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Diffusion of Electric Vehicles and Novel Social Infrastructure from the Viewpoint of Systems Innovation Theory

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SUMMARY This paper describes diffusion of electric vehicles and novel social infrastructure from the viewpoint of systems innovation theory considering both human society aspects and elemental technological aspects. Firstly, fundamentals of the systems innovation theory and the platform theory are mentioned. Secondly, discussion on mobility from the viewpoint of the human-society layer and discussion of electrical vehicles from the viewpoint of the elemental techniques are carried out. Thirdly, based on those, R & D, measures are argued such as establishment of the ubiquitous noncontact feeding and authentication payment system is important. Finally, it is also insisted that after the establishment of this system the super smart grid with temporal and spatial control including demand itself with the low social cost will be expected.

key words: *systems innovation, electric vehicle, battery, diffusion, ubiquitous power feeding and authentication payment system, electric vehicles last 10 m's problem, five principles of systems innovation*

1. Introduction

In the United States, the Ford Model T emerged about a century ago and marked a start of motorization. In Japan, a rapid motorization occurred after the 1950s and the post-motorization age is approaching. Revisions to Japanese traffic laws, strong traffic safety measures, and the development of driving assistance systems have contributed to the reduction of illegally-parked cars, traffic jams, and in the recent eight year period the halving the number of traffic fatalities [1]. There is a large environmental impact due to automobile usage and there is significant incentive to reduce this impact.

CO_2 is often pointed out as a cause of the global warming trend, and it has been discussed to cut social dependence on fossil fuels. With a view to the modal shift to non-fossil fuel power plant, the diffusion of electric vehicles that can utilize the regenerative electric power is expected to contribute reduction of the effects on the environment; many projects and discussions have addressed these topics, e.g., [2].

On the other hand, from the viewpoint of human society, in addition to the CO_2 reduction, change in society's sense of values of vehicles as a status symbol has been observed recently. A trend in the urban young adult segment is not to desire vehicles with a decrease in car ownership and a partial modal shift to bicycles. Moreover, considering performance advances in batteries and payment systems as elemental technology, we can see the future solution [3].

From the viewpoint of the systems innovation theory, considering the shift from car traffic to an electric vehicle society, this paper describes research and development in technology and measures that are desired to be taken to provide a solution; i.e., realization of the "Ubiquitous power feeding and authentication payment environment" by settlement of "Electric vehicles last 10 m's problem" with diffusion of the reasonable authentication payment systems; in addition, this paper also describes that "the super smart grid" issue will be important after the realization of the above mentioned environment.

2. Systems Innovation and Platform Theories [3]–[9]

2.1 The Three Layer Model from Science and Engineering to Human Society

The author has proposed a three layer model from science and engineering to human society as shown in Fig. 1 to clarify the location of the systems innovation theory. The first layer is the elemental technology layer that mainly consists of subdivided traditional science and engineering fields. The third layer is the human society layer (i.e., where we exist); the second layer is the systems innovation layer to create innovative systems to be useful for human society utilizing technologies from the subdivided science and engineering layer.

The upper layer has system-like and collective meanings. On the contrary, the lower layer has subdivided and elemental meanings.

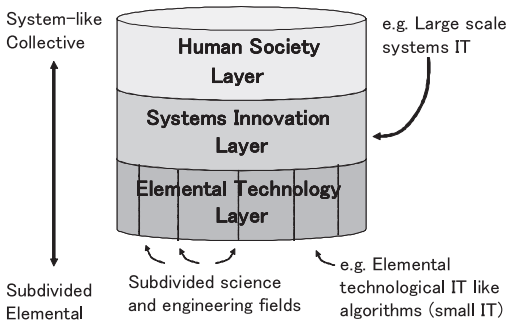

Fig. 1 Three layer model from science and engineering to human society.

