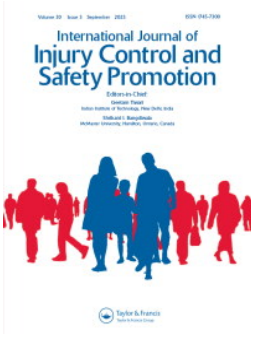

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RESEARCH ARTICLE

Road traffic mortality in Iran: longitudinal trend and seasonal analysis, March 2011-February 2020

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ABSTRACT
Road traffic mortalities (RTMs) and injuries are among the leading causes of human fatalities worldwide, particularly in low-and middle-income countries like Iran. Using an interrupted time series analysis, we investigated three interventional points (two government-mandated fuel price increases and increased traffic ticket fines) for their potential relation to RTMs. Our findings showed that while the overall trend of RTMs was decreasing during the study period, multiple individual provinces showed smaller reductions in RTMs. We also found that both waves of government-mandated fuel price increases coincided with decreases in RTMs. However, the second wave coincided with RTM decreases in a smaller number of provinces than the first wave suggesting that the same type of intervention may not be as effective when repeated. Also, increased traffic ticket fines were only effective in a small number of provinces. Potential reasons and solutions for the findings are discussed in light of Iran's Road Safety Strategic Plan.

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Road traffic fatalities; interrupted time series analysis; change point detection; SARIMA; road safety policy

1. Introduction

1.1. Background

Road traffic injuries (RTIs) and mortalities (RTMs) are among the main concerns for public health around the world, as every day 3,400 people lost their lives due to road-related crashes around the world in 2018 (World Health Organization, 2019). While a plethora of efforts such as the Global Decade of Action for Road Safety (United Nations, General Assembly, 2010) and the inclusion of road safety in the Sustainable Development Goals (United Nations, 2016) aim to decrease the number of mortalities, future projections of global mortalities indicate that the programs' goals will not be met (Foreman et al., 2018; Inada et al., 2020). As more than 90% of global road-related mortalities occur in low- and middle-income countries, there is an increased focus on identifying effective interventions that can decrease road-related mortalities and injuries in these countries (Wegman et al., 2017; World Health Organization, 2019).

In Iran, a country with a population of 85 million and more than 30 million registered motorized vehicles, the Road Safety Commission Secretariat has implemented a Road Safety Strategic Plan, to decrease road-related injuries and mortalities (Ministry of Roads & Urban Development, 2009). The plan, drafted in 2009, underlines the importance of increasing road safety in the country for all road users and lists 16 strategic objectives that should be realized under the plan, such as the reduction of speeding, measures to improve pedestrian safety, or improvements of road-related medical services. According to the Road Safety Strategic Plan, the initial goal for the number of road-related mortalities was to reduce the number of 30 mortalities per 100,000 population (mortality rate of 2008) to 9 mortalities per 100,000 population by the year 2020. However, between March 2019 and 2020 (the year 1398 in the Shamsi calendar), 16,940 road users died in road-related crashes in Iran (Iranian Legal Medicine Organization, 2020), which translates to 20.16 road-related mortalities per 100,000 population. This is approximately twice the number that was aimed at and indicates that the goal of the Road Safety Strategic Plan has likely not been met. While mortality numbers have decreased from 30 to 20.5 mortalities per 100,000 population per year between 2008 and 2016/2017, the impact was not strong enough to successfully achieve Iran's long-term goals for road-related mortalities (Iranian Legal Medicine Organization, 2020; Ministry of Roads & Urban Development, 2009).

Apart from government-instituted road safety measures, research shows a relation between the economy of a country and road-related mortalities. During times of economic downturns, e.g. when economies shrink as a result of factors

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such as currency devaluation, unemployment (Wegman et al., 2017), and rise in fuel prices (Delavary et al., 2020), road users decrease their mileage and drive more cautiously (Chi et al., 2015). Moreover, the rate of motor vehicle collisions (MVCs) and fatalities resulting from other driving behaviours, such as speeding (Chi et al., 2013; Wolff, 2014), can be decreased (Chi et al., 2010, 2013, 2015; Naqvi et al., 2020; Safaei et al., 2021). Based on a study in the UK, a 1% increase in fuel prices would result in a 0.4% reduction in fatalities (Naqvi et al., 2020). Safaei et al. (2021) found that a one-dollar increase in adjusted gasoline price leads to a 1.9% reduction in the number of non-motorbike fatal crashes on US roads. In Iran, unlike in most other countries, the fuel price does not change on a daily basis, but is government-mandated and stable over a specific period of time. Changes in fuel prices are only infrequently made by the government to handle economic crises and implement various safety-related scenarios to decrease MVCs and pollution and encourage people to use public transport (Delavary et al., 2020; Fatemi & Alizadeh, 2019).

Besides increasing fuel prices, law enforcement including the presence of police (Castillo-Manzano et al., 2019; DeAngelo & Hansen, 2014) and traffic citations and fines (de Figueiredo et al., 2001; Makowsky & Stratmann, 2011; Mashhadi et al., 2017), and increased fixed penalties (Elvik, 2016) have been found to affect MVCs. A meta-analysis investigating the relationship between traffic violations and MCVs found that one unit increase in the standard deviation of tickets led to a decline in MCVs by 30% of the standard deviation of collisions (Elvik, 2016). A study in Brazil found that a strict penalty scoring system and increased fines led to an overall 21.3% decrease in MVCs and a 24.7% reduction in immediate deaths on Brazilian highways (de Figueiredo et al., 2001).

1.2. Current study

In this study, we investigate the effect of the first and second waves of rise in fuel prices and increased ticket fines as a part of a law enforcement program on Iran's RTMs in the study period of March 2011-February 2020. In addition, we analyze the overall trend of RTM on a country and province level, to learn about Iran's progress in its Road Safety Strategic Plan (Ministry of Roads & Urban Development, 2009). In our investigation, we employ time series modelling to study the frequency of road-related mortalities in road-related mortality data of Iran, i.e. we analyze the timely distribution of registered mortalities to identify patterns in the occurring mortalities. It is important to mention that focusing solely on road-related fatalities (without accounting for injuries of varying severity) is a common methodological approach in research related to road safety and injury prevention (Yannis et al., 2011; Yousefzadeh-Chabok et al., 2016).

In this scope, interrupted time series (ITS) analysis and Seasonal Autoregressive Moving Average (SARIMA) modelling (Lavrenz et al., 2018) have been used to study the effect of road safety programs on RTIs, RTMs, and MVCs. ITS and SARIMA have been used in multiple studies in the field of road safety research. These studies include but are not limited to investigating the trend of pedestrian mortality in Iran (Jamali-Dolatabad et al., 2022), analyzing the impact of lowering permitted blood alcohol concentration on MVCs and alcohol consumption (Haghpanahan et al., 2019) and the effect of fuel prices on RTMs (Naqvi et al., 2020) in the UK, evaluating an enforcement road safety program in Malaysia (Sim et al., 2022), evaluating the role of the Decade of Action for Road Safety 2011-20 in Serbia (Deretić et al., 2022), investigating the effect of a penalty points system on severe RTIs in Kuwait (Akhtar & Ziyab, 2013), and analyzing the effect of COVID-19 on RTMs and MVCs in Greece (Sekadakis et al., 2021). However, while researchers have used time series analysis to examine patterns in road-related mortalities in Iran (Delavary Foroutaghe et al., 2020), no detailed analysis of the influence of seasonal components and individual change points has been conducted, and no detailed analysis of changes in traffic mortality on a province level has been performed. Comparative analysis has been conducted for other countries in the past to identify patterns in road-related mortalities and locate change points in the mortality data, i.e. when the number of mortalities changes outside of expected parameters (Sheng et al., 2018; Yousefzadeh-Chabok et al., 2016) but has not been conducted for the effect of policy measures on RTMs. To investigate whether policy measures implemented in Iran relate to RTMs, change point detection (CPD) and ITS analyses are employed (Zhao et al., 2019).

