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To What Extent Can Speed Management Alleviate the Range Anxiety of EV?

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Abstract

Based on actual use data recorded by a volunteer driving an EV under the condition that the distance involved in his weekday commute to and from the workplace was almost equal to the catalogue travel mileage, both speed management and refraining from the use of auxiliary devices such as the heater are indicated as measures to alleviate the range anxiety of the EV. Firstly, to clarify the performance specifics, electricity consumption rate (ECR) when using the highway or public roads and when using auxiliary devices was calculated. Highway driving involved 1.4–1.9 times higher average speed and 1.2–1.3 times higher ECR when compared to driving on public roads. ECR when using the heater increased to 1.4 times the value when no auxiliary devices were used. The use of headlights, wiper, or air conditioning had a relatively small effect on ECR. On the basis of these results, the effect on actual vehicle range extension of reduction of cruising speeds on the highway was evaluated and speed reductions of 10 km/h from 100 to 90 and 20 from 100 to 80 gave 7% and 12% improvement in actual vehicle range, respectively. The effect of speed management on the ECR was smaller than the non-use of the heater but larger than the non-use of air conditioning.

Keywords: BEV (battery electric vehicle), energy consumption, vehicle performance, speed management

1 Introduction

Evaluation of small-sized electric vehicle (EV) was carried out by examining the EV both in real world conditions and by using the chassis dynamometer facility. This study showed that the EV, which was made by a small company in India, could be used with almost no limitations, even though its acceleration ability is a bit less than the internal combustion engine vehicles (ICEVs). For this test EV, the actual vehicle range excluding range anxiety (RA) was 49 km per charge. Use of the EV on an expressway was not considered due to the maximum speed of 65 km/h [1].

Subsequently, there was a change in circumstances surrounding EVs. Major car manufacturers have brought to market EVs with performance comparable to that of ICEVs with the exception of name-plate range. The travel mileage listed in the EV catalogue is relatively short, for example 120–200 km per charge. This value is around 1/3 to 1/5 that of ICEVs, or 1/10 of that of hybrid EVs.

Although we can extend vehicle mileage by installing extra batteries, this would entail higher initial purchase costs for the EV and longer times for fully charging the battery. This does not represent a realistic solution. The values listed in the vehicle catalogue did not, however, reflect full conditions indicated by actual use of the EV [2]. The actual vehicle mileage is considerably shorter than the catalogue value as electricity use for an EV in real world conditions was much higher.

In order to clarify the possibility of replacement of ICEVs, actual long-term data from actual passenger cars used by citizens of Tsukuba-city of Japan were used. We analyzed the inconveniences which substitution by EVs would entail. Calculation results indicated that an EV with battery capacity of 16 kWh or more could satisfy almost all conditions which should be met in order that the vehicle might be used [3].

On this occasion, actual vehicle use data, whereby a volunteer used an EV under the condition that the distance involved in his weekday commute to and from the workplace was almost equal to the catalogue travel mileage, was collected. In such cases, the driver must always be aware of RA of the vehicle. Some previous research has been conducted with respect to the reduction of RA, and what was needed to improve the performance of the EV itself [4]. There were also indications that the driver's experience of driving an EV facilitated a drop of 35% in RA [5].

In order to reduce RA, there are some means with respect to energy management for vehicle use, such as reduction of running energy and decrease of electricity consumption. With regard to reduction of the energy to move a vehicle, drivers may decrease the acceleration energy, control the maximum speed when driving, and recover deceleration energy.

In this paper, we examine the effect of such changes in which the car was driven on the extension of the distance per charge, especially maximum speed management.

2 Research method

2.1 Vehicle specifications

Table 1 shows the specifications of the vehicle used for collecting data in the real world conditions. The battery installed is a lithium-ion type with a capacity of 10.5 kWh, and its catalogue travel mileage per charge was 120 km.

2.2 Travel routes

The volunteer resides in the Tokyo Metropolitan Area approximately 50 km from Tsukuba-city. Fig. 1 shows the geographical relationship between the two points. The vehicle was used for a round trip between his home and our institute. The routes between the two points were chosen by the volunteer. One route included the Joban expressway as 32 km of the route, which depends on which interchange was used by the volunteer.

