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Does "Driving Range" really matter?

The hidden cost of Internal Combustion Engine Vehicles and the potentially new value proposition of Electric Vehicles: Two cases from urban and rural Japan

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Abstract

This article proposes the selection model of optimal powertrain for usage conditions especially between Internal Combustion Engine Vehicles (ICE vehicles) and Battery Electric Vehicles (BEVs), which is possible “Disruptive Innovation” stated by Christensen (1997).

Using the statistics provided by official data of Japan, author estimated the average of actual maximum driving range of ICE vehicle currently sold. The analysis revealed that the actual fuel efficiency and maximum driving range of ICE vehicles is much lower than nominal one published by OEMs. After that, citing two cases of Japan, author examines the fit between the usage pattern and the choice of power train.

Discussing these cases and analysis, the author conclude that that the driving range of BEV dose not solely matter for optimal choice of powertrain. Rather, the driving range and the fit between usage patterns and the availability of “charging place” jointly affect to the optimal choice.

Key words: Innovation; Disruptive Innovation; Value Proposition; Diffusion of Innovation; Automotive Industry; Innovative Power Train; Fuel Efficiency; Driving Range; Electric Vehicle; Urban Mobility

Introduction and Research Motivation

Seven years have passed since the first practical electric vehicle launched in the market. In addition, it has passed more than 15 years since the car using an electric motor for hybrid power train introduced by Toyota. These facts suggest that it is appropriate timing to examine the impact and effect of the electrical power train as a "disruptive" technology for the automotive industry.

On the other hand, when we see the current situation of the automotive industry, it is doubtful that a specific disruptive technology will establish a dominant position in the future. In fact, the market share of EVs in Europe, USA, and Japan are only less than 1% as Table 1 shows. This data implies that the diffusion of vehicles with electric powertrain struggles all over the world.

Table 1: Number of EVs sold and its market share in Europe, USA, and Japan

	Number of Vehicles sold in 2014	Number of EVs* sold in 2014	Market Share of EVs* in 2014
Europe	12,550,707	75,331	0.60%
USA	16,435,286	118,773	0.72%
Japan**	5,562,752	29,809	0.54%

*: "EVs" consists from Battery EV, Plug-in HEV, and Battery EV with Range Extender.

Source: ACEA (Europe), EDTA (USA), JADA (Japan Vehicle), and CEV-PC (Japan EV)

What is the major obstacle of BEV diffusion? There is some discourse on this issue, such as purchasing price, number of charging stations, and driving distance. Deloitte Tohmatsu Consulting, LLC. (2015) pointed out that the biggest concern of BEVs was the price, and the next was the driving range. At the same time, the report pointed out that more than 80 per cent of consumers demands BEVs to have 320 km or more of maximum driving range. In this article, the author focuses on the issue of driving range to examine the performance gap between ICE vehicles and BEVs as a disruptive innovation.

Though, the maximum driving range itself has been less mentioned in the sales and marketing of ICE vehicles, as we can hardly find the figure on the catalogue. This is the initial motivation of the research. This research tries to calculate the actual performance gap between ICE vehicle and BEV in terms of driving range and propose the decision model of optimal powertrain mentioning the usage pattern of cars. In this paper, the author explore the potent new value proposition analyzing the cases in Japan. At the same time, revisiting the key performance indicator of existing value proposition, the author give more precision into the analysis of the performance gap between incumbents and new innovation.

The structure of this article is as below. At first, the author surveys the prior literature on innovation and diffusion of Alternative Fuel Vehicles (AFVs) to align the current situation of BEV innovation. Assessing the technological change of BEVs according to the concept of "Architectural Innovation (Henderson & Clark, 1990)" and applies the concept of "Disruptive Innovation (Christensen, 1997)" into the BEVs. Then, the author analyses the data official data on fuel consumption by vehicles to grasp the actual performance gap of driving range between ICE vehicles and BEVs. Subsequently, the author proposes two short cases to propose the unfit between usage pattern and selection of the power train. Using the case and data, the author discusses selection model of an optimal power train of vehicles.

Literature review

Prior research on innovation and technological change

There are several types of axis to distinct the patterns of innovation and technological change, such as radical / incremental (Dewar and Dutton, 1986), competence-enhancing / competence-destroying (Tushman & Anderson, 1986), modular / architectural (Henderson & Clark, 1990), and sustaining / disruptive (Christensen, 1997). The author focuses the latter two concept to define the innovation of BEVs in this article, since prior research define the BEVs as radical or disruptive innovation (Barkenbus, 2009: Midler & Beaume, 2010; Pohl & Elmquist, 2010) without close investigation.

