Journal of Transport & Health 32 (2023) 101687

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Effects of tougher school zone laws on road traffic safety in school zones for children in South Korea

Sang Jun Eun

Department of Preventive Medicine, Chungnam National University College of Medicine, 266 Munhwa-ro, Jung-gu, Daejeon, 35015, Republic of Korea

ARTICLE INFO

Keywords:
School zone
Road traffic injury
Child
Controlled interrupted time series analysis
Law enforcement
Republic of Korea

ABSTRACT

Introduction: New school zone laws in Korea were enforced in March 2020 to increase penalties for traffic violations and preferentially install road safety equipment including automated traffic enforcement devices in school zones. This study aimed to evaluate the effectiveness of tougher school zone laws on school-zone-related road traffic outcome (RTO) rates for children aged 0–12 years in Korea.

Methods: Monthly child RTO rates in school zones were calculated per million vehicles and per million children using data on police-reported road traffic crashes, registered motor vehicles, and registered resident population between 2015 and 2021: the intervention series involved school-zone-related rates and the non-equivalent control series involved total and non-school-zone-related rates. The effectiveness of the laws on RTO rates in school zones was assessed using the Bayesian structural time-series models under the controlled interrupted time-series design.

Results: The results found that considering the trends in the overall and non-school-zone-related RTO rates, enforcement of the laws did not significantly reduce any school-zone-related RTO rates for children aged 0–12 years, both per million vehicles and per million children: equivalent fatality, road traffic injury (RTI), severe RTI, minor RTI, and road traffic crash rates.

Conclusions: The ineffectiveness of Korea's new school zone laws on child RTO rates in school zones implies that other effective measures need to be accompanied to improve children's road traffic safety in school zones, rather than just focusing on raising the severity of punishment. Further research is needed to ensure the effectiveness of school zone laws and measures to mitigate child road traffic casualties in school zones.

1. Introduction

Road traffic injuries (RTIs) are a serious threat to children's public health (Li et al., 2016). Despite the decreasing trend of the burden from RTIs, among children aged 0–14 years, 93,700 children died and 8 million disability-adjusted life years were lost because of RTIs in 2019 worldwide (Global Burden of Disease Collaborative Network, 2020), accounting for nearly a quarter of the burden of injuries. While low- and middle-income countries disproportionately bear nine-tenths of the health burden of RTIs, more than half of the macroeconomic costs of RTIs come from high-income countries (Chen et al., 2019). Child RTIs are still an unneglectable road safety issue, even in high-income countries, in that RTIs in children generate more costs than in adults, are preventable and unacceptable, albeit on a small scale, and are a major contributor to the mortality gap between socioeconomic groups (Grous, 2019; Li et al., 2016).

E-mail address: zepplin7@cnu.ac.kr.

https://doi.org/10.1016/j.jth.2023.101687
Received 3 January 2023; Received in revised form 25 April 2023; Accepted 16 August 2023
Available online 30 August 2023

Abbreviations

AAPSC	Act on the Aggravated Punishment, etc. Of Specific Crimes
BSTS	Bayesian structural time-series
CITS	controlled interrupted time-series
CrI	credible interval
EF	equivalent fatality
RTA	Road Traffic Act
RTC	road traffic crash
RTD	road traffic death
RTI	road traffic injury
RTO	road traffic outcome
SD	standard deviation

In South Korea (hereafter referred to as Korea), the RTI mortality rate per million children aged 0–14 years fell by 95.3% from 88.3 in 1995 to 4.1 in 2020 (ITFOECD, 2022), reaching about 70% of the average of OECD countries. However, the child pedestrian fatality rate was 2.7 in 2020, the fifth highest among OECD countries (ITFOECD, 2022), suggesting the need to continuously strengthen road safety for children (Sul et al., 2014).

To protect children from RTIs, since 1995, school zones in Korea have been designated for roads within a radius of 300–500 m from the main entrance of kindergartens, elementary schools, and childcare centers/private teaching institutes with 100 or more children (National Police Agency, 2019). In school zones, the driving speed of vehicles could be restricted to 30 km/h or less, school zone signs had to be placed, safety facilities or equipment could be installed, and heavier penalties including fines and demerit points were imposed for traffic violations (National Police Agency, 2019).

Meanwhile, on September 11, 2019, a 7-year-old boy was hit and killed by a vehicle while crossing a crosswalk without traffic signals in a school zone, which shaped public opinion demanding stricter punishment for drivers who caused road traffic deaths (RTDs) within the school zone (Chung, 2020). Therefore, the National Assembly of Korea enacted the Min-sik Law, named after the victim, which revised two related laws to strengthen punishment for those who cause RTIs involving children within school zones and improve school zone safety (Ministry of Justice, 2019; National Police Agency, 2019). The revision of the Act on the Aggravated Punishment, etc. Of Specific Crimes (AAPSC) allowed a driver who caused the RTD of a child aged under 13 years in a school zone by violating traffic rules to be sentenced to life imprisonment with labor (Ministry of Justice, 2019). The amendment to the Road Traffic Act (RTA) provided a legal basis for the preferential installation of automated traffic enforcement devices and safety equipment (e.g., crosswalk traffic signals, safety signs, and speed humps) in school zones (National Police Agency, 2019). The new school zone laws were enacted on December 24, 2019, and enforced on March 25, 2020 (Ministry of Justice, 2019; National Police Agency, 2019). Details of the legislation are summarized in Table 1.

Evidence has shown that automated speed enforcement and area-wide traffic calming measures (e.g., speed humps, increasing

Table 1
New school zone laws in South Korea.

Act	Regulation	Before legislation	After legislation
Act on the Aggravated Punishment, etc. Of Specific Crimes (Ministry of Justice, 2019)	Aggravated penalty	None; penalty under the Act on Special Cases Concerning the Settlement of Traffic Accidents,	When a driver violated the duties in school zones to obey the speed limit of 30 km/h or to drive while paying attention to the children's safety
	For RTIs in school zones	Fine: ≤20 million KRW Imprisonment without labor: ≤5 years	Fine: ≥5 million KRW, ≤30 million KRW Imprisonment with labor: ≥1 year, ≤15 years
	For RTDs in school zones	Fine: ≤20 million KRW Imprisonment without labor: ≤5 years	Imprisonment with labor: life imprisonment for an indefinite term or ≥3 years
Road Traffic Act (National Police Agency, 2019)	Management of school zones	None; management under the Rules on Designation and Management of Protection Areas for Children, Senior Citizens, and Persons with Disabilities (Joint Ordinance of the related Ministries), Preferential installation of signal apparatus for a crosswalk on an arterial road in school zones Request by local governments to road management authorities to install safety equipment in school zones	Preferential installation of unmanned traffic regulation equipment on the roads in school zones Preferential installation of safety equipment in school zones or mandatory request by local governments to road management authorities to install safety equipment in school zones - Signal apparatus for a crosswalk on an arterial road which is at the nearest distance to the main entrance of a facility designated as a school zone - Speed restriction signs and crosswalk safety signs - Facilities for preventing overspeeding or slipping of motor vehicles, among road appurtenances - Other facilities or equipment prescribed by the Joint Ordinance of the related Ministries