2. Methods

2.1. Data description

Data on road-related mortalities in Iran are available through the Iranian Legal Medicine Organization (ILMO), which publishes monthly mortality data for each of Iran's 31 provinces (Iranian Legal Medicine Organization, 2020). Currently, mortality data are available for the timespan of March 2011-February 2020 (Iranian Legal Medicine Organization, 2020). A single instance of a road-related mortality/death is registered by the hospital and forwarded to the ILMO, if the victim of a traffic crash has passed away on arrival, or dies within a 30-day time frame after being brought to the hospital, which is in line with WHO registration guidelines (WHO, 2018). The WHO uses ILMO data for their road-related mortality assessment of Iran and does not assume a large amount of underreporting for mortalities. It should be noted that in the course of this study, limited access to traffic injury data was encountered, which led the authors to focus their research efforts on road fatalities. The attempt to obtain such data in Iran was initiated, although it was acknowledged that its accessibility was not straightforward, and it was not publicly available. Consequently, the acquisition of this data was anticipated to be a time-consuming process and was aborted. In addition to the RTM data from ILMO, the time points of government-mandated fuel prices, and an increase in traffic fines are used for analyses. Fuel prices increased on the 1st of June 2013 (before: 4000 Rials equal to 0.1 USD per litre, after: 10000 Rials equal to 0.25 USD per litre) and on the 15th of November 2019 (before: 10000 Rials equal to 0.12 USD per litre, after: 30000 Rials equal to 0.36 USD per litre) (France 24 2019). On the 1st of April 2016, a package of increased traffic fines concerning various risky driving behaviours such as speeding, illegal overtaking, and drunk–driving was implemented. For instance, the fine for drunk–driving was quadrupled (i.e. from 1,0000,000 equal to 29 USD to 4,000,000 Rials equal to 116 USD) (Delavary Foroutaghe et al., 2020).

2.2. Overview of RTM data

Yearly mortality numbers registered in all of Iran (ILMO, 2020) are presented in Figure 1. Descriptively, a steep decline can be observed from 2011 to 2015 with a moderate increase for the next year and then mortality numbers appear to be invariant until 2018 when another moderate decrease can be observed until the end of the study period.

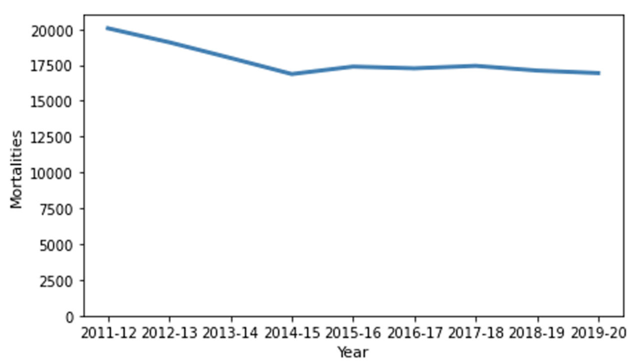

Figure 1. Road-related mortalities registered by the Iranian Legal Medicine Organization. The year range was used to show the equivalent of years in the Shamsi calendar which renews every March.

The absolute number of mortalities in the individual provinces of Iran is presented in Figure 2 for the last year of the available data (March 2019—February 2020). It can be observed that the number of road-related mortality varies widely across Iran's provinces, with some provinces, e.g. Fars, Tehran, and Razavi Khorasan having a comparably high number of road-related mortality, while other provinces, e.g. Ilam and Ardebil, having a comparatively low rate.

To facilitate a more detailed analysis, the monthly incidence rate of road-related mortalities in Iran (reported by the ILMO) was calculated. This incidence rate, i.e. the occurrence of new mortalities in the observed time frame (e.g. monthly), is commonly used to relate the number of occurring mortalities during a given time frame to the population (Beck, Dellinger, & O'neil 2007; Khan et al., 2020). The incidence rate is calculated as the number of road deaths per 100,000 population. Population estimates are calculated by aggregating the numbers of birth and deaths in Iran with previous records of population numbers. These data are available from the National Organization for Civil Registration (National Organization of Civil Registration, 2020).

To visualize the overall trend in road-related mortality in individual provinces and to relate the mortality number to the population in individual provinces, differences in the yearly incidence rate of the last year of available data (March 2019 to February 2020) and the first year of available data (March 2011 to February 2012) are presented in Figure 3. From Figure 3, it can be observed that for most provinces, the incidence rate of road-related mortalities decreased between 2010 and 2020. In addition, differences in the extent of decreases can be observed, with some

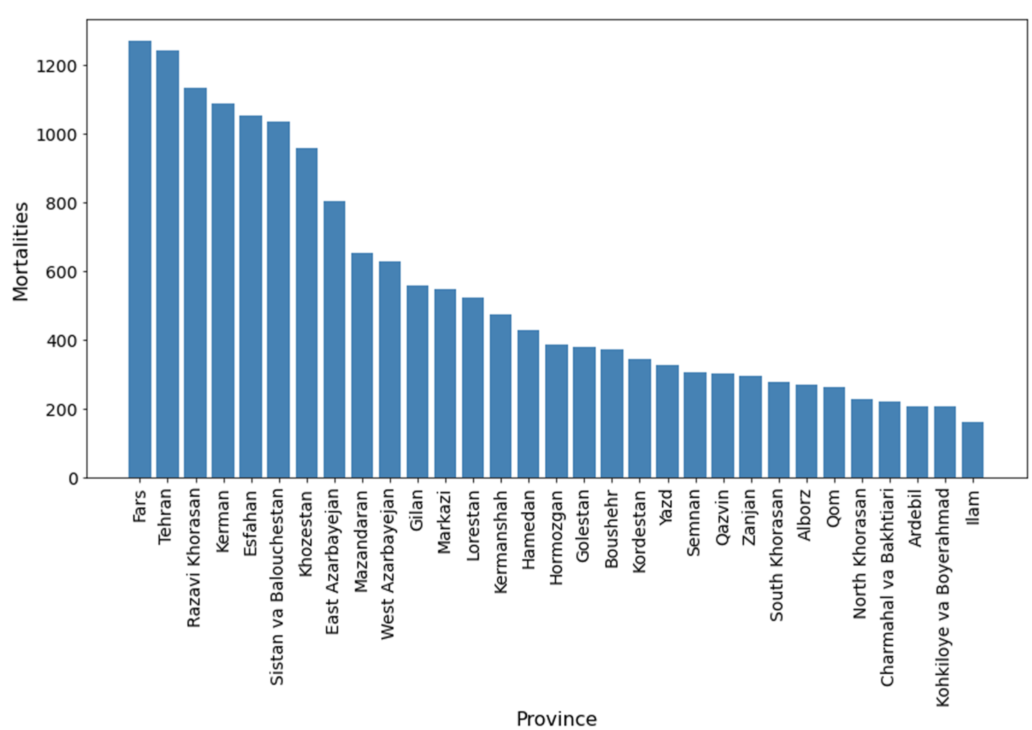

Figure 2. Total road-related mortality numbers in Iran's provinces between March 2019 and February 2020.

