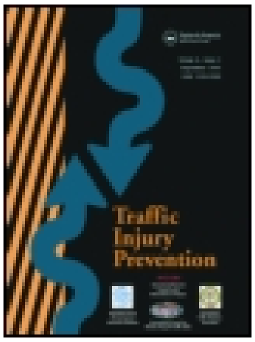

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Estimate of safety impact of lane keeping assistant system on fatalities and injuries reduction for China: Scenarios through 2030

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ABSTRACT

Objective: The objective of this research is to assess the number of casualties in China's road traffic accidents that can be reduced by lane keeping assistant (LKA) through 2030, based on the historical data on the number of fatalities and injuries in China and the proportion of LKA planed in China policy.

Methods: The analysis was divided into 4 main parts: (1) Predict injuries and fatalities caused by traffic accident in China without LKA through 2030; (2) Apply the methodology to estimate the percentage reduction in injuries and fatalities assuming 100% penetration rate of LKA; (3) Predict the penetration rate of intelligent vehicles with LKA system through 2030 under Chinese government policy planning; (4) Calculate the specific number for the reduction in injuries and fatalities with LKA through 2030.

Results: According to the historical accident data, the fatalities caused by traffic accidents without LKA are predicted to be 55,686 in 2020, 51,420 in 2025, and 47,484 in 2030, while the injuries are 188,285, 164,135, and 143,163. The percentage reduction with 100% penetration rate was calculated to be 14.8% for fatalities and 10.1% for injuries. Based on the China policy, the market penetration rate of intelligent vehicle with LKA was predicted to be 44.2% in 2025 and 77.7% in 2030. With the great increase of market penetration rate, the maximum reduction in injuries and fatalities from 2018 to 2030 was calculated. Compared to the previsions without LKA, 3370 fatalities and 7359 injuries will be reduced in 2025, while the specific number is 5465 fatalities and 11,270 injuries in 2030. Considering the three main limitations of LKA, the adjusted result would become approximately 1/9 of the original ideal result to be 375 fatalities and 818 injuries in 2025, while the specific number is 608 fatalities and 1253 injuries in 2030.

Conclusions: The safety impact of LKA system on traffic crash fatalities and injuries reduction in China has been estimated. The results indicate that LKA system has considerable potential benefit in China. Interaction design with the driver, setting of the minimum travel speed and adaptability of the harsh conditions of the camera are the breakthrough points for maximizing safety benefits. The safety system of the intelligent vehicle has different benefits in different countries.

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Safety impact; lane keeping assistant; intelligent vehicle; crash avoidance; fatalities reduction; injuries reduction

Introduction

The road traffic safety situation around the world is not optimistic. Over 3700 people die on the world's roads every day and tens of millions of people are injured or disabled every year. And the number of annual road traffic deaths on the world's roads has reached 1.35 million (WHO 2018). Annually about 63,000 people are killed and 226,000 people are injured in road traffic accidents in China (The Ministry of Public Security of the People's Republic of China 2017).

The development of intelligent vehicles has become an ideal way to reduce road traffic accidents (Kuang et al. 2018a, 2018b, 2019). According to the "Made in China 2025" strategy published by the Chinese government, the intelligent vehicle is defined as a new generation of vehicle equipped with advanced sensors, controllers and actuators, in combination with modern network communication technologies (China Daily 2015; Kuang et al. 2019). Considering the complexity of China's road traffic conditions, intelligent vehicles in China are divided into five levels: Driver Assistance (DA), Partial Driving Automation (PA), Conditional Driving Automation (CA), High Driving Automation (HA), and Full Driving Automation (FA). And typical systems for intelligent vehicle in China include Automatic Emergency Braking and lane keeping assistant (LKA) (Ministry of Industry and Information Technology 2017). This research focused on the safety impact of LKA,

The definition of LKA is that LKA system is equipped on the intelligent vehicle as an active safety system to prevent unintentional lane departures during high speed driving.

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The system is designed to assist the driver to return to the current driving lane by means of sound, dashboard display reminder, steering wheel vibration, and automatic steering force, based on the lane line information recognized by the camera.

