Effects of the Inter-Vehicle Communications on the Transmission of Incident Information with Simulation Studies

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This paper presents simulation studies on the effect of the inter-vehicle communications on the incident transmission system, and investigates the relationship between the information transmission over the inter-vehicle communications and the penetration rate of the communication unit. The inter-vehicle communications with the 5.8 GHz DSRC (Dedicated Short Range Communications) and a traffic flow based on the time headway on an expressway are modeled for the simulation. The simulation results show that the information relayed via equipped vehicles can be transmitted at the level of the practical use when the penetration rate is over 20 %.

Keywords: ITS, AVCSS, Inter-Vehicle Communications, Incident, Penetration Rate

1. Introduction

The inter-vehicle communications, one of the four communication systems defined in ITS system architecture in America and in Japan [1], are the communications means for a driver or a vehicle with other drivers or other vehicles at any location at any time [2]. The feature is that the inter-vehicle communications enable each driver or each vehicle to get the data that are difficult or impossible to measure from the vehicle. They can extend the horizon of a driver and on-board sensing systems, which makes the inter-vehicle communications much beneficial in both safety and efficiency of the road traffic.

The inter-vehicle communications technologies are applicable to safe driving systems and automated driving systems in AVCSS (Advanced Vehicle Control and Safety Systems) as well as traffic information systems and driver information systems in ATMS/ATIS (Advanced Traffic Management Systems/Advanced Traveler Information Systems). Table 1 summarizes the ITS applications of the inter-vehicle communications. They include systems where vehicles communicate with other vehicles not only directly, but also indirectly via roadside communication units and leakage coaxial cables.

One of the earliest studies on the inter-vehicle communications is that started by JSK (Association of Electronic Technology for Automobile Traffic and Driving) in Japan in the early 1980s [3]. In the platooning systems including an automated platoon by California PATH [4] and Chauffeur in EU [5], and cooperative driving systems in Japan [6]-[8] in the late 1990s and 2000, the inter-vehicle communications played an essential role in the vehicle control, because the data on other vehicles necessary for the platooning had to be transmitted over the inter-vehicle communications. In addition, there is a simulation study hat indicates CACC (Cooperative ACC) that uses the inter-vehicle communications in normal ACC (Adaptive Cruise Control) is effective on the increase in the road capacity [9]. Recent applications of the inter-vehicle communications also include the transmission of the information on incidents or emergencies from a preceding vehicle to the followings [10][11].

As show in Table 1, the role of the inter-vehicle communications is essential in the ITS communications, and can greatly contribute to safety and efficiency of the road traffic, but they involve the serious issue on the penetration rate of the communication unit. An effective system with the inter-vehicle communications would require some amount of the penetration rate of the communication unit, because the communications are performed between or among drivers or vehicles. There is, however, only a few works on the evaluation of the penetration rate and the system effects of the inter-vehicle communications [12].

The system dealt in this paper is the incident information transmission system from a lead vehicle to following vehicles on expressways over the inter-vehicle communications [13][14]. This paper investigates how the information on incidents or accidents can be transmitted over the inter-vehicle communications with the 5.8 GHz DSRC to the following vehicles as shown in Figure 1, and presents simulation results of the relation between the information transmission and the penetration rate. This study is featured by that it is based on the real

Table 1. Applications of the inter-vehicle communications

	Driving directions of vehicles	Examples of information transmitted
Among individual vehicles	the same	- incident from a lead vehicle - decelerating and accelerating from a preceding vehicle - intension of drivers in preceding vehicles - emergency vehicle approaching
	Oncoming	- road information ahead
	the same/on coming/ crossing	- intension of drivers
	Crossing	- locations and speeds of other vehicles
Within a platoon	the same lane	- lateral and longitudinal vehicle control
Among platoons	the same/ the same lane	- longitudinal control between platoons
	at a ramp	- merging control

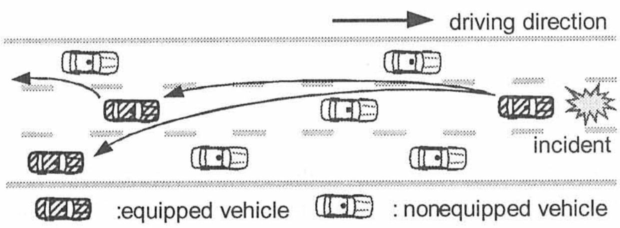

Figure 1. The incident transmission system over the inter-vehicle communications.

world data; it uses the propagation characteristics of the 5.8 GHz DSRC measured with the communication unit employed for the cooperative driving [7][8], and the traffic data acquired on the expressways [15]. Following the general introduction to the inter-vehicle communications, the simulation algorithms and the simulation results will be described.