Table 1: Vehicle specifications

Dimension			
	Length	(mm)	3395
	Width	(mm)	1475
	Height	(mm)	1610
	Curb weight	(kg)	1070
	No. of passengers	(persons)	4
Performance by JC08 driving cycle			
	Electricity consumption rate at AC outlet	(Wh/km)	110
	Travel mileage	(km)	120
	Maximum speed	(km/h)	130
Main battery			
	Types		lithium ion
	Nominal voltage	(V)	270
	Total capacity	(kWh)	10.5

2.3 Data collection

A record was taken in advance of departure and arrival at destination for the EV. The temperature, weather, time and date, and value of the odometer were recorded. Information as to whether the auxiliary devices (AUXs), such as air conditioning, headlights, or heater had been used was also recorded. The battery was charged at our institute using the built-in AC200V charger in the morning and charged in half an hour at the charging station near the volunteer's house using the DC20kW quick charger at night. The level of electricity charge was also recorded on each occasion. A GPS logger was used to record the route in map form as well as the vehicle speed. Measuring or recording items and devices used are shown in Table 2.

2.4 Analysis method

Based on the information collected, data were classified according to the purpose of vehicle use and the route chosen. It was further adjusted and arranged depending on the use or non-use of AUXs. To clarify the actual performance of the vehicle, electricity consumption rate (ECR) was calculated for each condition. The effect of speed management on the extension of vehicle mileage was evaluated by comparing the difference among ECRs.

Table 2: Items recorded or measured and sources

Items	Source
Distance traveled (km)	odometer in vehicle
Electricity charged (AC-based kWh) (DC-based kWh)	AC200V energy meter at our institute
	DC20kW quick charger near volunteer's house
Route and vehicle speed (longitude, latitude, km/h)	GPS logger
Weather and temperature (fine/rainy/-, degree Celsius)	data from Japan Meteorological Agency

3 Results and discussion

3.1 Daily vehicle use

Data collection started on 12 March 2012 and continued until 12 June 2013. Table 3 summarizes the monthly vehicle use data. This EV was used every weekday and some weekend. The main purpose of vehicle use on weekday was the commute from the volunteer's home to his workplace in the morning and the return trip at night. The distance of each trip usually was very close to half of the catalogue mileage described in Table 1, with battery charging being required twice a day.

3.2 ECR for commute to the workplace

Fig. 2 shows the relationship between the average speed for each trip and ECR for the morning commute to work. In cases when the highway was used, average speed varied from 32 to 65 km/h and AC-based ECR was from 121 to 209 Wh/km. Considering that the ratio of available capacity to nominal capacity of the battery is 0.8, the EV could only be used for around one hour and the distance possible to travel was 51 km, which is less than half of the catalogue value.
In cases when public roads were used, average speed was between 22 and 39 km/h and AC-based ECR was from 114 to 181 Wh/km. When this vehicle was used on public roads, two and half hours and 67 km of driving time and distance were

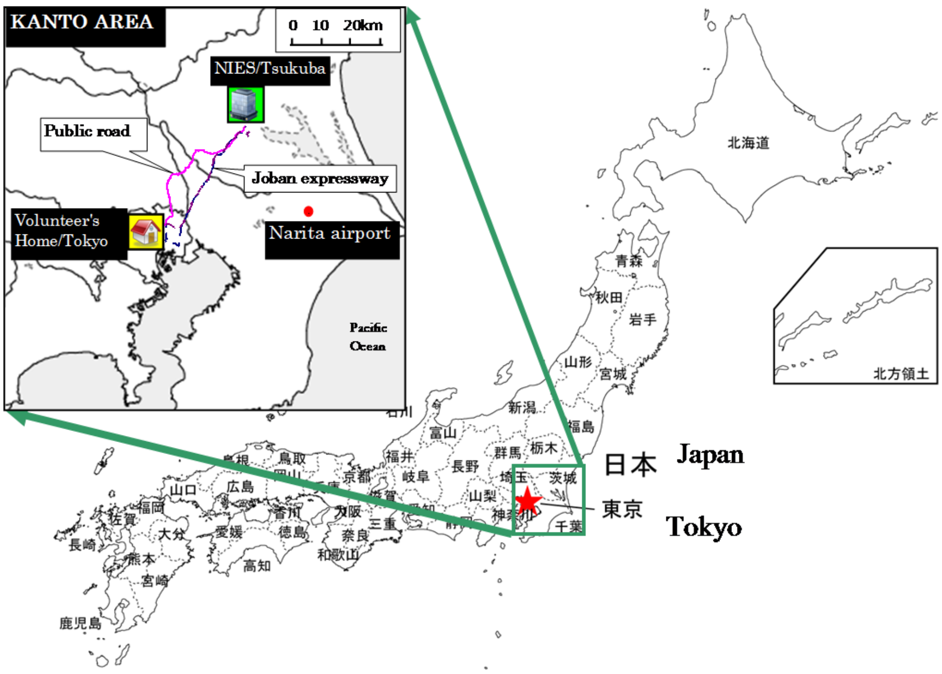

Fig. 1 Geographical relationship between the volunteer's home and our institute

available. This translates to a distance 1.3 times that of highway use. The characteristics of the commute to the workplace in the morning are summarized in Table 4 according to the use of AUXs.