Three limitations of LKA need to be mentioned. First, the driver may shut down the system due to the presence of an uncomfortable alarm. Vehicles from nine manufacturers such as Mazda and Mercedes-Benz fitted with lane keeping systems were observed at service departments during 2016. Systems were turned on in 51% of 983 vehicles (Reagan et al. 2018). Lane departure warning use across every ignition cycle over the course of a year among nearly 2000 owners of General Motors vehicles nationwide through the vehicles' OnStar systems, and found that the systems were turned on for about 50% of driving time (Flannagan et al. 2016). It is observed in another research that lane departure warning was activated on 40% of Honda (Reagan and McCartt 2016). Second, it does not work if the speed is lower than the minimum active speed set by the manufacturer. The minimum active speed is usually 60 or 65 km/h (37 or 40 miles/h). Third, if the lane markings are not recognized well by the camera because of the bad weather or darkness, it will also affect the effectiveness. Field tests of a prototype indicated that only 36% of the time worked well when road lane marking is not clear (Wilson et al. 2007). Gordon found that system can play 90% of the capacity during the daytime but only 20% during nighttime because of the light condition (Gordon et al. 2010). But, in order to assess the biggest potential benefit of LKA applications in China, the research makes assumptions that the LKA system is always turned on, LKA works well in all speed ranges and all weather conditions. And then, the influences of these three limitations are discussed clearly at the end of the article. This will help illustrate the benefits of breaking through their limitations. Such discussion mode can better help the government to formulate policies and enterprise managers to formulate technical plans.

LKA system is considered to be an effective technique for avoiding lane-changing crash. Several researchers have reported the number of single-vehicle, head-on, and sideswipe collisions that can be prevented by LKA. Based on the vehicle records in the USA 2004–2008 NASS GES and FARS files, Jermakian estimated that the system would be relevant to a 6% of single-vehicle, 27% of head-on, and 27% of sideswipe crashes (Jermakian 2011). Based on the Police-reported data for crashes from 25 states of United States, Cicchino reported a reduction in police-reported single-vehicle, sideswipe, and head-on crashes in vehicles equipped with lane departure warning (Cicchino 2018). A Swedish study found that lane departure warning reduced single-vehicle and head-on injury crashes under certain conditions among of Volvo vehicles (Sternlund et al. 2017). Based on the crash data of E.U., it is reported by Wilmink that LKA system has the potential to reduce 70% injuries and fatalities caused by the collision besides the road with pedestrian or obstacle or other single vehicle, 7% of head-on collision and 20% of sideswipe collision (Wilmink et al. 2008).

The LKA system of intelligent vehicles has different benefits in different countries and regions. Crashes due to lane departures are among the deadliest collision types. The eIMPACT project assessed the socio-economic effects of Intelligent Vehicle Safety Systems (IVSS) and their impact on traffic, safety and efficiency (Kulmala 2010). The high estimate would be 8596 injuries that can be avoided by LKA in European Union in 2020 (Wilmink et al. 2008). Passenger vehicle crashes due to unintentional lane departure killed 13,000 people in the United States in 2015 (Cicchino 2018). Of all crashes with passenger car occupant fatalities in Sweden in 2010, 46% of them related to lane departure without prior loss of control could be avoided (Sternlund et al. 2017). But in China, that number is bound to be very different.

The safety benefits are closely related to market penetration rate of the safety system. Penmetsa estimated that in 2020, 2.7% of single-vehicle lane departure crashes could be avoided in the state of Alabama if 8.5% of the fleet has LDP with 20% effectiveness (Penmetsa et al. 2019). In European Union, 0.4% fatalities and 1% injuries could be reduced if the penetration rate is 10% (Wilmink et al. 2008). China has introduced policies to promote typical active safety technologies equipped on the intelligent vehicle such as LKA, ACC, and so on. "Medium and Long Term Development Plan of Automobile Industry" published by the Chinese government plan that the penetration rate of new intelligent vehicles in 2020 is 50%. In 2025, the penetration rate of new intelligent vehicles is 80%. Until 2030, all new cars are intelligent vehicles (Ministry of Industry and Information Technology 2017).

This article aims to evaluate the safety impacts of LKA system in China. To predict the specific number of injuries and fatalities that can be avoided by LKA system annually, it is necessary to consider the trend of Chinese automobile market, Chinese automobile industrial policy, and Chinese historical data of road traffic accidents.