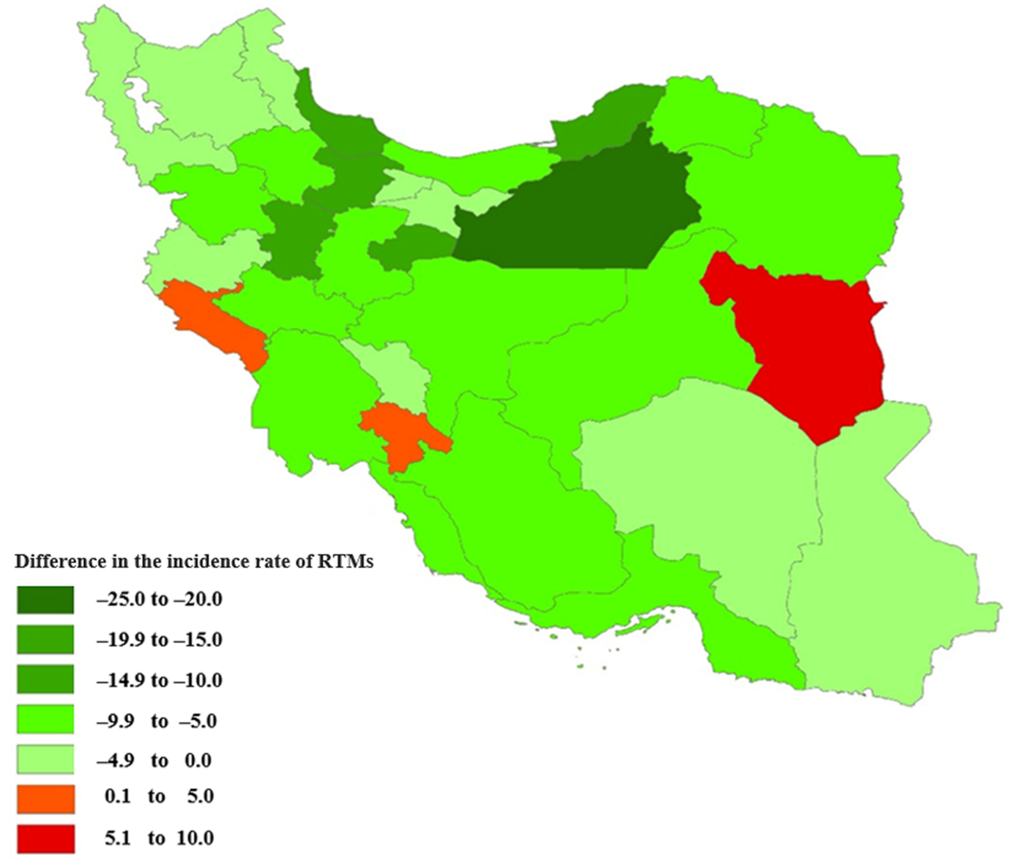

Figure 3. Visualization of difference in the incidence rate of RTMs of Iranian provinces between 2011 and 2020.

provinces, e.g. Semnan, Golestan, and Gilan showing larger declines, while other provinces, e.g. Kerman, both East and West Azerbaijan and Tehran, in line with Figure 2, show comparably small decreases or even increases in road-related mortality incidence rates (e.g. South Khorasan). To this end, provinces can be separated into three different groups: a) Substantial Decreasers, i.e. those provinces that showed a decrease of up to 5 RTM per 100,000 people (dark green in Figure 3). b) Minor Decreasers, i.e. those provinces with a decrease in RTMs between 4.9% and 0% (light green in Figure 3). And finally, c) Increasers, i.e. the provinces that show an increase in RTMs (orange and red in Figure 3). In Iran, when comparing the rate of RTMs between 2011 and 2020, there are 22 Substantial Decreasers, nine Minor Decreasers, and three Increasers.

While it is possible to integrate data and descriptively identify absolute differences and trends in road-related mortality data for the whole country, and individual provinces, additional tools of analysis are available to mathematically identify the exact nature of the interventional effects and to detect seasonal and trend components, contributing factors, and singular changes in the number of road-related mortalities. These methods will be presented in the following.

2.3. Statistical analysis

This section explains the statistical analyses that were conducted on the data. First, time series modelling is described followed by tests for checking the trends and seasonality and finally the CPD algorithms.

2.3.1. ITS analysis

To mathematically analyze and model time series data, Box-Jenkins models were used. The so-called SARIMA model integrates seasonal (S), autoregressive (AR), integrative (I) and moving average (MA) models (Chatfield, 2019). SARIMA represents a special case of time series modelling, as it can be applied to non-stationary data and data containing seasonality (Box et al., 2015; Makridakis et al., 1998).

In this study, time series regression with the following formula is used to mathematically identify trends and seasonal components in mortality data using the Box-Jenkins method (for details see Hyndman & Athanasopoulos, 2012; Makridakis et al., 1998).

$$Y_t = \beta_0 + \sum_{i=1}^{n} \beta_i X_t + N_t \quad (1)$$

where X_t, Y_t, and N_t represent level shift interventional variables, response variable and a SARIMA model, respectively. There were three interventions ($n = 3$) consisting of the first wave of increase in fuel prices in June 2013, increased traffic ticket fines in April 2016, and the second wave of increase in fuel costs in November 2019. Under the assumption that an intervention occurs in u time, a dummy variable equal to 0 before the intervention and 1 after that can be applied (Hyndman & Athanasopoulos, 2018). In order to check if the residuals are white noise, residual plots were examined for zero mean and the Ljung-Box (LB) test was conducted to test for autocorrelation. The alternative hypothesis of the test is that the residuals of ITS models are uncorrelated. We also checked for the normality of residuals with the Kolmogorov Smirnov (KS) test (Hyndman & Athanasopoulos, 2018). The alternative hypothesis of this test is that the residuals do not follow the normal distribution.

2.3.2. Trend and seasonal statistical tests

To analyze the trend of the studied time series nonparametric Cox & Stuart trend test was used. The alternative hypothesis in this test is that the time series has a monotonic upward (downward) trend. Also, the Kruskal Wallis test was conducted for seasonal analysis. The alternative hypothesis is that time series has a seasonality. These tests can be found in 'trend' package of R software (Pohlert, 2016). The significance level of 0.05 was considered for all statistical tests in the study.

2.3.3. Multiple change point detection

Apart from trends and repeating seasonal influences, it is possible to investigate time series data for individual time points in which the number of registered traffic mortalities changed singularly. As mentioned in the introduction section, both traffic interventions and economic events can influence traffic-related behaviors and how they change over time. Hence, CPD can reveal which points have changed in the data over the study period. Broadly speaking, change point analysis assumes an ordered sequence of data and seeks to identify selective changes in the statistical properties of the data (e.g. mean or variance), with the possibility to identify multiple change points (Aminikhanghahi & Cook, 2017). Various procedures divide the data into $m+1$ parts if there are m points to extend a single to multiple CPD.

