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Idea creation: Function Synthesis Approach with Simplification and Evaluation

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Abstract

Product engineer is being required to design attractive products in a short product development cycle from stakeholder. And, its attraction is influenced a great deal by idea creation in a conceptual design phase of this cycle. On the other hand, K. Yoshioka and H. Hasegawa proposed the FSA (Function Synthesis Approach) to create a combination of a large number of functions in a short period of time. FSA become a conceptual design support tool that combines the PSO (Particle Swarm Optimization) and the particle method of USIT. However, FSA is only to outputting combination of large numbers of functions. For this reason, there is a need to provide a way to support the conceptual design process systematically. Therefore, this paper proposes a method to systematically support the conceptual design process from the output of the FSA. This systematic process is consisted from two phases. First, the design solution is built by combination of large number of function via using axiomatic design and function structure method. Next, it is evaluated by using UCP (Use Case Points) method. And, this paper described these phases via example to the refrigerator.

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Keywords: Particle Method, USIT, PSO, Function Structure, Axiomatic Design, Use Case Points;

1. Introduction

Product engineer is being required to design attractive products in a short product development cycle from stakeholder. And, its attraction is influenced a great deal by idea creation in a conceptual design phase of this cycle. However, idea creation heavily depends on a creativity of engineer or engineering team through the experiences and technical knowledge of them. Moreover, to explore one big hit product, great numbers of ideas are required [1]. From above-mentioned, it is difficult to maintain enough period of its creation into the short cycle. To overcome this difficulty, K. Yoshioka and H. Hasegawa have developed the FSA (Function Synthesis

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Approach) which is combined the emergent computation, PSO (Particle Swarm Optimization), and the particle method of USIT [2]. The FSA can draw on new ideas from combination of functions, which automatically emerged by particle behaviour via PSO algorithm, with the use of physical effects and laws. However, to allow outputting combination of large numbers of functions, it is difficult for anyone to draw an idea simply. Moreover, FSA does not have an evaluation method of obtained idea for validation of requirement—quality and cost estimations. In this paper, as a simplification approach of idea creation, the independence axiom of the axiomatic design theory and the function structure method of the systematic approach by Pahl et al. (P&B method) were introduced. And, as an idea evaluation method, UCP (Use Case Points method) for a cost estimation of combination of functions was introduced.

This paper proposed FSA/SE (Function Synthesis Approach with Simplification and Evaluation) process, the process adds simplification and evaluation phases to FSA. The proposed FSA/SE process is shown in Fig 1.

According to FSA/SE, the second chapter presents an overview of the FSA. The third chapter presents a method to simplify the combination of a large number of functions using the independence axiom and the function structure method as the simplification phase. The fourth chapter described a generalization of the UCP method for product development and evaluated obtained combination of functions by using it. Chapter 5 discusses the result of the FSA/SE process and brings the concluding remarks. In addition, this paper discusses the FSA/SE process via an example of the refrigerator.

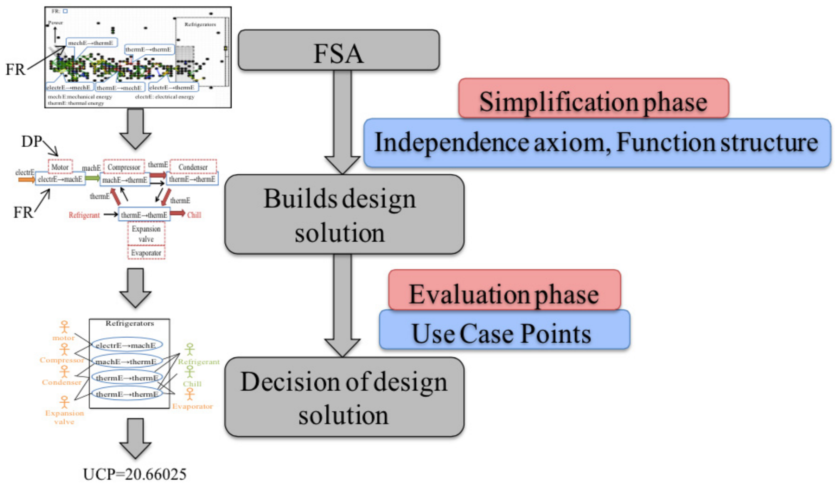

Fig.1. Overview of the FSA/SE process

Nomenclature

FSA	Function Synthesis Approach
PSO	Particle Swarm Optimization
FSA/SE	Function Synthesis Approach with Simplification and Evaluation
SDS	Structure Design Space
FR	Function Requirements
DP	Design Parameter
UCP	Use Case Points
SFD	Structure Function Diagram
UCD	Use Case Diagram
TCF	Technical Complexity Factor
EF	Environmental Factor
UML	Unified Modelling Language