This article is organized as follows. The next section describes the research method and data. Following that, injuries and fatalities without LKA in China through 2030 and the injuries and fatalities that could be avoided by LKA each year was predicted. The final section provides the conclusive remarks.

Methods

The evaluation method used in this study was that injuries and fatalities without LKA through 2030 multiplied by percentage of injuries and fatalities reduction with LKA through 2030 to get specific figures for the reduction in injuries and fatalities with LKA through 2030, as shown in Figure 1.

Injuries and fatalities without LKA through 2030

The frequency of road traffic crashes follow a random distribution associated with driving behavior, vehicle conditions, and environmental factors such as road conditions and weather. To predict accurately death toll caused by road traffic

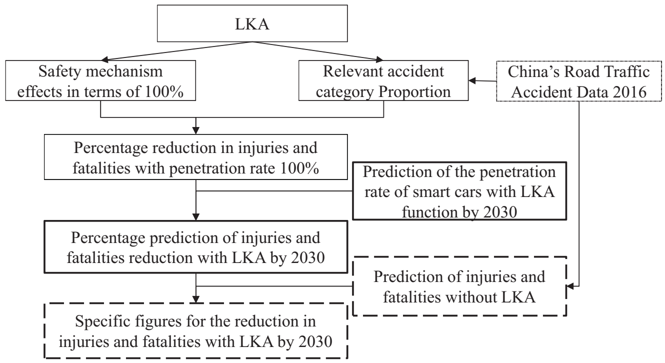

Figure 1. Evaluation method used in this study.

accidents, Grey–Markov model was set up. Prediction of injuries and fatalities caused by accident was carried out.

The Grey–Markov model is a relatively mature model. It can visually show its trend relationship with time. The Grey–Markov prediction model is divided into two main parts. The first part is the establishment of the Grey model (Zhang 2016), and the second part is to use the Markov theory to correct the Grey model prediction results to improve the prediction accuracy (Wang 2017). The Markov chain is a stochastic process in which both time and state are discrete. The basic mechanism is to describe the change of a dynamic stochastic process as a transition between several different states. Use state transition probability matrices to describe state transitions to predict the next state (Li et al. 2009).

The injuries and fatalities in China caused by road traffic accidents during 2019–2030 was predicted based on the situation of in 2008–2016. The data for 2017 and 2018 are not yet available through open channels. It should be mentioned that the injuries in this study refer to severe injuries, because detailed data on severe injuries can be found. The injuries and fatalities during 2008 to 2016 were shown in Table 1 (The Ministry of Public Security of the People's Republic of China 2017).

Percentage prediction of injuries and fatalities reduction with LKA through 2030

The evaluation method used in this part was the percentage reduction in injuries and fatalities with penetration rate 100% multiplied by penetration rate of intelligent vehicles with LKA system through 2030 to get percentage of injuries and fatalities reduction with LKA through 2030

Prediction of the percentage reduction in injuries and fatalities with penetration rate 100%

Thulin indicated that the traffic safety has three primary dimensions of exposure, risk and consequence (Thulin et al. 1994). Here, exposure is measuring the magnitude of being exposed to accidents, usually expressed in person, ton or vehicle kilometers or hours traveled. Risk means the ratio of the number of accidents to exposure. Consequence means the ratio of the number of injured people to the number of accidents. The definition for fatalities is similar. These three dimensions have a multiplicative relationship with regard to safety (Nilsson et al. 2004). On the basic of the 10-point list proposed by Draskóczy et al. (1998), a framework for safety assessment of active safety technology cover three primary dimensions was proposed by Kulmala. The list proposed by Draskóczy was at the time of its development mainly used to either illustrate all the possible ways in which ITS can affect safety (Draskóczy et al. 1998). For the purpose of an assessment framework, the mechanisms was somewhat adapted by Kulmala (2010). The framework for safety assessment of intelligent systems that cover these dimensions is the nine-point list of safety mechanisms.

