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An Integrated Computer-Aided Design Environment for Customizing Product/Service Systems

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Abstract. Manufacturers begin to give more and more customizing offerings and services of their products in order to create the values that really fits customers' needs and wants rather than to supply materialized products directly. Systematic design approaches and modularized computer-aided design systems are the key to reduce the design complexity and would lead to successfully converge divergent thinking and creativity to the specifically defined problems. Therefore, this research aims to propose a creative design system framework with an integrated method of customizing product/ service systems (PSSs) for the solution modularization. A systematic design model consists of three phases:1) identify problems and initial design (IPID); 2) design trimming and resolution generation (DTRG); 3) interaction mapping and design evaluation (IMDE). In phase I, we can understand customer requirements through interviewing by knowledge elicitation methods and root cause analysis. In phase II, we can generate more possible service components related to a specific product characteristic by innovative principles of the theory of inventive problem-solving. In phase III, we can assign the interactions between service components and customer needs to create PSS solution modules. A computer-aided design system environment, called SCO Explorer, is developed based on the above design phases and theoretic concepts to represent a solution design environment with the design requirements and to determine the input parameters of each phase. As the result shows that we verified the usefulness of the design method and tool by applying to existing PSSs by an electronic manufacturer to carry out a PSS solution.

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Keywords. Product service systems, systematic design model, computer-aided design environment, customized manufacturing.

Introduction

This paper is based on the outputs of the Product service systems (PSS)-based solution development project in Singapore by the NTU-Delta co-lab. Due to the heterogeneity and complexity during the development of PSS, the design chain and a collection of the integrated tools and software environment for developing PSS solutions is a major challenge to integrate service, product and even software (Lee et al., 2017). Product-service systems (PSS) can be taken as a new selling concept in which both tangible product and immaterial services are combined to fulfill customer's requirements (Lee et al., 2017). During a PSS's concept design, different expertise is also needed in order to create a high-value PSS. Thus, the challenges of its implementation while proceeding with informal techniques or involving numerous human-language interactions that create unnecessary and unwanted iterations among groups of designers in different divisions or companies. As such, the poor design knowledge sharing and undocumented knowledge keeping results in uncertainty and poor customer requirement focus when designing new PSS. Hence, this study attempts to propose a systematic design approach and modularized computer-aided design system to cope with the above challenges.

1. Design overview: the methodology at a glance

1.1. Phase I: Identify problems and initial design (IPID)

The TRIZ problem formulator (Lee et al, 2014) can analyze domain need knowledge and the specific context of the industry or the case company. We can take these results as a solid foundation to identify resolutions after the above analysis. Based on the model, we may determine the customer requirements as the key problems in the case company. This is an effective way to acquire design needs, especially when the problem itself is still ambiguous.

1.2. Phase II: Design trimming and resolution generation (DTRG)

Forty invention principles of TRIZ were deduced by Altshuller, producing an efficient approach that lets designers acquire possible resolutions without domain experience (Lee et al, 2014; Wang et al., 2016). These principles are generic suggestions which are used to solve technical and non-technical problems. Using these principles and referring to their examples, we can choose several principles related to the problem and customer requirements in the specific case company.

1.3. Phase III: Interaction mapping and design evaluation (IMDE)

The QFD matrix can successfully extend customer needs and transfer quality into production-service systems (Lee et al., 2016, Fogli & Guida, 2013). Generally, a complete QFD process provides a traceable path from customer concerns and needs into the service development process and from conceptual design to market launch (Chen et al., 2009; Yan et al., 2009). The QFD matrix can be adopted in the evaluation of customer requirements to specific functions.

2. The computer-aided design system Framework and Case illustration

2.1. Framework of SCO Explorer

We conduct a computer-aided design system named SCO Explorer based on the above methodologies. The framework and the functions of SCO Explorer are shown in Figure 1. Firstly, we have a design rule base and design phase library based on the design theories in three phases of solution design. This can help designers to obtain design requirement and think about resolutions step by step under the guidance of design theories. Secondly, six functions are designed, namely service concept wizard, service design organizer, design concept editor, stakeholder editor, service evaluator and design concept viewer. Designers can conduct the design under the working space and design interface. Finally, the whole system can be taken as a PSS solution case base. While doing solution design, we can conduct the design refer to the previous cases.

