THEORETICAL EXPLANATION OF "Y-GAYA" THROUGH GENERAL DESIGN THEORY

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Abstract

"Y-gaya", which is a habit that engineers thoroughly discuss for long period of time, has been seen as a prominent mechanism to realize synthesis of design leading to actualization of brand new product. Though its effectiveness has been discussed empirically and given philosophical explanations, there has never been any theoretical explanation or systematized methodologies. This paper attempts to understand effectiveness of "Y-gaya" based on general design theory as a theoretical foundation. As a result, it is found that quite large part of "Y-gaya" could be understood through general design theory, whereas there are some factors (such as culture and human factors) still not to be proven or explained. In the end, this paper discusses future prospects for systematization of "Y-gaya".

Keywords: Design theory, Design practice, Organisation of product development, Teamwork, Creativity

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1 INTRODUCTION

In the past, Japan experienced historical high economic growth, which was led by the development of manufacturing industries. Even with lack of resources or capital, remarkable new products, such as the *Shinkansen* and *Walkman*, were created and swept the global market. In this era, Japanese engineers thoroughly discussed technologies, solutions, values and so on, which led to creation of unconventional products. At Honda Motor, such an occasion where engineers gather and thoroughly discuss for long periods of time is called "*Y-gaya*" named after "*waiwai-gayagaya*", which is an atmosphere of many people talking to each other with engagement, enthusiasm, excitement and so on. Well-known products such as *CVCC* (*Compound Vortex Controlled Combustion*, world's first technology complied with Muskie Act), the *Super Cub* others have been created through "*Y-gaya*".
However, recent efficiency-focused business circumstances have diminished "*Y-gaya*" as it requires much time to accomplish. Japanese manufacturing industries face severe cost and quality competition with emerging economies. To overcome this situation, the need for creating brand new products is increasing. In fact, Japan's Ministry of Economy, Trade and Industry initiated an investigation on the employment of design thinking in industries. Systems engineering is also seen as a clue to realize brand new products. At the same time, "*Y-gaya*" started to receive attentions from Japanese engineers.

2 PURPOSE AND APPROACH

2.1 Literature review

"*Y-gaya*" has been discussed in several literatures. Kobayashi (2012) explained "*Y-gaya*" in relation to spirit and philosophy of Honda. Homma (2015) proposed methods to reproduce "*Y-gaya*". Nagasawa and Kino (2016) discussed "*Y-gaya*" with Honda Motor's corporate culture through interviews. Kobayashi (2012), Homma (2015), and Nagasawa and Kino (2016) tried to explain and hands-on "*Y-gaya*" through experience-based or philosophical explanations. However, academic systematization such as design thinking or systems engineering has not been established yet for "*Y-gaya*".

2.2 Purpose of this paper

The aim of this study is to systematize "*Y-gaya*" so that the creation of brand-new products and services can be accelerated. For systematization of "*Y-gaya*", several steps needs to be taken. First, a theory of "*Y-gaya*" should be established through the observation of it. Second, methodologies for effective "*Y-gaya*" should be discussed and verified through empirical study. Third, design support methods and tools should be developed. This paper is the first attempt to establish a theory of "*Y-gaya*". As a first step, effectiveness of "*Y-gaya*" is explained through establishing such a theoretical foundation.

2.3 Approach

To explain the effectiveness of "*Y-gaya*", General Design Theory (Yoshikawa, 1985; Tomiyama and Yoshikawa, 1986; Tomiyama et al., 1989) is employed as a basis for a theoretical foundation. As General Design Theory is a mathematical theory to explain design and the design process based on set theory, it is possible to discuss correctness analytically. This paper attempts to explain the effectiveness of "*Y-gaya*" based on definitions and theorems advocated in General Design Theory.

3 Y-GAYA

3.1 Japanese working culture and Y-gaya

To understand "*Y-gaya*", a key feature of Japanese working culture should be explained. Individuals do not have specific task descriptions, which allows engineers to be collaborative and thus improve designs even in detailed design. This makes Japanese products known for high quality. The relationship between competitive advantage and culture is discussed by Fujimoto (2006).