- Mechanism 1: Direct in-vehicle modification of the driving task
- Mechanism 2: Direct influence by roadside systems
- Mechanism 3: Indirect modification of user behavior
- Mechanism 4: Indirect modification of non-user behavior
- Mechanism 5: Modification of interaction between road users.
- Mechanism 6: Modification of exposure.
- Mechanism 7: Modification of modal choice.
- Mechanism 8: Modification of route choice.
- Mechanism 9: Modification of accident consequences only

In many cases, the LKA system keeps the car in a state of minimal lane change (Sternlund 2017). The relevant safety mechanisms of LKA system are described as mechanism 1, mechanism 3, and mechanism 6 by Wilmink et al. (2008). It is reported by Wilmink that for mechanism 3, drivers will become careless and less alert because they may rely on ancillary functions, which would increase 3% of the fatality risk and 1.5% of injury risk. For mechanism 6, due to the existence of LKA, the driver will often go out in a relatively poor driving situation, which will increase 1% of the certain fatality exposure and 0.8% injury exposure. And, for mechanism 1, relevant accidents will be avoided. LKA system has the potential to reduce 70% injuries and fatalities caused by the single vehicle collision besides the road with pedestrian or obstacle or other single vehicle, 7% of head-on collision, and 20% of sideswipe collision (Wilmink et al. 2008). But the specific value of the benefit brought by mechanism 1 needs to be combined with the corresponding proportion of the causes of road traffic accidents in China.

The proportion of different types of road traffic accidents is a key variable to evaluate the safety benefits of LKA in China. It is generally acknowledged that the benefits of the active safety function of intelligent vehicles vary from country to country. The basic data was used from the "Annual Report on Road Traffic Accidents of China (2016)," published by the Chinese Government. According to the accident data, all collisions are divided into three categories, single vehicle collision, two vehicle collision, and other collision. Among them, the single vehicle collision is divided into collision on the road with pedestrian, collision on the road with obstacles, and collision besides the road with pedestrian or obstacle or other single vehicle. Two vehicle

Table 1. The injuries and fatalities during 2008 to 2016 in China.

Years	2008	2009	2010	2011	2012	2013	2014	2015	2016
Injury	304,919	275,125	254,075	237,421	224,327	213,724	211,882	199,880	226,430
Fatality	73,484	67,759	65,225	62,387	59,997	58,539	58,523	58,022	63,093

collision is divided into head-on collision, rear-end collision, sideswipe collision, single collision, and other collision with two vehicles. The definition of the head-on collision is that collision between two moving/waiting vehicles traveling in opposite directions. The definition of the rear-end collision is that collision between two moving/waiting vehicles, traveling in the same direction, one in front of the other. The definition of the sideswipe collision is that collision between two moving/waiting vehicles traveling in the same or opposite direction, side-by-side. The definition of the angle collision is that collision between two moving/waiting vehicles traveling in different directions, but not opposite, usually such as collisions at intersections. The proportion and the number of injuries and fatalities of each type was counted, as shown in the Appendix A (see supplementary information).

The effect coefficient of mechanism 1 is calculated through Eq. (1).

$$\mathrm{EC}_{m1} = sum(EC_{m1,vi} * PA_{vi}) \tag{1}$$

Where EC_{m1} is the is the percentage of road traffic injuries and fatalities reduced by the result of mechanism 1; $\mathrm{EC}_{m1,vi}$ is the percentage of injuries and fatalities of type i that can be reduced by the result of mechanism 1; PA_{vi} is the proportion of accidents of type i in China.

The percentage reduction in injuries and fatalities with penetration rate 100% is calculated through Eq. (2) (Wilmink et al. 2008).

$$\mathrm{EC} = (1 + EC_{m1}) * (1 + EC_{m3}) * (1 + EC_{m6}) - 1 \tag{2}$$

Where EC is the percentage reduction in injuries and fatalities with 100% LKA penetration rate; EC_{mi} is the percentage of road traffic injuries and fatalities reduced by the effect of mechanism i.

Prediction of the penetration rate of intelligent vehicles with LKA function through 2030

The market penetration rate per year is directly determined by the number of all vehicles and the vehicles with LKA. With the development of China's economy, the Chinese auto market will also grow rapidly in the long run. The number of vehicles sold and registered in China from 2005 to 2017 was announced by the Ministry of Public Security of China.