Through analyzing the change of knowledge of components and architecture, innovations can be classified into four patterns as incremental, modular, architectural, and radical (Henderson & Clark, 1990).

Regarding the technological characteristics of BEVs currently sold in the market of developed countries, the pattern of their technological choice is diversified among vehicle models. Some of them, such as Renault ZOE, Nissan LEAF and VW E-Golf can be categorized as "Modular Innovation." Since they were developed using incumbent architecture of ICE vehicles. The engine under the front hood was replaced by electric motors and the fuel tank replaced by batteries. On the other hand, the other such as BMW i3 and Tesla Model S can be categorized as "Radical

Innovation." Since they introduced completely different architecture from existing ICE vehicles. BMW developed body cell using CFRP and installed electric motor on the rear axle. Tesla, which is a new entrant, developed aluminum floor integrated with battery and installed motors on both of front and rear axle.

This data shows that the categorization of technological change of BEVs is yet unsettled since each company attempts the different types of the technological solution to develop BEVs. Even in some case, it would not be defined "Radical," unlike the exiting literature.

<u>Prior research on "Disruptive Innovation"</u>

Christensen (1997) pointed out that the "Disruptive Innovation" is the innovation with cheaper price and lower performance than the existing product. The logic of the disruption is that the "Introducing New Value proposition." Citing the case of the hard disk drive industry, it revealed that the defeat of the existing champion company occurs when the new and smaller form of drive introduced.

The new and smaller disk drives perform less than the existing one in terms of capacity and access speed. And counter-intuitively the existing companies do not elaborate to develop this type of disk drives, since the customer of existing companies have no interests in such a less-performed products. Subsequently, the new disk drives find the new market and diffuse into it, thanks to the cheaper price and smaller form, which new market highly valued as a new value proposition. Finally, the disruptive innovation gets the rapid improvement of it performance using the "Sustaining Innovation" and capture the market of existing company after all.

There is some controversy on the concept of "Disruptive Innovation." Markides (2006) states that it should be distinct among radical product innovations, business-model innovations, and technological innovations. Gans (2016) pointed out that there are many cases of the problematic overusing of the disruptive innovation theory and its narrow source of theory as problem. However, the significance of the theory and its logic mentioning the organizational behavior against the technological change is useful to examine the potential of new innovation.

Hereafter, there is a question whether BEVs is "Disruptive" or not. Though Christensen (1997) itself discussed about the issue of BEV, the data and circumstances has been changed at all during this decade. Thereafter, the author attempts to apply this theory onto the automotive industry.

i-MiEV, the first practical mass produced BEV was introduced from MMC, which is the existing ICE vehicle producer, in 2009. And it was followed by Nissan Leaf in 2010. On the new entrant side, Tesla Motors began to sell Model S, its first self-developed practical vehicle, in 2012. As of 2016, the BEVs are sold from both of existing companies and new entrants, however, some of existing ICE producers such as Toyota and Mercedes-Benz hasn't sold BEVs yet.

The sales growth rate of BEVs is much higher than that of ICE vehicles, even though the price is higher and the performance of driving range is lower than ICE vehicles. Therefore, evaluating the innovation of BEVs in terms of "disruptiveness" is yet too early as well since no incumbent OEMs has exit from the industry and the market share of BEVs is still small. However, with analyzing the characteristics of innovation through case study, its extent of potential "disruptiveness" can be assessed.

The question to distinct the disruptiveness of the innovation is “what is “New Value Proposition” of BEVs?” In the following section, the author hypothetically proposes the new value proposition of BEVs as the “new pattern of charging” using the “charging base” located locally in the home of users.

Prior research on the diffusion of AFVs

When assessing the “disruptiveness” of innovation, it can be useful to examine the driver of diffusion to evaluate the value proposition of innovations. Prior researches on the diffusion of AFV, such as NGV, BEV, PHEV, and FCEV, have revealed the factors stimulating or preventing the diffusion of AFVs using agent-based modelling and descriptive analysis.

A case of PHEV shows that the “mainstream” market bias becomes an obstacle of diffusion of AFVs and it can be overcome with more efficient policy to cultivate niche markets, which accelerates the diffusion of complementary assets of the AFVs (Green et al, 2014).

The failure of NGV diffusion in Germany was caused by coordination failure in complementary markets, legal regulations, bounded rationality of consumers, information asymmetry, and principle-agent problem between OEMs and government (von Rosenstiel et al., 2015).

