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Original Article

Road Traffic Safety in Developing Countries: Taking China as an Example

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Abstract

Background: Road traffic accidents are still serious, especially in developing countries. This paper takes China as a typical example of a developing country with rich characteristics related to road traffic safety for analysis.

Methods: Temporal, spatial, road traffic accidents and economic information were gathered from the China Statistical Yearbook. Principal components analysis (PCA) was employed to establish a comprehensive indicator to represent road traffic safety based on different types of road traffic accidents information. Pearson correlation analysis and Eta coefficient test were performed to analyze whether time and space characteristics would affect the established indicator. Then the established indicator was introduced as dependent variable while year and regions as independent variables in the mixed linear model (MLM). At last, single-element regression model was built to study the impact of GDP per capita on road traffic safety.

Results: In PCA, the variance explained by the established indicator was 93.993%. The results of Pearson correlation analysis and Eta coefficient test suggested that time and region were both related to the established indicator. MLM showed that the year, the regions and the interaction between them influenced road traffic safety in China significantly. The single-variable regression analysis indicated that, with the increase in GDP per capita, road traffic safety initially decreased and then increased.

Conclusion: Road traffic safety in China was grim and changed greatly between different regions and years. This might be attributed to the yearly economic development and disparities among regions. .

Keywords: Road traffic safety; Developing countries; China

Introduction

According to the WHO, an estimated 1.35 million people die in road traffic accidents each year, and road traffic injuries have become the top killer for people aged 5-29 (1). Road traffic accidents remain a significant global public health issue (2, 3), and they are influenced by economic factors (4, 5). The registered motor vehicles in low- and middle-income countries accounted for 60% of the total number around the world while the road traffic death toll accounted for about 93% (1). Which means the road traffic safety in the developing countries are much worse than that in developed countries.

As a developing country, the number of China's road traffic accidents in 2020 was 244674, resulting in 61703 deaths and 250723 injuries (6). China is facing a bad road traffic safety situation (7), and thus be representative of developing countries. What's more, the economic development in China changes with time and varies greatly among different regions, making the characteristics of the road traffic accidents rich in China. Considering the feature diversity, China is also a good sample to study the road traffic safety in the developing countries.

Most road traffic safety analyses in China were targeted at finding out the influencing factors of the crashes in specific areas or road sections. Xie et al. (8) probed into the relationship between land use and severe crashes in Wuhan. Li et al. (9) studied the traffic crash characteristics in Shenzhen and considered road type, weather conditions, peak hours and bad driving behavior as major factors to the traffic accident rate. Peng et al. (10) collected the real-world data of the rear-end accidents between trucks in Changsha and Zhuzhou. The relative speed had a great influence on the severity of truck collisions. Wang et al. (11) believed different driving tendencies would change the rear-end accident probabilities in the signalized intersections. Sun et al. (12) surveyed the spatiotemporal characteristics of traffic accidents in tunnel sections. About 58% crashes occurred in the entrance and exit zones, and the rear-end accidents were the most common type of tunnel crashes.

Relatively few road traffic safety studies were conducted at the national level in China. Wang et al. (13) described the changes of road traffic accidents and economic losses over time from 1996 to 2015. Yu et al. (14) analyzed the road traffic injuries in the eastern, central and western regions based on the data from 2012 to 2017. There were significant differences among the three regions, and there was a significant positive correlation between the gross domestic product (GDP) and road traffic injuries.

Although the road traffic safety in China have been analyzed from the perspective of time trend and spatial differences in the previous studies, further work is still needed to include the latest data and consider more about spatiotemporal interaction. Based on regional data in China from 2011 to 2020, this paper aimed at finding out the spatiotemporal characteristics of road traffic safety in China and analyzing the role of the economic development in the road traffic safety.

Methods

Data source and description

Temporal, spatial, road traffic accidents and economic information were drawn from the China Statistical Yearbook spanning from 2011 to 2022, published by the National Bureau of Statistics of China. China Statistical Yearbook divided 31 provinces into seven regions according to geographical location, natural conditions and social factors. Each region contained 3~7 provincial administrative regions, which was shown in Table 1. Data of Taiwan, Hong Kong and Macau were not available and were excluded from the study.