2. Simulation models and algorithm

The traffic flow model and the inter-vehicle communication model in this study are static, because this work aims at the precursor analysis of the incident transmission over the inter-vehicle communications. The simulation has been conducted with the Monte Carlo Method. For the simulation, the inter-vehicle communications and the traffic flow on expressways have been modeled.

2.1. Simulation models

2.1.1. Inter-vehicle communications. The model of the inter-vehicle communication system for this simulation study is based on that used in the cooperative driving [7][8]. The specifications are shown in Table 2, and the characteristics measured on our test track are shown in Figure 2.

The reason why the 5.8GHz DSRC was modeled as the inter-vehicle communications is that the feasibility of the communications technology of the 5.8GHz DSRC was not only already employed in the road vehicle communications for the ETC but also verified in the inter-vehicle communications for the vehicle platooning control [7][8]. In addition, in the near future there will be a possibility that the DSRC for ETC and for the inter-vehicle communications will be compatible, where the car navigation system could tell the location which system should work.

In this simulation study, the static simulation model of the communications has been employed, because the transmission time of the incident information is so short that the vehicles can be regarded that they are not driving. The characteristics of the communications that must be modeled for the simulation are, thus, only the propagation characteristics in Figure 2.

The propagation characteristics show that the communications range covers about 550 m, when the minimum receiving level is set to –85 dBm, and the maximum bit error rate is set to 10^{-3}, which is the standard rate for mobile communications. However, even within the range, there are areas, 44 m – 52 m, 90 m – 135 m, and 175 m – 195 m, where the communications cannot be performed due to the constructions on the test track, which may cause the receiving level dip. In the simulation, the areas where the communications cannot be performed are taken into the model.

Table 2. Specifications of the inter-vehicle communications

Frequency	5.8 GHz
Output power	10 mW
Antenna	Omni-directional
MAC Protocol	CSMA Protocol

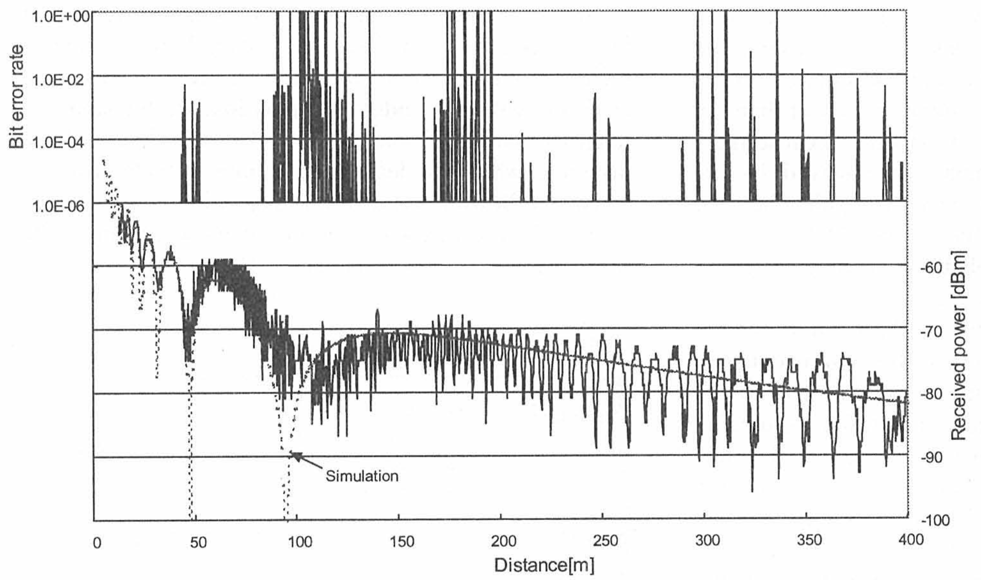

Figure 2. The propagation characteristics of the 5.8 GHz DSRC measured on our test track.