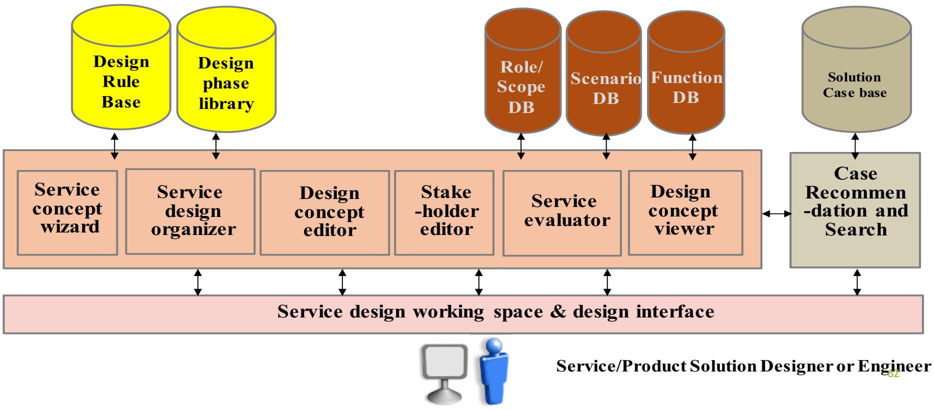


Figure 1. The computer-aided design system Framework

- Service concept wizard can help designers to analyze the service context and to distinguish the design need base on the theory-based design rule base and design phase library.
- Service design organizer can provide designers to expand and clarify related methodologies in the service design phases according to the different domains suggested by service concept wizard.
- Design concept editor can provide designers or engineers to input and edit a new service system. This is the most basic functionality of the SCO explorer. In order to acquire the knowledge of service cases for service design in service CAD efficiently, it is necessary to provide the interface to describe a service model with ease.

- Design concept viewer can provide designers or engineers to display the service-design components that designers focus on.
- Stakeholder editor can provide designers to store their basic profiles and their customer needs about the problems or points of view.
- Service evaluator provides designers to evaluate and filter the final service resolutions or design functions of the service system.

2.2. Phase 1: IPID user interface and unsatisfied customer requirements of case illustration

The case company's policy goals were to provide its employees with clear and complete health and nutritional information about their meals, as well as to provide a good working environment, to let them feel joyful and relieved and sense of belonging. However, the company staff's canteen was running almost exclusively by contract employees. That means many of the above values are not well satisfied to company staffs. Thus, they attempted to figure out the key points and to build a new service system and process to solve the staff canteen's service supplying problems. For eliciting customer requirements, this research conducted interviews with eight company staffs that have meals in canteen every day.

Then, the analysis work is conducted by analyzing the content and reducing the raw interview data into several ladders of the attributes, consequences, and values first, then we can integrate the entire A-C-Vs ladders into a list (A-C-Vs, as shown in table 1). After the analysis of customer's requirements, we can understand four insufficient aspects of customer dissatisfaction including "dining environment", "efficiency", "meals" and "interaction" aspects.

Table 1. List of A-C-Vs analysis

Attributes	**Consequences**	**Values**
Adequate seats (1)	Nutritious (17)	Feel joyful (30)
Delicious (2)	Saving time (18)	Happiness (31)
Efficient meal supply (3)	Desire to eat (19)	Feel relieved (32)
Fair price (4)	Comfortable (20)	Satisfaction (33)
Sufficient air condition (5)	Avoiding long queue (21)	Sense of belonging (34)
Photo menu (6)	Easy to find seats (22)	Good working life (35)
Meal ordering kiosk (7)	Saving money (23)	
Stored value card (8)	Good appetite (24)	
Frequent meal changing (9)	Comfortable dinging (25)	
Providing nutrition information (10)	Good sanitation (26)	
Feedback channel (11)	Good word of mouth (27)	
Booking for meal-ordering (12)	Easy to make decision (28)	
Queuing machine (13)	Good communication (29)	
Providing fruit (14)		
Multiple choice of meals (15)		
Clean tableware, kitchen and recycling area (16)		

By using the problem analysis of SCO explorer in IPID (as shown in Figure 2), it can help the designer to organize the useful functions (UFs) and harmful functions (HFs). In this case, four UFs and two HFs are analyzed. UFs are (1) operators can provide more nutritious and diverse meals, less-queening process, (2) companies need regular surveys of meals ideas and employee's satisfaction, good response and communication channel is needed, (3) meals design, dining environment maintenance and efficient process should require positive support for operators, (4) contract operators are well-managed by staff canteen. HFs are (1) health claim of canteen and diversity of meals are not easy to support by contract operators (restaurants) so that (2) employees' complaints about this are delivered. IPID can help the designer to organize the relationship of UFs and HFs and represent the problem model. Then, it can help us to define key problems. In this case, four statements that cause the unsatisfied customer requirements are figured out, which are (1) insufficiency of nutrition information of meals, (2) lack of regular meal-change for diverse and attractive meals, (3) order process time should be shorten, (4) information linkage between canteen and restaurants should be raised.

2.3. Phase 2: DTRG user interface and proposed resolutions of case illustration

According to the unsatisfied customer requirements in phase I, key principles can be found and selected from the 40 general principles shown in DTRG user interface (as shown in Figure 3). They are No. 10 (prior action), No.18 (Mechanical vibration), No. 27 (Cheap short-living objects), No. 28 (Mechanics substitution), No. 34 (Discarding and recovering) and No. 35 (Parameter changes). Then, we can determine and input how to coordinate these principles to design a new service system. In this case, the service design concept can be obtained from (1) doing something to fit customer needs in advance, (2) developing multiple services, (3) provide product trials, demos or one-time-use objects, (4) deploy a new service interface with new senses, (5) adding a convenient service facility that can reuse its elements, (6) design a new service process that can bring closer partnerships.

