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Intelligent Vehicles' Effects on Chinese Traffic: A Simulation Study of Cooperative Adaptive Cruise Control and Intelligent Speed Adaption

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***Abstract*— With the rapid development and wide deployment of intelligent vehicles, they will exert significant impacts on traffic efficiency not only in developed countries, but also in developing countries such as China. This paper focuses on the effects of Cooperative Adaptive Cruise Control and Intelligent Speed Adaption on Chinese urban, highway and rural traffic. Through several parallel microscopic traffic simulations of Chinese contexts considering different road types and penetration rates, we find that these intelligent vehicle technologies can generate noticeable decrease in travel time and increase in travel speed for urban traffic, especially in the morning and evening peak time, but not quite effective on highways and in rural areas. The study also indicates the importance of their market penetration rate to technological effects. Furthermore, based on the characteristics and simulation results of Chinese traffic, we propose some suggestions for developing countries to make better use of these advanced technologies.**

Keywords*— Chinese traffic, cooperative adaptive cruise control, intelligent speed adaption, travel time, travel speed, simulation study

I. INTRODUCTION

Intelligent vehicles (IVs) have attracted most attention from the academia and industry in the transportation domain. Their commercialization will bring about great benefits for road safety, traffic efficiency and environmental protection [1-4]. IV technologies can affect vehicle behaviors directly or indirectly to increase traffic flow and stability, mainly by assisting in longitudinal or lateral vehicle control [1, 2, 5-10]. On the other hand, the real-time communication and close interactions between IVs and their surroundings will support more effective and smarter traffic management [11-15, 17]. A lot of researches have shown that IV technologies will increase the traffic speed, capacity and stability, as well as reduce the travel time and congestion, such as (Cooperative) Adaptive Cruise Control (ACC or CACC), Intelligent Speed Adaption (ISA) [5-12], Intersection Assistant [13, 14] and platooning systems [15, 16, 17].

China is one of the key regions for IV development and application, faced with various traffic problems. China have most congested urban areas due to its large and rapidly increasing vehicle population and immature road infrastructure. 21 Chinese cities ranked among the 100 most congested cities worldwide in 2016 [18]. China also lacks efficient and advanced traffic management technologies and systems, and deployment of intelligent transportation systems is limited to its developed districts. Furthermore, as express delivery business booms in this e-commerce era, logistics costs has also become a key topic for Chinese transportation industry. In order to solve these problems, the Chinese government has formulated several policies such as "Made in China 2025" and "Internet Plus Transportation" strategies to promote IV development and deployment [19]. Considering the fact that China has characteristic road types and traffic contexts, the practical effects of IV technologies may be different from other countries. Thus a study into the impacts of IVs on Chinese traffic will provide reference for developing countries to better exploit IV technologies.

This paper focuses on the impacts of CACC and ISA on the travel time and speed of Chinese traffic. CACC enables the equipped vehicle to adjust its speed and headway according to the status information of preceding vehicles, while ISA restricts the vehicle's speed within a reasonable range. These two technologies can change longitudinal speed immediately and operate during most of the maneuvers, resulting in more direct and obvious traffic impacts than others [2]. Their traffic impacts need to be assessed with a microscopic traffic simulation model, based on the characteristics of IVs and Chinese traffic. However, since the popularization of IV technologies may take a long time, especially in developing countries, a mixed traffic stream comprised of equipped and unequipped vehicles will exist for several decades and the technologies' market penetration plays an important role in their effects [1, 2, 10]. Therefore we present a market model in this paper to better describe the application conditions of CACC and ISA.

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The rest of this paper is structured as follow: The establishment of the traffic simulation model and market model as well as their data collection are presented in section II. Then section III shows the results of several simulations considering different traffic contexts and market penetration rates in China. Finally we come up with several conclusions and suggestions in section IV.

II. Model Establishment and Data Collection

A. Road and Traffic Model

The simulations are conducted using PTV VISSIM software, which allows freely modeling road infrastructures, users and their interactions in detail. In order to fully reflect the effects on the whole traffic, we categorize Chinese roads into three levels: urban roads, highways and rural roads. Their parameters are set as shown in Table I, according to Chinese technical standards of road engineering [20, 21]. For each kind of road, similar control logic of signal timing is adopted when they exist, including time to go straight and turn left, time to turn right and yellow intervals.