2.1.2. Traffic flow. There are some ways to describe a traffic flow model on expressways, including a microscopic model like a car following model and a macroscopic model based on the *q-v* relation. The traffic model in this study is based on the distribution of the time headway measured on expressways, as shown in Figure 3 [15]. The reason of the employment of the model is that the vehicle locations that are close enough to the real world traffic flow are necessary in the simulation. The headway distribution may vary with the vehicle speeds, but in the simulation the distribution is regarded not to be affected by the vehicle speeds.

2.2. Simulation algorithm

After the time headway of each vehicle is generated with random numbers, the distribution of which has the form in Figure 3, and the mean speed of the vehicles is given, the locations of vehicles are determined. The dispersion of the vehicle speeds is not taken into account, but the every vehicle is assumed to drive at the same speed, which is called as the mean speed here. In addition, the equipped vehicles (vehicles that have the communications unit) are determined with random numbers based on the penetration rate.

The combination of the propagation characteristics in Figure 2 and the vehicle locations on the expressways will provide the information transmission characteristics. Since this simulation has been conducted with the Monte Carlo method, the simulation with the same parameter of the speed is repeated 200 times to investigate the information transmission probability when the penetration rate is given.

The information can be transmitted not only to following vehicles but also to the preceding vehicles, but in the simulation only the following vehicles receive the information and relay it to the following vehicles again. This assumption can be justified by sending the localization data by the GPS together with the information.

Table 3 shows the parameters set up list in the simulations. The simulation will be basically conducted for an expressway of a single lane, and the opposite lane is not taken into consideration, and in the last part it will be conducted for a two-lane expressway.

3. Simulation results

The first step of the simulation studies is the investigation of the communication probability that the communications can be performed between a vehicle that transmits the information and a vehicle that receives it

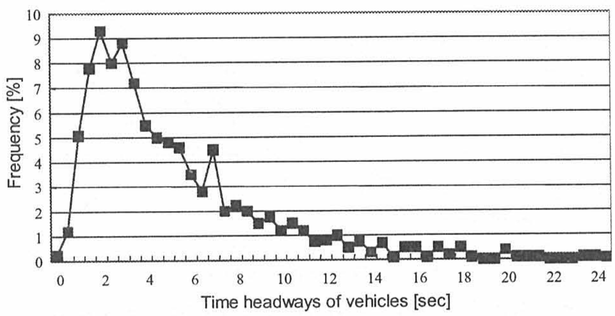

Figure 3. The distribution of the time headways of vehicles on expressways.

Table 3. Simulation parameters set up list

Expressways traffic flow model (Traffic volume [veh./h], Time headway [sec])	636.1 [veh./h] (Average time headway: 5.669 [sec], Single lane roadway), 1180.6 [veh./h] (Average time headway: 3.053 [sec], Single lane roadway), 1269.7 [veh./h] (Average time headway: 5.669 & 5.782 [sec], Two lane roadway)
	1200 [veh./h] (Fixed time headway: 3[sec], Single lane roadway)
Vehicle speed [km/h]	50,70,100
Penetration rate [%]	2,5,10,15,20,25,30,45, (5,10,20,30,40,50,60,70,80,90)

for once on a single lane expressway. In this case, since the information relay is not taken into account, the probability will be nearly equal to the penetration rate of the communication unit. The communication probability will be smaller than the penetration rate, because there are the areas where date cannot be received by the receiving level dip. Figure 4 shows a result when the mean vehicle speeds are 50 km/h and 70 km/h. It is shown that communication probability decreases to about that 80% more to the diffusion rate.

In order to verify the validity of the random number generation for the simulation, the traffic volume obtained with the data in Figure 3 and those with the random numbers have been compared. The traffic volume in Figure 3 is 635.03 vehicles/h (an average of the time headway becomes 5.67sec) and that by the random numbers is 636.1 vehicles/h. The data, thus, show the validity of the random number generation.

The second step of the simulation is the investigation on the range of the information transmission by relaying it with equipped vehicles also on a single lane expressway. The assumption for the simulation is the same as the previous one. In the simulation in this case, a simplified communication condition is assumed, and the packet collisions and the reception of the same information from different vehicles are not taken into account.