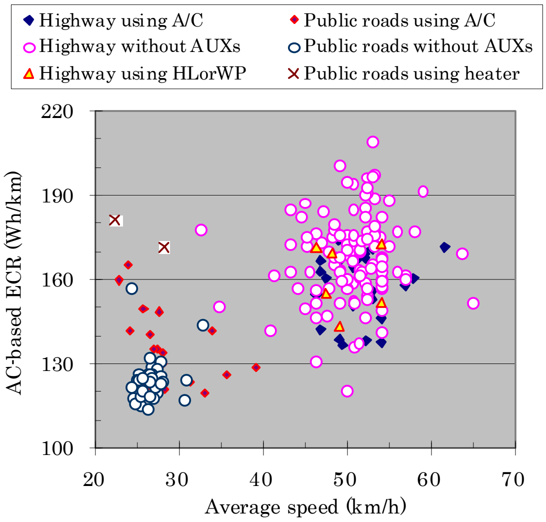

Fig.2 Relationship between average speed and ECR on commute to workplace by route

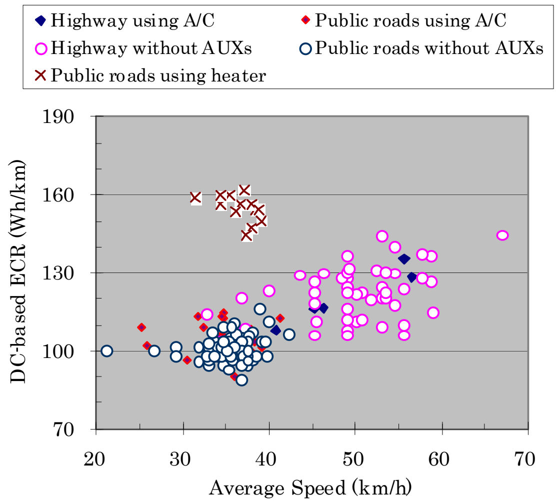

Fig.3 Relationship between average speed and ECR on return commute to domicile by route

3.3 ECR for return commute to the domicile

Nighttime use of a vehicle entails the inclusion of electricity consumption for headlights. The electricity charged was from the DC20kW quick charger, and this value did not include the converting efficiency from AC to DC. Consequently, we must take into account this

Table 3: Monthly data for EV use

Period	No. of days used	Frequency of use (trips)	Monthly distance (km)	Accumulated charging frequency	Average daily travel distance (km/day)
12 Mar 2012	17	32	1725	32	101.5
Mar 2012	23	45	2538	77	110.3
May 2012	19	35	1869	112	98.4
Jun 2012	21	42	2233	154	106.3
Jul 2012	25	48	2652	202	106.1
Aut 2012	26	49	2658	251	102.2
Sep 2012	18	35	2064	286	114.7
Oct 2012	21	44	2556	330	121.7
Nov 2012	19	38	2288	368	120.4
Dec 2012	16	28	1516	396	94.8
Jan 2013	21	39	2265	435	107.9
Feb 2013	22	41	2218	476	100.8
Mar 2013	24	44	2577	520	107.4
Apr 2013	24	45	2466	565	102.8
May 2013	18	36	2171	601	120.6
until 12 Jun 2013	8	16	957	617	119.6
Total	322	617	34753		108.5

difference when calculating ECR, as compared with the results from the commute to work. Fig. 3 illustrates the ECR for the return commute. When the highway was used, the average speed ranged from 33 to 67 km/h and ECR was from 104 to 145 Wh/km on a DC basis. The applied DC-to-AC ratio is 0.8, so the AC-based ECR ranged from 130 to 181 Wh/km. This value was similar to the one for the commute to work inasmuch as the difference of average speed and headlights were not taken into consideration. On the other hand, when using a public road, average speed ranged from 21 to 42 km/h and ECR was from 89 to 116 Wh/km, except in cases when the heater was used. When converted to AC-based ECR, values ranged from 111 to 162 Wh/km. The AC-based ECR is within a range similar to that obtained for the commute to work. The characteristics for the return commute to the domicile at night are summarized in Table 5 according to the use of AUXs.