RTIs: road traffic injuries; RTDs: road traffic deaths.
Note: Both laws were enacted on December 24, 2019 and enforced on March 25, 2020; Annual average currency rate in 2021: 1 USD = 1189 KRW.

visibility of traffic signs, and redistribution of traffic flows) can reduce RTDs, RTIs, and road traffic crashes (RTCs) involving pedestrians (Bunn et al., 2003; Inada et al., 2020; Namatovu et al., 2022; Quistberg et al., 2019; Vecino-Ortiz et al., 2018; Wilson et al., 2010). However, there are limited studies on whether these countermeasures are effective in reducing child RTIs in school zones (Grundy et al., 2009; Inada et al., 2020). School zones with lowered speed limits seem to be effective in reducing RTCs, although their effectiveness in reducing vehicle speed is mixed (Grundy et al., 2009; Inada et al., 2020; Sun et al., 2018). But no studies have focused on evaluating the effect on road traffic outcomes (RTOs) of strengthening punishment for traffic violations in school zones, despite the mixed effectiveness of increasing penalties on road traffic safety (Sakashita et al., 2021).

Also, most research evaluating the impact of school zones on road traffic safety was based on simple study designs (e.g., controlled before-after and uncontrolled interrupted time-series studies) (Inada et al., 2020; Sun et al., 2018), so there were few studies considering both within-group variations over time and time-varying confounding (Degli Esposti et al., 2021; Grundy et al., 2009; Lopez Bernal et al., 2018).

Therefore, the purpose of this study was to estimate the effects of new tougher school zone laws in Korea on the equivalent fatal RTI, non-fatal RTI, and RTC rates in school zones for children aged 0–12 years, through a controlled interrupted time-series (CITS) design using Bayesian structural time-series (BSTS) models.

2. Material and methods

2.1. Data

Between January 2015 and December 2021, the total, school-zone-related, and non-school-zone-related numbers of RTDs, RTIs, and RTCs reported to the police for children aged 0–12 years were obtained monthly according to the type of legal violations from the Police Road Accident Database in the Traffic Accident Analysis System (KoROAD, 2022). RTD was defined as death within 30 days of the RTC (KoROAD, 2022). RTI was categorized into severe, mild, and minimal depending on the length of the period required for treatment: severe for at least 3 weeks, mild for at least 5 days and less than 3 weeks, and minimal for less than 5 days (KoROAD, 2022). The type of legal violation was classified as centerline violation, signal violation, violating intersection crossing procedure, non-compliance with pedestrian protection obligation, non-compliance with safe driving obligation, and other traffic violations (KoROAD, 2022), to reduce a small number of cases in the numerator. The monthly numbers of registered motor vehicles, including motorcycles, and resident registration population of children aged 0–12 years for the corresponding period were acquired from the Total Registered Motor Vehicles and Vital Statistics data, respectively (Statistics Korea, 2022).

2.2. Variables

The outcome variables were equivalent fatality (EF), RTI, severe RTI, minor RTI, and RTC rates in school zones by month, which were calculated as the monthly number of RTOs in school zones per 1,000,000 vehicles and per 1,000,000 children aged 0–12 years, considering that the number of vehicles increased by 21.4% and the number of children aged 0–12 years decreased by 14.6% during the study period (Statistics Korea, 2022). The road traffic EF rate was used instead of the RTD rate owing to no or too few monthly RTDs. The EF was estimated by applying the weights based on the cost of RTCs in Korea as follows: $EF = number\ of\ RTDs + number\ of\ severe\ RTIs \times 0.1168 + number\ of\ mild\ RTIs \times 0.0068 + number\ of\ minimal\ RTIs \times 0.0033$ (KoROAD, 2022). Mild and minimal RTIs were combined into minor RTIs.

Potential control series included monthly rates of total and non-school-zone-related RTOs and those based on the type of legal violation. Because road safety laws and systems differ by nation and are usually enforced nationwide, it can be difficult to find suitable control series (Brodersen et al., 2015; Eun, 2021; Lopez Bernal et al., 2018). In this case, non-equivalent control series, such as total or non-school-zone-related RTO rates that reflect overall road safety efforts or are not influenced by school zone laws, can be used (Brodersen et al., 2015; Eun, 2021; Lopez Bernal et al., 2018). While the effects of diverse confounding events (e.g., business cycle, road transport infrastructure) on outcome variables may be controlled by using control series, it is vulnerable to selection bias, meaning systematic differences between the treatment and control series that confound actual intervention effects (Degli Esposti et al., 2021; Eun, 2021; Lopez Bernal et al., 2018). A synthetic counterfactual approach was employed to minimize selection bias (Degli Esposti et al., 2021), and covariates that could precisely estimate the trend of the intervention series with a one-step mean absolute percentage error of less than 5% were used as non-equivalent control series to satisfy the parallel trend assumption.

The intervention effects of two school zone laws were estimated by setting the pre-period from January 2015 to February 2020 and the post-period from March 2020 to December 2021.

2.3. Statistical analysis

The effects of school zone laws on RTO rates were estimated using BSTS models. Details of the BSTS models are presented elsewhere (Brodersen et al., 2015; Scott and Varian, 2014). The BSTS model is comprised of time-series and regression components (Brodersen et al., 2015; Scott and Varian, 2014). A time-series component depicts temporal and seasonal trends in data using state-space models, where an observation equation links observations with unobserved latent states and a state equation determines how the latent states vary over time (Brodersen et al., 2015; de Vocht et al., 2020; Eun, 2021; Scott and Varian, 2014). A regression component constructs synthetic counterfactuals from covariates by inducing sparsity through a spike-and-slab prior on the regression coefficients, thereby measuring intervention effects (Brodersen et al., 2015; de Vocht et al., 2020; Eun, 2021; Scott and Varian, 2014). Post-intervention counterfactual outcomes are generated conditional on the pre-intervention response series and the pre- and post-intervention control series through Bayesian model averaging, and the difference between the measured and counterfactual outcomes in the post-period is regarded as the intervention effect (Brodersen et al., 2015; de Vocht et al., 2020; Eun, 2021; Scott and Varian, 2014). The Bayesian credible intervals (CrIs) are provided, and posterior tail-area probabilities are interpreted as traditional p-values (Brodersen et al., 2015; de Vocht et al., 2020; Eun, 2021).