3.2 Origin of Y-gaya

Honda Motor entered into four-wheeled automobile development after success with motorcycles. The H1300 that aimed to be an epoch-making car installing a transverse air-cooled engine was developed

under an initiative of Soichiro Honda, the founder of Honda Motor (Honda Motor, 1968). The H1300 had outstanding specifications compared to other cars of the time. However, due to excessively difficult requirements, the team faced many problems in the development process. As a result, the H1300 caused many troubles in development and even in use and resulted in unfavourable reputation from customers. The failure of the H1300 provoked skepticism of the top down approach, led by Mr. Honda. Further, the importance of a user-centric view was recognized. There was an assumption that even a talented engineer cannot oversee a product as a whole when its scale exceeds a certain limit. Then, the need for designers of different specialities to thoroughly discuss the design target was confirmed. Afterwards, Honda Motor restructured the development process so that a group of engineers contributes to realization of a product, from the establishment of a design target to individual solutions for each part. By combining expert knowledge and a strong will under the conditions that the design target is shared among the team, this development process can create a product that overwhelms the one made by the top-down approach. This was a belief that lead to the establishment of "*Y-gaya*".
The first "*Y-gaya*" took place when the Civic was developed. Failure of the Civic would have meant Honda Motor exiting from the four-wheeled automobile market, thus motivating the establishment of "*Y-gaya*" in an attempt to ensure success. To involve many specialists with different positions in the corporate hierarchy, spontaneous rules emerged where during the "*Y-gaya*" corporate hierarchy must be ignored and confrontation between each engineer based on technological knowledge is encouraged regardless of his/her roles or responsibilities. "*Y-gaya*" started with discussing the design target of the Civic. Here, the design target was not a required specification but how the product is desired to be or what users desire from the product. This desire is called "*Yokkyuu*", Japanese translation of desire, and shared among the development team throughout the development process. The "*Yokkyuu*" of the Civic was "compact but can have pride to own". After the "*Yokkyuu*" was agreed and shared among the team, topics of discussion were shifted to the means to realize a product or technologies that fulfil "*Yokkyuu*". The most important recognized theme of the development was trade-off between mass of drive train and interior space. Though the technical trend of engines at that time was for higher output and number of revolutions, the team shifted focus to realization of a compact engine. This solution was achieved by a user-centric view and knowledge to judge technological availabilities.

3.3 Key features of Y-gaya

"*Y-gaya*" was born as explained above. Later, it obtained and embedded several essential features. Among them, the most important features: "*Shikou-kyoutu*" (common thought), "*Anbai-kagen*" (proper seasoning), and "*3Gen-shugi*" (3 real -ism, -realism).

3.3.1 Shikou-kyoutu (common thought)

"*Y-gaya*" starts with sharing the knowledge of the specialists. Then discussions go on about current problems and themes, or value to users for a long period of time. By having a sufficiently long discussion, "public-stance" opinions disappear from the course of discussions and bona fide opinions dominate it. Furthermore, individual interests and value to the company are diminished and replaced by user and social value. As a result, the "*Yokkyuu*", which works as a strong design target, is fermented and shared within a team. "*Yokkyuu*" expresses what the product is desired to be for a user and society. Fundamental of "*Shikou-kyoutu*" is to share "*Yokkyuu*" within a team. After "*Yokkyuu*" is shared, direction of design and development of individual parts and technologies is kept consistent towards a common design target.

3.3.2 Anbai-kagen (proper seasoning)

"*Y-gaya*" takes place in several phases of development. Once "*Shikou-kyoutu*" of "*Yokkyuu*" is made, parts and technologies are developed in separate locations. At certain phases, the required performance level of each item in development must be coordinated. This coordination of the required performance levels is called "*Anbai-kagen*". "*Anbai-kagen*" is not to compromise one part for the purpose of achieving the other. The discussion is what level needs to be achieved in light of "*Yokkyuu*". Therefore, "*Yokkyuu*" must be "achievably demanding".

3.3.3 3Gen-shugi (3 real -ism)

Though "*Y-gaya*" is an arena for unrestricted discussions, there are three principles to be followed when expressing an opinion or criticism. They are called "*3Gen-shugi*": "*Genba*" (real place), "*Genbutu*" (real

artefact), and "*Genjitu*" (real phenomenon). "*Genba*" means to discuss based on the actual place where the matter happens. In the case of automobile development, the actual situation that a car is used is an illustrative example. Likewise, "*Genbutu*" and "*Genjitu*" mean to discuss based on the actual artefact (e.g. car, door handle, bumpers) and actual phenomena (e.g. experimentally- or disciplinarily-supported combustion theory) respectively. By consistently following "*3Gen-shugi*", engineers become free from corporate values or individual mind-sets. Therefore, discussions in "*Y-gaya*" stick to the development of a product that realizes user values.

3.4 Forms of Y-gaya

As shown in Figure 1, depending on number of attendees and time span, "*Y-gaya*" takes three forms: wedding party form, conference form, and cram school form (Shimizu, 2015).