In this study, we used the 'Rbeast' package to decompose the time series into separate components, such as trend, and periodic/seasonal variations. There are several uses for this package, including detecting change points, seasonal and trend components, and deriving nonlinear trends and credible uncertainty measures (e.g. the occurrence probability of change points over time) (Zhao et al., 2019, 2022).

3. Results

In the following, results on seasonal and trend tests and CPD are presented first to understand and detect changes in trend and seasonal components in provincial and aggregate RTM data, followed by ITS analysis of the data to quantify the observed changes in the RTM data.

3.1. CPD results

Figure 4 shows the decomposed trends and seasons of Minor Decreasers (i.e. the top nine panels in the figure with green titles) and Increasers (the bottom three panels with red titles) that performed worse regarding RTM reduction throughout the study period. Similar plots for the Substantial Decreasers, as well as the aggregate data (Total), are presented in Appendix. Here, probability shows the chance of observing a change point in the trend and seasonal components of the data. Additionally, the p-values for the non-parametric Cox and Stuart trend and Kruskal-Wallis tests are shown by '*' in front of 'Trend' and 'Season' titles of each province, respectively. Overall, the Cox and Stuart trend test revealed that similar to the aggregate data (See Figure A1b, last panel), about two-thirds of the provinces (21 out of 31) had a monotonic upward/downward trend ($p<0.05$). The Kruskal-Wallis test showed that only six (out of 31) provinces had no seasonality ($p>0.05$) while the result for the aggregate data (panel 'Total' in Figure A1b) was contrary ($p<0.05$). The trend component analysis in Figure 4 confirms the descriptive data from Figure 3: the trend of RTMs in Minor Decreasers is decreasing but with less steep lines compared to panels in Figure A1 after each intervention and fewer provinces with a statistically significant trend, i.e. four out of nine provinces in Figure 4 vs 17 out of 19 in Figure A1. All these four provinces, i.e. Alborz, Chaharmahal & Bakhtiari, East Azerbaijan and Tehran showed a level shift after the first wave of rise in fuel prices suggesting the effectiveness of this intervention (see the instances of $p>0.05$ in the probability distribution plots of these four provinces in Figure 4). However, this has not been observed after increased ticket fines and the second wave of rise in fuel prices (Probability < 0.05). This could help understand why these provinces were less successful in RTM reduction. Moreover, two (out of nine) provinces namely Alborz and Ardebil did not have seasonality in their RTM data suggesting that they did not experience regular and predictable changes. A change in the seasonal component can be seen in both Alborz and Ardebil between the increased ticket fines and the second wave of rise in fuel prices (Probability > 0.05) suggesting that some external factors could influence variations in the RTMs of these provinces.

Finally, looking at the bottom three panels reveals that none of the Increasers had a significant upward/downward trend and that their trends are flat-shape. For Ilam, no seasonality in RTM data was detected as there were four instances of changes in its seasonal component with two of them placed between the first wave of rise in the fuel prices and increased ticket fines. The other two changes in seasonality happened some months before the second wave of the rise in fuel prices (Probability > 0.05). Also, a level shift in the trend of RTM can be seen in the 42^{nd} month (Probability > 0.05). While the trend for Kohgiluyeh & Boyer-Ahmad was quite flat-shape, South Khorasan showed three instances of level shifts (Probability > 0.05) before and after the first wave of rise in fuel prices.

3.2. ITS analysis

Table 1 shows the results of the ITS analysis on the aggregate data and 31 provinces of Iran. For each province, the

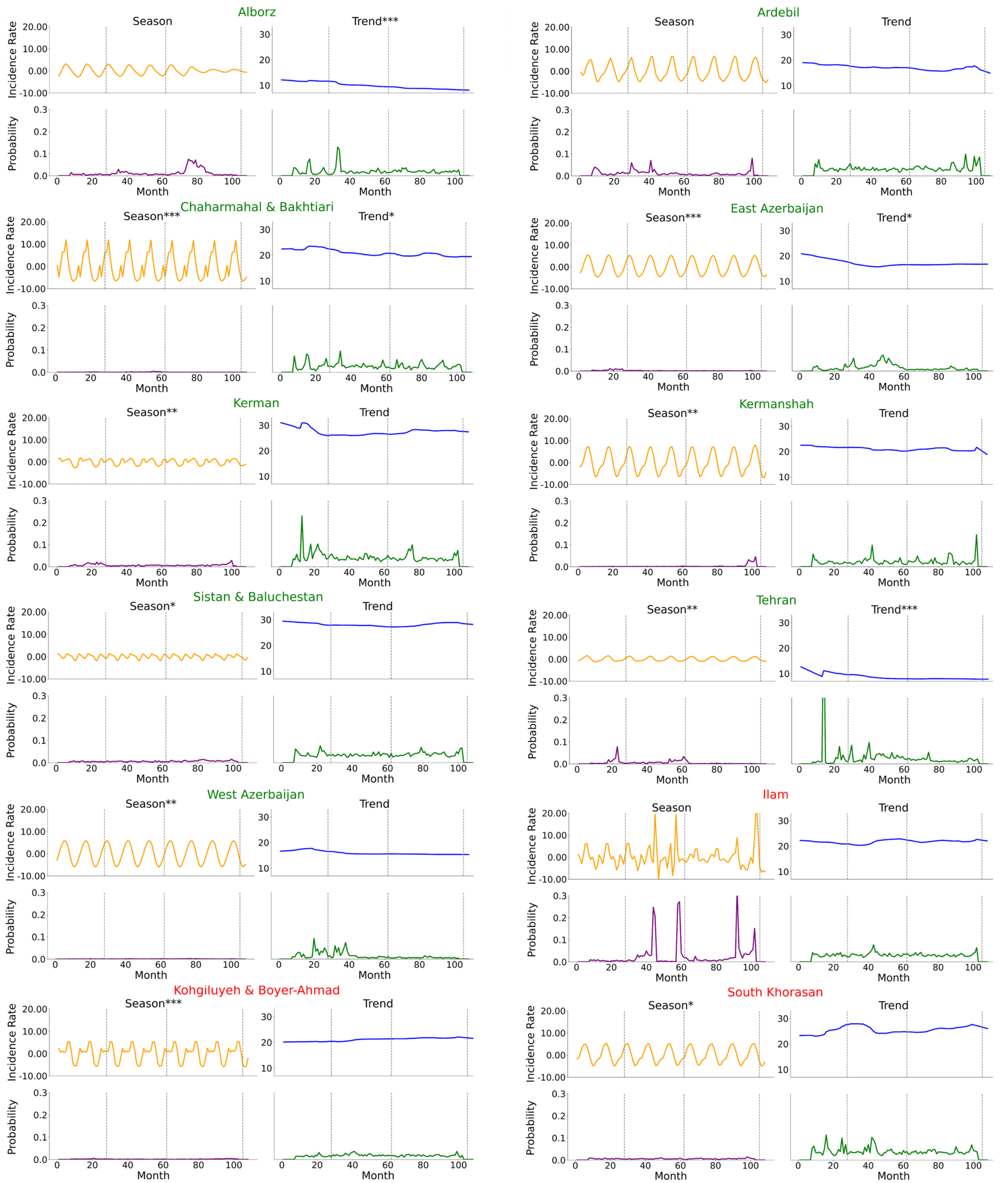

Figure 4. Decomposed trends and seasons of Minor Decreasers (green titles) and Increasers (red titles); the vertical lines from left to right show the month when the first rise in fuel prices, increased ticket fines and the second rise in fuel prices happened, respectively. Note $*p < 0.05$, $**\ p < 0.01$ and $***p < 0.001$.

estimates for each intervention, p-values and confidence intervals (CI) as well as the results for LB and KS tests are presented. Also, the difference in Gross Domestic Product (DGDP) between the first and last year of the study for each province is noted as an economic indicator. The results indicate that the first wave of rise in fuel prices was associated with a decrease in the number of RTMs of more than half of the provinces (16 out of 31; see row 'a' in Table 1; $p < 0.05$) with Tehran having the highest −18.85% (95% CI, −28.8% to −8.91%) and North Khorasan the lowest decline −3.61 (95% CI, −6.9% to −0.33%) among all provinces. This is in line with the overall results of the

Table 1. Results of the ITS analysis on the aggregate and provincial data of Iran.