TABLE I. Assumption about Road Parameters

Road levels		Speed limitation (km/h)	Road width (m)	Number of lanes (one-way)
Urban roads	express way	80	15	4
	arterial road	60	15	4
	secondary trunk road or below	40	7.5	2
Highways	main road	100	11.25	3
	ramp	60	3.5	1
Rural roads		60	3.75	1

For urban roads, we consider the diversity of geographic location, economic strength and traffic demand among different cities. Therefore we choose six cities as samples of Chinese urban traffic, including Beijing, Shanghai, Guangzhou, Shenzhen, Chongqing and Kunming. They belong to the first and second tier cities, covering the north and south, as well as east and west of China. To establish the traffic model of these cities, we separately define their traffic stream in all-day time and peak period, vehicle fleet composition and road network topology. The traffic parameters of selected cities are extracted from their local annual reports of traffic statistics in 2016, which are listed in Table II. Moreover, each city's typical road geometry is taken into account, modeled on a certain district from the real-time city map as shown in Fig. 1.

TABLE II. Assumption about Urban Roads of Different Cities

Cities	ATF (veh/h /ln)	PTF (veh/h /ln)	PCV	DS (km/h)	PR
Beijing	1796	2449	4.60%	47.71	11:15:74
Shanghai	1409	1921	10.71%	46.74	34:27:38
Guangzhou	819	873	4.90%	42.83	18:27:55
Shenzhen	600	750	4.10%	46.15	23:35:42
Chongqing	1450	2175	7.42%	47.40	10:22:68
Kunming	1426	2150	5.70%	46.57	9:19:71

a. ATF: All-day Traffic Flow; PTF: Peak-period Traffic Flow; PCV: Proportion of Commercial Vehicles; DS: Desired Speed; PR: Proportion of Roads (express way, arterial road and secondary trunk road or below)

Fig. 1. Urban road geometry of different cities (1–Road shape modeled in VISSIM; 2-A real district in the map of Beijing)

For highways and rural roads, there is no obvious difference across the country. Hence we simply use the statistics data of national transportation industry published by Ministry of Transport in 2016 to describe the traffic on highways or rural roads, as shown in Table III. The road shapes are also designed to simulate real-world situations. The highway model consists of a main road and two ramps, thus covering free-flow conditions as well as merging and diverging activities. And the rural road model is a motorway connecting three junctions with narrower roads and lower desired speed. Fig. 2 illustrates the two types of road models.

TABLE III. Assumption about Highways and Rural Roads

Road levels	ATF (veh/h/ ln)	PCV	DS (km/h)	DH (m)	DA (m/s^2)	ROW
High-ways	340	5.6%	100	100	[-2.5,3.5]	Priority for main road
Rural roads	484.9	5.4%	60	50	[-2.5,3.5]	Priority for main road

a. DH: Desired Headway; DA: Desired Acceleration; ROW: Right of Way at intersections

Highway

Rural road

Fig. 2. Road geometry of highway and rural road (modeled in VISSIM)

B. Vehicle Model

Considering the different impacts on road traffic, the running vehicles are simplified as two major categories. It is assumed that passenger cars' size is 4.5 meters long and 1.8 meters wide, while commercial vehicles' size is 10 meters long and 2 meters wide. The vehicle models are supposed to have similar powertrain performance parameters including the function and distribution of the maximum acceleration and deceleration, as well as the desired deceleration.

The most important part of the vehicle model is how to simulate the behaviors of IVs and conventional vehicles. Firstly the CACC function in this study is supposed to cover the full speed range, which means the equipped vehicle can stop and go at any speed autonomously. Compared with normal drivers, CACC enables further and wider field of vision. To distinguish the driving behaviors of equipped and unequipped vehicles, Wiedemann 99 car-following model is adopted and modified. Table IV presents the longitudinal movement parameters of the vehicles, which are derived from [8, 22], considering that Chinese drivers are more cautious and prefer conservative driving strategies. Secondly the ISA function ensures that the vehicles will never exceed the limitation of roads and operate at an appropriate speed.