Table 1: Regions and contained provinces

Number	*Region*	*Provinces*	*Abbreviations of the provinces*
R1	North China	Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia	BJ, TJ, HB, SX, IM
R2	Northeast China	Liaoning, Jilin, Heilongjiang	LN, JL, HLJ
R3	East China	Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong	SH, JS, ZJ, AH, FJ, JX, SD
R4	Central China	Henan, Hubei, Hunan	HN, HHB, HHN
R5	South China	Guangdong, Guangxi, Hainan	GD, GX, HHHN
R6	Southwest China	Chongqing, Sichuan, Guizhou, Yunnan, Tibet	CQ, SC, GZ, YN, TI
R7	Northwest China	Shaanxi, Gansu, Ningxia, Qinghai, Xinjiang	SSX, GS, NX, QH, XJ

The information extracted from the China Statistical Yearbook was sorted into 310 records by year and province. The specific content in the records included:

1) **Temporal and spatial information:** Temporal information referred to the year. And spatial information mainly included provinces and corresponding regions.
2) **Road traffic accidents information:** The road traffic accidents information includes the number of traffic accidents, death toll, and the number of injured people. And to ensure comparability of the data, the vehicle population is taken into account.
3) **Economic information:** This paper considers both GDP and GDP per capita as crucial factors. GDP is defined as the result of the production activities of all permanent residents of a country (or region) within a specific period. GDP per capita is the quotient of total GDP and the population. Both are essential indicators for measuring the economic situation of a country or region.

Statistical analysis

Principal component analysis (PCA) is a linear dimensionality reduction method, which use the original data to generate a new set of independent comprehensive indicators while minimizing the loss of information (15). In this paper, PCA was used to establish a comprehensive indicator of the road traffic safety based on the number of traffic accidents, death toll and number of injured people.

Pearson correlation analysis and Eta coefficient test were performed to examine the relationships between time and road traffic safety, as well as between space and road traffic safety.

Mixed liner model (MLM) is a method developed based on the traditional linear model (LM) for non-independent data, which contains both fixed effects and random effects. Three MLM models were considered in this paper to analyze the impact of year and region on the comprehensive indicator established by PCA.

Single-element regression model was built to study the impact of GDP per capita on road traffic safety. All the statistical analyses were done by SPSS 20.0. (IBM Corp., Armonk, NY, USA).

Results

Construction of the road traffic safety indicator

The data collected in this paper were the number of traffic accidents, death toll and number of injured people. Pearson correlation analysis based on data from 2011 to 2020 showed that the correlation between the number of traffic accidents and the death toll was r_1=0.896 (*P*<0.01); the correlation between the number of traffic accidents and the number of injured people was r_2=0.986 (*P*<0.01); the correlation between the death toll and the number of injured people was r_3=0.845 (*P*<0.01). They reflected the road traffic safety from different angles while they were correlated significantly. The number of traffic accidents, death toll and number of injured people were standardized and processed by the PCA to obtain a comprehensive indicator. The indicator contained most information of the original data, and solved the problem of data collinearity at the same time.

SPSS software was used for PCA analysis. Only one principal component with eigenvalue greater than one was generated; the component score coefficients were 0.352, 0.334 and 0.346 respectively; the variance contribution rate of principal component was 93.993%.

The comprehensive indicator was established based on the results of the PCA analysis, and the final indicator of the road traffic safety is shown in Equation [1]:

$$RTS=1/\left(\frac{0.352X_1+0.334X_2+0.346X_3}{V}\times 100+10\right)$$

[1]

Where RTS is a comprehensive indicator representing the level of road traffic safety; X_1, X_2, X_3 indicates the standardized values of the number of traffic accidents, death toll and number of injured people respectively; V denotes the vehicle ownership, in 10000.

The frequency distribution of provincial indicator of RTS from 2011 to 2020 in China is shown in Fig. 1. The distribution range of the RTS was wide. The minimum value of the indicator was 0.0974 appearing in Hubei in 2020 and the maximum value of the indicator was 0.2029 appearing in Tibet 2011. Nevertheless, the distribution also showed a certain degree of aggregation. According to statistics, about 80% of the data was in the range of 0.097 ~ 0.103.