Time series	DGDP[1]	Effect	Estimate	Std. error	z value	Pr(>|z|)	95% CI	LB[2]	KS[3]
Alborz	0.2	Effect (I1[4])	−3.367	1.758	−1.915	0.055.	[-6.81, 0.08]	0.06	0.6
		Intervention(I2[5])	−2.138	1.66	−1.287	0.197	[-5.39, 1.12]		
		Intervention(I3[6])	−1.086	3.841	−0.282	0.777	[-8.62, 6.44]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Ardebil	0.21	Intervention(I1)	−3.24	1.691	−1.916	0.055.	[-6.55, 0.07]	0.28	0.76
		Intervention(I2)	−1.673	1.712	−0.977	0.328	[-5.03, 1.68]		
		Intervention(I3)	−6.361	3.215	−1.978	**0.047***	[-12.66, −0.06]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
West Azerbaijan	0.08	Intervention(I1)	−5.151	2.376	−2.167	**0.03***	[-9.81, −0.49]	0.58	0.65
		Intervention(I2)	3.791	2.192	1.729	0.083.	[-0.51, 8.09]		
		Intervention(I3)	−2.295	4.967	−0.462	0.644	[-12.03, 7.44]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
East Azerbaijan	0.47	Intervention(I1)	−10.542	2.701	−3.903	**0***	[-15.84, −5.25]	0.86	0.63
		Intervention(I2)	2.461	2.399	1.025	0.305	[-2.24, 7.17]		
		Intervention(I3)	4.4083	5.671	0.777	0.437	[-6.71, 15.53]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Boushehr	0.58	Intervention(I1)	−2.48	1.634	−1.51	0.129	[-5.68, 0.72]	0.79	0.71
		Intervention(I2)	−0.622	1.451	−0.428	0.668	[-3.47, 2.22]		
		Intervention(I3)	2.477	3.431	0.722	0.47	[-4.25, 9.2]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Charmahal va Bakhtiari	0.03	Intervention(I1)	−2.27	1.751	−1.297	0.195	[-5.7, 1.16]	0.07	0.8
		Intervention(I2)	0.289	1.562	0.185	0.853	[-2.77, 3.35]		
		Intervention(I3)	−0.261	3.207	−0.082	0.935	[-6.55, 6.02]		
		Noise			SARIMA(2,0,0) $(0,1,1)_{12}$				
Esfahan	0.82	Intervention(I1)	−8.192	3.791	−2.16	0.03*	[-15.62, −0.76]	0.12	0.44
		Intervention(I2)	−6.223	3.788	−1.642	0.1	[-13.65, 1.2]		
		Intervention(I3)	−4.997	7.069	−0.707	0.479	[-18.85, 8.86]		
		Noise			SARIMA(0,0,0) $(1,1,0)_{12}$				
Fars	−0.19	Intervention(I1)	−7.062	3.9	−1.81	0.07.	[-14.71, 0.58]	0.22	0.56
		Intervention(I2)	−2.059	3.78	−0.544	0.585	[-9.47, 5.35]		
		Intervention(I3)	−17.571	8.036	−2.186	0.028*	[-33.32, −1.82]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Gilan	0.43	Intervention(I1)	−11.028	2.119	−5.202	0*	[-15.18, −6.87]	0.09	0.57
		Intervention(I2)	0.156	1.893	0.082	0.934	[-3.55, 3.87]		
		Intervention(I3)	−16.116	5.182	−3.109	0.001*	[-26.27, −5.96]		
		Noise			SARIMA(3,0,0) $(0,1,1)_{12}$				
Golestan	0.25	Intervention(I1)	−8.338	2.305	−3.617	0*	[-12.86, −3.82]	0.37	0.7
		Intervention(I2)	0.336	2.0661	0.163	0.87	[-3.71, 4.39]		
		Intervention(I3)	2.032	4.927	0.412	0.68	[-7.63, 11.69]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Hamedan	0.08	Intervention(I1)	−9.259	1.994	−4.642	0*	[-13.17, −5.35]	0.9	0.68
		Intervention(I2)	−2.607	1.772	−1.471	0.141	[-6.08, 0.87]		
		Intervention(I3)	−4.055	4.187	−0.968	0.332	[-12.26, 4.15]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Hormozgan	0.1	Intervention(I1)	1.507	1.243	1.211	0.225	[-0.93, 3.94]	0.34	0.73
		Intervention(I2)	−2.034	1.088	−1.869	0.061.	[-4.17, 0.1]		
		Intervention(I3)	−3.172	3.223	−0.984	0.325	[-9.49, 3.15]		
		Noise			SARIMA(0,0,2) $(0,1,1)_{12}$				
Ilam	−0.19	Intervention(I1)	0.664	1.714	0.387	0.698	[-2.7, 4.03]	0.26	0.79
		Intervention(I2)	−1.53	1.866	−0.82	0.412	[-5.19, 2.13]		
		Intervention(I3)	−2.884	3.257	−0.885	0.375	[-9.27, 3.5]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Kerman	0.71	Intervention(I1)	−9.489	4.56	−2.08	0.037*	[-18.43, −0.55]	0.22	0.61
		Intervention(I2)	8.124	4.84	1.678	0.093.	[-1.36, 17.61]		
		Intervention(I3)	−4.03	9.296	−0.433	0.664	[-22.25, 14.19]		
		Noise			SARIMA(1,0,0) $(1,1,1)_{12}$				
Kermanshah	0.07	Intervention(I1)	−2.927	2.203	−1.328	0.184	[-7.25, 1.39]	0.16	0.61
		Intervention(I2)	1.625	1.957	0.83	0.406	[-2.21, 5.46]		
		Intervention(I3)	−9.471	4.627	−2.047	0.04*	[-18.54, −0.4]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
South Khorasan	0.17	Intervention(I1)	2.275	1.693	1.343	0.179	[-1.04, 5.59]	0.08	0.83
		Intervention(I2)	1.088	1.504	0.723	0.469	[-1.86, 4.04]		
		Intervention(I3)	−3.592	3.555	−1.01	0.312	[-10.56, 3.38]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Razavi Khorasan	0.44	Intervention(I1)	−7.695	5.927	−1.298	0.194	[-19.31, 3.92]	0.18	0.57
		Intervention(I2)	−10.247	4.856	−2.11	0.034*	[-19.77, −0.73]		
		Intervention(I3)	−18.276	9.345	−1.955	0.05.	[-36.59, 0.04]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				

(*Continued*)

Table 1. Continued.