In the first decade of 21st century, the number of companies that develop BEVs was hugely increased. Though both of large incumbent and new entrant develop EVs, there is a difference of targeted market and diffusion strategy (Sierzchula et al, 2012; Dijk, 2014). Descriptive analysis shows that financial incentives and number of charging stations per capita affects the adoption late of BEVs in a certain country

(Shafiei et al., 2012; Sierzchula et al., 2014). Additionally, awareness campaigns and word of mouth would effective for short to medium term, and vehicle abandon policy should be employed (Zhang et al., 2011; Browne et al., 2012)

An agent based model analysis using the data of Berlin shows that the BEV-exclusive zoning for city center and tailored incentives for each heterogeneous customer needs (Wolf et al, 2015).

One of the problem of these prior research is that they focus only the existing value proposition of vehicles. Foster (1986) pointed out that comparing the performance indicators used for incumbent products, innovative products performs less than incumbent ones. Therefore, it is intuitive to be resulted that BEVs should enhance its performance of driving range and charging time to accelerate the diffusion regarding prior research. At the same time, prior research pay more attention to “public” charging stations meanwhile pays less attention to “personal” charging station (Bae, 2012), since there is no concept of “personal” gas station historically. Thereafter, these kind of research can hardly distinct the “new customer value proposition,” which drives a company into new market with new architectural technologies (Christensen 1992).

Comparison of driving range between ICE vehicles and BEVs

In this section, the author analyzes the performance gap between the existing product and potentially "disruptive" product in terms of driving range, which can be the biggest justifier not to buy BEVs by customers.

It is easy to find the driving range of a BEV from its catalogue and the OEMs emphasize the improvement of this performance indicator. On the other hand, we can hardly find the driving range of ICE vehicles from their catalogues. Usually OEMs emphasize fuel efficiency as their performance indicator and the competition of the performance is very serious.

Thus, here arise one question. "People emphasize BEVs incompetency citing its shorter driving range, but is there any precise information about the driving range of ICE vehicles?" One of the possible answer of it is "We don't need to take care of it, because the maximum driving range of ICE vehicles should be long enough citing the fuel efficiency data."

How can we calculate the driving range of ICE vehicles? The simplest way is to multiply the fuel efficiency of with the capacity of the fuel tank. The figure proposes the driving range of C-segment vehicle models sold in Japan.

Table 2: Calculated Driving Range of c-segment car sold in Japan

OEM	Name of Vehicles	Fuel tank (l)	JC08 (km/l)	Range (km)
Toyota	Aqua_HEV	36	37	1332
Toyota	Yaris	42	21.6	907.2
Nissan	Note	41	23.4	959.4
Nissan	Micra	41	21.4	877.4
Honda	Fit	40	21.8	872
Honda	Fit (smaller tank)	32	26	832
Honda	Fit_HEV	40	33.6	1344
Honda	Fit_HEV (smaller tank)	32	36.4	1164.8
Mazda	Demio	44	24.6	1082.4
VW	Polo	45	21.9	985.5
Audi	A1	45	22.9	1030.5
Peugeot	208	50	18.2	910
Citroen	C3	50	19	950
Mini	Mini ONE (3Dr)	40	19.2	768
Mini	Mini COOPER (5Dr)	40	17.9	716
Fiat	500	35	24	840
Average		40.8	24.3	973.2

The calculated driving range of these vehicles is so much longer than the one of BEVs sold in Japan. At a glance of this difference, there seems to be no room for BEVs in Market. But there is some problem of comparison.

Both of the fuel efficiency indicator if ICE vehicles and driving range indicator of BEVs can hardly describe the actual performance of cars. These indicators show only the fixed pattern set by authorities such as MLIT of Japan, EPA of USA, and EU. And there has always been the controversy about the gap between actual performance and the nominal performance.