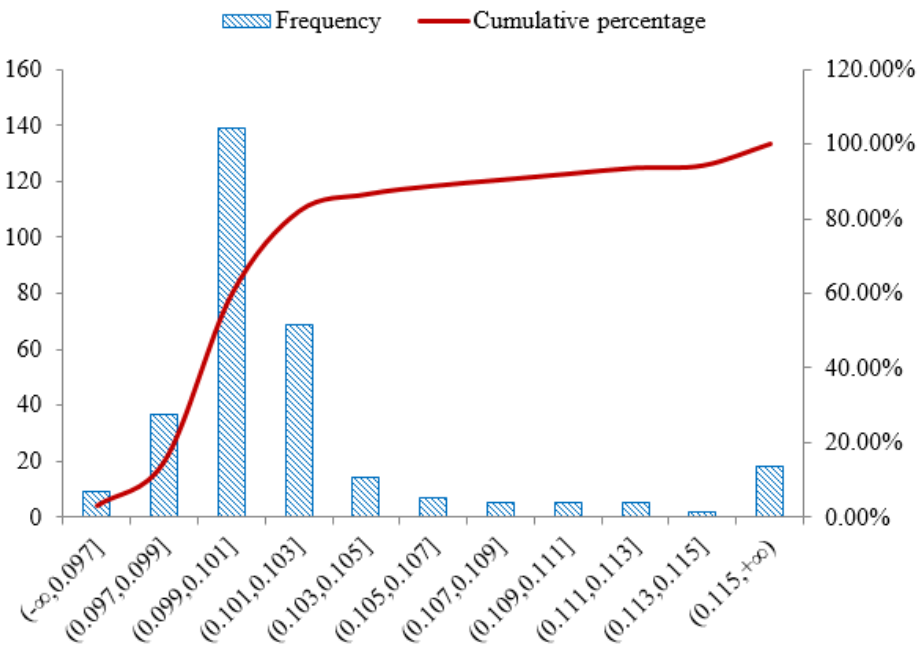

Fig. 1: Frequency distribution histogram of the provincial RTS in China from 2011 to 2020

Influence of time and space on RTS

Influence of time on RTS

The changes of China's provincial RTS from 2011 to 2020 are shown in Table 2. The year was taken as a continuous variable to analyze its impact on the RTS. Pearson correlation analysis showed that the correlation coefficient between the year and RTS was r = -0.136 (P<0.05). The RTS was weakly correlated with year in China.

Table 2: Descriptive statistics of the provincial RTS in China from 2011 to 2020

Year	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Mean	0.106	0.105	0.104	0.104	0.103	0.103	0.102	0.102	0.102
SD	0.019	0.015	0.012	0.011	0.009	0.008	0.007	0.006	0.005

Influence of space on RTS

The descriptive statistics of the RTS in different provinces and regions are shown in Table 3. Regions were taken as a classification variable to analyze its impact on the RTS. Eta coefficient test showed that ETA (310) =0.364, ETA^2=0.132, indicating that there was a significant correlation between regions and the RTS, and 13% of RTS could be predicted by regions.

Table 3: Descriptive statistics of the provincial RTS in provinces and regions

Region			***R1***					***R2***	
Province	BJ	TJ	HB	SX	IM	Total	LN	JL	HLJ
Mean	0.101	0.102	0.100	0.100	0.102	0.1010	0.100	0.102	0.102
SD	0.000	0.001	0.000	0.000	0.000	0.0009	0.000	0.001	0.001
	R3								
Total	SH	JS	ZJ	AH	FJ	JX	SD	Total	HN
0.101	0.103	0.099	0.099	0.098	0.099	0.101	0.099	0.100	0.010
0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.002	0.001
R4			R5					R6	
HHB	HHN	Total	GD	GX	HHHN	Total	CQ	SC	GZ
0.010	0.010	0.100	0.098	0.100	0.112	0.103	0.101	0.099	0.101
0.002	0.001	0.001	0.001	0.002	0.006	0.007	0.000	0.001	0.004
			R7						China
YN	TI	Total	SSX	GS	NX	QH	XJ	Total	
0.100	0.151	0.111	0.101	0.103	0.115	0.110	0.101	0.106	0.103
0.001	0.026	0.023	0.000	0.001	0.007	0.004	0.000	0.007	0.011

MLM considering temporal and spatial effects

Repeated measurement data from 2011 to 2020 was analyzed in this paper. Obviously, they were not independent. Therefore, MLM was employed, with the dependent variable being RTS, and the independent variables being region and year. In establishing the models, the region was set as a factor, the year was set as a covariate with its repetition effect considered, and the repetition covariance type was set as "compound symmetry".