Time series	DGDP[1]	Effect	Estimate	Std. error	z value	Pr(>|z|)	95% CI	LB[2]	KS[3]
North Khorasan	0.1	Intervention(I1)	−3.618	1.675	−2.159	0.03*	[-6.9, −0.33]	0.64	0.81
		Intervention(I2)	−0.563	1.541	−0.365	0.714	[-3.59, 2.46]		
		Intervention(I3)	−3.522	3.511	−1.003	0.315	[-10.4, 3.36]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Khozestan	−7.12	Intervention(I1)	−12.989	3.78	−3.436	0*	[-20.4, −5.58]	0.84	0.46
		Intervention(I2)	2.157	3.362	0.641	0.521	[-4.43, 8.75]		
		Intervention(I3)	4.062	7.736	0.525	0.599	[-11.1, 19.23]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Kohkiloye va Boyerahmad	−1.57	Intervention(I1)	1.801	1.049	1.716	0.086.	[-0.26, 3.86]	0.41	0.87
		Intervention(I2)	1.578	0.901	1.751	0.079.	[-0.19, 3.35]		
		Intervention(I3)	−2.226	2.496	−0.891	0.372	[-7.12, 2.67]		
		Noise			SARIMA(0,0,0) $(1,1,1)_{12}$				
Kordestan	0.12	Intervention(I1)	−0.71	1.661	−0.427	0.668	[-3.97, 2.55]	0.16	0.65
		Intervention(I2)	0.39	1.467	0.266	0.79	[-2.49, 3.27]		
		Intervention(I3)	−0.317	3.893	−0.081	0.935	[-7.95, 7.31]		
		Noise			SARIMA(0,0,0) $(1,1,1)_{12}$				
Lorestan	0.06	Intervention(I1)	−8.911	1.918	−4.645	0*	[-12.67, −5.15]	0.2	0.74
		Intervention(I2)	2.167	1.716	1.262	0.206	[-1.2, 5.53]		
		Intervention(I3)	0.862	4.057	0.212	0.831	[-7.09, 8.81]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Markazi	0.15	Intervention(I1)	−9.91	2.539	−3.902	0*	[-14.89, −4.93]	0.5	0.84
		Intervention(I2)	0.581	2.256	0.257	0.796	[-3.84, 5]		
		Intervention(I3)	−1.635	5.332	−0.306	0.759	[-12.09, 8.82]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Mazandaran	0.59	Intervention(I1)	−7.647	2.601	−2.939	0.003*	[-12.75, −2.55]	0.79	0.42
		Intervention(I2)	−10.52	2.311	−4.552	0*	[-15.05, −5.99]		
		Intervention(I3)	1.3934	5.462	0.255	0.798	[-9.31, 12.1]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Qazvin	0.07	Intervention(I1)	−8.583	2.362	−3.633	0*	[-13.21, −3.95]	0.56	0.73
		Intervention(I2)	−0.666	2.362	−0.282	0.777	[-5.3, 3.96]		
		Intervention(I3)	0.75	4.091	0.183	0.854	[-7.27, 8.77]		
		Noise			SARIMA(0,0,0) $(0,1,0)_{12}$				
Qom	0.14	Intervention(I1)	−0.675	2.608	−0.258	0.795	[-5.79, 4.44]	0.5	0.64
		Intervention(I2)	0.051	2.62	0.019	0.984	[-5.09, 5.19]		
		Intervention(I3)	−1.024	5.061	−0.202	0.839	[-10.94, 8.9]		
		Noise			SARIMA(1,0,1) $(1,1,0)_{12}$				
Semnan	0.2	Intervention(I1)	−5.162	1.733	−2.977	0.002*	[-8.56, −1.76]	0.45	0.81
		Intervention(I2)	0.018	1.54	0.012	0.99	[-3, 3.04]		
		Intervention(I3)	0.776	3.64	0.213	0.831	[-6.36, 7.91]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Sistan va Balochestan	0.15	intercept	75.443	3.0556	24.689	0*	[69.45, 81.43]	0.13	0.68
		Intervention(I1)	−0.523	3.856	−0.135	0.892	[-8.08, 7.04]		
		Intervention(I2)	6.017	3.524	1.707	0.087.	[-0.89, 12.93]		
		Intervention(I3)	−9.501	6.822	−1.392	0.163	[-22.87, 3.87]		
		Noise			SARIMA(0,0,0) $(0,0,1)_{12}$				
Tehran	4.46	Intervention(I1)	−18.853	5.074	−3.715	0*	[-28.8, −8.91]	0.82	0.09
		Intervention(I2)	−3.36	4.538	−0.74	0.459	[-12.26, 5.54]		
		Intervention(I3)	−4.058	9.598	−0.422	0.672	[-22.87, 14.76]		
		Noise			SARIMA(1,0,0) $(0,1,1)_{12}$				
Yazd	0.47	Intervention(I1)	−4.7	1.797	−2.615	0.008*	[-8.22, −1.18]	0.89	0.74
		Intervention(I2)	0.459	1.596	0.288	0.773	[-2.67, 3.59]		
		Intervention(I3)	5.356	3.773	1.419	0.155	[-2.04, 12.75]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Zanjan	0.25	Intervention(I1)	−2.579	1.837	−1.403	0.16	[-6.18, 1.02]	0.84	0.72
		Intervention(I2)	−1.612	1.646	−0.979	0.327	[-4.84, 1.61]		
		Intervention(I3)	3.407	3.837	0.888	0.374	[-4.11, 10.93]		
		Noise			SARIMA(0,0,0) $(0,1,1)_{12}$				
Total	–	Intervention(I1)	−143.468	43.67	−3.285	0.001*	[-229.06, −57.87]	0.37	0.64
		Intervention(I2)	−30.893	41.109	−0.751	0.452	[-111.47, 49.68]		
		Intervention(I3)	−130.519	65.405	−1.995	0.045*	[-258.71, −2.33]		
		Noise			SARIMA(2,0,0) $(0,1,1)_{12}$				

*$p < 0.05$.
** $p < 0.01$.
***$p < 0.05$.
1. Difference in GDP between the first and last year of the study.
2. Ljung–Box test.
3. Kolmogorov-Smirnov.
4. Seasonal Moving Average.
5. I1: First rise in fuel prices (2013).
6. I2: Increased ticket fines (2016).
7. I3: Second rise in fuel prices (2019).
8. Autoregressive.
9. SARIMA.

CPD analysis (See Figure 4 and Figure A1) where several provinces showed a downward level shift after this intervention. However, after the increased traffic fines, only two provinces showed a decrease in the number of RTMs (see row 'b' in Table 1; $p < 0.05$): Razavi Khorasan, −10.24% (95% CI, −19.77% to −0.73%) and Mazandaran, −10.52% (95% CI, −15.05% to −5.99%). The second rise in fuel prices was associated with a decline in the number of RTMs in four provinces (see row 'c' in Table 1; $p < 0.05$). These were Ardebil, −6.36% (95% CI, −12.66% to −0.06%), Fars, −17.57% (95% CI, −33.32% to −1.82%), Kermanshah, −9.47% (95% CI, −18.54% to −0.4%) and Gilan, −16.11% (95% CI, −26.27% to −5.96%). Overall, in line with CPD results, none of the interventions was effective in reducing RTMs in Increasers. Additionally, the results for the whole country showed that both the first and second waves of rise in fuel prices were effective in reducing the number of RTMs nationwide (see 'Total' in Table 1; $p < 0.05$).