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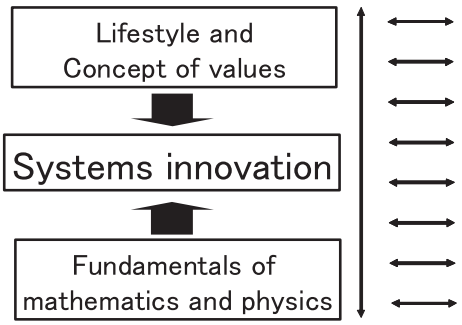


Fig. 2 Two important matters for systems innovation, and desired project organization structure for research and development as well as systems diffusion.

2.2 Fundamentals of Systems Innovation and Project Organization Structure

In the above mentioned systems innovation theory, the author has pointed out that there are two important matters for systems innovation as shown in Fig. 2; i.e., accurate consideration of people's lifestyle and concept of values, and understanding of fundamentals of mathematics and physics to indicate the desired project organization structure for research and development as well as systems diffusion. And the author has also proposed the importance of collaboration between the director that considers all the layers and experts in each layer.

2.3 Five Principles of Systems Innovation

The author has proposed the five principles of systems innovation described below:

(1) The most significant concept is that systems exist for human society. Systems innovation (planning, design and diffusion) should be done with this concept;
(2) Existing technology should be made the most use of; even if modification is needed, the least modification should be done. When utilization of legacy systems or subsystems is impossible, we try to do the systems or subsystems innovation;
(3) Platforms are common property of all humankind. Platforms should be designed with following "the platform's cardinal rule" and should be nonexclusively created with collaborative activity; applications on the platforms and devices to support the platforms should be competitively supplied. In addition, the basic design should be considered under the premise that systems will continue to migrate and evolve;
(4) Systems innovation should be considered under the condition that people's belongings are within one device and multiple cards (One Device/M Cards' law);
(5) Government is a promoter. After the promotion period the systems should not require any further subsidy.

Here, "the platform's cardinal rule" proposed by the author means basic design scheme that is independent of not only particular applications on the platform but also particular sub-platforms under the platform. In addition, the premise of systems migration means that platforms have the property of buffers (vertical division) without their final forms, and have basic design to continue to evolve.

Moreover, "One Device/M Cards' law" means the condition of constraint that is considered important by the author in the step of making the concretization way down the stairs mentioned below; i.e., human beings tend to move with such limited belongings as one device and multiple cards, therefore if a system requires users to carry something beyond this limit, the system tends to be hard to start-up and diffuse. However, extremely small portable music players, glasses, and key rings, etc. are not included.

In addition, there is one more important matter. If a system is planned on the premise of 100% diffusion, it is hard to start-up and to diffuse; systems should be designed to work well under the low diffusion rate as well as the high diffusion rate.

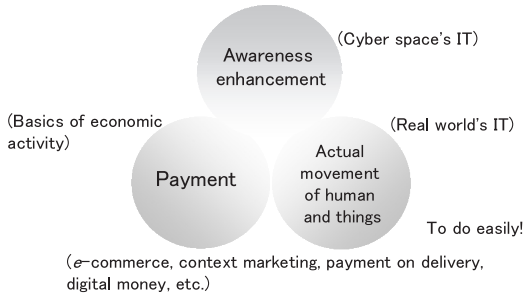


Fig. 3 Ubiquitous age systems innovation economic vitalization triangle.

2.4 Ubiquitous Age Systems Innovation Economic Vitalization Triangle

The author has proposed the ubiquitous age systems innovation economic vitalization triangle that consists of three elements for systems to become in society as shown in Fig. 3. The first element is the information technology for cyber space like the internet beyond time and space explosively developed in the 20th century; awareness enhancement is a basic element in it, and the cyber space is its main subject. The second element is intended for actual movement of human and things; in another word, real world's information technology that will be more and more important in the 21st century. The third element is the payment to exchange provided things or services and the appropriate value; this is the basics of economic activity.