Figure 5 shows a result, which depends on the vehicle speeds, because the inter-vehicle distances calculated with the time headway distribution vary with the speeds. It shows that when the penetration rate is more than 70 %, the range that the information can be relayed (the transmission ranges) exponentially increases. The details when the penetration rate is small in Figure 5 are shown in Figure 6.

Figure 7 also shows a simulation result, where the penetration rate is more minutely assigned, and the positions of the vehicles and those of the vehicles equipped with a communication unit are assigned with random numbers. The results in Figure 6 and Figure 7 are similar with minor differences, although the simulation methods are different.

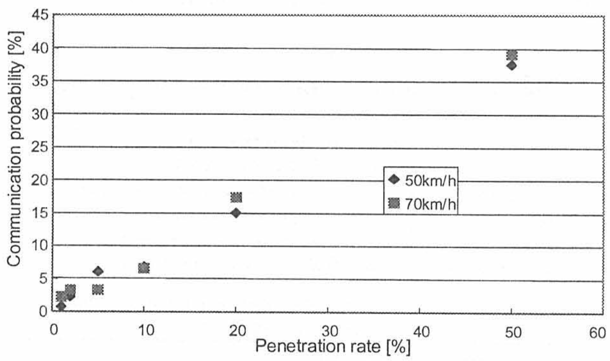

Figure 4. The communication probability vs. the penetration rate.

Since the results indicate the transmission ranges of the incident information, they should be evaluated regarding the collision avoidance. In order to avoid the collision with the incident transmission, the transmission ranges should be longer than the safe inter-vehicle distance, which is defined as a inter-vehicle distance when a following vehicle can stop without a collision even if the preceding vehicle instantaneously stops. The safe inter-vehicle distance is 26.18 m, 45.53 m, and

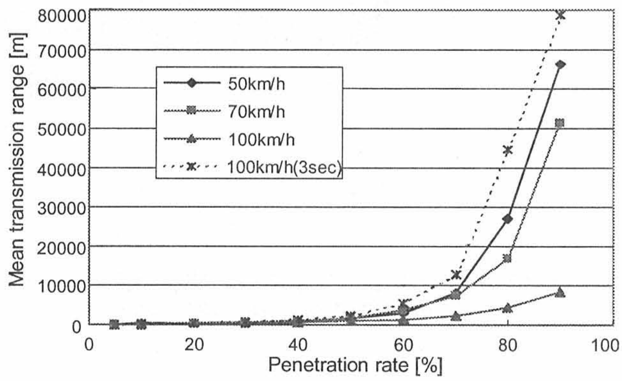

Figure 5. The transmission ranges vs. the penetration rate.

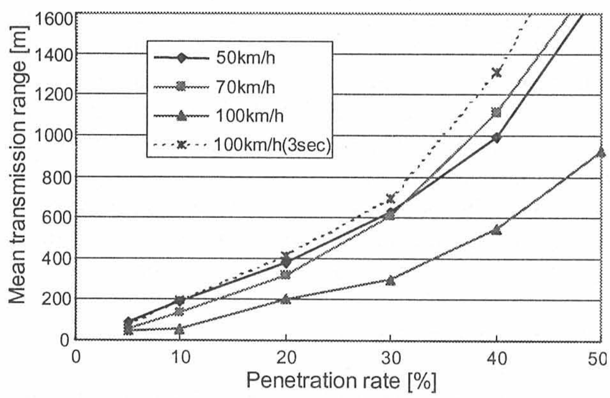

Figure 6. Detail of the transmission ranges vs. the penetration rate in Figure 5.

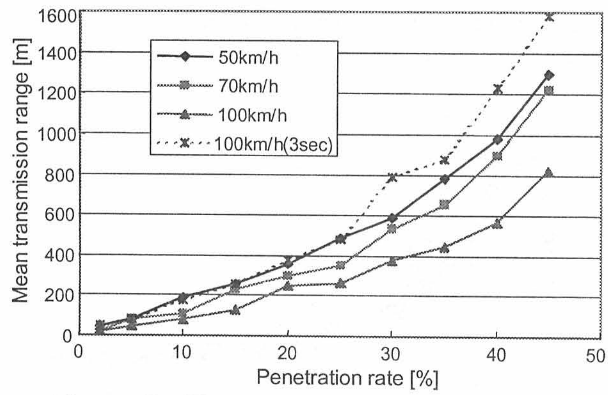

Figure 7. The transmission ranges vs. the penetration rate when the vehicle positions are random.