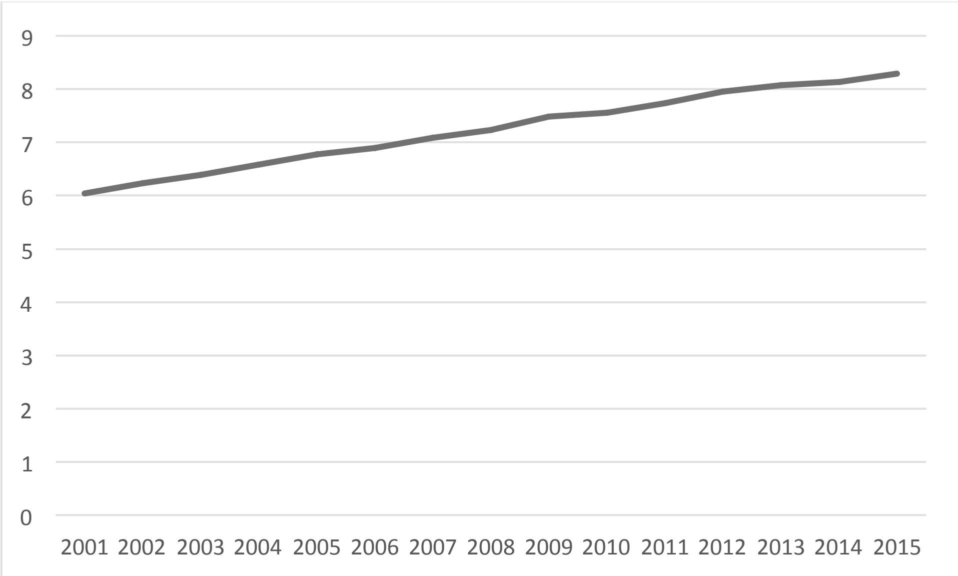
The data from MLIT shows that the total usage of fuels and the total mileage run by vehicles monthly. Using these data, the average actual fuel consumption by vehicles can be calculated. The figure 3 shows that the average actual fuel consumption is much lower than a nominal one calculated from the catalogue. There might be some critics that the aggregate data contain older vehicles with lower performance.

Figure 3: Transition of actual Fuel Efficiency from 2009 to 2015

Fuel Efficiency (km/l)	2009	2010	2011	2012	2013	2014	2015
Regular Car	8.29	8.26	8.33	8.36	8.36	8.50	8.80
Small Car	11.27	11.27	11.31	11.42	11.28	11.44	11.61
HEV	16.15	16.26	16.11	16.04	16.03	15.91	15.96
Micro Car	12.50	12.60	12.82	13.12	13.32	13.85	13.73
Total Average	10.54	10.64	10.77	10.98	11.12	11.50	11.70

AIRIA (2016) stated that the average age of the passenger vehicle in Japan is 8.29 years as of March 2015. At the same time, the yearly average actual fuel consumption of vehicles shows that the improvement of actual fuel consumption is between one per cent and two per cent per year for this 7 years.

Figure 4: Transition of average age of passenger vehicles in Japan, 2001-2015 (unit: year)



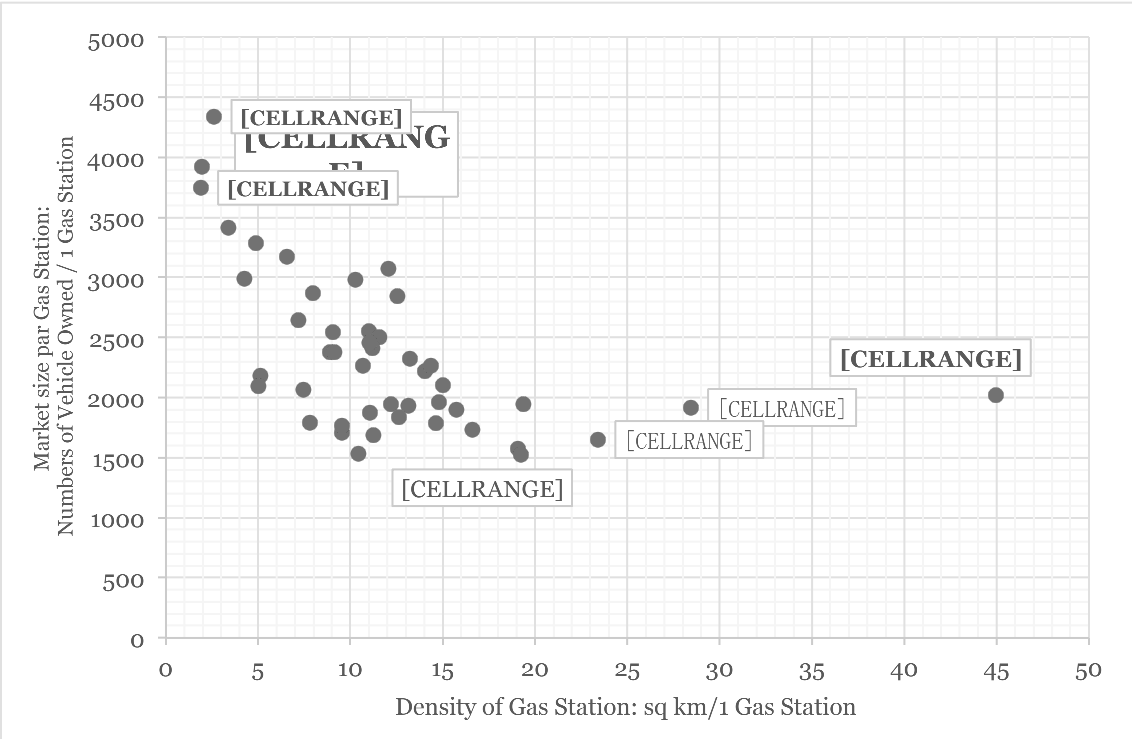
At the same time, as seen on the figure 4, the average age of the passenger vehicle steadily increasing for more than a decade. These facts show that the actual fuel efficiency of cars only slowly improving and the actual driving range of ICE vehicles keeps to be calculated between 400 and 500 km during this period.

