertainty. In addition to visually inspecting AD casualty rates, as mentioned above, the stability of the series can be intuitively assessed statistically by utilizing a test of heteroscedasticity, that is, a non-constant variance, such as the McLeod–Li test [34]. With a p-value significant at <0.05, at different lags from 1 to 20, the null hypothesis of the McLeod–Li test, that the series variance is constant, is rejected. Thus, heteroscedasticity or non-stationary variance was present in AD casualty rates, confirming the graphical inference outlined above. Heteroscedasticity is often rectified by allowing appropriate data transformations. The square root and natural logarithm of the original time series typically produce good results [34]. Both transformations produced similar results using the AD causality rates, reducing heteroscedasticity and stabilizing the time series variance. Therefore, in addition to first-order non-seasonal ($d = 1$) and seasonal ($D = 1$) differencing, the AD casualty rates were square-root-transformed.

The extensive publicity campaigns and announcements regarding the black point system before its implementation in 2009 may have obscured the breakpoint that defined the pre-and post-intervention periods. Fig. 1 shows a significant change in the mean of the time series. This seemingly produces two segments of different slopes: the first extends from January 2007 to the end of September 2009 (pre-intervention period), showing an increasing trend, and the second extends from the beginning of October 2010 to the end of December 2013 (post-intervention period), showing a decreasing trend.

To test for structural changes in the AD casualty data and empirically confirm the presence and exact location of the breakpoints, we used the methodology detailed by Zeileis et al. [31]. The BIC suggests three breakpoints when a regression model with a time trend is fitted to the square-root-transformed AD casualty rates. The dates corresponding to these breakpoints were September 30, 2007; July 31, 2008; and December 31, 2009. The year 2007 marked the implementation of new safety measures as part of the revised federal traffic law. An unsustainable decline in casualty rates followed the deployment date and subsequent fluctuations, which generally assumed an upward trend in casualty rates (Fig. 3). A similar pattern followed the 2008 breakpoint when new safety measures were introduced. The lack of proper enforcement may explain why the introduced safety measures did not result in the expected sustainable reduction in casualty rates. According to Aberg [35], enforcement is required to increase the effects of safety rules and measures and must be seen as effective. The situation after December 31, 2009, is different; in 2009, the black point system was implemented with increased monetary fines and license/vehicle confiscation penalties [9,11]. December 31, 2009, was followed by a steady decline in casualty rates, as noted above and depicted in Fig. 3. Therefore, the empirical evaluation of AD casualty data using Zeileis et al.'s [31] methodology utilizes December 31, 2009, as a breakpoint defining the pre-and post-intervention periods for the ITSA. A casualty rate of 28.8 per 100,000 residents was reported on this date, which dropped to 17.4 casualties per 100,000 residents on October 1, 2010 (Fig. 3).

Putting these results in context, a UAE Police press release [35] revealed that 260,000 drivers in the UAE had incurred black points by the end of 2009, suspending 4592 driving licenses exceeding 24 black points. The number of suspended licenses in 2010 dropped to 3672 against an increase of 269,00 drivers, thus incurring black points.

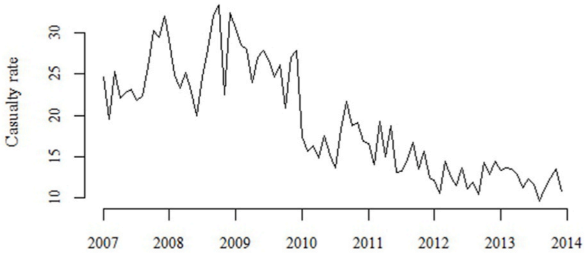

Fig. 1. Monthly rates of road crash casualties per 100,000 residents of the Emirate of Abu Dhabi, January 2007–December 2013.

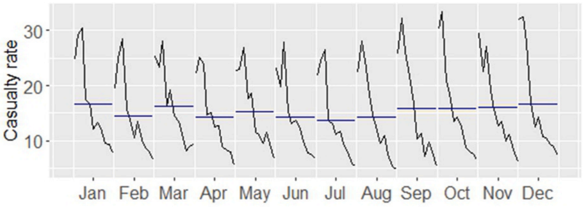

Fig. 2. A seasonal subseries plot depicting the underlying monthly pattern and changes. The horizontal bars in the plot show the average monthly casualty rate per 100,000 residents of Abu Dhabi Emirate over the study period, 2007–2013.