All three elements (i.e., awareness enhancement, actual movement and payment) should be intuitive or easy for the users to understand to allow the system to be easily accepted.

2.5 The Germ of Idea in Systems Innovation

Figure 4 illustrates the germ of idea in systems innovation;

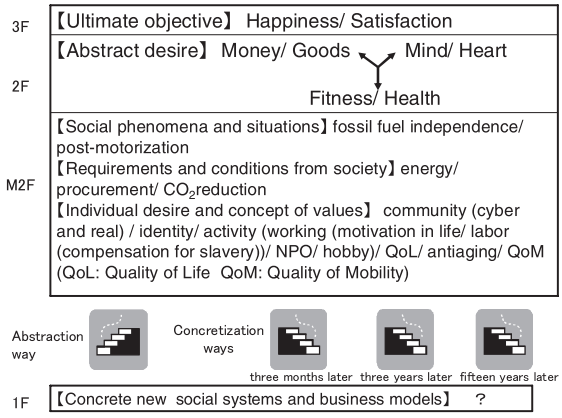


Fig. 4 Germ of idea in systems innovation; the abstraction way up the stairs, and concretization ways down the stairs.

i.e., the abstraction way up the stairs, and the concretization ways down the stairs. In systems innovation, the way of thinking of easy application of elemental technology or superficial utilization of idea is ineffective; it is important to make appropriate abstraction step-by-step at the first phase of systems innovation like making abstraction way up the stairs, and it is also important to make appropriate concretization step-by-step with considering social and technological conditions mentioned below at the second phase of systems innovation like making the concretization way down the stairs. Systems realization is required or planned at fixed periods; e.g., three months later, three years later, or fifteen years later, etc. Therefore each solution three months later, three years later, or fifteen years later has its own particular boundary conditions satisfied; i.e., development of elemental technology at that time, research and development at that time, people's lifestyle and concept of values at that point, people's belongings at that time.

Such a layered step-by-step way yields different but reasonable systems innovation that has a higher probability of success.

3. Consideration of Mobility Related Matters from the Viewpoint of the Human Society Layer

3.1 Soaring of Fossil Fuels Pricing and CO_2 Reduction [3]

In 2008, the soaring fossil fuel prices and the rapid deterioration of the economic situation which started the financial crisis of the United States have given rise to the following phenomena in Japan:

(1) Reduction in the use of automobiles
(2) A partial modal shift to bicycles
(3) Decline of new-car sales

It is too easy that there are only economic reasons to give account of the phenomena. The soaring fossil fuel prices in 2008 reduced the road traffic, and traffic congestion in Japanese expressways was considerably suppressed. In that sense, in particular, for higher socioeconomic groups, the rise in fuel has not always negative meanings.

In recent years, even before the economic crisis there was declining sales in large and high-fuel consumption vehicles. There was large demand for hybrid vehicles that can reduce CO_2 emission among large and expensive cars. Receiving media converge, CO_2 reduction has become important matter; everyone must make consideration to the matter. Therefore, incentives to buy vehicles with high fuel consumption could decline. A few years ago, Hollywood actors actively started to purchase hybrid cars. This behavior can give the reason of the abovementioned conjecture. This way of thinking will soon become common in society.

The demand shift to low CO_2 emission vehicles from traditional vehicles becomes more than just a trend; each auto company has strengthened the response of the trend, however, in the not-so-distant future, people will desire CO_2 zero emission vehicles not CO_2 reduced emission vehicles.

Under such a situation, shift to mobility by natural energy or nuclear power generation and electricity energy from mobility that depends on fossil fuels is a natural tendency.