Meanwhile the driving range of BEVs depends upon the capacity of batteries. The average capacity is increasing faster than the improvement of fuel efficiency. Additionally, IID Inc. (2015) analyzing the OBD2 data of Nissan Leaf and shows that the gap between nominal and actual performance of the Nissan Leaf is narrow. Then, the performance gap of driving range between BEVs and ICE vehicles can be said narrower than believed.

<u>Background of the case: Accessibility to gas station</u>

In Japan, the number of gas stations is rapidly decreasing while the number of cars owned by consumers is gradually increasing. This means that the accessibility to the gas station is becoming worse. Especially in the countryside of Japan, the number of gas station and its accessibility is worse than the urban side. The figure shows that both the density of gas stations and the number of vehicles par gas station in the countryside is much lower than that of urban side.

Figure 5: Analysis of the accessibility to gas station by prefecture



Regarding the figure above, the density of gas station is so much varied among prefectures in Japan. There is one gas station per 1.86 square km in Tokyo while there in one gas station per 44.56 square km in Hokkaido. This difference directly affects to the availability of gas stations for customers. Moreover, the market size of a gas station is varied as well. In Tokyo, there are 3019 vehicles par gas station while there are 1778 vehicles par gas station in Hokkaido. This difference affects to the business circumstances of each gas station and the decline rate of it.

The accessibility to gas station affects to the frequency of refueling from customer point of view. If nearest gas station locates far from the home, users tend to go gas station less frequently. Meanwhile, users tend to avoid running out of gas as well. Thus, users of vehicles struggle with this dilemma and prefer to buy ICE vehicles with higher fuel efficiency rather than BEVs, which has a shorter driving range.

Describing the following two cases in Japan, the author highlights the unfit between the power train of vehicles and the usage patterns, mentioning about the context of refueling.

Case of countryside in Japan: Small agricultural business and micro-truck

One of the representative case showing the disadvantage of ICE vehicles would be the small agricultural business in the countryside in Japan. They operate multiple numbers of micro trucks so called "Kei-Tora" in Japanese and light duty trucks for daily business and consume tens of liters of gasoline every day.

In Yamanashi prefecture, which located 100 km west from Tokyo, there are numbers of small agricultural business growing peaches and grape in the Kofu basin and on the slope of its peripheral mountains. In many cases, their firm field scatter around the area and they need to run around their fields and the trip distance of their trucks is 50 to 100 km per day. At the same time, the truck is fully loaded with tools, workers and harvests. Then, the fuel efficiency performance and the actual driving range of trucks become much worse than nominal index.

Moreover, the distance between firm fields and gas station becomes the burden for their operation. According to Figure 5, the density of gas stations in Yamanashi prefecture is one gas station per 10.36 square km, which is more than five times less dense than that of Tokyo. Then they have to drive 15 minutes or more to reach the nearest gas station. The fact makes vehicle users go to refueling in good time to avoid running out of gas. At the same time, it takes about one hour to go and refuel.

One owner of such a business says, "We have to refuel each truck twice or three times a week. During the busiest period, we have to assign one employee dedicate for refueling. The labor cost of it reduces the profit." This can be calculated that if the business operates 10 trucks, each truck needs to be refueled three times a week, and it takes 1 hour to go refuel, 30 hours of working hours spent in one week.

The owner said "The worst thing is the running out of gas in the middle of an operation. Then it is needed to go the gas station suspending the task. It significantly reduces the occupancy rate and productivity."

Wrapping up this case, there is unfit between the usage pattern of the vehicle and the location of gas stations. This unfit causes the problem on daily operation and business profit.

Case of urban side in Japan: Taxis in Tokyo

In Tokyo, 19 of i-MiEV and Nissan Leaf introduced as taxi in 2012. However, almost all of these vehicles retired from taxi usage and sold in used car market by 2015. A few Tesla Model S serves as limousine in Tokyo as of 2016. Using the other words, BEVs were incompetent against ICE vehicles in the taxi market of Tokyo.