3.4 Influence of the use of AUXs on ECR

The influence of the use of AUXs such as headlights, air conditioning, and the heater on ECR was examined. Of AUXs investigated, the heater had the most significant influence on ECR, with the ECR value being 1.4 times larger with the use of the heater as compared to the use of wipers or air conditioning (plus headlights in all cases; Table 5). Because the ECR value when using a highway is 1.2–1.3 times larger than that when driving on public roads, this precludes the use of the heater when driving on highways (Tables 4 and 5). The use of air conditioning or headlights had no similar influence on changing driving conditions. Figs. 4 and 5 show the seasonal changes of ECR for the commute to the workplace and return commute to the domicile, respectively. In both cases, ECR showed a similar range of values under the same AUX-use conditions. The distribution of ECR was caused by the differences in traffic under the real world driving conditions.

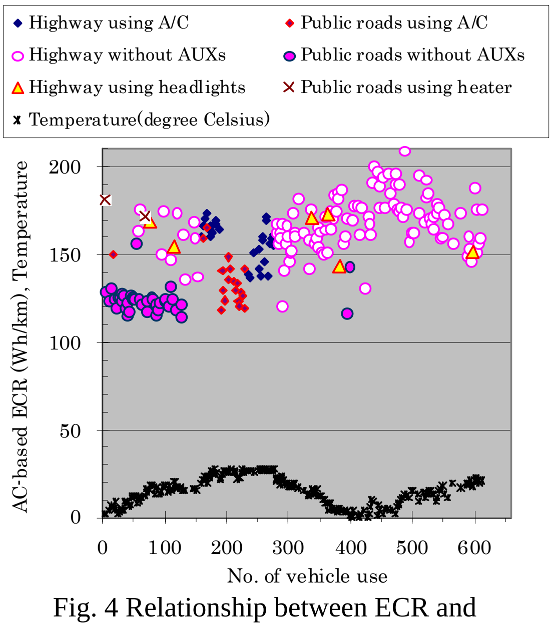

Fig. 4 Relationship between ECR and temperature for commute to workplace

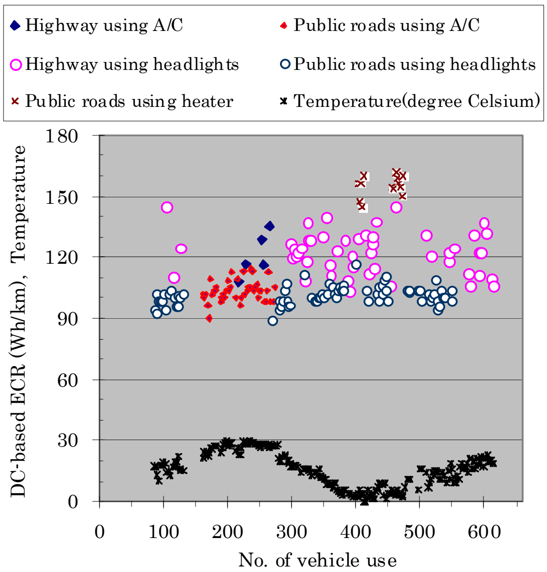

Fig. 5 Relationship between ECR and temperature for return commute to domicile

3.5 Driving range extension effect of reducing cruising speed

We studied the effect of speed management on driving range extension using data from the night commute, as it was judged that congestion on the highway during the morning commute would impact this value. The distance over which the volunteer used the highway was approximately 32 km, and he aimed to maintain the vehicle speed at 100, 90, and 80 km/h on respective nights. ECR for each journey was calculated according to evening return trip distance and electricity charged at the DC20kW quick charger. Fig. 6 shows the speed profiles when the vehicle was driven at the cruising speeds of 80, 90, and 100 km/h. Except when driving on the highway, the vehicle conditions such as time spent driving and speed driven were strongly affected by the traffic.