3.2 Lifestyle and Concept of Values [3]

In the past, to possess s large luxury car with greater fuel consumption was a proof of success; Elvis Presley as well as Marilyn Monroe did; i.e., this meant a social status symbol. Nowadays, this way of thinking is less common. On the other hand, [10] reports a new trend that young people in urban are away from cars in Japan. In addition, there is a considerable reduction in the number of car magazines. The trend of commuters' partial modal shift to bicycles from cars became obvious in when the fuel prices soared 2008. However after recovering in the previous price level, many commuters have kept using bicycles. This means there are several reasons, other than economic ones, for the continued use of bicycles:

(1) Fitness/good for health
(2) Being a good habit and enjoyable
(3) Being often time efficient
(4) Feeling good about zero emission
(5) Feeling good for wind and for moving by own power

Bicycles have been in good demand before the economic crisis in Japan, the U.S. as well as Europe; in particular, resent years, expensive sports type bicycles have been in good demand [11]. This phenomenon means that shifts to using bicycles are not necessarily caused by economic reasons.

After enacting the basic low for transport (Loi d'orientation des transports intérieurs) in France in 1982, e.g., [12], [13], modal shift from automobiles to bicycles and light rail transit (LRT) happened and the total extension of bike lanes have been more than 400 km. Here the most important point is how to share the roads with the various modes of transport.

People including elderly persons desire to join various communities and to search for identity. It is difficult to re-

spond requests for everyone's mobility only by mass transit; personal transport means are required for people for all ages. Such a situation, exclusive lanes for bicycles and slowly-moving very small vehicles are desired.

3.3 Exhausted Provincial Shopping Streets, Lifestyle and Mental Inertia

In Japan, many provincial shopping streets have become unpopular and many businesses are forced out of business. There are varied reasons for this, such as a shrinking or aging population, however, one of the reasons is the change in lifestyle as a result of motorization. Forty years ago, there were not so many cars in rural area, and people usually moved by bicycle or on foot. When shopping for dinner or shopping for articles for daily use, people often purchased various things at various private concerns using adaptable transport means; there were consumers' shop-around behaviors known as "kaiyu" (e.g., [14]) and side trip behaviors. After motorization, because of automobile, people tend to go to destination directly from home or departure places. Mighty shopping centers with large parking lots were necessity.

Nowadays people in urban areas tend to walk or to use bicycles in comparison with suburban areas because of use of stations, etc; this means that "kaiyu" is enlarged and it becomes easy for customers to make stops at attractive stores.

People have mental inertia, and everyone tends to resist losing a convenient lifestyle. Information technology (IT) has small inertia, machinery like automobile has middle inertia, and infrastructure like road has large inertia; IT could change in two years, machinery could change in ten years, and infrastructure could change in more than 50 years. However, mental inertia is different from those; mental inertia sometimes resists changing, however is capable of variation, and lifestyle may change in a short time with a new way of thinking. As a result, "kaiyu" and side trip behaviors could happen with economic revitalization.

Such consideration is important in systems innovation. The 20th century's vehicles as typified in the Model T Ford have their genesis in horse-drawn carriages. A gasoline engine replaced the horses, but the size of vehicle was similar to a carriage.

Human beings like lightly dressed comfort and liberty; mobility capability and vehicle size may be trade-off problems with keeping safe performance. Paradigm shifts to "vehicles easy to get off (mobility devices)" or "vehicles easy to do kaiyu and side trip (mobility devices)" from "vehicles easy to drive (traditional vehicles)" may happen.

4. Consideration of Electric Vehicles from the Viewpoint of the Elemental Technology Layer [3]

4.1 Meanings of Electric Energy

When discussing energy problems like use of natural energy or CO_2 emission problems, it is important to consider totally including the power production phase (e.g., [15]) not only the final consuming phase at vehicles. From this viewpoint, electric power production by natural energy and its direct use by electric motors for the power of propulsion are reasonable.