The cause of incompetency was driving range. These two vehicle models had 100 km to 200km of nominal driving range. And the actual driving range of these cars was much less than the nominal one. In an extreme case, Nissan Leaf, which has 200 km of nominal range could run only 100 km or less.

On the other hand, the daily average travel distance of taxi in Tokyo is more than 400 km. Therefore the BEV taxi needed to charge its battery three or more times a day.

Moreover, the traveling distance of each customer is highly varied. For example, if the customer orders go Narita International Airport from Shinjuku, the driving distance is around 80 km one way. This means that the BEV taxi has possibility to charge its battery on the way to the airport with its customer. Even if the taxi could reach the airport without charging, it needs to charge its battery to get back to Tokyo.

Wrapping up this case, there is unfit between the usage pattern of taxi and the performance of driving range as well as the charging time. This unfit causes the defeat of BEV taxi in Tokyo.

Discussion

Regarding these two contrasting cases, the fit between usage pattern and performance is critical to select the optimal powertrain for vehicles. In the first case, the workplace and traveling route are fixed and the gas station is distant from the workplace. At the same time, multiple vehicles are cooperating in operation. Then, refueling becomes the cause of task interruption and labor cost.

Otherwise, in the second case, traveling route and distance is not fixed ex ante. At the same time, each vehicle is operating independently and can easily find its nearest gas station. Thus, keeping the driving range longer is critical to their business and refueling it is not the burden while longer charging time of BEVs is undesirable because it lowers occupancy rate.

Thereafter, the author hypothetically proposes a decision model of an optimal power train of vehicle mentioning mileage and refuel. As discussed, if the potential users can own their "base" to charge the BEV, they can recharge their vehicles every day. On the other hand, it is not realistic to assume that the potential users of ICE vehicles own gas station by themselves. Thus, the users of ICE vehicles have to visit the nearest gas station to refuel their vehicles as the fuel decrease up to a certain level.

This means that the driving range of ICE vehicles cannot always be fully exploited while BEV with their own base can enjoy its maximum performance every morning. The graph below shows the difference of the transition of each car's driving range. As shown, even though the maximum driving range of BEVs is shorter than ICE Vehicle, daily recharge enables to exploit the full capacity every day.

When the owners of BEVs have their own charging base at home, BEV becomes an indifferent choice from ICE vehicle in terms of everyday usage if the following inequality is fulfilled.

D(expect/day) < rMax(Vehicle) and t(charge to max) < t(idle time on each day)

d(expect/day): expected travel distance per day

rMax(Vehicle): maximum range of the vehicle chosen t(charge to max): charging time to maximum range

t(idle time on each day): idle time of vehicle on each day

In detail, it can be explained that as below. Regarding the first inequality, if the daily driving distance is longer than the maximum driving range of vehicle, ICE vehicle has its advantage of quicker refuel. However, this situation rarely occurs in actual usage by consumers since the driving range of cars are far more than average driving distance.

Meanwhile, the situation of fleet users is different in many cases. Especially, daily driving distance of taxi is more than 200km every day. The Japanese law sets the limit of daily driving distance of taxi driver as 365km.

Regarding the second inequality, if the charging time to compensate the consumption of each day is longer than its everyday idle time, the daily maximum driving range steadily decreases. This case can be occurred on EVs with large battery capacity.

On the other hand, no ICE vehicles have this issue since the refuel takes a few minutes even if the fuel tank has 100 liter capacity. Though, ICE vehicles need to go nearest gas station to refuel.

Figure 6: Comparing the transitions of daily maximum driving range, assuming the constant driving pattern between BEVs and ICE vehicles.

Assumption 1: Mean trip distance: 30km / day, S. D. of trip distance: 10km

Assumption 2: BEVs can recharge every night, ICE vehicles go refueling when the rest of driving range below 100 km.