Local level models were built, but seasonality was not considered due to the lack of improvement in the model fit. Assuming that the incremental errors in the state process are low, Gamma priors were specified for the distribution of variance (Brodersen et al., 2015; Eun, 2021). Expected explained variance was set at 80% and the arithmetic mean of the outcome in the pre-period was used as priors for the mean of each outcome (de Vocht et al., 2020; Eun, 2021). The inverse-Gamma prior for standard deviation was set to 5% of a standard deviation with an upper limit of 100% of the standard deviation in pre-period (de Vocht et al., 2020; Eun, 2021). Convergence of the Markov Chain Monte Carlo algorithms was assessed using visual inspection of trace plots, Heidelberger-Welch stationary and halfwidth tests, Geweke tests, and Raftery and Lewis's diagnostics, (Eun, 2021). Autocorrelation was checked by the autocorrelation function and partial autocorrelation function plots, Durbin-Watson statistics, and Ljung-Box tests (Eun, 2021). Precision was evaluated by a one-step mean absolute percentage error (Eun, 2021). Analyses were performed with 10,000 to 250,000 iterations until all diagnostic criteria were satisfied and the BSTS models precisely predicted the counterfactual estimates for outcomes (Supplementary Table S1).

Whether intervention effects were specific to the timing of the intervention and the intervention series was evaluated by falsification tests using false implementation times (6 months earlier and later than the actual intervention time) and substitution of the outcome series with each non-equivalent control series (Craig et al., 2017; de Vocht et al., 2020; Eun, 2021). Sensitivity was tested with more and less informative priors for the local level standard deviation that were set to 1% and 10% (Eun, 2021), and by estimating EFs with different weights: (a) *EF* = *number of RTDs* + *number of severe RTIs* × 0.5 + *number of mild RTIs* × 0.3 + *number of minimal RTIs* × 0.1 using the inverse of the equivalent property damage only weights (Cho et al., 2014) and (b) *EF* = *number of RTDs* + *number of severe RTIs* × 15/90 + *number of mild RTIs* × 5/90 + *number of minimal RTIs* × 2/90 based on the demerit points (Lee, 2019).

Statistical analyses were performed in *R* (V.4.1.0) using the *CausalImpact* (Brodersen et al., 2015), *bsts* (Scott and Varian, 2014), and *MarketMatching* (Larsen, 2021) packages.

3. Results

Table 2 shows the descriptive statistics before and after law enforcement in school zones and non-school zones. The monthly average numbers of motor vehicles in the pre-period and post-period were 24, 368, 605 and 26, 687, 082, and the numbers of children aged 0–12 years were 5,841,271 and 5,338,760, respectively. Although all RTOs in non-school zones were lower in the post-period than the pre-period, there were no consistently significant differences between the pre-period and post-period of RTOs in school zones. Monthly RTO rates and their numerators and denominators are presented in the Supplementary Data.

Fig. 1 presents actual and synthetic counterfactual trends in EF, RTI, and RTC rates in school zones among children aged 0–12 years between 2015 and 2021 in Korea. In the pre-period, most RTO rates slightly decreased, but RTI, minor RTI, and RTC rates per million children aged 0–12 years tended to marginally increase.

Table 2
Descriptive statistics based on monthly averages for road traffic outcomes in school zones and non-school zones.

Road traffic outcome	School zones					Non-school zones				
	Pre-period		Post-period		p-value	Pre-period		Post-period		p-value
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Number of equivalent fatalities	2.4	1.2	1.8	0.9	0.040	27.3	7.6	16.5	4.6	<0.001
Number of road traffic injuries	42.8	14.4	46.9	19.2	0.300	1100.9	207.3	858.1	168.5	<0.001
Number of severe road traffic injuries	14.3	6.2	11.5	5.6	0.063	151.8	47.5	85.2	28.4	<0.001
Number of minor road traffic injuries	28.5	10.1	35.4	14.6	0.049	949.1	167.3	772.9	142.0	<0.001
Number of road traffic crashes	41.0	13.5	44.0	17.9	0.411	873.3	174.5	687.0	141.1	<0.001
Per million vehicles										
Equivalent fatality rate	0.099	0.051	0.068	0.035	0.003	1.131	0.347	0.620	0.171	<0.001
Road traffic injury rate	1.762	0.604	1.757	0.722	0.973	45.360	9.324	32.148	6.301	<0.001
Severe road traffic injury rate	0.592	0.269	0.431	0.212	0.013	6.285	2.143	3.194	1.071	<0.001
Minor road traffic injury rate	1.170	0.413	1.326	0.548	0.169	39.075	7.409	28.954	5.302	<0.001
Road traffic crash rate	1.686	0.569	1.648	0.675	0.798	35.999	7.853	25.739	5.276	<0.001
Per million children aged 0–12 years										
Equivalent fatality rate	0.409	0.203	0.338	0.169	0.144	4.661	1.230	3.101	0.852	<0.001
Road traffic injury rate	7.333	2.482	8.797	3.573	0.038	188.379	34.710	160.874	31.890	0.002
Severe road traffic injury rate	2.451	1.047	2.151	1.031	0.250	25.894	7.775	15.969	5.281	<0.001
Minor road traffic injury rate	4.882	1.760	6.646	2.743	0.009	162.485	28.418	144.906	27.026	0.014
Road traffic crash rate	7.015	2.327	8.248	3.322	0.061	149.399	29.078	128.815	26.707	0.005

SD: standard deviation.
Note: The pre-period was 62 months from January 2015 to February 2020, and the post-period was 22 months from March 2020 to December 2021; P-values were calculated between pre-period and post-period by *t*-test.