4. Discussion and conclusions

In this study, Iran's RTMs between March 2011 and February 2020 were analyzed employing CPD algorithms, trend and seasonal analysis, and ITS modelling. Our findings show an overall downward trend in the number of road users killed on the roads in Iran. We further found that both the first and second waves of the government-mandated rise in fuel prices were associated with decreasing RTMs throughout the study period, nationwide. This is in line with previous research showing that change in fuel prices could change the pattern of RTMs (Chi et al., 2015, Naqvi et al., 2020). However, the results for the increased traffic ticket fines were different and ITS analysis showed a decrease in RTMs in very few provinces after this intervention and no effect was found for the whole country of Iran. This is in line with the Luca (2015) study which found that while tickets could help to reduce non-fatal collisions, they did not affect fatalities.

Investigating the provincial data revealed that in line with the whole country, more than half of the provinces experienced a decline in RTMs after the first rise in fuel prices with the capital having the highest drop and the provinces being relatively equally located within the country with a tendency towards the west side. Unexpectedly, while four of these provinces namely East and West Azerbaijan, Kerman and Tehran were affected by this intervention, they did not show clear improvement over the study period and were among the provinces with lower RTM reductions (i.e. Minor Decreasers; see Figures 3 and 4). Additionally, unlike the results for all of Iran, the second government-mandated increase in fuel prices was ineffective in reducing the RTMs in most provinces including the mentioned four. One potential explanation for this finding is that the transport system could potentially have reached its maximum capacity to respond to such changes, indicating that further interventions of a similar type might not be effective. In other words, while an initial increase in fuel prices could lead to people driving less, as they try to save money, an additional increase in fuel prices might not have the same effect, as drivers have already limited their driving as much as possible, and only essential car trips remain, which cannot be further reduced. Existing research suggests that an increase in fuel prices has usually a short to medium lifetime. For instance, Chi et al. (2010) observed that while an increase in inflation-adjusted gasoline prices reduced the total monthly crash number for a year, it did not show any impact in the longer term. Significant decreases in RTM due to the second increase in fuel prices were only observed for four provinces (Ardebil, Fars, Gilan and Kermanshah) and this decrease was strong enough to significantly decrease the level of RTMs for the whole of Iran.

The decomposed trends and seasonal data for Minor Decreasers revealed that most of these provinces had a relatively flat-shape and statistically non-significant trend (five out of nine) with drops mostly after the first rise in fuel prices confirming the ITS analysis results. Also, ITS analysis confirmed the CPD results by showing that none of the interventions played a role in reducing RTMs in Increasers. Some changes in the seasonal components of these provinces (both Minor Decreasers and Increasers) were observed between the interventions that understanding the reasons behind them could help to better understand why they were less successful in reducing RTMs. There might be some other external factors such as currency devaluation that could affect these provinces more (Delavary et al., 2020).

This study has several limitations. As a main limitation, our analysis only includes registered road-related mortality in Iran until February 2020, since the COVID-19 pandemic was announced in Iran and the trend of RTMs changed due to the pandemic and its subsequent restrictions (Delavary et al., 2020). Future studies should focus on the role of the pandemic on RTM data, disentangling the potential impacts of this phenomenon from other contextual factors. This will help paint a more accurate picture of road safety during the pandemic. Another limitation was that while the two government-mandated fuel price increases occurred simultaneously and uniformly across Iran, the level of enforcement, including factors such as the number of monthly registered police officers related to the increased ticket fines, may vary among the provinces for which the data were not available which may influence the effectiveness of the interventions. In addition, a notable limitation arose as the authors did not have access to individual-level and detailed collision data, including information about the parties involved, collision locations, and other pertinent details as the available data do not distinguish between different categories of road users killed in traffic. Hence, no road user category-specific conclusions could be drawn. While the methods used to identify trends, seasonality, change points, and differences between provinces are appropriate, they cannot help infer causality or relation of our findings to other variables, e.g. legislative measures or economic occurrences, due to this study's design. This is because the role of confounding variables such as weather conditions, economic factors, and road infrastructure with respect to each province could not be determined in this study. As for economic factors, for example, we investigated the correlation between each province's GDP and their annual RTMs and did not find any significant relationships between these two variables for 28 out of 31 provinces. Future studies could rely on other economic factors such as currency devaluation and inflation (Delavary et al., 2020), unemployment rate (Haque, 1993), and/or the Human Development Index, including the GINI index (Haghighi et al., 2020) to have a better account of the impact of economics on road safety.

For weather conditions, national and provincial data regarding weather conditions, such as rainfall and temperature time series, are not publicly available in Iran, which is part of the limitations of this study. These factors usually influence traffic exposure and volume, which are mostly related to the quantity and quality of crashes regarding their seasonal components which were captured by time series regression with SARIMA error. However, one of the main objectives of this study was to investigate the trend of road-related mortalities, which is less affected by weather conditions. Also, the association between weather conditions and RTMs is less clear with previous research showing contradictory results. For instance, some studies, such as Saha et al. (2016), showed that this only contributed to 16% of the fatal crashes in the US over an 18-year study period. A potential relationship among the geographical locations of provinces within Iran and how these geographical factors could have affected road traffic mortalities were not explored in this study. In light of the differences in the impact of the three interventions on the different provinces of Iran, and the large geographical variance within the country, this is a promising factor to include in future research. Overall, it is highly recommended that future studies try to combine other datasets from other resources, such as the reports by the traffic police and insurance companies, with ILMO's data, which is a challenging yet achievable goal.

In conclusion, this study indicates that the absolute number of road-related mortality is decreasing in Iran. Despite this, the decreasing trend in RTMs was not strong enough to achieve the RTM reduction targets, laid out in Iran's Road Safety Strategic Plan (Ministry of Roads & Urban Development, 2009). Different effects of implementing similar types of preventive measures (increasing fuel prices) over time, the potential ineffectiveness of implemented legislative measures (law enforcement by increasing fines), as well as differences in RTM reduction among Iranian provinces due to the interventions, have potentially contributed to this shortcoming in road safety progress. These findings should be considered by Iranian road safety actors in their efforts to further decrease road-related mortality in Iran. Moreover, other road safety initiatives could also be evaluated using such an approach if deployed to improve road safety, such as graduated driving license access or post-licensing interventions aimed at specific clientele, like aging drivers or motorcyclists.