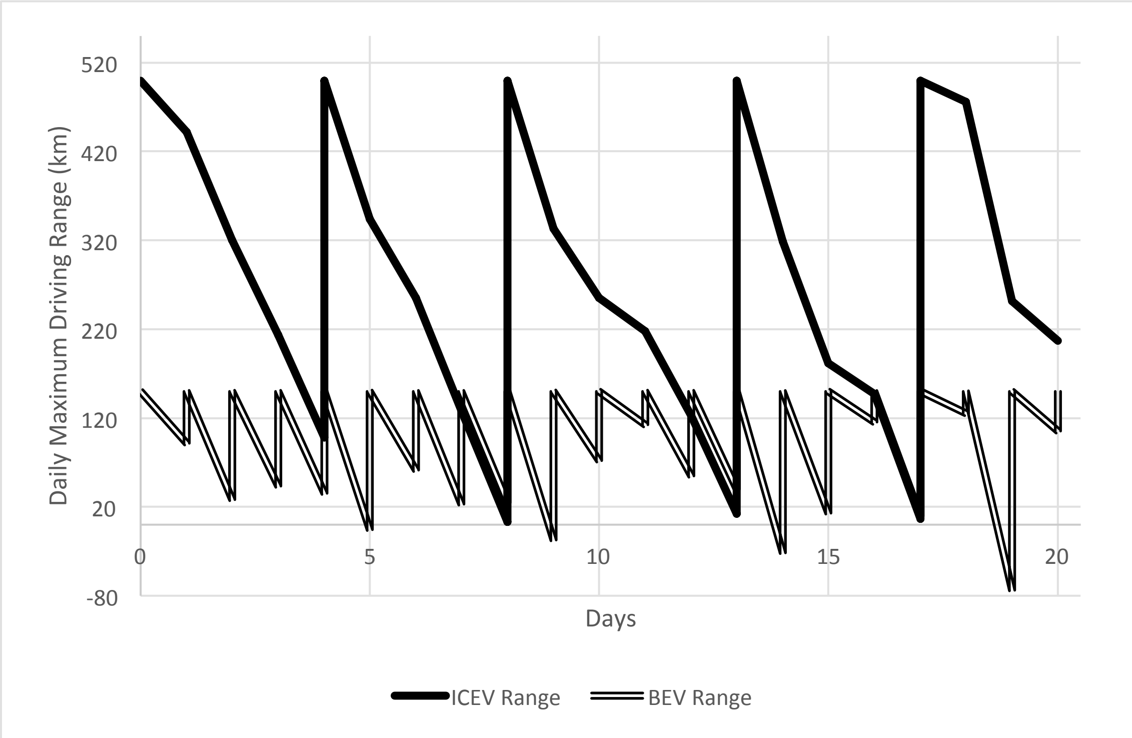
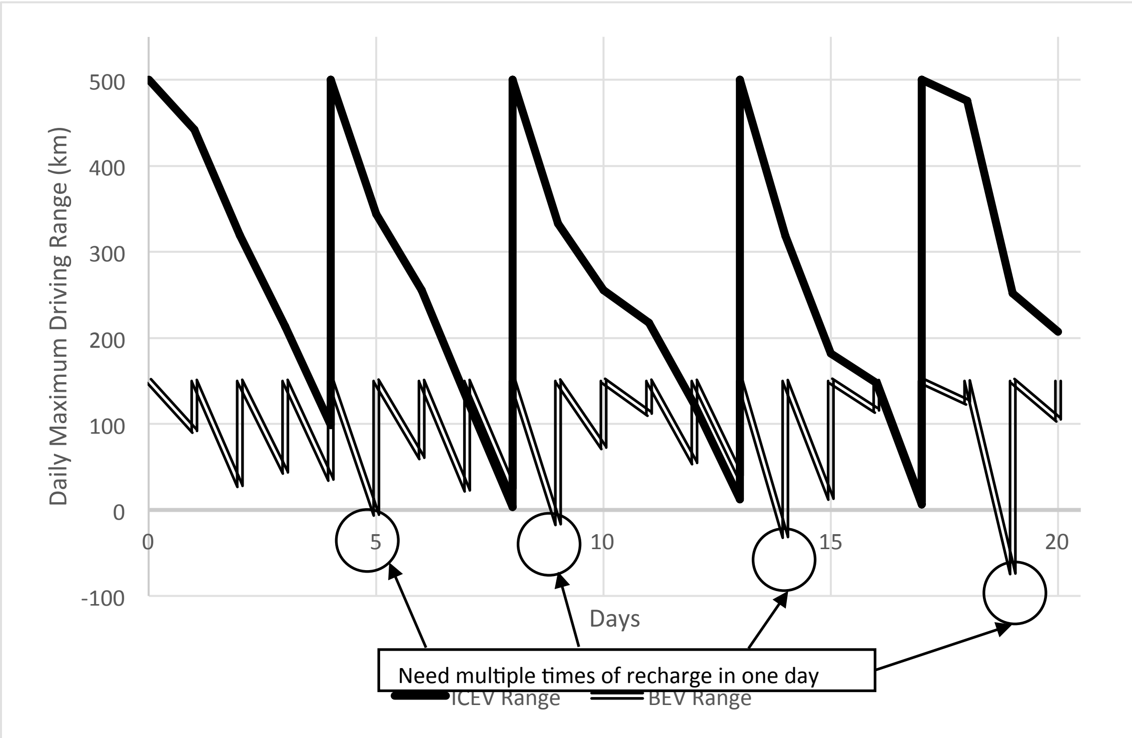


Figure 7: Comparing the transitions of daily maximum driving range, assuming a varied driving pattern between BEVs and ICE vehicles.