- Wedding party form
  - Number of attendees tends to exceed 50. It continues about 2 days and 1 night. The purpose of this form is to foster empathy throughout a company or divisions, or to share common targets.
- Conference form
  - 10 to 20 attendees. 1 day units are repeated several times. The purpose of this form is to break stereotypical ideas by hearing opinions of others or to extract and showcase ideas.
- Cram school form
  - About 5 attendees. 3- to 7-day units are repeated several times. The purpose of this form is to concentrate on a specific topic and solve a problem by a limited number of specialists.

Figure 1. Forms of Y-gaya (edited form (Shimizu, 2015))

3.5 Types of attendee

For the success of "*Y-gaya*", engineers who specialize in different domain knowledge need to attend. Besides, different attitudes play important roles in "*Y-gaya*". Attendees can be categorised by their attitudes into three types: *enthusiast*, *moon rocket* and *raccoon*.

- Enthusiast
  - An *enthusiast* is an usher of "*Y-gaya*" who has enthusiasm and confidence in success of development. The important role of *enthusiasts* is to hold up high the "*Yokkyuu*" (desire) and uphold it throughout entire development.
- Moon rocket (rocket scientist)
  - A *moon rocket* is a specialist of each domain. He makes dispassionate judgement based on technological knowledge. The important role of *moon rockets* is to contribute to course of discussion by logical thinking supported by advanced and experienced domain knowledge.
- Raccoon (in Japan, *raccoon* is seen as an animal that can bewitch humans)
  - A *raccoon* overlooks the course of discussion in "*Y-gaya*". The important role of the *raccoon* is to change the direction of discussions when a discussion reaches deadlock and to remind attendees to recur to user-centric views. The talent is fostered through long experiences.

4 GENERAL DESIGN THEORY

Before explaining "*Y-gaya*" through General Design Theory, General Design Theory is briefly explained in this section. In this paper, conceptual explanation is the focus and mathematically rigorous explanations are avoided.

This paper explains General Design Theory in four parts; 1) Knowledge for design, 2) Knowledge acquisition, 3) Mathematical theory of design, and 4) Theory for design processes.

General Design Theory captures design as an operation to/of knowledge. Thus, first of all, the expression of knowledge is explained. Second, the structuring of the knowledge is explained. Third, based on the

expression of knowledge, mathematical theory of design is explained. Finally, theory of how design goes on as a process is explained.

4.1 Knowledge for design

This section explains the expression of knowledge for design proposed in General Design Theory. As shown in Figure 2 a), knowledge is expressed as a set of elements that each denote a known entity. As a limit of knowledge, a universal knowledge is assumed. A universal knowledge is a set that comprises concepts of entities human beings can perceive throughout the entire past to future. Human beings abstract entity concepts groups by sorting them in view of meaning to us (e.g. red, fast). As a result, for instance, function phases are introduced to a set of entity concepts as abstract concepts.

4.2 Knowledge acquisition

When a human acquires a new entity concept, he gives meaning to the entity concept by abstract concepts that include it. Through this operation, abstract concepts are reconfigured. In this way, acquisition and structuring of knowledge goes on. Function phase is a type of abstract concept that sorts entity concepts by function to humans. Sorting is not only to divide entity concepts by true or false but to metricize them with things like strength (e.g. kind of red < quite red < deep red). Figure 2 b) shows metrication where a new level (red ellipse) is introduced by perceiving a new entity concept (red x).

4.3 Mathematical theory of design

Design discussed in General Design Theory is to actualize an entity that complies with requirements. As requirements are meanings for human beings, function phases are introduced so as to reflect requirements and employed as filters to sort entity concepts (Figure 2 c)). By assuming a universal knowledge, upon describing all requirements as function phases, an intersection of subsets recognized for each function phase has at least one entity concept as long as function phases do not contradict with each other. Therefore, by choosing an entity concept from the intersection, a design that complies with the requirements is achieved.

In reality, human knowledge is a far cry from a universal knowledge. Generally, when we have to design, we have never perceived any entity concept in the intersection, which is the possible design solution space. Furthermore, function phases are also incomplete. Therefore, actual design needs a process assuming incomplete actual knowledge.