78.94 m, when the vehicle is driving at 50 km/h, 70 km/h and 100 km/h, respectively. The distance is calculated with the marginal inter-vehicle distance of 2 m, the driver response time of 1 sec, and the friction coefficient between the tire and road of 0.8 [16]. As the vehicle speed becomes higher, the safe inter-vehicle distance becomes longer, but the transmission ranges becomes shorter as shown in Figure 6 and Figure 7. The transmission ranges becomes longer as the penetration rate becomes higher. The penetration rate when the incident transmission system is feasible must be at least about 20 %, because the results in Figure 6 and Figure 7 show that the transmission ranges is between 200 m and 400 m for any vehicle speed with the penetration rate.

The results in Figure 5 and Figure 6 depend on the vehicle speeds, because the inter-vehicle distances calculated with the time headway distribution vary with the speeds. The vehicles, which are in the neighborhood of the incident and receive incident information, can slow down before they encounter the incident. Furthermore, that a platoon slows down when it receives the incident information is favorable to the incident transmission. When vehicles slow down and the space headways become short, it would increase the possibility of the information transmission. If a vehicle receives the information on an incident that occurred far forward, it will allow the vehicle to make detour to avoid the congestion caused by the incident.

The figures also show the transmission ranges when the time headway is 3 sec, thus, the traffic volume is 1200 vehicles/h, and the vehicle speed is 100 km/h, as a reference. When the vehicle speeds are higher or the time headways are shorter, the transmission probability will increase and the transmission ranges will become longer, which will prevent the expansion of the influence of the incident. Incident information is wide spread if it increases transmission probability and the transmission ranges gets long when a vehicles speed is high and time headway is short. Under such conditions, it is easier to ensure the safety by preventing the influence of an incident from expanding.

The more the traffic volume is, the smaller the variance of the time headway becomes. Figure 8 shows the distribution of the time headway when the traffic volume is high. The traffic volume is 1179.17 vehicles/h, and, thus, the average of the time headway is 3.05 sec. Figure 9 is a simulation result with the time headway in Figure 8, and it shows that the transmission ranges becomes longer. Even if the penetration rate is low, the effect of the incident transmission increases, when the traffic volume is high. Figure 9 indicates that the penetration rate when the incident transmission system is feasible is around 10 to 15 %. However, the transmission ranges does not increase as much as the traffic volume increases. The traffic volume in Figure 8 is 1.85 times as much as that in Figure 3, but the corresponding transmission ranges in Figure 9 is only 1.48 times as much as that in Figure 7.

Simulation for a two-lane expressway has been also conducted. Figure 10 shows the distribution of the time headway on the high-speed lane of the same expressway as in Figure 3. The simulation result is shown in Figure 11. The traffic volume in the fast lane is 622.68 vehicles/h, and, thus, the average of the time headway is 5.78sec. The total traffic volume of two lanes becomes 1257.71 vehicles/h. The increase rate in the transmission ranges is higher than the increase in the traffic volume, and it show that the incident transmission system is more effective on a two lane expressway than on a single lane expressway. In particular, the increase at the speed of 70 km/h is remarkable, and the traffic data used in the simulation are similar to the data of the real traffic on an expressway. In this case the incident transmission system is feasible when the penetration rate is about 10 %.

If the receiving level dip is ignored, the transmission ranges is decided by the number of the vehicles equipped with the communication unit and their locations in the communication range (in this case 550m). For example, the space headway in Figure 3 when the vehicle speed is 100 km/h will be 157.47 m, which means that there exist only 3 vehicles in the communication range. If the penetration rate is less than 30%, the probability of the transmission will be very small.

The simulation results show that there is a possibility that the minimum transmission ranges and the standard deviation are 0 m even if the penetration rate is more than 40 %. This indicates that the simulation results are possible indices rather than the design guidelines.

4. Conclusions

This paper presented simulation studies on the evaluation on the information transmission over the inter-vehicle communications, when the communications use the technology of the 5.8 GHz DSRC. The results show that the incident information can be transmitted over the range at practical use, when the penetration rate of the communication unit is more than 20 %, and in some cases more than 10 %.