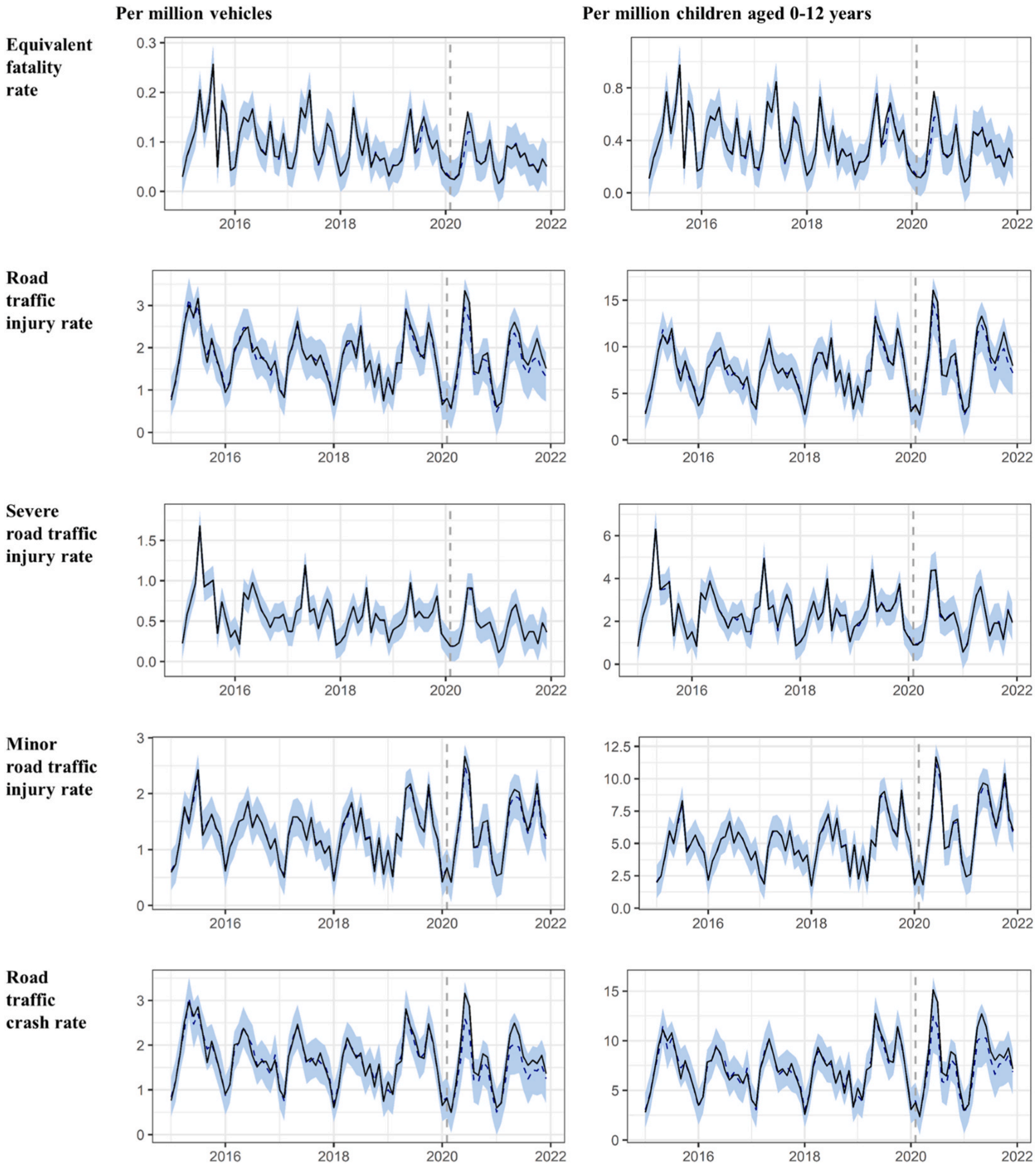

Fig. 1. Actual (continuous line) and synthetic counterfactual (hyphenated line) time-series and 95% credible intervals (shaded area) for road traffic outcome rates in school zones for children aged 0–12 years in South Korea, 2015–2021.

Table 3 describes the effects of Korea's new school zone laws on RTO rates in school zones. The stricter school zone laws had no statistically significant impact on school-zone-related RTO rates for children aged 0–12 years, both per vehicle and per population. For RTO rates in school zones per million vehicles, during the post-period between March 2020 and December 2021, on a monthly average basis, the EF rate increased insignificantly by 0.002 (95% CrI −0.019 to 0.023), RTI rate by 0.18 (95% CrI −0.16 to 0.55), severe RTI rate by 0.003 (95% CrI −0.101 to 0.108), minor RTI rate by 0.06 (95% CrI −0.12 to 0.24), and RTC rate by 0.23 (95% CrI −0.11 to 0.55), which represented increases of 3.2% (95% CrI −29.2%–35.5%), 11.2% (95% CrI −10.6%–35.1%), 0.8% (95% CrI −23.6%–25.2%), 4.6% (95% CrI −9.5%–18.7%), and 15.9% (95% CrI −7.5%–38.9%), respectively. Cumulatively, the EF rate increased by 0.05 (95% CrI −0.43 to 0.51), RTI rate by 3.9 (95% CrI −3.7 to 12.2), severe RTI rate by 0.08 (95% CrI −2.23 to 2.37), minor RTI rate by 1.3 (95% CrI −2.7 to 5.2), and RTC rate by 5.0 (95% CrI −2.3 to 12.2). Regarding school-zone-related RTO rates per million children aged 0–12 years, the EF rate changed by 0.009 (95% CrI −0.074 to 0.094), RTI rate by 0.64 (95% CrI −0.72 to 2.24), severe RTI by −0.015 (95% CrI −0.458 to 0.424), minor RTI rate by 0.19 (95% CrI −0.55 to 0.94), and RTC rate by 0.99 (95% CrI −0.48 to 2.40), indicating changes of 2.9% (95% CrI −22.6%–28.4%), 7.8% (95% CrI −8.9%–27.5%), −0.7% (95% CrI −21.1%–19.6%), 3.0% (95% CrI −8.6%–14.6%), and 13.6% (95% CrI −6.6%–33.0%), respectively. The EF rate cumulatively changed by 0.21 (95% CrI −1.64 to 2.06), RTI rate by 14.1 (95% CrI −15.9 to 49.4), severe RTI rate by −0.34 (95% CrI −10.07 to 9.34), minor RTI rate by 4.3 (95% CrI −12.2 to

Table 3
Estimated effects of stricter school zone laws on road traffic outcome rates in school zones for children aged 0–12 years in South Korea.

Road traffic outcome	Average absolute effect (95% CrI)	Cumulative absolute effect (95% CrI)	Relative effect (95% CrI)	Posterior tail-area probability of effect
Per million vehicles				
Equivalent fatality rate	0.002 (−0.019, 0.023)	0.05 (−0.43, 0.51)	3.2% (−29.2%, 35.5%)	0.423
Road traffic injury rate	0.2 (−0.2, 0.6)	3.9 (−3.7, 12.2)	11.2% (−10.6%, 35.1%)	0.164
Severe road traffic injury rate	0.003 (−0.101, 0.108)	0.1 (−2.2, 2.4)	0.8% (−23.6%, 25.2%)	0.474
Minor road traffic injury rate	0.1 (−0.1, 0.2)	1.3 (−2.7, 5.2)	4.6% (−9.5%, 18.7%)	0.263
Road traffic crash rate	0.2 (−0.1, 0.6)	5.0 (−2.3, 12.2)	15.9% (−7.5%, 38.9%)	0.091
Per million children aged 0–12 years				
Equivalent fatality rate	0.01 (−0.07, 0.09)	0.2 (−1.6, 2.1)	2.9% (−22.6%, 28.4%)	0.412
Road traffic injury rate	0.6 (−0.7, 2.2)	14.1 (−15.9, 49.4)	7.8% (−8.9%, 27.5%)	0.192
Severe road traffic injury rate	−0.02 (−0.46, 0.42)	−0.3 (−10.1, 9.3)	−0.7% (−21.1%, 19.6%)	0.473
Minor road traffic injury rate	0.2 (−0.6, 0.9)	4.3 (−12.2, 20.7)	3.0% (−8.6%, 14.6%)	0.305
Road traffic crash rate	1.0 (−0.5, 2.4)	21.7 (−10.5, 52.7)	13.6% (−6.6%, 33.0%)	0.097

CrI: credible interval.