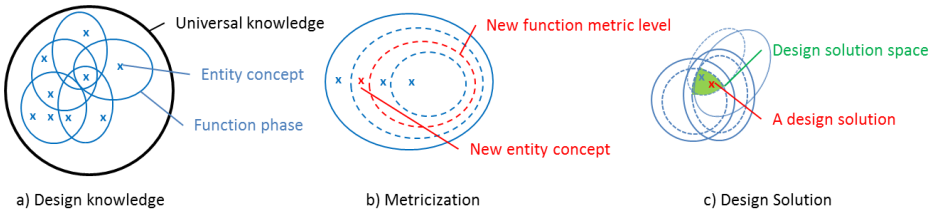

Figure 2. Knowledge operations in General Design Theory

4.4 Theory for design processes

General Design Process (Yoshikawa, 1981; Tomiyama and Yoshikawa, 1986) proposes several routes to achieve a design solution from requirements. Figure 3 shows two representative routes. In this figure, design process is expressed as conversion from a function set (each blue x denotes function concept) to a design solution (each black x denotes entity concept). Though there are five routes proposed in General Design Process, the other three routes are a combination of these two basic routes. The left upper route, called bricoleur process, is a process to compose a product by combining parts that were selected by their meanings or functions. Here, empirical knowledge are function concepts categorised by entity phases. Therefore, entity phases are selected to comply with required function concepts. Then, these entities are combined to create an entity concept. The right bottom route, called the engineer process, is a process to obtain a design solution by means of technological (natural scientific) knowledge through abstraction via attributes of entity concepts. Here, scientific knowledge is entity concepts categorised by function phases. Therefore, required function phases work as filters for entity concepts. Because function phases are metricized very well in scientific knowledge, it is possible to explore design solutions by means of calculation in domain knowledge.

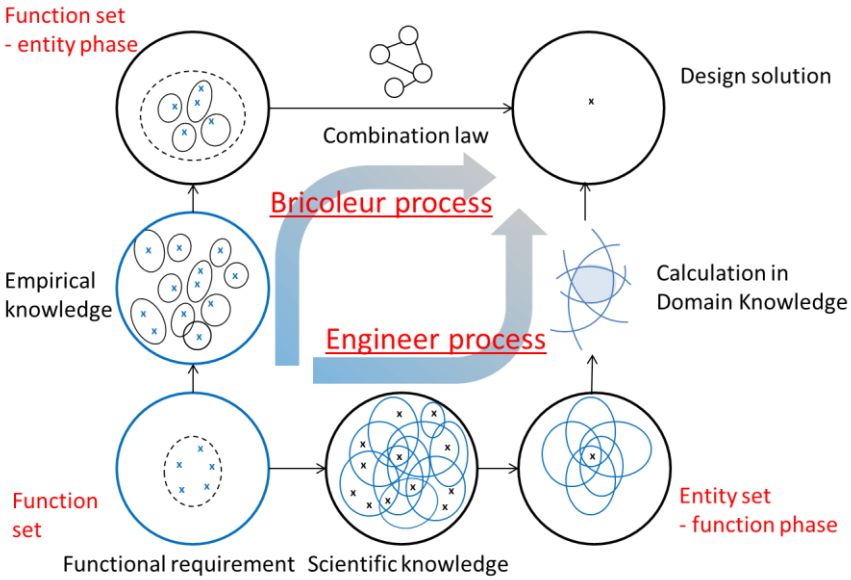

Figure 3. Two typical routes of general design process

5 THEORETICAL UNDERSTANDING OF Y-GAYA THROUGH GENERAL DESIGN THEORY

5.1 Knowledge processing in Y-gaya

Engineers with different specialities are gathered in "*Y-gaya*". For instance, knowledge transitions of two designers (A and B) are described in Figure 4 a). They share similar knowledge (entity concepts) and have their own knowledge as well. Likewise, how they structure knowledge (function or other types of abstract concepts) is also close in some parts and different in other parts. If they thoroughly share their knowledge, they understand each other's knowledge and take it as perceived knowledge (both entity and abstract concepts). In Figure 4 a) strength of colour shows level of perception. Strong colour means that he can realize the entity concept while weak colour means that he only knows that it is achievable.

5.2 Shikou-kyoutu

As explained above, "*Shikou-kyoutu*" is to share "*Yokkyuu*" (desire), or a design target. In General Design Theory, function phases that give value to human beings are employed as filters to sort design solutions. However, as shown in Figure 4 b), structuring of knowledge, including function phases, is different between engineers. Thus, perceived value structures, which is the way a man evaluates values of entities, are also different. As shown in Figure 4 b), when engineers perceive different value structures, they understand the value structures, and integrate them into a new common value structure (purple circles) applied for a product. The common value structure would be a basis for evaluating design solutions. This common value structure for a product is "*Yokkyuu*". There are also non-value oriented phases of knowledge such as physical, technical or economic phases. These phases are integrated into value-oriented phases in the course of "*Y-gaya*", as engineers discuss in light of user-centric views. For instance, in Figure 4 b), economic phase and technological phase (blue circles) are replaced with a user-centric phase (purple circle).