2. Function Synthesis Approach

The outline of FSA is as follows. First, the actual situation in design problem is sketched as 2D image on the Structure Design Space (SDS). Next, technology constraints are defined on the SDS via comparing the actual situation with an ideal solution image, as "important area or non-important area" by using point, line or face symbols as numeric information. By closing up to the important area or being off from the non-important area via PSO algorithm, particle behaviours are controlled or optimized. Moreover, each particle has one function, input (I) and output (O) of mechanical, electrical, hydraulic, or thermal energy. Moreover, if particle meets up other particle in the SDS and particle's I/O energy matches other particle's I/O, both particles connect and move together. The result of FSA is represented by using points as particles and a line as a function linkage as shown in Fig 2. An idea is drawn on by reverse-resolving the physical effects or laws of each function (particle) from particles distribution and energy flow between functions (particles). An example of the refrigerators is shown in Fig 2.

2.1. Particles control method

The particles control method is proposed. The algorithm of this method is as follows. First, Weight Symbol is the part relevant to realization of the ideal solution that should be focused as important area or point. And Anti-Weight Symbol is the part irrelevant to one that should be set some kind of constraint (non-important area). These constraint symbols are defined as numeric information which constrains behaviours and evaluates positions of particles. For deciding particles behaviour, a function of Table 1 is handed over to its behaviour. And, the relationship between input and output of the particle element behaviour is defined as shown in Table 2. Table 2 denotes a reverse resolution that can derive physical effects and laws. These particles are deployed randomly on the SDS with information of position and velocity and behaviour. Particle behaviours are defined by following formulas used PSO algorithm.

$$X_i^{t+1} = X_i^t + V_i^{t+1} \tag{1}$$

$$V_i^{t+1} = \omega \cdot V_i^t + \{c_1 \cdot r_1 \cdot Distance_{Weight-Particle_i} \cdot WD - c_2 \cdot r_2 \cdot Distance_{AntiWeight-Particle_i} \cdot WD_{Anti}\} \tag{2}$$

Where x_i^t and v_i^t, denote a position and a velocity of particle i on t step. r_1 and r_2, denote uniform random number [0, 1]. ω, c_1 and c_2, denote the constant of inertia and the weight factor of each evaluated value [0.5, 0.9]. WD and WD_{Anti}, denote the importance of weight when the Weight Symbol are placed, the importance of weight when the Anti-Weight Symbol are placed, respectively.

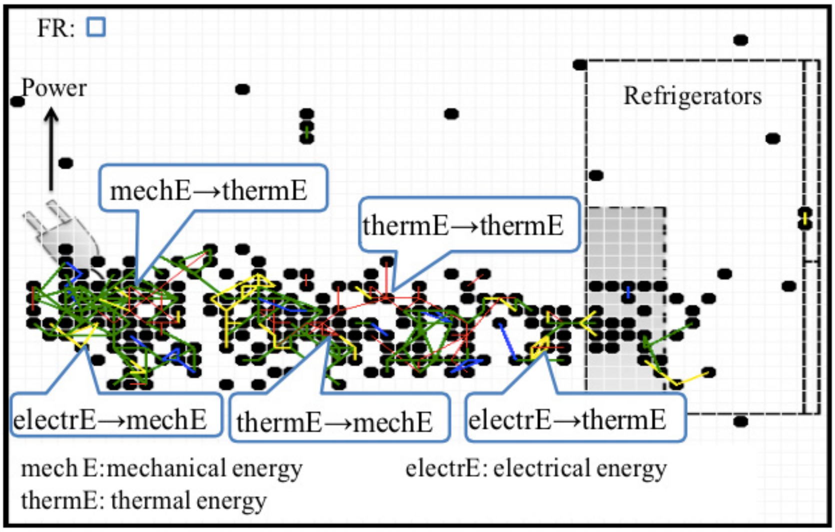

Fig.2. Outline of FSA for refrigerator

Table.1. List of generally valid functions [3]

Characteristics Input(I)/Output(O)	Generally valid functions	Symbols	Explanations
Type	Chage		Type and outward from of I and O differ
Magnitude	Vary		I < O I > O
Number	Connect		Number of I > O Number of I > O
Place	Channel		Place of I ≠ O Place of I = O
Time	Store		Time of I ≠ O