TABLE IV. LONGITUDINAL MOVEMENT PARAMETERS OF DIFFERENT VEHICLES

Parameter index	Parameter	Unequipped vehicles	Equipped vehicles
CC0	Standstill distance	1.5m	1.0m
CC1	Headway time	1.4s	0.7s
CC2	Following variation	4m	1m
CC3	Threshold for entering 'Following'	-8	-1
CC4	Negative 'Following' threshold	-0.35	0
CC5	Positive 'Following' threshold	0.35	0
CC6	Speed dependency of oscillation	11.44	0
CC7	Oscillation acceleration	0.25m/s^2	0.25m/s^2
CC8	Standstill acceleration	3.5m/s^2	3.5m/s^2
CC9	Acceleration at 80km/h	1.5m/s^2	1.5m/s^2
FoV	Field of vision	250m, 2veh	500m, 10veh

C. Market Model

The penetration rate of IV technologies will generate significant impacts on their practical effects, since the mixed traffic stream may affect the driving patterns of both equipped and unequipped vehicles [10]. According to the *Technology Roadmap for Energy Saving and New Energy Vehicles* of China, the penetration rate of driver assistance functions in new vehicles will reach 50% in 2020, 80% in 2025 and 100% in 2030, including CACC and ISA [19]. We calculate the market penetration of IV technologies based on these targets with the following equations:

$$P_t = M_t / N_t = (M_{t-1} + m_t - ms_t) / (N_{t-1} + n_t - ns_t)$$

$$m_t = tp_t n_t \quad (1)$$

where: P_t is the penetration rate of CACC and ISA in year t, M_t is the number of equipped vehicles, N_t is the number of all running vehicles, m_t is the annual sales of equipped new vehicles, n_t is the annual sales of all new vehicles, ms_t is the number of equipped vehicles which are scraped, and ns_t is the number of all scraped vehicles. tp_t is the target penetration rate in new vehicles as set in the roadmap, which is estimated with linear interpolation year by year.

The annual vehicle sales in China are supposed to have exponential growth in the next few years. And according to Chinese statistics and regulations, we assume that the average service life of vehicles is ten years, which means:

$$ns_t = n_{t-10} \quad (2)$$

III. SIMULATION RESULTS OF CHINESE TRAFFIC SCENARIOS

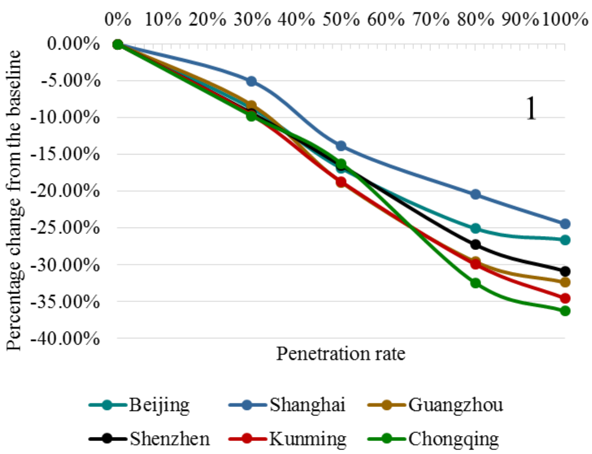
Based on the established models above, several parallel simulations with different traffic contexts and market penetration rates are conducted. The simulations refer to the targets of the aforementioned Chinese roadmap and set penetration rates as 0, 30%, 50%, 80% and 100%, and the scenario with no equipped vehicles is regarded as the baseline for traffic effects estimation. We focus on the impacts of CACC and ISA on travel time and speed, which directly affect the passengers' experience and the logistics costs. For each scenario above, simulations are repeated for five times and they have quite similar outcomes. Therefore their averages are adopted as the results.