Assumption 1: Mean trip distance: 70km / day, S. D. of trip distance: 50km

Assumption 2: BEVs can recharge every night, ICE vehicles go refueling when the rest of driving range below 100 km.



Additionally, assuming that the driving pattern is constant every day such as commuting and routinized operation, the value of BEVs is enhanced thanks to the daily recharging, as we can see on Figure 6. Meanwhile, assuming that the driving pattern is varied every day such as taxi and non-routinized operation, the value of ICE vehicle is enhanced thanks to quicker refuel and longer maximum driving range as discussed above. In some case, BEVs need to recharge multiple times per day as we can see on Figure 7.

Using this model, it is found that usage patterns of major consumers can be covered with BEVs as well as ICE vehicles. However, the cost and labor of refueling would make BEVs more reasonable than ICE vehicles.

Prior research expected that BEVs would be adopted as smaller city cars in urban area, with limited needs of mobility and higher willingness to pay for eco-friendly innovations (Sierzchula et al, 2012). However, this article suggested that BEVs with shorter driving range are rather not suitable for usage in urban area because it is difficult to keep personal "charging base." With the new value proposition of personal charging base, which is more available in the countryside, the performance gap between ICE vehicles and BEVs can be narrowed.

<u>Conclusion:</u>

As Christensen (1997) pointed out, "Disruptive Innovation" is not attractive for existing companies because its lower performance doesn't attract the existing customers. Applying this fact, BEV can be a kind of "Disruptive Innovation." In this article, the author pointed out that the performance gap between ICE vehicle and BEV is rather smaller in actual usage condition using the statistical data of vehicle usage in Japan.

After that, the author pointed out that the changing pattern of usage enables the overcome the performance gap between ICE vehicle and BEVs. If there is "charging base" for each BEV, the user can enjoy its maximum performance and become free from the burden of refueling. If the usage pattern of major customers fits with this "new value proposition", BEVs can become "Disruptive Innovation."

On the other hand, there is still some "room" that ICE vehicle has advantage against BEVs. Citing the case of taxi in Tokyo, if the traveling distance is longer and not expectable, the longer charging time harms the value of BEVs. Especially, if the occupancy rate of the vehicle and availability for the customer are the critical for its business, such as taxi, ICE vehicle would be best solution for taxi business until the performance gap of charging time will be overcome.

The discussion of the cases proves that there are three performance indicator, such as driving range, charging / refueling or charging time / refueling frequency, significantly affect to the selection of optimal power train of vehicles.
Therefore, different from the statement of Christensen (1997), which pointed out that the "Disruptive Innovation" finally disrupt the existing company and products, multiple technological solution will co-exist in the automotive industry according to the findings of this article unlike the hard disk drive industry.

The findings of this article contribute to both of consumers and companies to help their selection of optimal power train of vehicles. Especially, the finding that BEV happens to be less competent in the urban side because of easier access to gas stations and difficulty to keep charging base for idle time points out the desirable measure for the diffusion of BEVs. From a strategic point of view, BEVs may rather accepted by consumers and business using vehicles in routinized pattern in the countryside. While shortening time of charging and expansion of charging station is critical to accelerate the diffusion of BEVs in urban side.

Additionally, the finding of this article implies that the better policy to accelerating the diffusion of BEVs would be financial support for installing "personal charging base" for consumers. Though prior research implied that increasing the number of "public charging station" to stimulate the diffusion of BEVs (Sierzchula et al., 2014), the outcome would be smaller because the disadvantage of charging time cannot be overcome through this solution.

And last but not least, there is obviously the limit of research in this article. Firstly, the data used is aggregated and only in Japan and outcome is highly contextualized. The preference of users and usage pattern may differ among countries. Secondly, it should be possible to gather the detailed data about usage patterns. And finally, it is argued that there is the technology race between BEVs and FCEVs (Ball et al., 2009). The comparison between BEVs and FCEVs is not done in this article, even though the selection model possibly be applied. Expanding the application of the model for multiple types of alternative fuel vehicles, it would become more better to describe and forecast the diffusion of AFVs.

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