Three models were built and compared. In Model I, the main effects of region and year were considered. The model is shown in Equation [2]:

$$RTS_{ijk} = (\mu_0 + \mu_{0j}) + region_i + year + \varepsilon_{ijk} \quad [2]$$

Where μ_0 represents the mean RTS value of 31 provinces; μ_{0j} refers to the RTS differences among the provinces; $region_i$ and $year$ denotes the main effect of the region and the year; ε_{ijk} is the residual error.

In Model II, the interaction between the region and the year was considered. The model is shown in Equation [3]:

$$RTS_{ijk} = (\mu_0 + \mu_{0j}) + region_i * year + \varepsilon_{ijk} \quad [3]$$

Where $region_i * year$ denotes the interaction between the region and the year.

In Model III, the main effects and interaction effect were comprehensively considered. The model is shown in Equation [4]:

$$RTS_{ijk} = (\mu_0 + \mu_{0j}) + region_i + year + region_i * year + \varepsilon_{ijk} \quad [4]$$

SPSS 20.0 software was utilized to fit the model, and the results are shown in Table 4.

Seen from Table 4, the fixed effect of the year in Model I was not statistically significant (P=0.581) and was excluded. Model II and Model III were further compared. The Akaike information criterion (AIC) of Model III was smaller than that of model II, indicating that the goodness-of-fitting of Model III was higher. Therefore, Model III was selected as the final model. The fixed effect estimation in Model III is shown in Table 5.

Table 4: Fitting results of the models

Model			*F value*	*Significance*	*AIC*
I	Fixed effect	Intercept	33.909	$P<0.001$	-2237.309
		Year	0.798	$P=0.581$	
		Region	27.975	$P<0.001$	
	Repeated effect	Year			
II	Fixed effect	Intercept	33.885	$P<0.001$	-2145.736
		Region×Year	4.636	$P=0.002$	
	Repeated effect	Year			
III	Fixed effect	Intercept	36.829	$P<0.001$	-2202.737
		Year	9.495	$P<0.001$	
		Region	30.402	$P<0.001$	
		Region×Year	9.442	$P<0.001$	
	Repeated effect	Year			

Table 5: Fixed effect estimation in Model III

Variables		*Estimation*	*Standard error*	*t value*	*P-value*
Intercept		1.553	0.440	3.529	0.001**
Year		-0.001	0.000	-3.288	0.001**
Region	R1	-1.259	0.623	-2.023	0.044*
	R2	-1.108	0.719	-1.541	0.125
	R3	-1.639	0.576	-2.844	0.005**
	R4	-1.193	0.719	-1.660	0.098
	R5	-0.082	0.719	-0.114	0.909
	R6	2.294	0.623	3.685	0.001**
	R7 (reference)				
Region*year	R1*year	0.001	0.000	2.015	0.045*
	R2*year	0.001	0.000	1.534	0.126
	R3*year	0.001	0.000	2.834	0.005**
	R4*year	0.001	0.000	1.651	0.100
	R5*year	0.000	0.000	0.111	0.912
	R6*year	-0.001	0.000	-3.678	0.001**
	R7*year (reference)				

In Table 5, ** and * represent the significant level is $\alpha=0.01$or $\alpha=0.05$, respectively

Fixed effect estimation in Model III showed that the main effect and the interaction effect of the year and the region had influence on the RTS in China.

In terms of the main effect, the year had a negative impact on road traffic safety (RTS), although the coefficient was small, indicating a weak downward trend in China's RTS in recent years. Regarding the region, RTS in north China and east China was lower compared to northwest China, while in southwest China, it was higher.

For the interaction effect, north China*year and east China*year had a positive impact on RTS, while southwest*year had a negative effect compared to northwest China*year.