5.3 Anbai-kagen

Design target is defined as the fulfilment of functions. To clarify the design target so as to objectively evaluate design solutions, the level of functions must be specified. By sloping function phases as shown in Figure 4 c), the design solution space is graded. As a result, the design solution area (green area) is converged (becomes smaller) through "*Anbai-kagen*". "*Anbai-kagen*" is the determination of the required level of each function. These slopes are metricizations of function phases. As the ways slopes are given are also different among engineers, common metricization is explored through discussions. By considering both "*Yokkyuu*" and technological availabilities, levels are set "achievably high".

5.4 Raccoon

After the design target is shared, design solutions are explored. For the exploration of design, the current state of knowledge of the team becomes a clue because neighbourhoods of known entity concepts are relatively easier to explore. As shown in Figure 4 d), when discussions are converged, exploration of design can fall into narrow technological viewpoints. At that time, owing to long experiences, *raccoon* can detect inclination to technological viewpoints and emphasis recurrence to user-centric views (red circles). As a result, excessive convergence of discussions can be avoided, thus exploration of wider design solution space (red area) is encouraged.

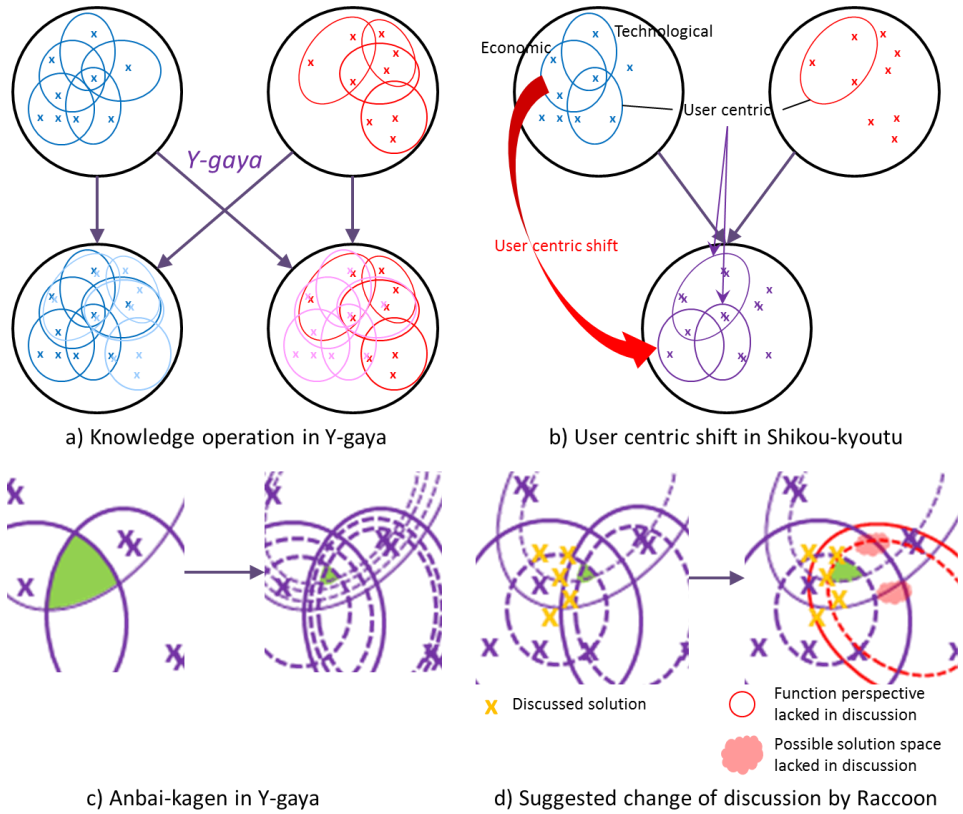

Figure 4. Knowledge operations in Y-gaya

5.5 Confrontation and consent between enthusiasts and moon rockets

In product design through "*Y-gaya*", "*Yokkyuu*" is shared ("*Shikou-kyoutu*") in the first step. Then, requirements are specified based on "*Yokkyuu*" (Figure 5). Finally, design solution is actualized (Figure 6). To place "*Yokkyuu*" in design place, event set is introduced. As General Design Theory attempts to explain design process as conversion from requirements (function set) to a solution (entity concept), it does not deal with what a product should be for users. Event set is a set of event concepts, which are events human beings can perceive through the entire past to future. "Considering events" means defining what events a product enables, thus what a product is desired to be.