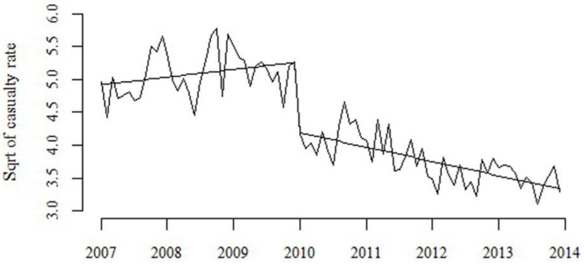

Fig. 3. Observed and fitted Abu Dhabi square root transformed (sqrt) casualty rates, breakpoint in December 2009.

4.2. ITSA: impact of the black point system on AD casualty rates

This study hypothesized that road safety interventions enacted in AD following the 2009 implementation of the black point system and other intervention measures immediately reduced crash casualty rates. For analysis, we first identified the ARIMA model, the noise component that best fits the pre-intervention data. This involved estimating the parameters and verifying and diagnosing the model residuals. Second, we added the intervention variables (S_t and R_t). The model can also include other control variables $\boldsymbol{x}$, which might reduce confounding effects and improve model fit.

Several alternative ARIMA models with different orders were fitted using pre-intervention (January 2007 to December 2009) casualty rates. The selected model was based on the lowest Akaike information Criteria (AIC) value. Table 1 displays the parameter estimates of the seasonal $\text{ARIMA}(0,1,1)(0,1,1)_{12}$ intervention model after adding the intervention variables. These are first-order non-seasonal MA, $\text{MA}(1)$, and first-order seasonal MA, $\text{SMA}(1)$, models. All estimated parameters, including the intervention variables, were statistically significant ($\text{p} - \text{value} < 0.05$). The residual analysis suggests that the fitted model is adequate, and the residuals are not different from white noise. The Ljung–Box test [33], with 24 lags and a null hypothesis of no autocorrelation in the model residuals, was not rejected ($p - value = 0.284$). The McLeod–Li test of variance heterogeneity [34] produced p-values ranging from 0.588–0.997 for lags 1–24, confirming the residuals' variance stability over time.

The ARIMA intervention model gave rise to a statistically significant step change of -0.735 with estimated 95% confidence limits of $(-1.366, -0.105)$ and a slope change of -0.028 with estimated 95% confidence limits of $(-0.054, -0.002)$ (Table 1). Fig. 4 shows the counterfactual expected continuous trend predicted by the fitted ARIMA model in the absence of intervention. Results suggest that, due to the intervention, the change in AD casualty rates was associated with an immediate, sustained drop of 0.54 (anti-square root of 0.735^2) per 100,000 residents in January 2010, with a further decrease of 0.001 (0.028^2) per 100,000 residents every month.

4.3. Study limitations

ITS analysis is a valuable tool for assessing the effects of interventions and other factors on road traffic crashes and injury data. However, due to data limitations, it was impossible to control for the influence of confounding variables or other factors that could affect the outcome, such as traffic variables and weather conditions. While crash rates per resident population can provide a basic understanding of road safety, they have limitations in accurately assessing risk exposure, accounting for variations in travel behavior, and possibly overlooking critical factors that need to be addressed to improve road safety, such as road conditions and enforcement

Table 1
Parameter estimates of a seasonal $\text{ARIMA}(0,1,1)(0,1,1)_{12}$ intervention model.

Parameter	Estimate	Std. Error	p-value	95% Confidence limits	
θ	− 0.836	0.182	0.000	− 1.193	−0.479
Θ	− 0.862	0.311	0.006	− 1.472	−0.252
ω	− 0.735	0.322	0.022	− 1.366	−0.105
δ	− 0.028	0.013	0.034	− 0.054	−0.002

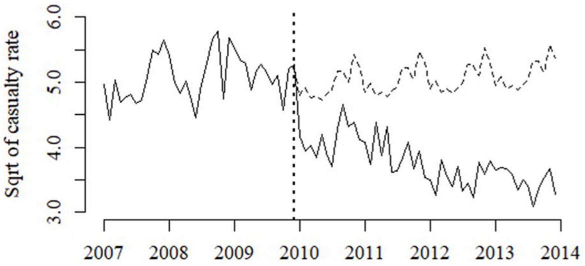

Fig. 4. Observed Abu Dhabi Emirate square root transformed (sqrt) casualty rates January 2007–December 2013 and the ARIMA counterfactual trend (dotted line) predicted in the absence of intervention.

efforts.