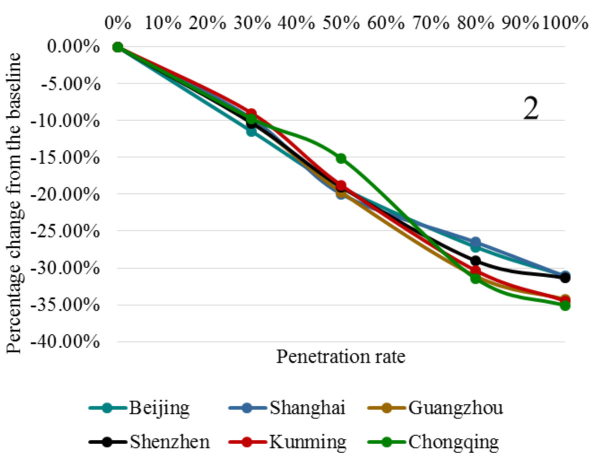
A. Impacts on Travel Time and Speed

The results of average travel time are presented in Fig. 3. For urban roads, CACC and ISA with 100% penetration rate are able to reduce the average travel time in all day by about 24.41% to 36.28%, while reduce the average travel time of peak period by about 31.06% to 35.11%. The impacts on different cities have a similar trend that the variation rate will be slightly higher at medium penetration rates than at low or high ones. However, the effects on second tier cities

(Kunming and Chongqing) are somewhat stronger than first tier cities. These cities have relatively large traffic flow due to the conflict between their large mobility demands and low proportions of high-level roads. Stop & Go function of CACC will improve vehicles' reaction time and speed in such heavy traffic. On the other hand, as latecomers of urbanization, they also achieve better urban planning, whose road networks involve fewer intersections and narrow passes in old towns. Therefore CACC and ISA can work better to realize higher travel speed and fewer acceleration or deceleration behaviors.

In contrast, CACC and ISA bring about less decrease in the average travel time on highways and rural roads. Even though all vehicles are equipped with the technologies, we can see only 10.59% and 9.16% reduction separately, which is significantly lower than the effects on urban roads. The reason for this difference may be that the traffic flow on highways and rural roads approximates to free flow and lacks traffic jams. Hence the real travel speeds can be more stable and approach the speed limits, which naturally offset the main effects of CACC and ISA.





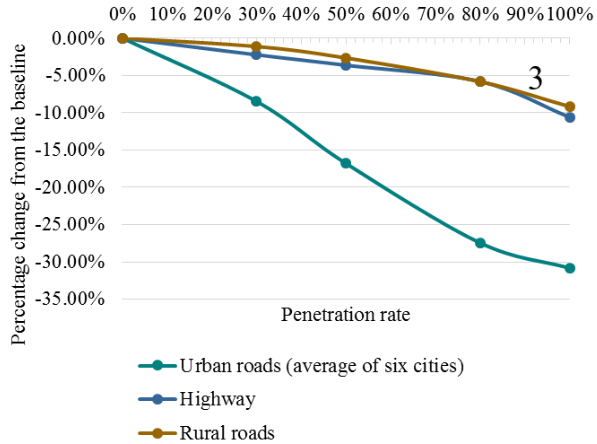
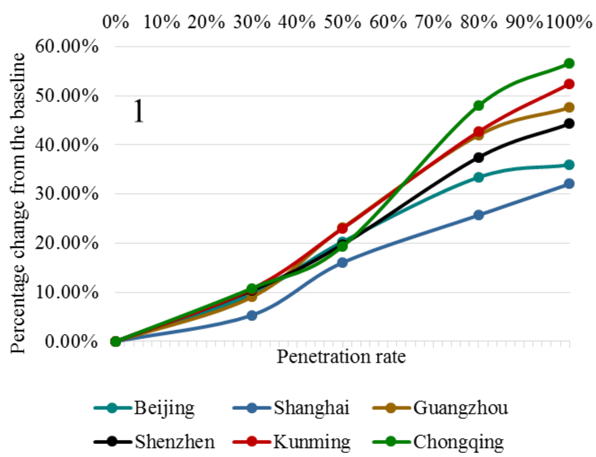