In this study, the penetration rate and the effect of the inter-vehicle communications are verified using the simple simulation by modeling the actual communications devices and traffic on the actual expressway. The transmission ranges have been obtained by assuming the distribution of the time headway, the speed of the vehicles, and the penetration rate of the communications unit. Since the simulation models were static, the delay in the communications, the collision of the packets, and the dynamic behavior of the traffic flow were not taken into consideration. When the simulation deals with the situation where the congestion due to the incident is growing, the results of the incident transmission would be more favorable, because the space headways of the vehicles under the congestion are becoming smaller and smaller. The future issues include the simulation studies with the traffic flow dynamics and the communication dynamics including the packet collision.

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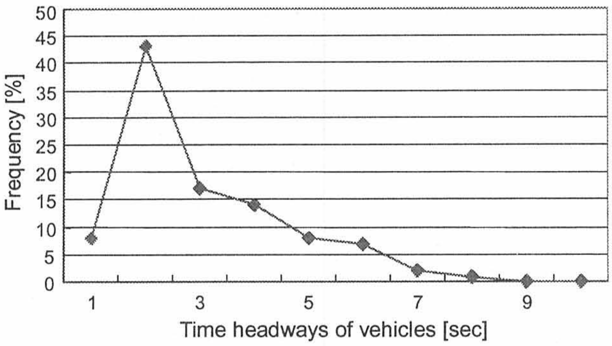

Figure 8. The distribution of the time headways of vehicles on expressways when traffic volume is high.

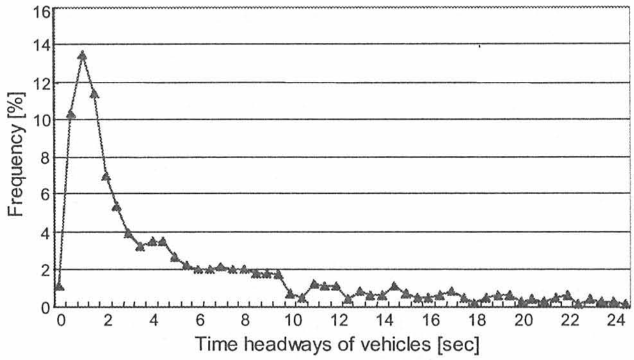

Figure 10. The distribution of the time headways of vehicles on a high-speed lane.

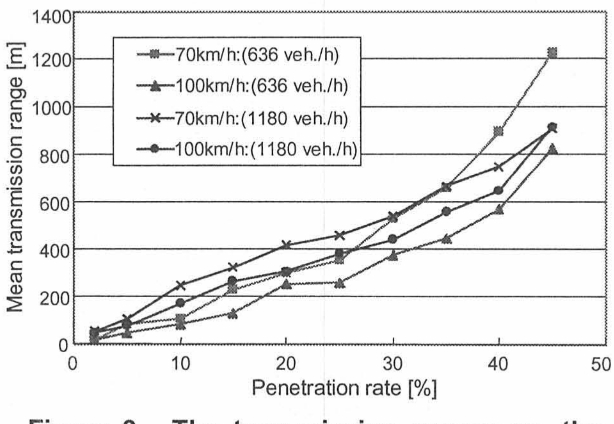

Figure 9. The transmission ranges vs. the penetration rate with the time headway in Figure 8.

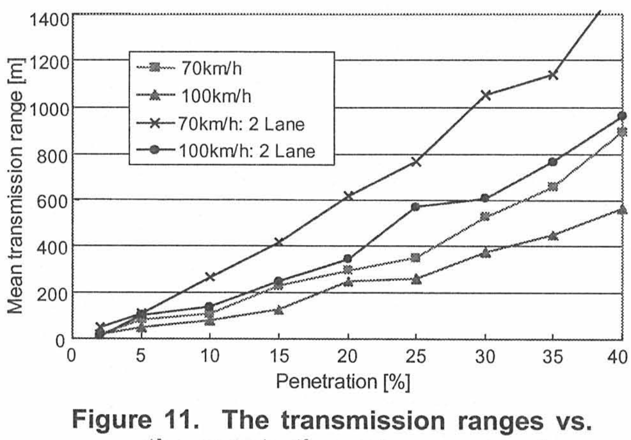

Figure 11. The transmission ranges vs. the penetration rate on a two-lane expressway.

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