Each running energy value was calculated based on the speed data shown in Fig. 6 and divided into two parts: (1) the energy used for driving on the highway (highway energy consumption), and (2)

Table 4: AC-based ECR and average speed in the "commute to workplace" case

Road type when using the car	Use of auxiliary devices	No. of data	Electricity consumption rate (Wh/km)		Vehicle speed (km/h)		Trip distance (km/trip)	
			Average	Std. dev.	Average	Std. dev.	Average	Std. dev.
Highway and public roads	Nothing	117	168	15	51	4	54	1
	Air conditioning	28	158	11	52	4	54	1
	Headlights or wiper	6	161	12	50	3	54	1
	Total	151	166	15	51	4	54	1
Only public roads	Nothing (+w/ wiper)	39	125	8	27	2	59	3
	Air conditioning	20	135	13	28	4	59	3
	Heater	2	177	7	25	4	58	4
	Total	61	130	14	27	3	59	3

Table 5: DC-based ECR and average speed in the "return commute to domicile" case

Road type when using the car	Use of auxiliary devices	No. of data	Electricity consumption rate (Wh/km)		Vehicle speed (km/h)		Trip distance (km/trip)	
			Average	Std. dev.	Average	Std. dev.	Average	Std. dev.
Highway and public roads	Headlights (+w/ wiper)	49	122	10	50	7	51	5
	Headlights with air conditioning	5	121	11	49	7	51	2
	Total	54	122	10	50	7	50	7
Only public roads	Headlight (+w/ wiper)	96	101	5	36	4	56	2
	Headlights with air conditioning	44	103	5	35	3	56	2
	Headlights w/ Heater	15	153	7	37	2	55	1
	Total	155	106	16	35	3	56	2

* In this case, the driver always uses headlights due to nighttime use.

that used on public roads. Highway energy consumption was around 70% of total running energy on all nights.

The effect of speed management on the extension of travel distance was examined using ECR under each condition. A 10-km/h decline from 100 km/h gave a 7% improvement in ECR and extended mileage by 5 km over the actual vehicle range. A 20 km/h decline improved ECR by 12% and the mileage added was 8 km over the actual vehicle range. The electrical output was reduced by 23% and 40% at speeds of 90 and 80 km/h as compared to that at 100 km/h, respectively. The time to reach the destination increased by 2 and 4.5 min, respectively, as a result of the speed reduction.

3.6 Comparison with other means of reducing RA

The effect of speed management on range extension was compared with other means, such as the decrease of AUX use. Of the AUXs, headlights and wipers are necessary devices when they are used. Thus, the comparison was performed for the use of air conditioning and the heater. As shown in Tables 4 and 5, we could find very little effect on the ECR by the use or non-use of air conditioning, whereas heater use had a significant influence on the ECR. By not using the

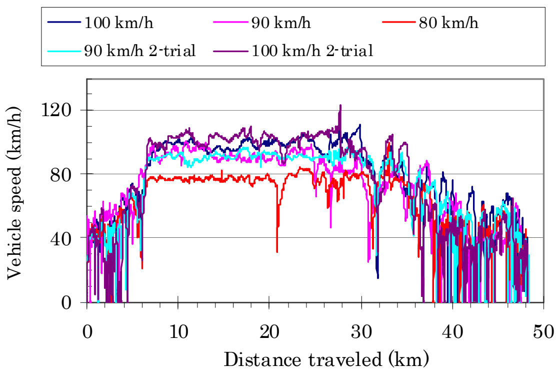

Fig. 6. Speed profiles on the highway trials

heater, the EV's range was extended by about 28 km. This effect was larger than that of reducing the cruising speed from 100 to 80 km/h.

An EV's heater has three main functions: defroster, defogger, and heating. The alternative plan for defrosting the windows is placing a sheet over the windows, at least the front window in order to prevent frost when the car is not in use. The defogger function can be replaced by using a product that prevents water droplets from becoming attached to a window. As for the third function, a driver can simply wear more clothing to prevent him or her from becoming too cold. These three means for non-use of the heater have commonly been discussed when we aim to improve the fuel economy of ICEVs. These are easy solutions.

4 Summary and conclusion

Based on actual use data recorded by a volunteer driving an EV where its catalogue mileage is almost equal to the daily travel distance from his home to his workplace and return commute, we found that both speed management and refraining from the use of AUXs, particularly the heater, were good measures for alleviating the RA of the EV. To clarify the performance specifics, we first calculated ECR when using the highway or public roads and when using AUXs. Highway driving involved 1.4–1.9 times higher average speed and 1.2–1.3 times higher ECR when compared to driving on public roads. When using a heater, ECR increased to 1.4 times the value when no AUXs were used. The use of headlights, wipers, or air conditioning had relatively small effects on ECR. Based on these results, we calculated that reducing cruising speed by 10 km/h from 100 to 90 and by 20 from 100 to 80 gave 7% and 12% improvements in actual vehicle range, respectively. The effect of speed management on the ECR was smaller than the non-use of the heater but larger than the non-use of air conditioning.

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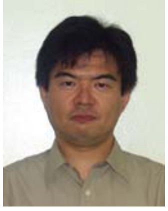

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