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Appendix

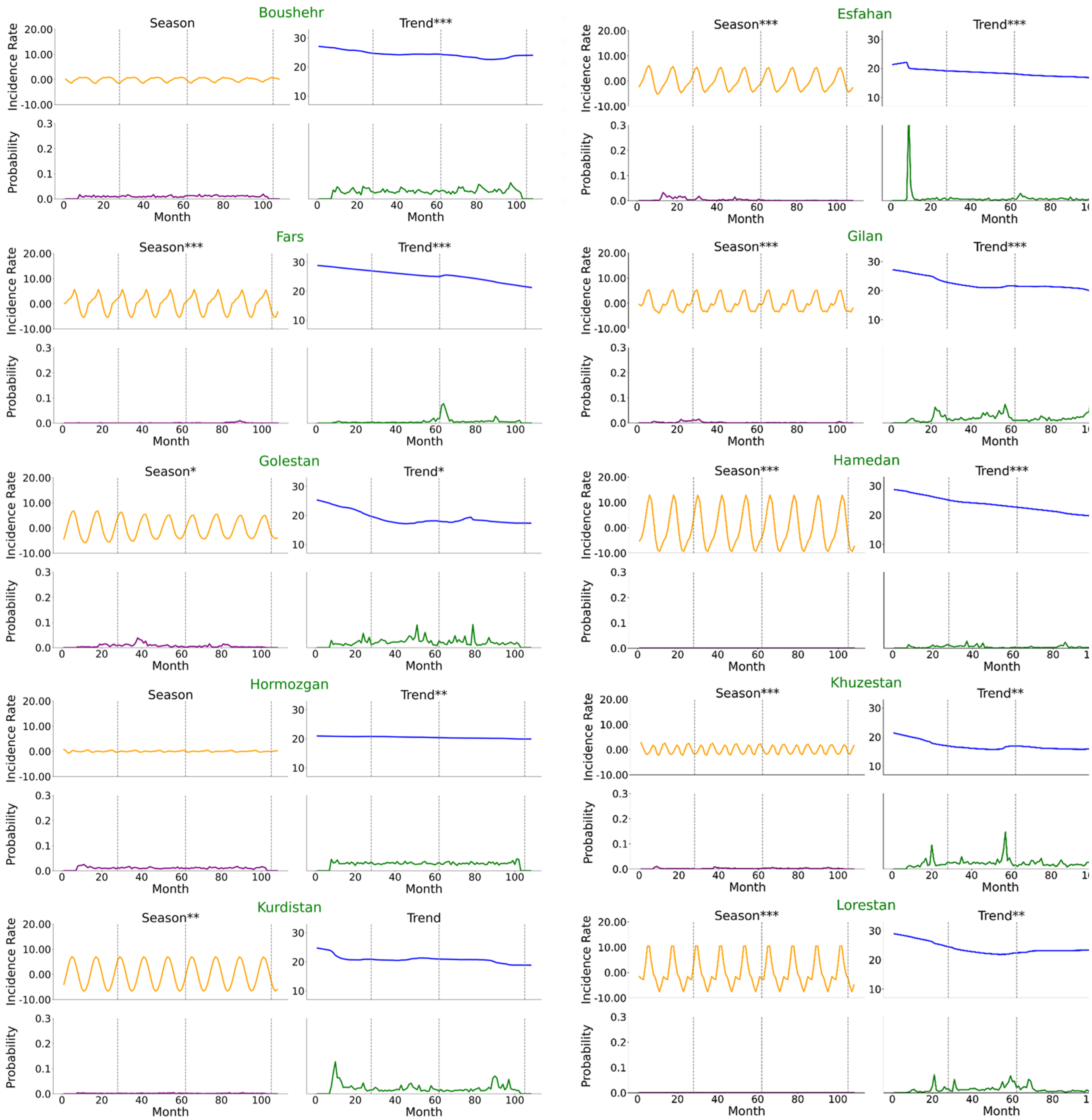

Figure A1. Decomposed trends and seasons of the first ten Substantial Decreasers which are placed alphabetically; the vertical lines from left to right show the month when the first rise in fuel prices, increased ticket fines and the second rise in fuel prices happened, respectively. The p-values for the non-parametric Cox and Stuart trend and Kruskal-Wallis tests are shown by '*' in front of 'trend' and 'Season' titles of each province, respectively. Note $*p < 0.05$, $** \ p < 0.01$ and $*** \ p < 0.001$.

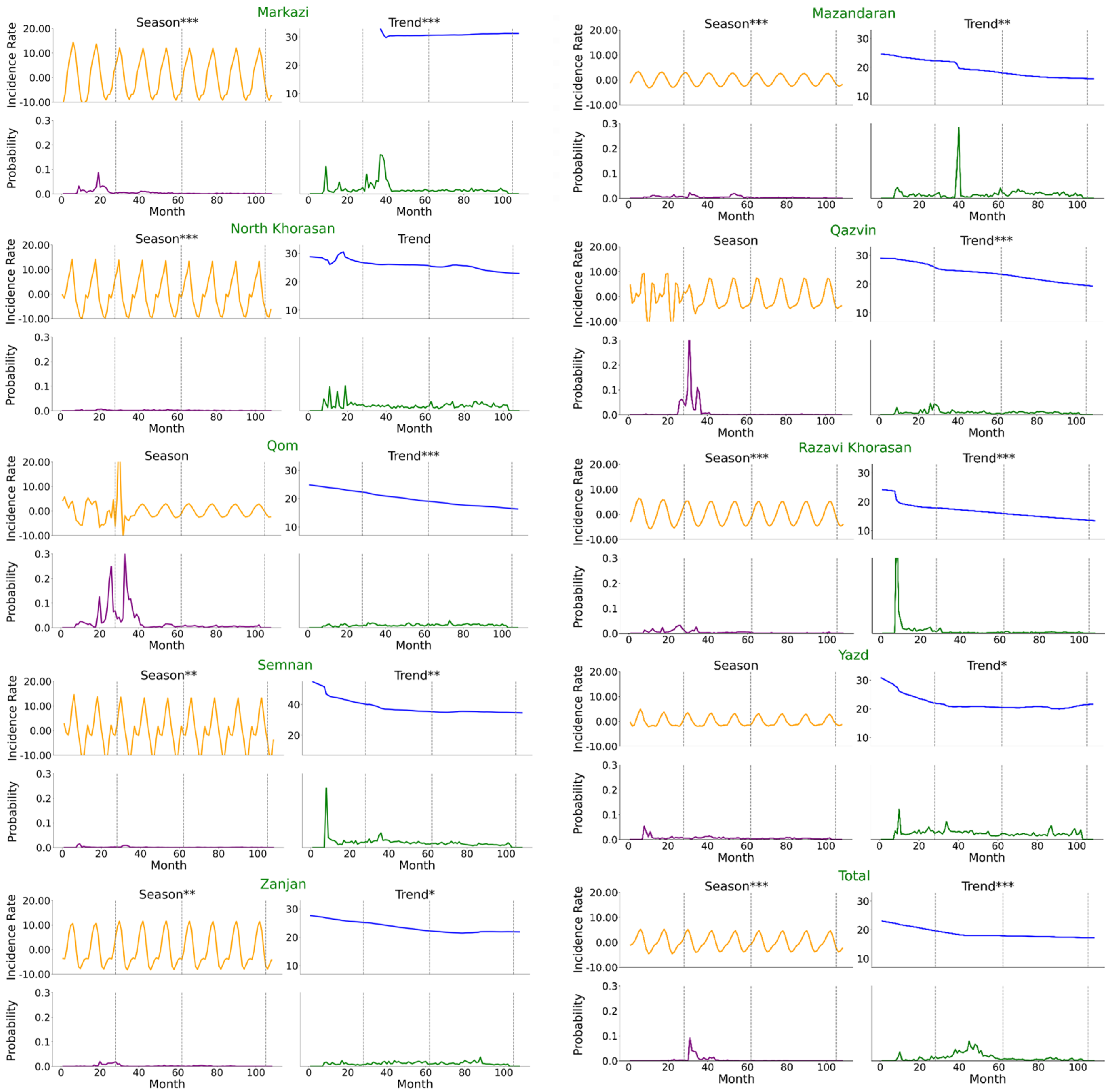

Figure A2. Decomposed trends and seasons of the remaining nine substantial decreasers as well as Iran's total data.