It is predicted by Xu that the average annual demand of China's auto market will reach 40 million vehicles around 2030 (Xu 2018). It is assumed in this research that the average annual growth rate is 1.7% from 2018 to 2020, 3.3% from 2020 to 2025, and 2.7% from 2025 to 2030. As a result, vehicle sales in each year from 2018 to 2030 can be calculated. According to national policy planning, 50% of new vehicles are intelligent vehicles in 2020, 80% of new vehicles are intelligent vehicles in 2025, and all new vehicles are intelligent vehicles in 2030 (Ministry of industry and information technology of China 2017). Assume that all intelligent vehicles are equipped with the typical driving assistance systems such as LKA. From this, the number of new vehicles equipped with the LKA system in each year from 2018 to 2030 can be calculated.

It is estimated that China will have the largest vehicle ownership in the world in 10 years. As the average vehicle age increases, some of these vehicles need to be scrapped. The latest policy of the Chinese government stipulates that cars should be scrapped when it runs for 600,000 kilometers (372,823 miles) (Ministry of Commerce of China 2012). To estimate the amount of scrapped vehicles in each year, it is usually assumed that the service life of vehicles is between 8 and 10 years (Research and Markets 2018). The estimated number of scrap vehicles had exceeded 6 million by 2017 and will grow at an annual rate over 10% (Research and Markets 2018). To obtain a relatively conservative forecast, this study assumes that vehicles should be scrapped after 10 years of use. The number of LKA fitted-vehicles in the fleet in 2018–2030 can be calculated by Eq. (3).

$$\mathrm{PR}_y = \left(\sum_{i=y-10}^{y} \mathrm{Num}_{in,i}\right) / \left(\mathrm{Num}_{h,y-1} + \mathrm{Num}_{s,y} - \mathrm{Num}_{\mathrm{scrape},y}\right) \tag{3}$$

Where PR_y is penetreation rate of intelligent vehicle with LKA system in the y year; $\mathrm{Num}_{in,i}$ is the number of sales of intelligent vehicle with LKA in i year; $\mathrm{Num}_{h,y-1}$ is the number of all passenger cars in China in the $y-1$ year; $\mathrm{Num}_{s,y}$ is the sales of passenger car in the y year; $\mathrm{Num}_{\mathrm{scrape},y}$ is the number of scrapped passenger cars in the y year.

Specific figures for the reduction in injuries and fatalities with LKA through 2030

Based on all of above basic calculation, specific figures for the reduction in injuries and fatalities with LKA through 2030 could be calculated by Eq. (4).

$$\mathrm{SI}_y = EC * PR_y * CN_y \tag{4}$$

Where SI_y is the safety impact of LKA that the number of injuries and fatalities could be reduced in the y year; EC is the percentage reduction in injuries and fatalities with LKA's penetration rate is 100%; PR_y is penetration rate of intelligent vehicle with LKA system in the y year; CN_y is the predicted number of injuries and fatalities without LKA in the y year.

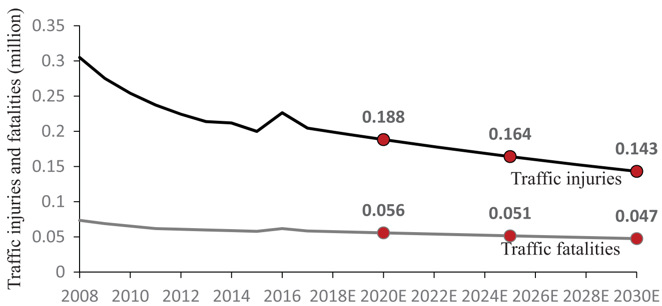

Figure 2. Traffic injuries and fatalities without LKA in China through 2030.

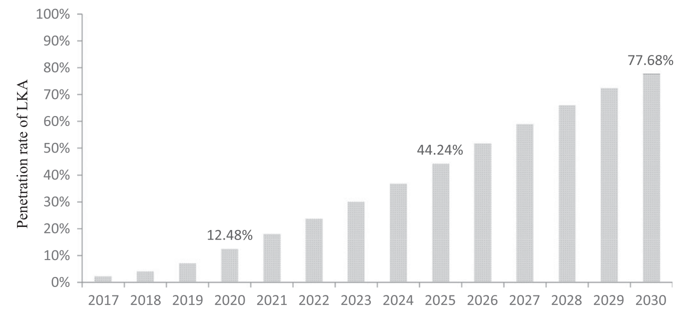

Figure 3. The market penetration rate of LKA system predicted through 2030.