Fig. 3. The change of average travel time (1-Result of all-day time in urban traffic; 2-Result of peak time in urban traffic; 3-Result of all-day time in different traffic)

The results of travel speed are shown in Fig. 4. When no vehicles are equipped with CACC and ISA, the all-day average travel speed in urban roads is between 28.36km/h and 33.48km/h. However if the penetration rate reaches 100%, the average value can be between 42.92km/h and 45.51km/h, with rate of increase between 32.06% and 56.65%. The increment effects can be more obvious in peak period with a range of 44.34% to 54.38%. At the same time, the speed increase is much less on highways and rural roads, with a percentage of only 2.72% and 4.86% respectively. These results are coherent with the ones of travel time, thus verifying the analysis above.



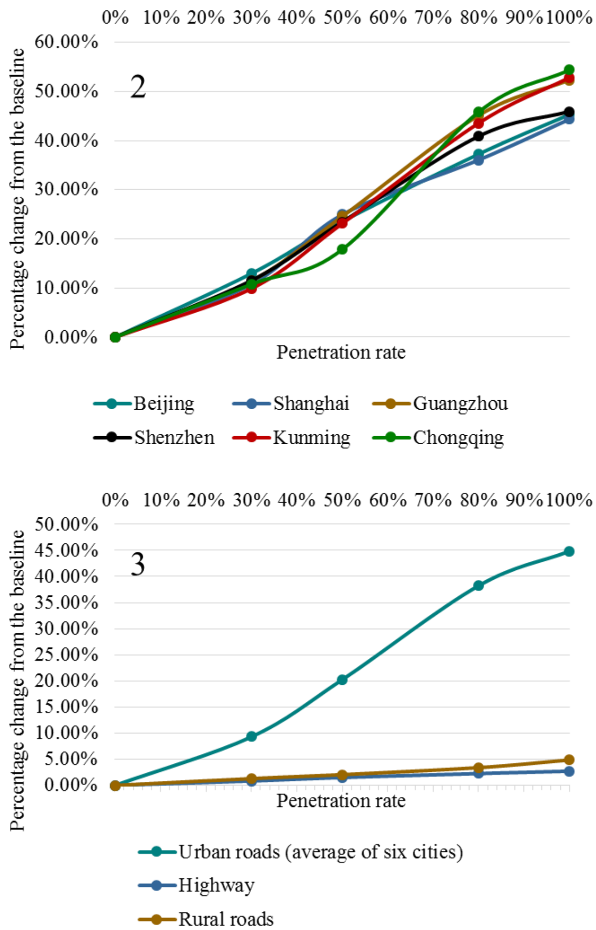


Fig. 4. The change of average travel speed (1-Result of all-day time in urban traffic; 2-Result of peak time in urban traffic; 3-Result of all-day time in different traffic)

B. *Predicted effects on Chinese Traffic*

According to the strategic plans of China, a large number of IVs will emerge on public roads in the next 10 to 15 years. Thus there will be mixed traffic of conventional vehicles and IVs in a certain period. Based on the aforementioned market model and data of Chinese vehicle sales and population, the penetration rate of CACC and ISA in China is predicted, as shown in Fig. 5. Since CACC and ISA mainly employ Vehicle-to-Vehicle communication, GPS and digital maps, they do not require many modifications and construction of road and network infrastructure. Thus their effects mainly depend on their penetration and usage rate. We anticipate that between 2022 and 2023, 30% of the running vehicles will be equipped and the average travel time in daily urban traffic will decrease by 5.08% to 9.75%. And the penetration rate can reach 50% between 2025 and 2026, resulting in a decrease between 13.82% to 18.76% in the average urban travel time. These effects are lower than expectation of the roadmap, which may need to be realized through other IV technologies. However the two devices investigated in this paper will still generate great benefits for Chinese transportation and economy.