20.7), and RTC rate by 21.7 (95% CrI −10.5 to 52.7).

The results of falsification tests showed non-significant 6-month effects from the false implementation times of 6 months earlier and later than the actual intervention time on RTO rates in school zones (Supplementary Table S2) and non-significant intervention effects for the alternative outcome variables substituted with each non-equivalent control series (Supplementary Table S3), denoting that the intervention effects were specific to the actual intervention time and outcome variables. In sensitivity analysis, when more and less informative priors and different weights for estimating the EF were applied, the effect sizes and posterior-tail-area probabilities changed to some extent, but the intervention effects were not statistically significant (Supplementary Table S4).

4. Discussion

This study evaluated the effects on school-zone-related RTOs of new school zone laws in Korea that enforced tougher punishments for road traffic casualties of children aged under 13 years and the preferential installation of road safety equipment including automated traffic enforcement devices in school zones (Ministry of Justice, 2019; National Police Agency, 2019). The revised school zone laws did not improve the EF, RTI, severe RTI, minor RTI, and RTC rates for children aged 0–12 years in school zones, considering the trends in the overall and non-school-zone-related RTO rates for the same age group.

The likelihood of legal violations depends on the perceived risk of apprehension and the perceived certainty, severity, and celerity of punishment when apprehended (Chen et al., 2020; Sakashita et al., 2021; Teodorescu et al., 2021). Although their relative effectiveness in deterring violations is mixed, it has been noted that the certainty of apprehension and punishment is more important to deter violations than the severity of punishment (Chen et al., 2020; Eun, 2021; Sakashita et al., 2021; Teodorescu et al., 2021). The stricter school zone law, the AAPSC, imposed heavier penalties on those who caused child road traffic casualties in school zones by increasing the fine and imprisonment period (Ministry of Justice, 2019), but it had no impact on road traffic safety in school zones, which was consistent with the related findings (Sakashita et al., 2021; Teodorescu et al., 2021).

However, another law, the RTA, required the preferential installation of automated traffic enforcement devices and safety equipment, including vertical deflection measures in school zones (National Police Agency, 2019), which are effective countermeasures to improve pedestrian road traffic safety (Bunn et al., 2003; Inada et al., 2020; Namatovu et al., 2022; Quistberg et al., 2019; Vecino-Ortiz et al., 2018; Wilson et al., 2010). Notwithstanding the implementation of the RTA for the preferential installation of automated traffic enforcement devices to guarantee the certainty of apprehension and punishment, so that the increased severity of punishment can have effects on road traffic safety for children in school zones (Sakashita et al., 2021; Teodorescu et al., 2021), insufficient enforcement of the RTA might have contributed to the ineffectiveness of school zone laws.

The proportion of school zones with automated traffic enforcement equipment increased from 6% in 2019 to 21% in 2020 and 52% in 2021 (Kang, 2022), but about half of school zones were still not equipped with automated traffic enforcement devices by the end of the study period, plausibly limiting the increase in the certainty of apprehension and punishment. Also, despite no publicly available data on the installation proportion of road safety equipment in school zones, even among the 29 road sections of 16 school zones where child RTDs occurred during 2017–2019, in 2021, 45%, 14%, and 10% had no pedestrian traffic signals, crosswalks, and speed humps, respectively (Moon, 2021). The effectiveness of traffic control measures (e.g., traffic signs and signals) may vary depending on traffic conditions and roadway environments (Zhao et al., 2015). Nevertheless, other effective traffic calming measures (e.g., horizontal shifts, roadway narrowing, and route restriction) were not further considered, possibly making the laws ineffective (Bunn et al., 2003; Inada et al., 2020; Kim et al., 2022; Vecino-Ortiz et al., 2018).

Besides, in Korea, more than 60% of child RTDs in school zones have resulted from non-compliance with legal obligations to protect pedestrians (e.g., stop at a crosswalk and not impeding the traffic of crossing pedestrians) and drive safely (i.e., avoid inattention and distraction in driving), whereas speeding has been responsible for a small proportion (≈1%) of child road traffic casualties in school zones during the pre-period, despite being the most lethal and common type of traffic violation (Architecture & Urban Research Institute and KoROAD, 2020; KoROAD, 2022; Moon, 2021). Speeding is a high-risk driving behavior that certainly needs to be addressed, but it should also be necessary to deter non-compliance with pedestrian protection and safe driving obligations, the most common causes of child RTOs in school zones (KoROAD, 2022). In spite of imposing aggravated punishment for those who caused child road traffic casualties in school zones due to non-compliance with driving while paying attention to children's road safety as well as speeding under the AAPSC (Ministry of Justice, 2019), the law failed to reduce the school-zone-related RTO rates for children.

Theoretically, stricter penalties may reduce violations by increasing the perceived costs of offending (Sakashita et al., 2021). Social norms and attitudes for child road traffic safety in school zones might have been strengthened by increasing the severity of punishment to the extent of being sentenced to life imprisonment with labor, which, however, could have had limitations in enhancing self-efficacy or perceived behavioral control to change driving behavior to avoid inattention and distraction in driving (Atchley et al., 2012; Dong et al., 2019; Sakashita et al., 2021), because driving while paying attention to pedestrian safety was a general duty that drivers were already aware of, and the law simply increased the penalties without additional specific measures to comply with this obligation (Ministry of Justice, 2019; National Police Agency, 2019). Unlike the explicit threshold for speeding, whether or not a driver complies with the safe driving obligation has been retrospectively determined by the judicial system according to the unpredictability and unavoidability of an RTC (Chung, 2020; Wu et al., 2020), which might have made it difficult to proactively motivate drivers to do or not to do specific driving behaviors (Atchley et al., 2012; Dong et al., 2019). This might also explain, at least in part, why the prohibition of parking and stopping within school zones in October 2021 (National Police Agency, 2020), which allowed road users to better predict the risk of RTCs by eliminating blind spots caused by parked and stopped vehicles, did not seem to contribute to ameliorating child RTO rates in school zones (Fig. 1).

Consistent with previous findings that policy measures in response to the COVID-19 pandemic (e.g., lockdown, social distancing, and quarantine) have decreased RTD, RTI, and RTC rates in most countries because of lowered traffic volumes (Shaik and Ahmed, 2022; Yasin et al., 2021), overall or non-school-zone-related RTO rates for children aged 0–12 years in Korea decreased (KoROAD, 2022), but school-zone-related RTO rates did not.