Table.2. The physical effects or laws [3]

Function	Input	Output	Physical effects						
E_{mech} → E_{mech}	Force, pressure, torque	Length, angle	Hooke (Tension/ compression./ bending)	Shear, torsion	Upthrust Poisson's effect	Boyle-Mariotte	Coulomb I and II	…	…
		Speed	Energy Law	Consevation of momentum	Consevation of angular momentum	…	…	…	…
		Acceleration	Newton's Law	…	…	…	…	…	…
	Length, angle	Force, pressure, torque	Hooke	Shear, torsion	Gravity	Upthrust	Bpyle-Moriotte	Capillary	…
			Coulomb I and II	…	…	…	…	…	…
	Speed		Coriolis force	Conservation of momentum	Magnus-effect	Energy law	Centrifugal force	Eddy current	…
	Accelera-tion		Newton's Law	…	…	…	…	…	…
E_{mech} → E_{hyd}	Force,length, speed, pressure	Speed, pressure	Bernoulli	Viscosity (Newton)	Torricelli	Gravitational pressure	Boyle-Mariotte	Conservation of momentum	…
E_{hyd} → E_{mech}	Speed	Force, length	Profile lift	Turbulence	Magnus-effect	Flow resistance	Back pressure	Reaction principle	…
E_{mech} → E_{therm}	Force, speed	Temperature, quantity of heat	Friction (Coulomb)	1st law	Thomson-Joule	Hysterisis (damping)	Plastic deformation	…	…
E_{therm} → E_{mech}	Temperature, heat	Force, pressure, length	Thermal expansion	Stream pressure	Gas Law	Osmotic pressure	…	…	…
E_{elektr} → E_{mech}	Voltage, current, magn.field	Force, speed, pressure,	Boit-Savart-effect	Electro-kinetic effect	Coulomb I	Capacitance effect	Johnsen-Rhabeck-effect	Piezoeffect	…
E_{mech} → E_{elektr}	Force, length, speed, pressure	Voltage, current	Induction	Electro-kinetics	Electro-dynamic effect	Piezoeffect	Frictional electricity	Capacitance effect	…
E_{elektr} → E_{therm}	Voltage, current,	Temperature, heat	Joule heating	Feltier-effect	Electric arc	Eddy current	…	…	…
E_{therm} → E_{elektr}	Temperature, heat	Voltage, current	Electr. conduction	Thermo-effect	Thermionic emission	Pyroelectricity	Noise-effect	Semiconductor, Super-conductor	…
E_{mech} ↔ E_{mech}	Force, length, speed, pressure	Force, length, speed, pressure	Lever	Wedge	Poisson's effect	Friction	Crank	Hydraulic effect	…
E_{hyd} ↔ E_{hyd}	Pressure, speed	Pressure, speed,	Continuity	Bernoulli	…	…	…	…	…
E_{therm} ↔ E_{therm}	Temperature, heat	Temperature, heat	Heat conduction	Convection	Radiation	Condensa-tion	Evaporation	Freezing	…
E_{elektr} ↔ E_{elektr}	Voltage, current	Voltage, current	Transformer	Value	Transistor	Transducer	Thermogal-vanometer	Ohm's law	…
…	…	…	…	…	…	…	…	…	…

3. Simplification phase

For simplification, this phase classifies the combination of large numbers of functions by the independence axiom of the axiomatic design theory [4, 5], and builds the design solution by using a function structure of the P&B method. We believe that new ideas include in the combination of large numbers of functions. However, those also are mixed in suitable combinations and in poor combinations. Therefore, simplification phase creates the matrix which enumerated FR and DP, because we delete poor combinations by using the independent axiom. For building SFD, it is necessary that the matrix is changed to satisfy an independence axiom. As the result, the design solution of independent or quasi- independent for FR is built by using SFD. The independent axiom is defined by following formula.

$$\{FR\} = [A]\{DP\} \tag{3}$$

Where FR, DP and A, denote is function requirements, design parameter and the design matrix, respectively. By using these, the steps of the simplification phase follow:

1. The FR defines the each combination. (as shown in Fig 2)
2. The DP is drawn on by the physical effects or laws of each function. (as shown in Fig 3 and Table 2)
3. Create a matrix of DP and FR. (as shown in Table 3 (a))
4. Input of the relationship of DP and FR. And, if it is affected, X is set. Otherwise, 0 is set. (as shown in Table 3 (b))
5. Delete poor combinations by using the independent axiom. (as shown in Table 3 (c))
6. Build the SFD using Eq. (3) (as shown in Fig 4).