Enthusiasts have strong "*Yokkyuu*" and stick to user value. Therefore, his/her design process takes left upper route in Figure 5 and 6, which is bricoleur process. In bricoleur process, conversion from desire to requirements is conducted by collecting function phases that comply with desired event concepts (Figure 5). As for conversion from requirements to solution, entity phases that comply with function concepts are combined to an entity concept (Figure 6).

In contrast, as *moon rockets* have specialized technological knowledge, they take right bottom route, which is the engineer process. In the engineer process's conversion from desire to requirements, feasibility of function concepts is tested by scientific knowledge. (Figure 5). As for conversion from requirements to solution, entity concepts that comply with function phases are calculated by scientific knowledge (Figure 6).

In "*Y-gaya*" *enthusiasts* and *moon rockets* thoroughly confront each other's opinions. After a long period of discussions with bona fide opinions, they finally reach an idea to which they can all consent. By

confronting user value-oriented opinions of *enthusiasts* and technologically-supported opinions of *moon rockets*, "*Y-gaya*" seems to effectively integrate two routes of the design process advocated in general design process (Yoshikawa, 1981). Therefore, a design solution does not make light of user values by too much inclination to technologies. Similarly, it does not neglect technologies by too much focus on user values.

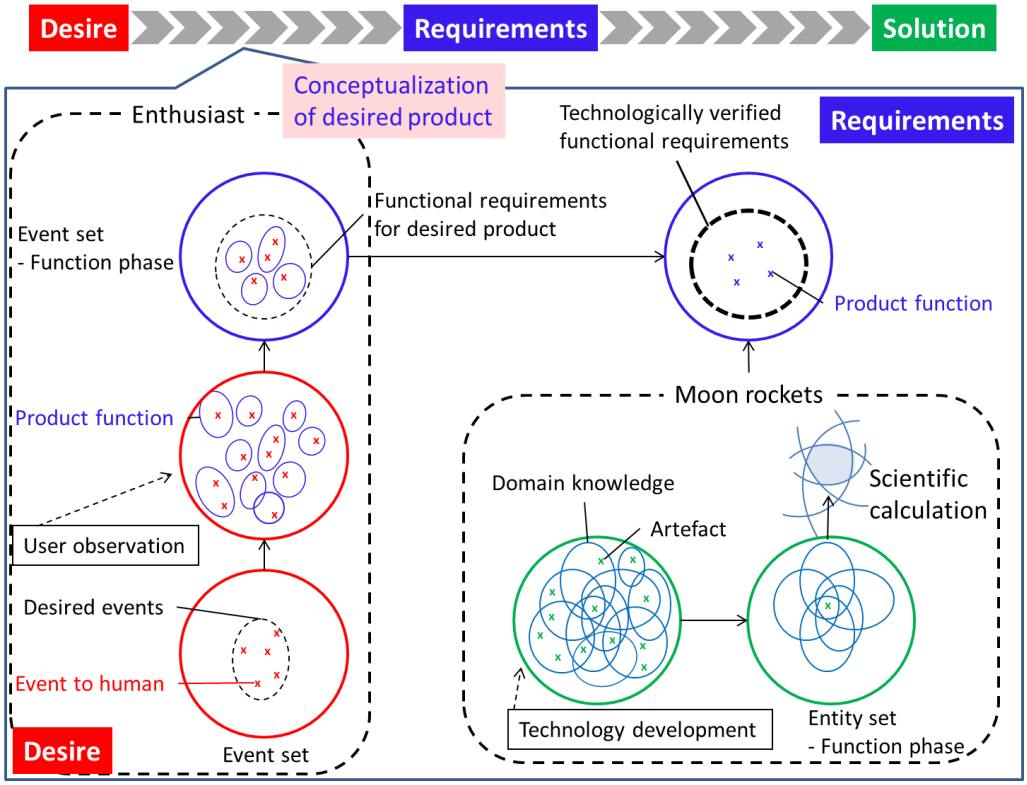

Figure 5. Specifying requirements based on desire in Y-gaya process

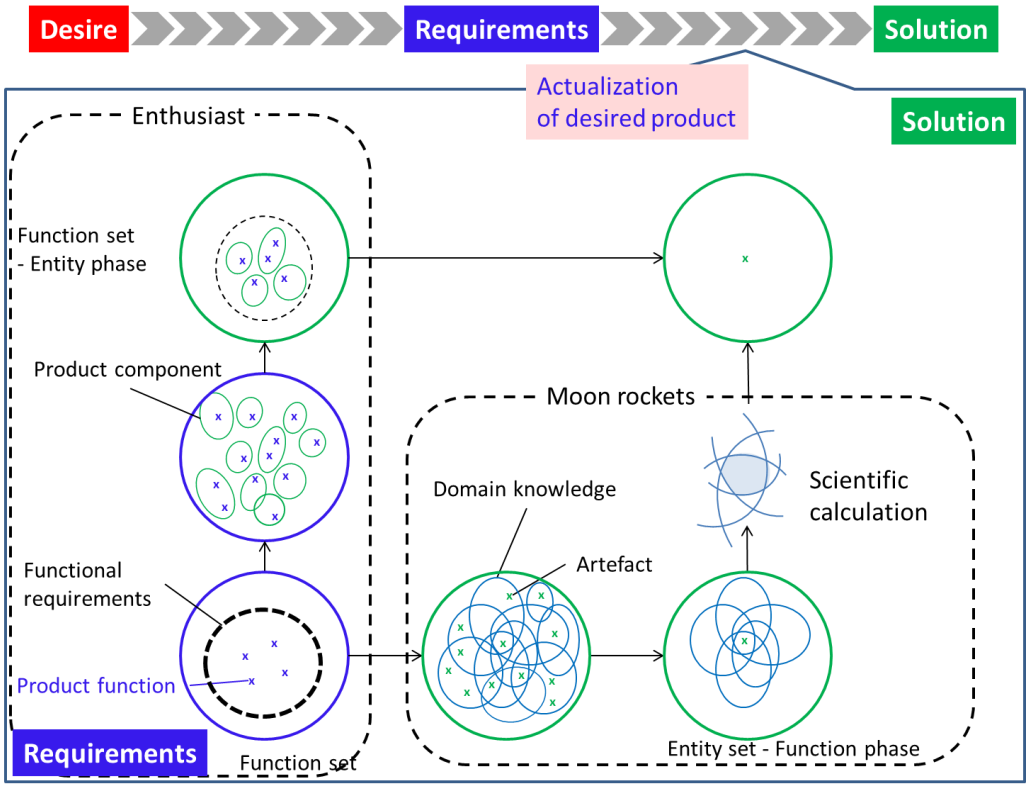

Figure 6. Actualizing design solution based on requirements in Y-gaya process

5.6 Fermentation of Yokkyuu (Desire)

Unique and core characteristics of "*Y-gaya*" is "*Yokkyuu*" (desire). As stated in Section 2.2, "*Yokkyuu*" expresses what the product is desired to be for a user and society. Before it is shared within a team, it is important to deliberate, and pursue the best possible "*Yokkyuu*". As "*Yokkyuu*" needs to be "achievably demanding," it is important to expect that it is technically possible and it enables the events that "*Yokkyuu*" refers to. Therefore, engineers have to know technologies and their outcome on human beings. Figure 7 shows fermentation of "*Yokkyuu*". Fermentation of "*Yokkyuu*" is the opposite flow of the design flow, desire-requirement-solution, shown in Figures 5 and 6. As expert engineers can foresee technological trends, it is possible to anticipate new entity concepts they can reach. Anticipated entity concepts signal new function concepts that enable them. If function concepts can be anticipated, it is possible to imagine the event concepts human beings can achieve. Therefore, if specialized domain knowledge is mapped with events via functions, it helps a team to establish what the product is desired to be for a user and society.

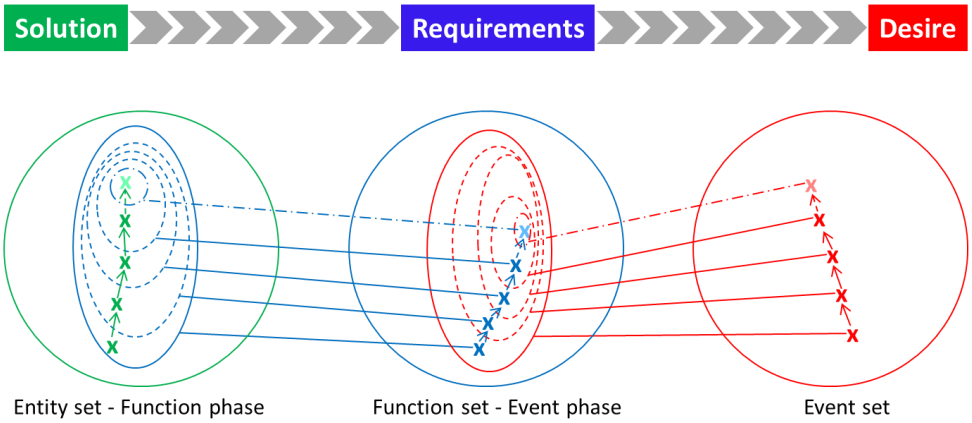

Figure 7. Fermentation of Yokkyuu based on mapping between entity function and event