The uncontrolled interrupted time-series analysis using the BSTS without covariates showed non-significant changes in school-zone-related RTO rates during the post-period that was immediately after the onset of the COVID-19 pandemic (February 2020), with decreasing tendency of EF and severe RTI rates and increasing tendency of RTI, minor RTI, and RTC rates (Supplementary Table S5). In Korea, schools were closed for 11 weeks since the onset of the COVID-19 pandemic, and children attended school for most of the post-period, despite restrictions on the number of students attending (UNESCO Institue for Statistics, 2022). Between 2019 and 2020, the traffic volume decreased by 12.1%, but only by 5.0% in residential areas with most of the school zones, and the use of passenger vehicles increased as the use of public transport plummeted (Architecture & Urban Research Institute and KoROAD, 2020; Metropolitan Transport Commission, 2022). Simultaneously, the numbers of motorcycles and RTCs involving motorcycles have surged due to increased demand for delivery services (Moon et al., 2022; Statistics Korea, 2022). Accordingly, in the post-period compared to the pre-period, the number of RTCs in school zones increased by 0.5%, but the number and share of RTCs involving passenger vehicles and motorcycles with lower case EF (i.e., EFs per crash) increased and the those of RTCs involving large and heavy vehicles (e.g., construction machineries and buses) with higher case EF decreased (KoROAD, 2022), possibly resulting in lowering the severity of RTCs with a slight increase in the volume of RTCs.

Several limitations should be noted. First, notwithstanding efforts to minimize time-varying confounding based on the CITS design, selection bias could not have been completely controlled due to differences between inside and outside school zones in characteristics (Lopez Bernal et al., 2018), such as road type, traffic volume, travel behavior, and the impact of the COVID-19 pandemic (Shaik and Ahmed, 2022). To control for the differential impact of the COVID-19 pandemic on school-zone-related and non-school-zone-related RTO rates, the most appropriate control series would be the RTO rates in the non-school zones where the distributions of road safety factors did not differ from those in the school zones among the places where the COVID-19 pandemic had no impact on road safety. However, it is challenging to find such control groups in the real world and was unable to identify equivalent or less non-equivalent control groups because only aggregate data with no relevant monthly information was available (KoROAD, 2022; Lopez Bernal et al., 2018). Nevertheless, considering the ineffectiveness of the laws on the synthetic counterfactual outcomes for the intervention group (Supplementary Table S6), the post-intervention synthetic counterfactuals for outcome series appear to have been constructed using non-equivalent covariates with adequate, if not perfect, control for time-varying confounding due to the COVID-19 pandemic. Additionally, after the onset of the COVID-19 pandemic, traffic volume did not increase in school zones and decrease in non-school zones, but decreased differentially in both. However, in uncontrolled interrupted time-series analyses (Supplementary Table S5), the laws did not reduce school-zone-related RTO rates as well, even though traffic volume decreased in residential areas with most of the school zones (Metropolitan Transport Commission, 2022). If an unadjusted differential influence of the reduction in traffic volume after the COVID-19 pandemic on RTO rates had remained, it would have reduced the effectiveness of the intervention. Therefore, the COVID-19 pandemic was not likely to have affected the findings of this study that the laws did not reduce child RTO rates in school zones.

Second, regardless of the use of official national RTC data, police data on RTCs could have understated the numbers of RTOs due to underreporting (Derriks and Mak, 2007; ITF, 2019). Even so, the definitions of RTOs in Korea were constant over the data period, therefore the trends of outcome and non-equivalent control series are unlikely to have been influenced by underreporting (Eun, 2021). Third, although the vehicle kilometers per person at risk of an RTC would be the most relevant denominator for calculating the RTO rates (Haghpanahan et al., 2019), the numbers of motor vehicles and population were used as denominators since monthly data on the numbers of drivers and kilometers driven were not available (Statistics Korea, 2022). Fourth, the number of designated school zones increased from 16,085 in 2015 to 16,912 in 2019, then decreased to 16,759 in 2021, but was not considered in the analysis due to the lack of monthly data (Statistics Korea, 2022). The number of RTOs in school zones, the numerator of outcome variables, would be expected to be positively related to the number of school zones. Yet, the actual RTO rates in school zones did not generally decrease during the post-period when the number of school zones decreased (Table 3 and Supplementary Table S5), implying that the number of designated school zones was unlikely to have influenced the results of this study. Lastly, due to the scarcity of available data (KoROAD, 2022), subgroup analysis (e.g., sex, age group, and type of RTC) could not be conducted comprehensively.

5. Conclusions

New school zone laws in Korea that centered mainly on imposing stricter penalties have failed to reduce EF, RTI, severe RTI, minor RTI, and RTC rates in school zones for children aged 0–12 years. To improve children's road traffic safety in school zones, along with the full enforcement of laws to detect traffic violations and install road safety equipment, area-wide traffic calming measures and prevention strategies to avoid driver inattention and distraction should be considered. Further research is needed to ensure the effectiveness of school zone laws and measures to mitigate child road traffic casualties in school zones.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution

Sang Jun Eun: Conceptualization; Data curation; Formal analysis; Methodology; Roles/Writing - original draft; and Writing - review & editing.

Ethics approval

This study was exempted from ethical approval by the Chungnam National University Institutional Review Board (IRB No. 202207-SB-101-01).

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author used Google Translate in order to check grammar and translate into English. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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.

Data availability

The authors do not have permission to share data.

Acknowledgements

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jth.2023.101687.

References

Architecture, Urban Research Institute, KoROAD, 2020. Mid- to long-term improvement plan and standard model for child and senior protection areas. In: Ministry of the Interior and Safety. Sejong. http://www.prism.go.kr/homepage/entire/downloadResearchAttachFile.do?workKey=001&fileType=CPR&seqNo=001&pdfConvYn=Y&researchId=1741000-202000069. (Accessed 13 October 2022).

Atchley, P., Hadlock, C., Lane, S., 2012. Stuck in the 70s: the role of social norms in distracted driving. Accid. Anal. Prev. 48, 279–284. https://doi.org/10.1016/j.aap.2012.01.026.

Brodersen, K.H., Gallusser, F., Koehler, J., Remy, N., Scott, S.L., 2015. Inferring causal impact using Bayesian structural time-series models. Ann. Appl. Stat. 9, 247–274. https://doi.org/10.1214/14-AOAS788.

Bunn, F., Collier, T., Frost, C., Ker, K., Roberts, I., Wentz, R., 2003. Area-wide traffic calming for preventing traffic related injuries, 2003 Cochrane Database Syst. Rev., Cd003110. https://doi.org/10.1002/14651858.Cd003110.

Chen, S., Kuhn, M., Prettner, K., Bloom, D.E., 2019. The global macroeconomic burden of road injuries: estimates and projections for 166 countries. Lancet Planet. Health 3, e390–e398. https://doi.org/10.1016/s2542-5196(19)30170-6.