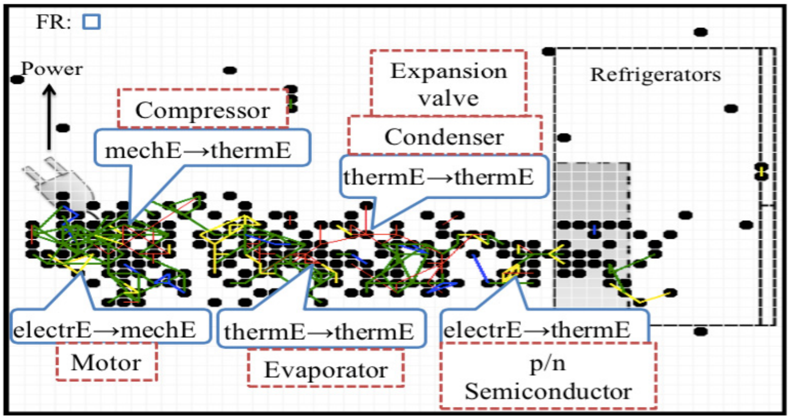

Fig.3. Create of DP by using Table 1

Table.3. (a) Create of matrix; (b) Input of the relationship; (c) Satisfy the independent axiom

	DP_1	DP_2	…
FR_1			
FR_2			
⋮			

(a)

	Moter	Compressor	DP_3	…
electroE→thermE	X	0	X	…
mechE→thermE	0	X	X	…
FR_3	0	0	X	…
⋮	⋮	⋮	⋮	…

(b)

	Moter	Compressor	DP'_3	…
electroE→thermE	X	0	0	…
mechE→thermE	0	X	0	…
FR_3	0	0	X	…
⋮	⋮	⋮	⋮	…

(c)

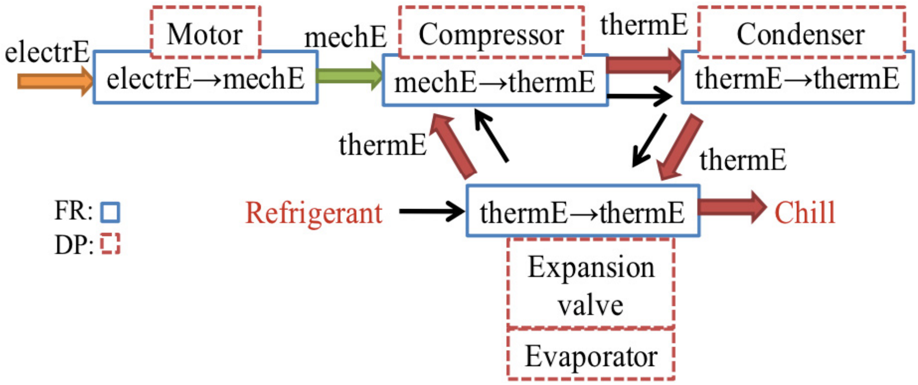

Fig.4: Build the SFD

4. Evaluation phase

For validation, this phase performs cost estimation of a design solution using the UCP method [6]. We believe UCP method can adequately evaluate a Structure Function Diagram (SFD) as a design solution from FSA. Because the UCP method can evaluate four complexities, i.e., use cases (functions via user's viewpoint), actors (DP and external materials), technologies and environments complexities in a conceptual design process by evaluating the Use Case Diagram (UCD) of UML. However, UCP method of original is suitable for software development. Therefore, in this paper, a generalization of the UCP method was carried out. The outline of the evaluation step is as shown in Fig 5.

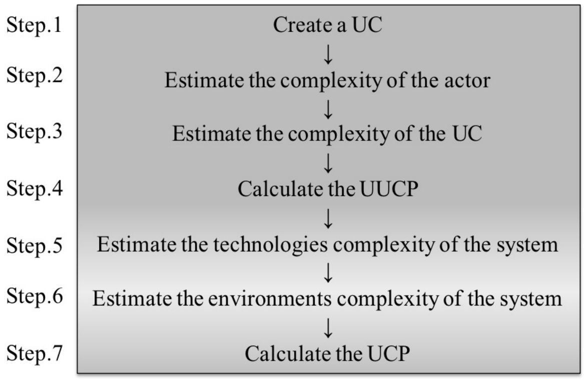

Fig.5. Overview of the Evaluation phase

4.1. Detail steps of UCP method

The detail steps of UCP method is explained as follows:

1. SFD is transformed to UCD—from FR to UC, from DP to design solution actor, and from external material to external actor as shown in Fig 4 and 6.