4.2 Diffusion Problems on Electric Vehicles and Batteries

Although problems of diffusion of electric vehicles are widely discussed (e.g., [16]) nowadays, one of main issues is on batteries as follows:

(1) battery capacity improvement
(2) boosting charge and cartridge for fully discharged situations
(3) repeat performance of charge and discharge
(4) reasonable charge schemes like noncontact power feeding
(5) charge related infrastructure and payment schemes

4.3 Essential Difference between Fossil Fuel and Electric Energy, and Non-contact Charge

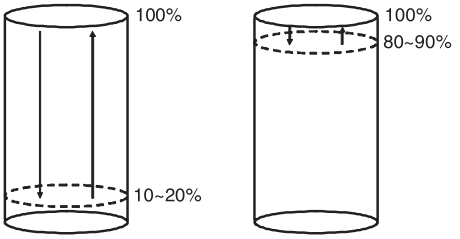
It is important to discuss essential differences between fossil fuel and electric energy; there are two differences as follows:

(1) Carriage manners
(2) Use manners

Firstly, let us discuss carriage manners. Liquid fossil fuels are combustible substance, and are required to convey from fuel fabrication plants to filling stations once. On the other hand, in the case of electric power, the power distribution grid has been widespread everywhere in Japan as well as worldwide, and the power is supplied into each building. Therefore "the last 10 m's" from each building to each vehicle is the main problem.

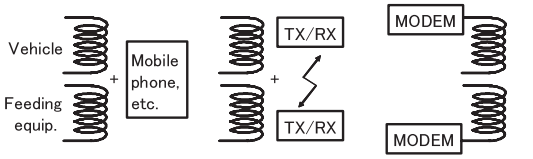
Secondly, let us consider how the use of the fossil fuel and electricity for cars will differ. There are a few users who fuel their cars when the capacity is at 95%, but these are extremely specific cases. However, in the case of batteries, if charging facilities are ubiquitous and if it is easy for all users to charge like non contact charger systems, each parking becomes a charging place, and in many cases, users repeatedly charge between 100% and 85% as shown in Fig. 5. Although the significant capacity and rapid charge ability is desired, it is not absolutely necessary. The repetition properties are rather than important.

Assume that the vehicle can get 300 km on a charge. After fully charging at home and a 15 km drive for a shopping center, 95% of the capacity remains; the vehicle's batter can be fully charged during the user's shopping. Even if a 150 km continuous drive at an expressway, half of the capacity remains; the vehicle's battery could be rapidly recharged during the driver's rest at a rest area at the expressway. If a continuous 300 km drive is complete, although rare, one of the following three means would be required; i.e., rapid charge, change of a cartridge type battery, or use of a fuel



(a) In the case of liquid fuel (b) In the case of electric charge

Fig. 5 Difference between fossil fuel and electric charge.



(a) Completely independent type (b) Parallel type (c) Integrated type

Fig. 6 Schemes of simultaneous operation both of power feeding and communication are divided into three categories.

battery. To realize such environmental arrangement, the following measures are desired:

(1) Development and standardization/universalization effort of simple noncontact power feeding systems for the last 10 m
(2) Development and standardization/universalization effort of simple boosting charge systems, simple cartridge type battery systems, or fuel battery systems for emergency use

After such an environmental arrangement, future vehicles might be though not that users would refuel when the fuel becomes few after some drive, but that users would step on the pedals without thinking fuel related matters like mobile phones with cradles at home.

In addition, complete solar battery cars sometimes become topics. Although feasibility study is desired, for a while it is considered that those are rather means for a longer drive, and simple noncontact power feeding systems for the last 10 m are also desired for electric vehicles diffusion.

From the viewpoint of systems innovation, sufficiently simple power feeding operation is important for social diffusion; in particular, almost automatic operation during parking is desired. From this way of thinking, a wired power feeding method is a disadvantage. The development of a universal/standard noncontact power feeding system for the last 10 m and its diffusion is one of the first priorities to allow for electric vehicles. The last 10 m's problem of broadband communications in buildings was settled by the wireless LAN technology, in a similar way, "Electric vehicles last 10 m's problem" should be settled by the noncontact charge systems technology.