Chen, T., Sze, N.N., Saxena, S., Pinjari, A.R., Bhat, C.R., Bai, L., 2020. Evaluation of penalty and enforcement strategies to combat speeding offences among professional drivers: a Hong Kong stated preference experiment. Accid. Anal. Prev. 135, 105366 https://doi.org/10.1016/j.aap.2019.105366.

Cho, J., Park, W.W., Kim, M., 2014. Development and application of traffic safety forecast index based on weather informations. Transp. Technol. Policy 11, 62–71. https://koreascience.kr/article/JAKO201413361962473.pdf.

Chung, J.J., 2020. The problems and scheme of the Act on the aggravated punishment of specific violent Crimes and road traffic Act. Korea Law Rev. 99, 157–194. https://doi.org/10.36532/kulri.2020.99.157.

Craig, P., Katikireddi, S.V., Leyland, A., Popham, F., 2017. Natural experiments: an overview of methods, approaches, and contributions to public health intervention research. Annu. Rev. Publ. Health 38, 39–56. https://doi.org/10.1146/annurev-publhealth-031816-044327.

de Vocht, F., McQuire, C., Brennan, A., Egan, M., Angus, C., Kaner, E., Beard, E., Brown, J., De Angelis, D., Carter, N., Murray, B., Dukes, R., Greenwood, E., Holden, S., Jago, R., Hickman, M., 2020. Evaluating the causal impact of individual alcohol licensing decisions on local health and crime using natural experiments with synthetic controls. Addiction 115, 2021–2031. https://doi.org/10.1111/add.15002.

Degli Esposti, M., Spreckelsen, T., Gasparrini, A., Wiebe, D.J., Bonander, C., Yakubovich, A.R., Humphreys, D.K., 2021. Can synthetic controls improve causal inference in interrupted time series evaluations of public health interventions? Int. J. Epidemiol. 49, 2010–2020. https://doi.org/10.1093/ije/dyaa152.

Derriks, H.M., Mak, P.M., 2007. Underreporting of Road Traffic Casualties. Organisation for Economic Co-operation and Development, International Transport Forum, Paris. http://www.internationaltransportforum.org/irtadpublic/pdf/repNDL2007.pdf. (Accessed 20 October 2022).

Dong, H., Jia, N., Tian, J., Ma, S., 2019. The effectiveness and influencing factors of a penalty point system in China from the perspective of risky driving behaviors. Accid. Anal. Prev. 131, 171–179. https://doi.org/10.1016/j.aap.2019.06.005.

Eun, S.J., 2021. Effects of stricter drunk-driving laws on alcohol-related road traffic death, injury, and crash rates in South Korea: a synthetic counterfactual approach using Bayesian structural time-series models. Accid. Anal. Prev. 163, 106455 https://doi.org/10.1016/j.aap.2021.106455.

Global Burden of Disease Collaborative Network, 2020. Global Burden of Disease Study 2019 Results. Institute for Health Metrics and Evaluation, Seattle. https://vizhub.healthdata.org/gbd-results/. (Accessed 1 August 2022).

Grous, A., 2019. The Impact of Road Traffic Accidents with Child Victims. Foundation Abertis, The London School of Economics and Political Science, United Nations International Children's Emergency Fund, London. https://www.abertis.com/media/news/2019/12/12/Abertis_Informe%20LSE_EN_M7.pdf. (Accessed 1 August 2022).

Grundy, C., Steinbach, R., Edwards, P., Green, J., Armstrong, B., Wilkinson, P., 2009. Effect of 20 mph traffic speed zones on road injuries in London, 1986-2006: controlled interrupted time series analysis. BMJ 339, b4469. https://doi.org/10.1136/bmj.b4469.

Haghpanahan, H., Lewsey, J., Mackay, D.F., McIntosh, E., Pell, J., Jones, A., Fitzgerald, N., Robinson, M., 2019. An evaluation of the effects of lowering blood alcohol concentration limits for drivers on the rates of road traffic accidents and alcohol consumption: a natural experiment. Lancet 393, 321–329. https://doi.org/10.1016/s0140-6736(18)32850-2.

Inada, H., Tomio, J., Nakahara, S., Ichikawa, M., 2020. Area-wide traffic-calming Zone 30 policy of Japan and incidence of road traffic injuries among cyclists and pedestrians. Am. J. Publ. Health 110, 237–243. https://doi.org/10.2105/ajph.2019.305404.

ITF, 2019. Road Safety Annual Report 2019. Organisation for Economic Co-operation and Development, International Transport Forum, Paris. https://www.itf-oecd.org/road-safety-annual-report-2019. (Accessed 29 July 2022).

ITF, OECD, 2022. IRTAD Database: Road Fatalities by Age and Road User. OECD Publishing, Paris. https://stats.oecd.org/Index.aspx?DataSetCode=IRTAD_CASUAL_BY_AGE. (Accessed 2 August 2022).

Kang, H., 2022. Two Years of Min-Sik Law, the Installation Rate of Speed and Enforcement Cameras Increased from 6% to 52%. National Assembly Library, Seoul. https://www.nanet.go.kr/lowcontent/assamblybodo/selectAssamblyBodoDetail.do?searchSeq=123957&searchNoSeq=20220504123957. (Accessed 18 July 2022).

Kim, Y.-J., Choi, J.-H., Hong, M.-H., 2022. A study on the improvement direction of the school zone: focusing on policy and design cases in Korea and Sweden. J. Korea Contents Assoc. 22, 116–124. https://doi.org/10.5392/JKCA.2022.22.02.116.

KoROAD, 2022. Traffic Accident Analysis System. Wonju: Korea Road Traffic Authority. http://taas.koroad.or.kr/. (Accessed 17 June 2022).

Larsen, K., 2021. MarketMatching: Market Matching and Causal Impact Inference. https://cran.r-project.org/web/packages/MarketMatching/index.html. (Accessed 1 July 2022).

Lee, S., 2019. A study on the estimating license demerit point about the items causing traffic accidents. J. Korean Soc. Transp. 37, 365–374. https://doi.org/10.7470/jkst.2019.37.5.365.

Li, Q., Alonge, O., Hyder, A.A., 2016. Children and road traffic injuries: can't the world do better? Arch. Dis. Child. 101, 1063–1070. https://doi.org/10.1136/archdischild-2015-309586.

Lopez Bernal, J., Cummins, S., Gasparrini, A., 2018. The use of controls in interrupted time series studies of public health interventions. Int. J. Epidemiol. 47, 2082–2093. https://doi.org/10.1093/ije/dyy135.