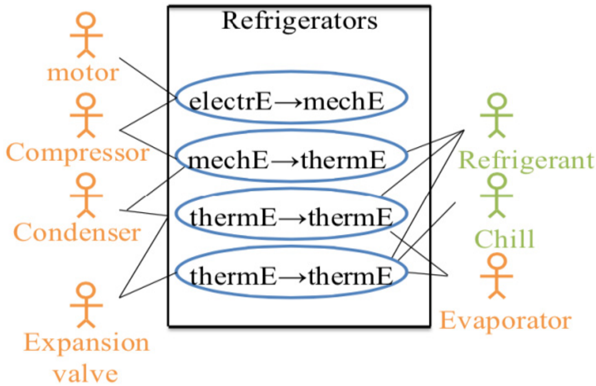

Fig.6. UCD was created from the SFD

2. Complexity of the actor evaluate in three types for each actor, simple, average or complex. The evaluation criteria are as shown in Table 4. In this evaluation, the actor is defined the evaluation criteria, based on the degree of freedom of the system response.

Table.4. Evaluate criteria of complexity of the actor

Actor Type	Definition	Weight
Simple	No degrees of freedom	1
Average	Degrees of freedom is 1 or 2	2
Complex	3 or more the degrees of freedom	3

3. Complexity of the UC evaluate in three types for each UC, simple, average or complex. The evaluation criteria are as shown in Table 5. In this evaluation, UC is defined the evaluation criteria, based on the number of transactions.

Table.5. Evaluate criteria of complexity of the UC

UC Type	Definition	Weight
Simple	Transaction number is 1 or 2	5
Average	Transaction number is 3 or 4	10
Complex	5 or more the number of transactions	15

4. *UUCP* is calculated by $Actor_{total}$ and UC_{total}. The *UUCP* is defined by following formula.

$$UUCP = Actor_{total} + UC_{total} \quad (4)$$

5. In this Step, the degree of technical complexity of the system is evaluated from the 13 items. And, each complexity of the technologies complexities evaluate in six types for that system, Unrelated=0, average=3 or Essential=5(This number is coefficient). And, *TCF* is calculated using these. The 13 items are as shown in Table 6. And, *TCF* is defined by following formula.

$$TFactor = \sum Weight * Coefficient \quad (5)$$

$$TCF = 0.6 + (0.01 * TFactor) \quad (6)$$

Table.6. Evaluate criteria of technical complexity of the system

Factor number	Meaning of the factors	Weight	Coefficient
T1	A large number of body or entity	2	
T2	Performance objectives	2	
T3	End-user efficiency	1	
T4	Complex internal structure or internal processing	1	
T5	Code or material is reusable	1	
T6	Easy to install	0.5	
T7	Traditional ones or its application	0.5	
T8	Portable	2	
T9	Easy to change	1	
T10	Concurrent use	1	
T11	Security	1	
T12	Access for third parties	1	
T13	Training needs	1	

6. In this Step, the degree of environment complexity of the system is evaluated from the 8 items. And, each complexity of the environments complexities evaluate in six stages for that system, Unrelated=0, average=3 or Essential=5(This number is coefficient). And, *EF* is calculated using these. The 13 items are as shown in Table 7. And, *TCF* is defined by following formula.

$$EFactor = \sum Weight * Coefficient \quad (7)$$

$$EF = 1.4 + (-0.03 * TFactor) \quad (8)$$

Table.7. Evaluate criteria of environment complexity of the system

Factor number	Meaning of the factors	Weight	Coefficient
E1	Familiar with the development process	1.5	
E2	Application experience	0.5	
E3	Object-oriented experience	1	
E4	Lead analyst capability	0.5	
E5	Motivation	1	
E6	Stable requirements	2	
E7	Part-time staff	-1	
E8	Difficult programming language	-1	

7. Finally, the UCP is calculated from UUCP, TCF and EF. UCP represents the degree of complexity to the system. The system is complex, when UCP is high point. UCP is defined by following formula.

$$UCP = UUCP * TCF * EF \quad (9)$$

4.1. Execution result of refrigerator using UCP

In this section, the result of evaluating UCD of Fig 6 is follows:

1. The result of evaluating the actor is as shown in Table 8. Table 8 was evaluated, based on Table 4. Evaluation of the motor is simple, because it is only to change electrical energy to mechanical energy. And, evaluation of the refrigerant is complex, because it is changed into various forms, liquid, solid, etc.