5. Discussion

This study showed that the Abu Dhabi Emirate's investment in road safety legislation and intervention policies yielded positive results. Specifically, the UFTL implementation in 2008 and safety measures, such as the black point system in 2009, significantly reduced the number of casualties per resident. Although it occurred slowly, the pattern of the AD casualty rates after 2009 maintained a downward trend over time.

Various countries and jurisdictions have developed their own traffic regulations and penalty systems [14]. The success of these systems varies depending on enforcement, public compliance, cultural variables, and infrastructure quality. Among all aspects that influence road safety in the UAE, cultural influences pose a significant problem. The country hosts a substantial expatriate population from various parts of the world. They originate from different backgrounds, driving cultures, behaviors, and training and testing systems, resulting in diverse road users. This reflects the country's road safety situation [36]. The primary contributing factors to road crash casualties that impede the sustainability of road safety in the UAE are driving behaviors, including distracted driving, such as using mobile phones, eating, engaging in other activities that divert attention from the road, and excessive speeding, particularly in areas with high pedestrian activity or poor road conditions [37]. Three months before and after the implementation of the black point system in Al-Ain city in the UAE in 2008 revealed no significant change in the speeding behavior of drivers as a result of the implementation of the black point system [9]. According to the author, enforcement was insufficient. Traffic law enforcement and strict implementation of the black point system, including penalties for traffic violations and the accumulation of black points on driving licenses, have recently gained power, generating a positive impact and significant decline in road crash casualties, leading to the promotion of responsible driving behavior and increased compliance with traffic regulations, as indicated by this study and confirmed by official police reports [38], http://tinyurl.com/Abu-Dhabi-Police. These results align with the findings of Sagberg and Ingebrigtsen [39], who indicate that penalty point systems significantly deter drivers at high risk of losing their licenses after their subsequent violation. Similar conclusions were reached by Gitelman et al. [14], who cited consistent effects of the demerit point system across driver groups, a significant decrease in road crash involvement, and a 70% reduction in committed traffic law violations following system implementation. Legislation and enforcement measures appear to be most effective in low- and middle-income countries [22]. However, many interventions remain understudied, and more comprehensive approaches that account for the complexities of the road transport system are desirable.

The lack of studies on safety interventions for AD and the UAE is a major limitation in implementing evidence-based interventions to reduce road crashes and casualty rates. One of the responsibilities of the AD Department of Transport is to enhance traffic safety. The design of road safety policies depends on robust indicators of the effectiveness of interventions. Such information would also justify expenditure and support for unpopular interventions. Moreover, the absence of evidence-based support can lead to unintended outcomes.

Overall, the findings suggest that legislation, driver deterrence and training, and enforcement improve traffic and road safety. Hence, high-quality studies and data are needed to evaluate interventions considering other potential factors in different contexts.

6. Conclusion

This study utilized traffic casualty data obtained from the Abu Dhabi Emirate Police database, which includes injuries of all types. The ITS method was employed to evaluate the impact of the revised UFTL road safety measures and the implementation of the black point system to reduce the rates of injuries caused by road crashes. The study findings provide evidence of enhanced road safety and a significant and continuing decrease in the rate of road crash casualties after the introduction of the UFTL and black point system in the Emirate of Abu Dhabi. An evident increase, followed by decreased casualties from road accidents, was observed before and after the intervention period. There is a noticeable and consistent seasonal variation in the rate of casualties. Compared to summer, the winter months were linked to higher average rates, possibly because of increased road user mobility and higher exposure to the risk of road crashes.

To the best of our knowledge, no previous studies on the UAE have addressed the impact of the black point system on road safety and driver behavior. Overall, this study offers insights into the effectiveness of the Revised Unified Federal Traffic Law in the Abu Dhabi Emirate and the implementation of the black point system. It emphasizes the necessity of comprehensive legislation, enforcement measures, and ongoing reviews to ensure road safety and safeguard the lives and well-being of road users. The findings of this study can serve as a basis for evidence-based policy decisions and further initiatives aimed at reducing road crash casualties and creating safer road environments.

Ethics statement

The study doesn't need ethics approval. No experiments were done. The research used anonymized records and data sets on road traffic crashes and casualties from the UAE Data Archive (Bayanat.ae) and Abu Dhabi Police Department's Database, where permissions have been granted and individuals cannot be identified.

Data availability statement

The data will be made available upon request from the corresponding author.

CRediT authorship contribution statement

Ibrahim Abdalla Alfaki: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing 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.

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