Metropolitan Transport Commission, 2022. 12.1% decrease in traffic volume in metropolitan areas due to COVID-19 pandemic. In: Sejong: Ministry of Land, Infrastructure and Transport. http://www.molit.go.kr/USR/NEWS/m_71/dtl.jsp?lcmspage=1&id=95086591. (Accessed 2 August 2022).

Ministry of Justice, 2019. Act on the Aggravated Punishment, Etc. Of Specific Crimes, No. 16829. Sejong: Korea Ministry of Government Legislation. https://www.law.go.kr/LSW/lsInfoP.do?lsiSeq=212381&ancYd=20191224&ancNo=16829&efYd=20200325&nwJoYnInfo=N&efGubun=Y&chrClsCd=010202&ancYnChk=0#0000. (Accessed 10 August 2022).

Moon, D., Jang, J.H., Cho, J.S., Choi, J.Y., Woo, J.-h., Choi, W.S., Hyun, S.Y., Lee, S.H., 2022. Changes in incidence and severity of commercial motorcycle accidents due to the use of delivery service platforms. J. Trauma Inj., 0031 https://doi.org/10.20408/jti.2022.0031 jti.2022.

Moon, J., 2021. Status of Safety in Protection Areas for Children. Korea Consumer Agency, Eumseong. https://www.kca.go.kr/smartconsumer/sub.do?menukey=7301&mode=view&no=1002075117&page=28. (Accessed 18 July 2022).

Namatovu, S., Balugaba, B.E., Muni, K., Ningwa, A., Nsabagwa, L., Oporia, F., Kiconco, A., Kyamanywa, P., Mutto, M., Osuret, J., Rehfuess, E.A., Burns, J., Kobusingye, O., 2022. Interventions to reduce pedestrian road traffic injuries: a systematic review of randomized controlled trials, cluster randomized controlled trials, interrupted time-series, and controlled before-after studies. PLoS One 17, e0262681. https://doi.org/10.1371/journal.pone.0262681.

National Police Agency, 2019. Road Traffic Act, No. 16830. Sejong: Korea Ministry of Government Legislation. https://www.law.go.kr/LSW/lsInfoP.do?lsiSeq=212383&ancYd=20191224&ancNo=16830&efYd=20200325&nwJoYnInfo=N&efGubun=Y&chrClsCd=010202&ancYnChk=0#0000. (Accessed 10 August 2022).

National Police Agency, 2020. Road Traffic Act, No. 17514. Sejong: Korea Ministry of Government Legislation. https://www.law.go.kr/LSW/lsInfoP.do?lsiSeq=222453&ancYd=20201020&ancNo=17514&efYd=20211021&nwJoYnInfo=N&efGubun=Y&chrClsCd=010202&ancYnChk=0#0000. (Accessed 10 August 2022).

Quistberg, D.A., Thompson, L.L., Curtin, J., Rivara, F.P., Ebel, B.E., 2019. Impact of automated photo enforcement of vehicle speed in school zones: interrupted time series analysis. Inj. Prev. 25, 400–406. https://doi.org/10.1136/injuryprev-2018-042912.

Sakashita, C., Fleiter, J., Cliff, D., Flieger, M., Harman, B., Lilley, M., 2021. A Guide to the Use of Penalties to Improve Road Safety. Global Road Safety Partnership, Geneva. https://www.grsproadsafety.org/wp-content/uploads/Guide_to_the_Use_of_Penalties_to_Improve_Road_Safety.pdf. (Accessed 29 July 2022).

Scott, S.L., Varian, H.R., 2014. Predicting the present with Bayesian structural time series. Int. J. Math. Model. Numer. Optim. 5, 4–23. https://doi.org/10.1504/ijmmno.2014.059942.

Shaik, M.E., Ahmed, S., 2022. An overview of the impact of COVID-19 on road traffic safety and travel behavior. Transport Eng. 9, 100119 https://doi.org/10.1016/j.treng.2022.100119.

Statistics Korea, 2022. Korean Statistical Information Service. Daejeon: Statistics Korea. http://kosis.kr/index/index.do. (Accessed 28 July 2022).

Sul, J.H., Lee, J., Kang, D.S., Lee, W.Y., Shim, J.I., Myeong, M., Huh, E., Lim, J.K., 2014. Korea's 95% Reduction in Child Traffic Fatalities: Policies and Achievements Korea Transport Institute. Goyang. https://english.koti.re.kr/user/bbs/BD_selectBbs.do?q_bbsCode=1017&q_bbscttSn=20140423000001336458&q_clCode=6&q_lang=eng. (Accessed 17 June 2022).

Sun, D., El-Basyouny, K., Ibrahim, S., Kim, A.M., 2018. Are school zones effective in reducing speeds and improving safety? Can. J. Civ. Eng. 45, 1084–1092. https://doi.org/10.1139/cjce-2018-0060.

Teodorescu, K., Plonsky, O., Ayal, S., Barkan, R., 2021. Frequency of enforcement is more important than the severity of punishment in reducing violation behaviors. Proc. Natl. Acad. Sci. U. S. A 118, e2108507118. https://doi.org/10.1073/pnas.2108507118.

UNESCO Institue for Statistics, 2022. Dashboards on the Global Monitoring of School Closures Caused by the COVID-19 Pandemic. UNESCO Institute for Statistics, Montreal. https://covid19.uis.unesco.org/global-monitoring-school-closures-covid19/. (Accessed 19 October 2022).

Vecino-Ortiz, A.I., Jafri, A., Hyder, A.A., 2018. Effective interventions for unintentional injuries: a systematic review and mortality impact assessment among the poorest billion. Lancet Global Health 6, e523–e534. https://doi.org/10.1016/s2214-109x(18)30107-4.

Wilson, C., Willis, C., Hendrikz, J.K., Le Brocque, R., Bellamy, N., 2010. Speed Cameras for the Prevention of Road Traffic Injuries and Deaths. Cochrane Database Syst. Rev., Cd004607 https://doi.org/10.1002/14651858.CD004607.pub4

Wu, S.K., Jang, H., Lee, D.-Y., 2020. Improvement Direction for Rational Application and Acceptance of the Min-Sik Laws. Korea Transport Insitute, Sejong. https://www.koti.re.kr/user/bbs/BD_selectBbs.do?q_bbsCode=1017&q_bbscttSn=20210112132252637&q_clCode=8&q_lwprtClCode=-1&q_art=&q_lang=. (Accessed 5 October 2022).

Yasin, Y.J., Grivna, M., Abu-Zidan, F.M., 2021. Global impact of COVID-19 pandemic on road traffic collisions. World J. Emerg. Surg. 16, 51. https://doi.org/10.1186/s13017-021-00395-8.

Zhao, X., Li, J., Ding, H., Zhang, G., Rong, J., 2015. A generic approach for examining the effectiveness of traffic control devices in school zones. Accid. Anal. Prev. 82, 134–142. https://doi.org/10.1016/j.aap.2015.05.021.