4.4 Payment Scheme, and Superposed Transmission for Authentication in Noncontact Charge Systems

When a user consumes electric power, the user must pay for it, and reasonable payment system is desired to be provided as shown in Fig. 3. Establishment of the reasonable and simple payment system with high security is important. From this viewpoint, at the noncontact power feeding, user or battery identification is important for asking at low cost as mentioned below.

Elemental technology for simultaneous operation both of power feeding and communication is mentioned as follows: schemes of simultaneous operation both of power feeding and communication are divided into three categories as shown in Fig. 6; i.e., (a) completely independent type, (b) parallel type, and (c) integrated type. Among them, (c) that is simultaneous operation of noncontact power feeding and communication between feeding systems and the vehicles using superposed transmission is expected, because superposed transmission is easy to use both fed battery control and settlement, in addition, it is exclusively guaranteed that the destination of communication and that of power feeding are the same. Although not for use in vehicles, superposed transmission scheme in the noncontact power feeding system has been proposed [17]. In addition to this, category (b) includes use of IC tags attached near the on-board power receiving circuits.

On the other hand, as payment systems for battery charge, use of IC equipped mobile phone terminals has been proposed by Kyushu Electric Power Co. Inc. (e.g., [18]) as follows: at a rapid charging facility, the user authentication is carried out by the abovementioned IC chip, and after that the user is asked for pay the electricity charges within a bill for the user's regular electric power charge combined.

Such a scheme is suitably applied to the noncontact feeding system with battery authentication using superposed transmission. While power feeding, generally a feeder system communicate with a battery for the battery's monitoring. At this time, the feeder system carries out authentication of the battery or the user, and an electric power company asks the user for the electric utility rate for a combined bill even if fed from anywhere. Such a combined electricity bill system might reduce the social cost for construction of a payment system.

Mobile phone companies ask contents fees for users within a bill combined on behalf of the content companies; if such a combined asking system for ubiquitous feeding is implemented, there will be no need for any payment system at each feeder, and electric vehicles will be widespread at an accelerated rate. In addition, new business models will be also established. Finally, three important items are mentioned below; i.e. authentication for the battery (or the user), low cost settlement scheme based on the authentication, and ubiquitous automatic feeding equipment.

5. Consideration from the Viewpoint of the Systems Innovation Layer [3]

5.1 Development Requirements and "Ubiquitous Feeding and Authentication Payment Infrastructure" Toward the Electric Vehicles Society

Based on the considerations above, let us summarize what systems innovation is reasonable:

(1) On power feeding systems, development and standardization/universalization effort of a simple noncontact feeding system so as to solve the "Electric vehicles last 10 m's problem," and development and standardization/universalization effort of simple boosting charge systems, simple cartridge type battery systems, or fuel battery systems for emergency use.
(2) On settlement systems, to accelerate diffusion of the simple noncontact feeding system with the user (battery) authentication function using the communication function between the grid and each vehicle by superposed transmission, development and standardization/universalization effort of a low cost settlement system asking combined electricity bills for home and offices.
(3) On power generation, to step up natural energy oriented facilities such as photovoltaic generation, geo-thermal generation, wind generation.

The above items would be three principal pillars for the society. For becoming ubiquitous in society, to facilitate smooth and various businesses is needed, and the early buildup of "ubiquitous feeding and authentication payment infrastructure" on the basis of items (1) and (2) mentioned above.

5.2 Diffusion from a Business Viewpoint

Considering from a business viewpoint, the following items are important:

(1) Development and construction of simple noncontact feeding systems
(2) Diversification of settlement, and introduction of point systems
(3) Increase of value-added parking lots that can feed; e.g., store parking lots or toll parking lots that become charge-free after some shopping, coin-operated parking lots that can feed, etc.
(4) Development of recovery measures and diffusion in the cases that batteries run down; such as boosting charge systems including batteries, sophisticated means of transmitting rapidly rechargeable places information, cartridge type batteries, fuel battery combination systems, etc.