Results

Injuries and fatalities without LKA in China through 2030

According to the data above and Grey–Markov model, the results of injuries and fatalities without LKA in China through 2030 are shown in Figure 2. The number of injuries and fatalities is generally decreasing. This means that although there is no promotion of intelligent vehicle assistant safety systems such as LKA, road traffic safety will increase for other reasons. Because historical data are decreasing. According to the prediction results of the Grey–Markov chain model, the fatalities caused by traffic accidents are 55,686 in 2020, 51,420 in 2025, and 47,484 in 2030, while the injuries are 188,285, 164,135, and 143,163. The maximum relative error of fatalities is -2.1% in 2013. The average relative error of fatalities from 2008 to 2016 is 1.0%. The maximum relative error of injuries is 2.7% in 2015. The average relative error of injuries from 2008 to 2016 is 1.3%. The predicted results without LKA system can be considered as a baseline in the safety impact assessment.

Percentage reduction in injuries and fatalities with penetration rate 100%

The percentage reduction in injuries and fatalities with penetration rate 100% means the upper limit of safety benefits. This upper limit is closely related to the proportion of various types of collision accidents in various countries. Based on the basic framework for safety assessment (Kulmala 2010) and proportion of various types of collision accidents in China, the effect coefficient of mechanism 1 were −18.1% for fatalities and −12.2% for injuries, which means because of the direct in-vehicle modification of the driving task, LKA systems could reduce the number of fatalities by 18.1% and the number of injuries by 12.2%. Except mechanism 1, mechanism 3, and mechanism 6 are also relevant mechanism. Consider these, the percentage reduction in injuries and fatalities with 100% penetration rate was calculated to be 14.8% for fatalities and 10.1% for injuries. The results pointed out the maximum safety benefits when all cars are equipped with LKA systems in China. In fact, the results were very different based on the same assessment framework using the EU's historical road traffic accident data as input. The effect of LKA on fatalities and injuries for full penetration was given as 15.2% reduction in fatalities and 8.9% reduction in injuries by the eIMPACT (Wilmink et al. 2008). The fundamental reason for this difference was the inconsistent composition of road traffic accidents between countries or regions. How much potential can be played every year depends on the LKA market penetration rate from 2018 to 2030.

Penetration rate of intelligent vehicles with LKA function through 2030

The market penetration rate of LKA system through 2030 is related to the national top-level strategy, policy and the development of automobile market. According to the model described above, penetration rate in each year was calculated as shown in Figure 3. Although, all new vehicles are required to be intelligent vehicle in 2030 by the Chinese policy, the market penetration rate of intelligent vehicle was predicted to be 77.7% in 2030 and 44.2% in 2025. Due to the huge number of vehicle ownership in China, it would take a certain amount of time for new intelligent vehicle with LKA to replace the traditional vehicle without LKA system. This can be seen as the lag of the market for car ownership relative to the policy planning of the new car market. If higher LKA market penetration rates are desired, policy planning needs to be designed to be more radical.

Specific number for the reduction in injuries and fatalities with LKA through 2030

The specific number for injuries and fatalities that could be reduced by LKA each year was determined by the predicted number of injuries and fatalities without LKA, the percentage reduction in full penetration and the penetration rate in each year. Based on the results above, the potential safety impact of LKA on the reduction in injuries and fatalities represented the biggest potential benefit of LKA was calculated, as shown by the dotted line in Figure 4. Obviously, LKA system can improve the safety of road traffic greatly in China. With the great increase of market penetration rate, the reduction in injuries and fatalities would increase year by year. According to the result, 5465 fatalities and 11,270 injuries will be reduced in 2030, while the specific number is 3370 fatalities and 7359 injuries in 2025. Although, all new vehicles sold are required to be intelligent vehicle in 2030 by the Chinese policy, the reduction would not reach the upper limit. This is because the actual market

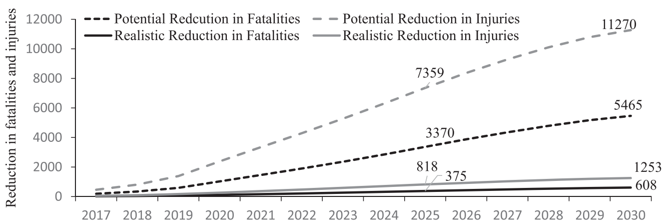

Figure 4. Number for the potential and realistic reduction in injuries and fatalities with LKA through 2030.