According to the fitting results of MLM, the variation of RTS in different regions and in different years were drawn (Fig. 2). From the perspective of the RTS value, the RTS in R6 (southwest China) area was the highest while the RTS of R1 (north China), R2 (northeast China), R3 (east China) and R4 (central China) were poor and the performance was relatively similar. And the RTS of R5 (south China) and R7 (northwest China) areas were in the middle.

From the perspective of the change trend over time, the RTS in R1 (north China), R2 (northeast China), R3 (east China) and R4 (central China) were relatively stable in recent years. R6 (southwest China) had the largest dispersion, indicating that the RTS in southwest China changed dramatically from 2011 to 2020. In addition, the dispersion in R5 (south China) and R7 (northwest China) regions were between the two, indicating that the RTS in south China and northwest China deteriorated to some extent.

From the perspective of change results, RTS in different regions were closer and closer. And by 2020, the regional RTS differences were very small.

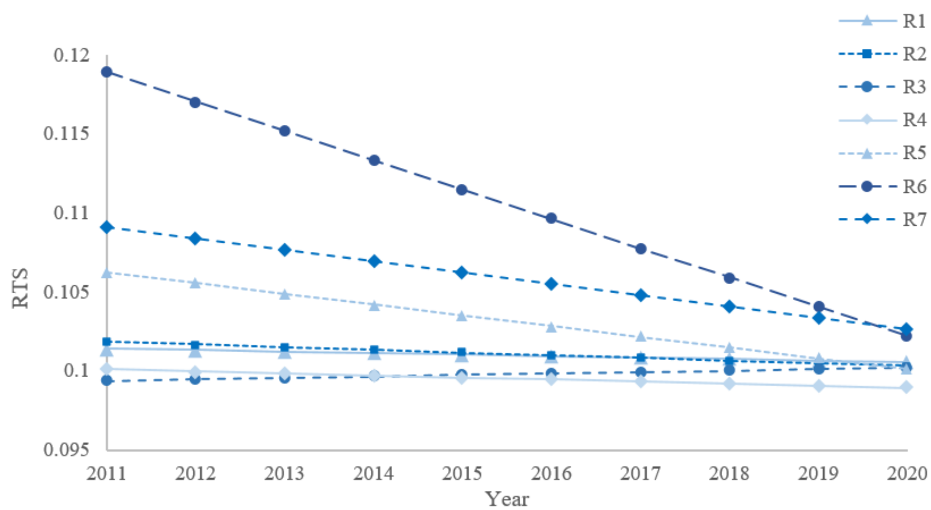

Fig. 2: RTS changes over time in different regions

Relationship between economy and RTS

The impact of economic development on RTS was complex. In order to further study the relationship between the two, three single-element regression models were established with GDP per capita as independent variable and RTS fitting value of MLM as dependent variable. The results were shown in Table 6.

Table 6: The information of single-element regression models

Model		*R^2*	*Adjusted R^2*	*RMSE*
Quadratic regression	$y=6\times10^{-12}x^2-8.666\times10^{-7}x+0.1305$	0.602	0.590	0.003
Logarithmic regression	$y=-0.01\ln(x)+0.2084$	0.490	0.483	0.003
Linear regression	$y=-1.582\times10^{-7}x+0.111$	0.373	0.364	0.003

Comparing the three models, it could be found that under the same RMSE, the R-square and the adjusted R-square of the quadratic regression were higher. Therefore, the fitting effect of quadratic regression was better. The three models were shown in Fig. 3.