Table. 8. Evaluate result of complexity of the actor at Fig 6

Actor	Weight
Moter	1
Compressor	1
Condenser	1
Expansion valve	1
Evaporator	1
Refrigerant	3
Chill	2
Total	**10**

2. The result of evaluating the UC and calculating the UUCP is as shown in Table 9. Table 9 was evaluated, based on Table 5. In addition, all UC type is simple, because UCD is created from a SFD satisfied the independent axiom, and is transformed via a lower level function structure of SFD.

Table. 9. Evaluate result of complexity of the UC at Fig 6

Use Case	Weight
Electr E → Mach E	5
Mach E → Therm E	5
Therm E → Therm E	5
Therm E → Therm E	5
Total	**20**

UUCP = Actortotal + UCtotal	**30**

3. The result of evaluating the technical complexity of the system is as shown in Table 10. Table 10 was evaluated, based on Table 6. Each technology factor was evaluated to account for modern technology.

Table. 10. Evaluate criteria of technical complexity of the system at Fig 6

Factor number	Meaning of the factors	Weight	Coefficient	Value
T1	A large number of body or entity	2	1	2
T2	Performance objectives	1	3	3
T3	End-user efficiency	1	0	0
T4	Complex internal structure or internal processing	1	3	3
T5	Code or material is reusable	1	3	3
T6	Easy to install	0.5	0	0
T7	Traditional ones or its application	0.5	3	1.5
T8	Portable	2	3	6
T9	Easy to change	1	3	3
T10	Concurrent use	1	3	3
T11	Security	1	0	0
T12	Access for third parties	1	0	0
T13	Training needs	1	0	0
Total	**Tfactor = Σweight * Coefficient**			**24.5**
TCF	**TCF = 0.6 + (0.01 * TFactor)**			**0.845**

4. The result of evaluating the environment complexity of the system and calculating the UCP is as shown in Table 11. Table 11 was evaluated, based on Table 7. Environmental factors are assumed to the average, until E6 from E1. Moreover, E7 and E8 are assumed to the Unrelated.

Table. 11. Evaluate criteria of environment complexity of the system at Fig 6

Factor number	Meaning of the factors	Weight	Coefficient	Value
E1	Familiar with the development process	1.5	3	4.5
E2	Application experience	0.5	3	1.5
E3	Object-oriented experience	1	3	3
E4	Lead analyst capability	0.5	3	1.5
E5	Motivation	1	3	3
E6	Stable requirements	2	3	6
E7	Part-time staff	-1	0	0
E8	Difficult programming language	-1	0	0
Total	**Efactor = Σweight * Coefficient**			**19.5**
EF	**EF = 1.4 + (-0.03 * EFactor)**			**0.815**
UCP	**UCP = UUCP * TCF * EF**			**20.66025**

To sum up, the calculated results of UCP for refrigerators was about 20 points. From this evaluation process, we believe that an accuracy numerical information of a cost for function's complexly of design solution was gotten by using this method.

5. Conclusion

In this paper, we proposed the FSA/SE process that added the simplification and the evaluation phases to FSA for supporting an idea creation. And, the thinking experiment using this process was performed. From this experimental result, we confirmed as follows:

(1)The simplification phase using the independent axiom was able to remove combinations of unnecessary functions from the combinations of large numbers of functions, which FSA drew on, and extract the combination of suitable functions.
(2)The function structure as the design solution was able to be structured by obtained combination of suitable functions on the simplification phase.
(3)To verify obtained design solution, the evaluation phase using UCP method was introduced, and the complexity of the design solution was able to be calculated.
(4)For validation of the evaluation phase, function structures of two kinds of vacuum cleaners and three kinds of displays were evaluated, and the validity check of these UCP values was performed via comparing the price of these products [7]. As the result, it confirmed that UCP values were a reasonable relation for cost.

From above-mentioned, we believe it is possible to create new ideas for design solutions in a short period of time through the FSA/SE process without relying on experience and knowledge of engineer or engineering term close to it.

Finally, in the future work, we are planning to include the modelling phase, which express the signal element and material element of SFD by using 1DCAE modelling method, into FSA/SE.

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