6 DISCUSSION

6.1 Explaining effectiveness of Y-gaya through General Design Theory

To explain effectiveness of "*Y-gaya*", this paper employed General Design Theory as a theoretical foundation. As a result, General Design Theory explains that if multiple people with different domain knowledge and roles (such as an *enthusiast* or *raccoon*) effectively cooperate, the expected product would be better. In "*Y-gaya*", confrontation between an *enthusiast* who sticks to user value and a *moon rocket* who puts more importance on technologies leads to the pursuit of better products, as best possible technologies are connected to user values. This could be seen as a mapping between function phase and scientific phase (such as physics, defined as a meta model in General Design Theory). Though it is not completely explained in this paper, upon establishment of the mapping between function phase and scientific phase, it is possible to explain how attainment of knowledge (both scientific and human) contributes to actualization of a better product.

As discussing "*Yokkyuu*" (desire) is a core concept of "*Y-gaya*", it is essential for theoretical foundation of "*Y-gaya*" to properly explain "*Yokkyuu*". By introducing an event set and counter mapping from entity to function and function to event, "*Yokkyuu*" could be explained in terms of General Design Theory. Thus, the attempt to employ General Design Theory as a theoretical foundation for "*Y-gaya*" seems to be successful. Further, the introduction of the event set and counter mapping, which are not referred to in General Design Theory, implies that there is potential to discuss product definition (what to make) whereas conventional General Design Theory discusses product actualization (how to make).

6.2 Cultural, human and other factors of Y-gaya

This paper explained the effectiveness of "*Y-gaya*" through General Design Theory with some extensions. This could be explained as mathematical set theory. However, there are assumptions that are difficult to explain or prove by set theory. For example, if function phases are converged to user-centric aspects and mapped with technologies, the resultant product would be better as it incorporates best

possible technologies to give value to users. But, there is an assumption that attendees of "*Y-gaya*" properly act so that use-centric views are mapped to technologies.
These kinds of assumptions are merely supported by empirical explanation shown in (Kobayashi, 2012, Homma, 2015 and Nagasawa and Kino, 2016). According to those articles and words from past practitioners of "*Y-gaya*", there are several factors needed to make "*Y-gaya*" actually work in the company. For example, there is the corporate culture that an engineer can ignore hierarchy as long as his opinion is scientifically supported. These cultural, human and other factors, which are oral traditions, should be experimentally supported.

6.3 Employment of social science

This paper explained the effectiveness of the parts of "*Y-gaya*" that can be dealt with mathematically. As discussed above, there are some parts still not to be proven or explained in this paper. To further explain and prove effectiveness of "*Y-gaya*", investigations and experiments based on social science seem to be needed. Currently, the research projects listed below are being prepared.

- Measure the time of transit of discussion into bona fide opinions, by observation.
- Capture and understand the transition of discussion into bona fide opinions by protocol analysis.
- Compare transitions of discussion between different groups that artificially have different cultures.

6.4 For systematization of Y-gaya

This paper is attempted to be a first milestone for systematization of "*Y-gaya*". Although the theoretical foundation is yet on the way, the authors project that further steps involve the establishment of methodology and development of support tools. Some methodologies and tools in systems thinking, systems engineering and design thinking seem to fit to "*Y-gaya*". Thus, comparison between "*Y-gaya*" and these emerging disciplines should be conducted. Fermentation of "*Yokkyuu*" (desire), which is core characteristics of "*Y-gaya*," should also be supported by methodologies and tools. Currently the combination of scene-based development and virtual engineering seems to be prominent. Applicability of scene-based development and virtual engineering should be further investigated.

7 CONCLUSION

This paper attempted to explain the effectiveness of "*Y-gaya*", which is a habit that engineers thoroughly discuss for a long period of time, through General Design Theory. As a result, employment of General Design Theory successfully explained that the probability of actualizing a product that gives higher value to users is raised by combining collective knowledge through long discussion with bona fide opinions. The explanation is further supported by introducing event sets and counter mapping from entity to function and function to event.

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