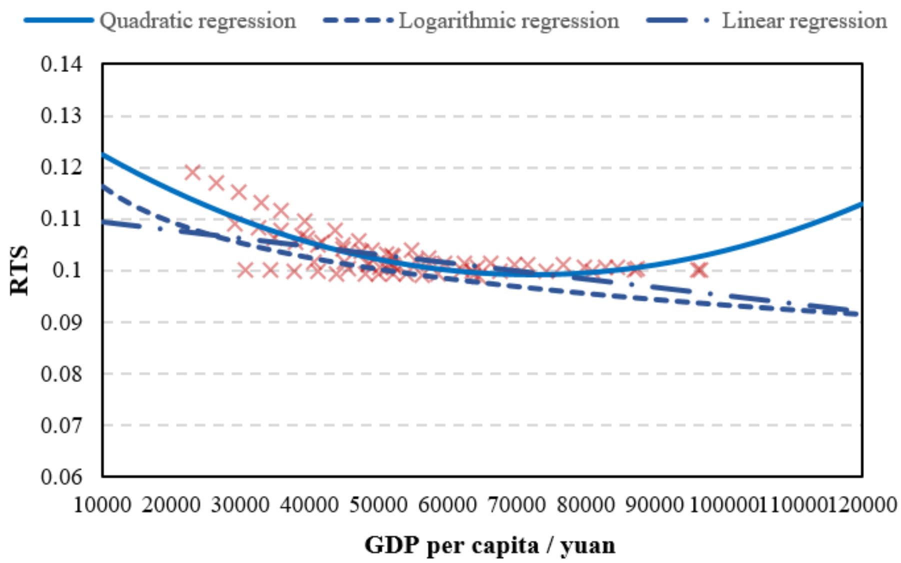

Fig.3: Relationship between GDP per capita and RTS

According to the quadratic regression model, when the per capita GDP was low, its growth would lead to a decline of RTS. However, when the GDP increased to a certain extent, its growth would promote the rise of RTS. The changes of the two trends occurred when the per capita GDP reached about 72000 yuan in China.

The model could explain the temporal and spatial differences of RTS in China to a certain extent. The growth of per capita GDP in most regions of China was limited to less than 72000 yuan. Therefore, RTS in most areas decreased with the increase of per capita GDP in recent years. RTS in East China alone showed a slow upward trend. Its per capita GDP increased from 50000 yuan to 96000 Yuan from 2011 to 2020, which might explain this phenomenon. In addition, the differences among regions usually showed that the higher the per capita GDP was, the poorer the RTS was.

Through the above analysis, it could be seen that the model was consistent with the actual situation in China.

Discussion

Economic development restricts the improvement of road traffic safety, which is a dilemma faced by all developing countries. As the largest developing country in the world, China is a good reference sample to study road traffic safety. Fig. 4 showed the growth rate of traffic accidents and casualties in China from 2011 to 2020. From 2011 to 2015, the growth rates of traffic accidents and casualties were negative. At this stage, China's road traffic accident control measures had played a significant positive role, and the level of road traffic safety had been significantly improved. In 2016, the number of traffic accidents and casualties ended the downward trend, and the three growth rates reached 13.3%, 8.7% and 13.3% respectively. In 2018, the number of traffic accidents and injuries in China rose sharply again, with growth rates of 20.6% and 23.3%. The road traffic safety management in China had encountered a bottleneck since 2016, and the road traffic safety problems should be paid attention to.