In addition, it would be difficult to be widely used for coin-operated vending machines of electricity for vehicle because of the following two reasons; i.e., the occupied time and the occupied area. It takes at least 20–30 minutes to charge, which is different from beverage vending machines. How to spend such a long time is a problem. Furthermore the occupied area of a beverage can is greatly different from that of a vehicle. This is a land value and parking space problem. This means that the introduction of feeding systems in parking lots is reasonable.

Also, in the shift to the electric automobile society, various possible business models are considered. However they are not mentioned further in this paper.

5.3 Countermeasure to Solve Problems of Employment Structure

The abovementioned electric vehicle shift in society might make a large change in employment structure. It is required to rush to develop attractive business models, and also to provide for the shift from current structure to new manufacturing, construction and service domains.

6. Super Smart Grid as a Result of the Ubiquitous Feed and Authentication Payment Environment

Currently, objects to consume the electric power are almost spatially fixed such as buildings with temporal variation and without spatial variation.

Fluctuating electric generation using natural energy or micro power generation requires the way of thinking of "smart grid," and it has often included that vehicles' batteries are regarded as distributed electric power storage though the electric energy of vehicles' batteries are variable.

Smart grids have been intended to spatially fixed power generation and spatially fixed power consumption without spatial variation. However, in the future, in the ubiquitous feeding authentication payment environment, many vehicles are ubiquitous, and carried out automatic noncontact power feeding. At this stage, feeding speeds are variable within the limits of the maximum speed, i.e., this means that the grid can control power consumption itself, i.e., controllable consumption both in time and space. In general, the cost is determined by the peak demand. Temporal and spatial controllability may contribute reduction of social costs. Here we call such a grid as "super smart grid." The super smart grid requires much research and development efforts.

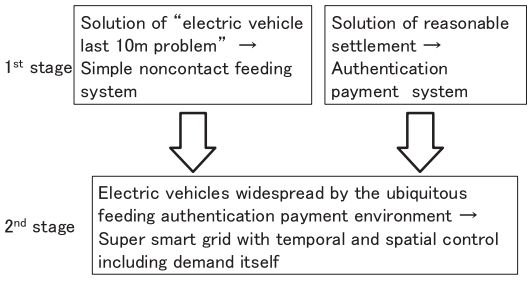


Fig. 7 Diffusion of electric vehicles and novel social infrastructure.

What is mentioned above is summarized as follows. As shown in Fig. 7, in the first stage, to solve the electric vehicle last 10 m's problem by a simple noncontact feeding system, and to solve the reasonable settlement problem by the authentication payment system, ubiquitous noncontact authentication payment environment will appear. After that, in the second stage, the super smart grid with temporal and spatial control including demand itself with the low social cost will be expected.

7. Conclusions

This paper has described diffusion of electric vehicles and novel social infrastructure from the viewpoint of systems innovation theory; in particular, it has been argued the importance to establish the ubiquitous noncontact feeding and authentication payment system, and also has expected the super smart grid.

Firstly, fundamentals of the systems innovation theory including the platform theory have been mentioned. Secondly, based on this theory, consideration of mobility has been carried out from the viewpoint of the human society layer. Thirdly, an argument of electric vehicles has been done from the viewpoint of elemental technology. Fourthly, introduced by the previous discussion, development and measures including business models and employment structure have been discussed, and it has been insisted that the establishment of the ubiquitous noncontact feeding and authentication payment system is important. Finally, it has also been insisted that the super smart grid with temporal and spatial control including demand itself with the low social cost will be expected after the establishment of the ubiquitous noncontact feeding and authentication payment system.

For further research, the author would like to propose a problem formulation and to make a study of appropriate solutions for the various problems discussed in this paper.

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