Table 2. The proportion of gear distribution in China collisions.

Transmission category	Gear	Collision distribution
Manual transmission	Neutral gear	19.04%
	1	1.61%
	2	3.46%
	3	6.96%
	4	5.39%
	>=5	7.46%
	Reverse gear	0.64%
	Unclear	33.68%
Automatic transmission	Automatic transmission	21.76%

penetration of LKA has not reached 100% in 2030. If the market penetration rate of LKA is full penetration in 2030, an additional 1570 deaths can be avoided. Promoted by China's current policy, the number of injuries and deaths that can be reduced through 2030 is already considerable. According to forecasts, fatalities that LKA can reduce in 2030 accounts for 8.7% of the total fatalities in 2016, while the injuries accounts for5.0%. There is no doubt that LKA plays an important role in improving road traffic safety.

Discussion

The above assessment is the biggest potential benefit of LKA applications in China. The research makes assumptions that the LKA system is always turned on and LKA works well in all speed ranges and all weather conditions. In fact, there are three main limitations of LKA affecting the actually safety benefits of LKA. First, the premise is that the driver needs to turn on the system. The driver may shut down the system due to the presence of an uncomfortable alarm. Based on these literatures mentioned in the introduction (Flannagan et al. 2016; Reagan and McCartt 2016; Reagan et al. 2018), it is assumed that 50% of drivers will turn on the LKA system.

Second, road lane line information could be recognized by the camera. There is an assumption that the percent of roads with proper markings in China is 100%. So, weather and lighting conditions are considered in this limitation. It is clearly stated that LKA equipped on the vehicle is not suitable for night time in some vehicle user manuals. But this study assumes that light conditions at night with street lights are equivalent light conditions at day time. So, it is considered to be a good light working condition during the day time and night time with street lighting. No lighting at night is considered invalid lighting conditions. In terms of weather, sunny and cloudy days are considered good working conditions, but severe weather such as snow, fog, rain and sand is considered an ineffective weather working condition. Based on the above definition, relevant data was found from the "Annual Report on Road Traffic Accidents of China (2016)." The proportion of all collisions distributed at day time or night time with street lighting is 84.3% in China, while distributed at night time without street lighting is 15.7%. The proportion of all collisions occurred on sunny and cloudy is 88.0% in China, while occurred on snow, fog, hail, rain, sand, and so on is 12.0%. Considering the weather and lighting conditions in China collision distribution, the proportion of that road lane line information could be recognized well by the camera is 74.2%, which was obtained by multiplication of the proportion of good weather and good lighting condition.

Third, the travel speed should be higher than the minimum active speed set by the manufacturer. Base on some LKA system equipped on the vehicles sold in China, it is assumed that the minimum active speed is 60 km/h (37 miles/h). According this hypothesis, data on collisions that travel speed over 60 km/h (37 miles/h) are sorted from "Annual Report on Road Traffic Accidents of China (2016)." There is one point need to explain that there is only the gear information of the collision vehicle in the original data, as shown in Table 2. It is assumed that the vehicle speed is higher than 60 km/h (37 miles/h) if the gear is at or above the fifth gear. So, the proportion of speeds higher than 60 km/h (37 miles/h) in all collisions can be calculated accurately as 30.0%, which is the ratio of the fifth gear(>=5) to the known manual gear(1,2,3,4,>=5) distribution of manual transmission. This was used as a proxy for LKA-applicable speeds.

Based on the above discussion, the probability of that LKA is in good working condition is 11.1%, which was obtained by multiplication of quantized results of the three main limitations above. The assessment for each year's reduction in injuries and fatalities would become approximately 1/9 of the original ideal result. Considering these three main limitations, the result was changed to that 608 injuries and 1253 fatalities would be reduced in 2030, while the specific number is 375 fatalities and 818 injuries in 2025, as shown by the solid line in Figure 4.

There are three development directions of LKA system to help improve the benefits for road safety. A good interaction design with the driver could improve the proportion of the driver turning on the LKA system. A lower setting of the minimum working travel speed could avoid more collisions that can be avoided. And, adaptability of the harsh weather and lighting conditions of the camera can avoid collisions in relatively more dangerous situations.

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