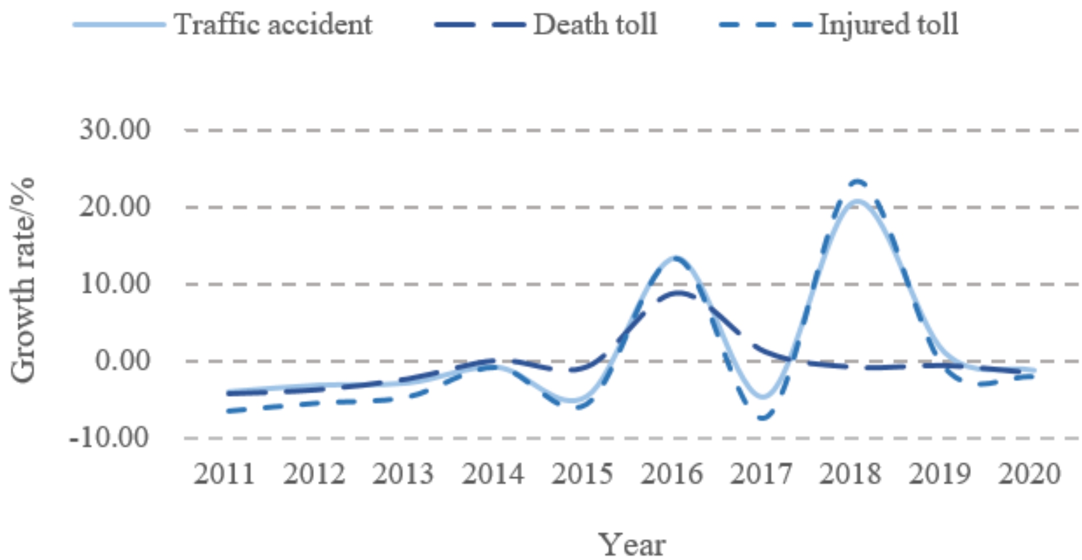

Fig. 4: Annual change of growth rate of traffic accidents and casualties in China from 2011 to 2020

The economic development in China changed over time and varied between regions, making road traffic safety characteristics diverse. From 2011 to 2020, GDP continued to rise steadily. Economic development had both positive and negative effects on the road traffic safety in China.

On one hand, economic development provided material conditions for the improvement of infrastructure, medical facilities and education, thus promoting road traffic safety to a certain extent.

1) Infrastructure improvement could effectively reduce road traffic accidents. For example, the application of interval speed measuring devices and electronic cameras could urge the drivers to improve their alertness, consciously abide by traffic regulations. So bad driving behaviors such as speeding could be curbed.
2) Better medical and health conditions could improve the rescue efficiency and avoid unnecessary traffic accident deaths (16).
3) More extensive publicity and education by mass media meant the improvement of people's consciousness of traffic safety, which can reduce violations of traffic rules.

However, economic development had also led to a series of new situations, which were negative to road traffic safety.

1) The tendency of urbanization in China led to a high degree of population aggregation in some regions. In addition, the increase of population density increased the probability of traffic accidents.
2) The improvement of people's income level had significantly increased the private cars ownership and the traffic flow density. In addition, some private cars were only limited to commuting, so the experience and skills of the drivers were insufficient to respond to possible emergencies on the road.
3) In the process of economic development, the regional division of labor was deepening day by day. The flow of raw materials and products made the traffic flow density increase. In addition, problems such as overtime driving and overloading were common in the transportation of operating vehicles, which had become a danger that could not be ignored to road traffic safety.

The quadratic regression model in Table 6 and Fig. 3 revealed the relationship between the economy and RTS in China. When the per capita GDP was less than a certain value, the negative impact of economic development on RTS was greater than the positive impact. And when the per capita GDP exceeded the certain value, the positive impact became dominant.

Regional data was used in this paper and the regional division in this paper was mainly based on geographical location. Each region was large enough and the climate and social factors in the same region were similar. However, economic development and traffic safety situation varied greatly in different regions. Similarities in the same regions and large differences among different regions allowed each region to be analyzed as a unit. The economic development of different regions in China was uneven, and the level of road traffic safety varied greatly. Based on regional data, this paper considered more abundant economic characteristics and traffic safety characteristics, which could represent the changes of traffic safety under different economic levels in developing countries to a certain extent. Thus, the generalizability of the research results was ensured. Developing countries could learn from the experience to estimate their own road traffic safety according to the economy, take targeted measures to reduce the negative impact and strengthen the positive impact of economic development. It would be helpful to solve the problems of road traffic safety in developing countries.

Conclusion

Road traffic safety situation was still grim in developing countries. Taking China as an example, road traffic safety showed obvious differences in time dimension and space dimension, and the road traffic safety in most areas tended to deteriorate in recent years. This phenomenon could be explained by the relatively low GDP per capita, the increase of GDP over time and the imbalance of regional economic development. They were also typical features of developing countries. Based the relationship between GDP per capita and RTS in China, the RTS change rule in developing countries is decrease first and then increase with the increase of GDP per capita. Government in developing countries should correctly handle the relationship between economic development and traffic safety and pay attention to the improvement of road traffic safety.

There were still some limitations in this study. When discussing the time change and spatial difference of traffic safety level, this paper focused on the impact of economic development. Because economic development can determine the vehicle ownership as well as the quantity and quality of infrastructure construction. In fact, some other factors, such as climate conditions, population density and population structure, may also affect road traffic safety to some extent. For example, too much rain and snow in a region will make the road surface slippery, which will threaten traffic safety. These factors will be further discussed in future research.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interest.

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