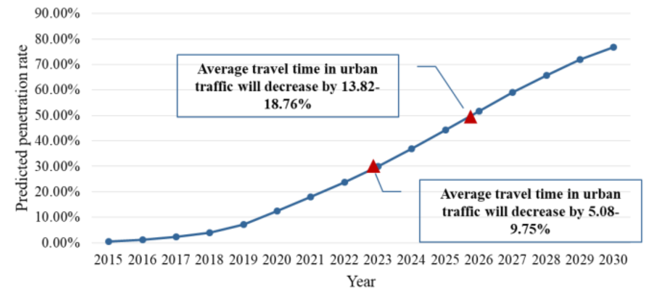


Fig. 5. Predicted market penetration of CACC and ISA in China

We conduct further analysis on the features of Chinese traffic according to Table V. Compared with the developed countries, CACC and ISA may be more effective in urban traffic of China. This is because China is faced with rapid economic growth, which produces a large amount of passenger and freight traffic volume, thereby raising the usage rate of urban roads. The traffic flow maintains high in the whole day, especially during the morning and evening rush hours. Furthermore, the traffic volume in rural areas plays an important role in China. The rural road mileage is about 4 million kilometers in 2016, which is 10 times as long as urban roads and 30 times longer than highways. Consequently the travel time spent on rural roads can take up about 40% of the total number, considering the average travel speed and traffic flow. Thus the time-saving effects of CACC and ISA on rural traffic also count for much, but they are not so important for developed countries due to their large urban areas and well-developed highway networks.

TABLE V. SOME SIMILAR RESEARCH RESULTS OF IV'S EFFECTS ON AVERAGE TRAVEL TIME (100% PENETRATION)

	China	the U.K. [22]	Netherland [9]
Technologies considered	CACC and ISA	connected and autonomous vehicles	ACC
Urban roads (all-day time)	-30.83%	-13.8%	NA
Urban roads (peak period)	-32.89%	-33.7%	about -50%
Highways	-10.59%	-9.2%	about 11%
Rural roads	-9.16%	NA	NA

IV. CONCLUSIONS

There is no doubt that IV technologies can exert specific positive impacts on traffic flow, whether in urban and rural areas or on highways. However for different types of countries, the diverse traffic conditions may influence their practical effects. This paper makes a contribution to the research into CACC and ISA's effects on Chinese traffic. We can expect a reduction in average travel time up to 36.28% and an increase in average travel speed up to 56.65%, assuming that all the running vehicles on urban roads are equipped. Nevertheless, the effects are much smaller on highways and rural roads, owing to the similarity between their real traffic flow and free flow scenario. For the first and second tier cities faced with heavy traffic load, low travel speed and frequent traffic jams, IV technologies provide them with efficient solutions.

However, these effects largely depend on the penetration rate, as well as the usage rate. The simulation results base on the premise that all equipped vehicles will function strictly according to the control logic of CACC and ISA systems. If the drivers deactivate the devices or interrupt their operations frequently, the IVs' behaviors will be similar to the conventional vehicles and weaken their positive effects [9], as in a low penetration scenario. Therefore the governments should carry out promotion policies to popularize IV technologies, such as mandatory regulations and subsidy schemes. And the automobile manufacturers and other relevant enterprises should also expedite their research and development activities of IV technologies to lower the costs and facilitate the sales. Moreover, the consumers should be able to acquire more user training through extensive publicity to ensure a high usage rate.

For the developing countries including China, their future road construction ought to build an intelligent environment which is suitable for IV deployment in order to improve traffic efficiency. For instance, connected roadside devices such as beacons, intelligent signal lights and communication base stations should be involved in the construction plans to enhance CACC's performance and robustness. Besides, the rural roads must not be overlooked due to their huge share in the whole traffic volume. And the promotion of IVs and intelligent transportation systems can also produce enormous economic benefits for these areas.

The future research can extend the scope of IV technologies, considering higher-level autonomous driving functions like Intersection Assistant and autonomous parking. Larger simulations and field data are needed to validate the results. The effects on traffic capacity and stability should also be a subject of further research. Besides, the influence of IV application conditions other than penetration rate need to be explored, such as technological level and infrastructure support. We will also work on the monetization assessment of IVs' traffic effects to analyze their cost effectiveness, especially in China. A multinational comparison study can provide specific suggestions for the stakeholders of different countries to take full advantage of IV technologies.

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