2.4. Phase 3: IMDE user interface and PSS system of case illustration

In this phase, we can conduct the evaluation by QFD matrix analysis from CRs-SRs to SRs-SFs (CR-customer requirements, SR-solution requirements, SF-solution functions) under the IMDE interface. We take this case for example. The first QFD service level analyzed the customer requirements (CRs) and solution resolutions (SRs) in the two deployment matrix axes (as shown in Figure 4). The weights will then be evaluated and obtained by an evaluation team. Using the QFD approach we set the relative CR weights (40%, 35%, 15%, 10%, respectively) with the product sum calculated as the sum of scores in the SR columns multiplied by their corresponding relative CR weights. In this way, the relative SR weights could be acquired (16%, 16%, 21%, 19%, 15%, 14% refers to "fit customer needs in advance", "multiple services", "trials, demos or one-time-using objects", "new service interface", "self-service facility", "effective process", respectively). We can set the weight in the 2nd QFD matrix, and input the corresponding relative degree to obtain the final solution functions.

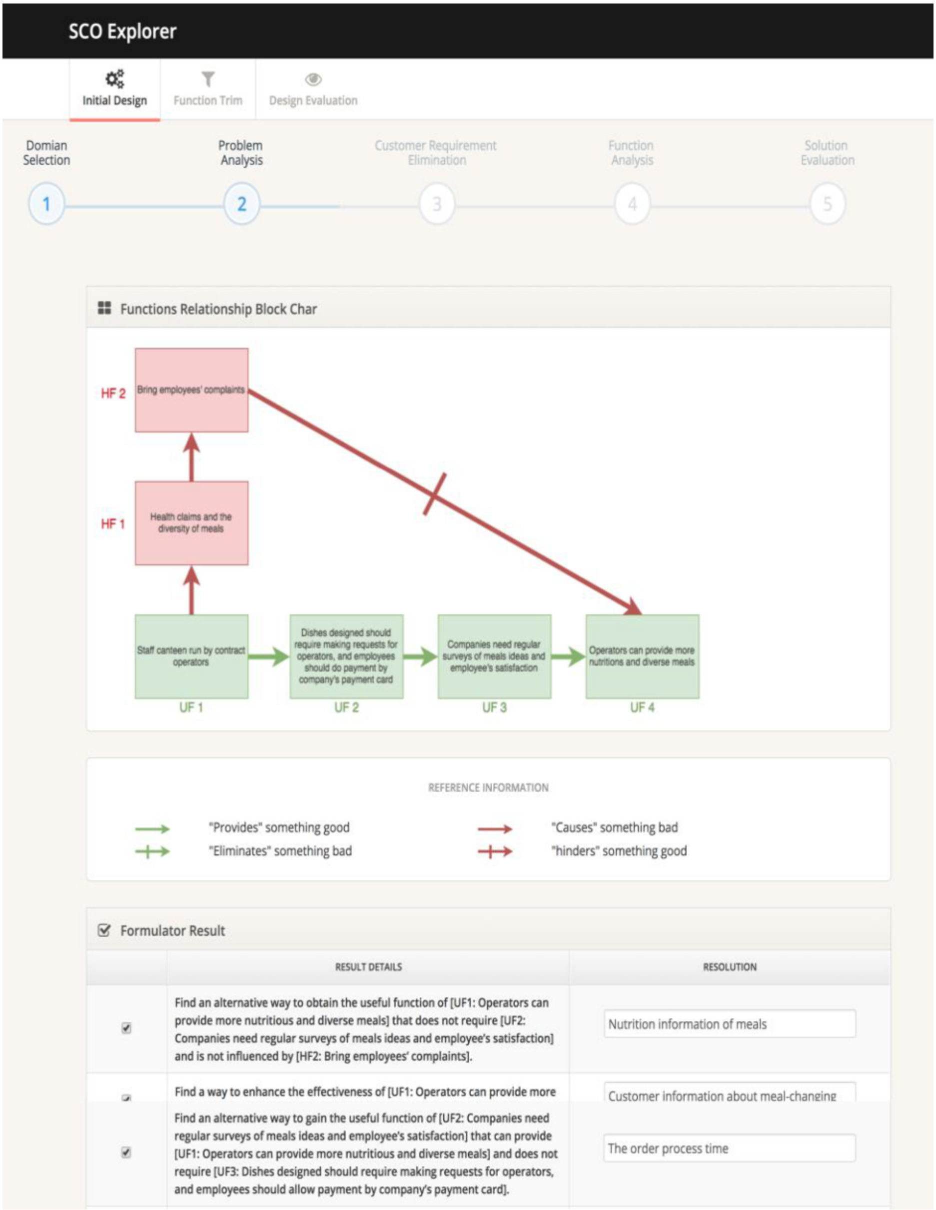
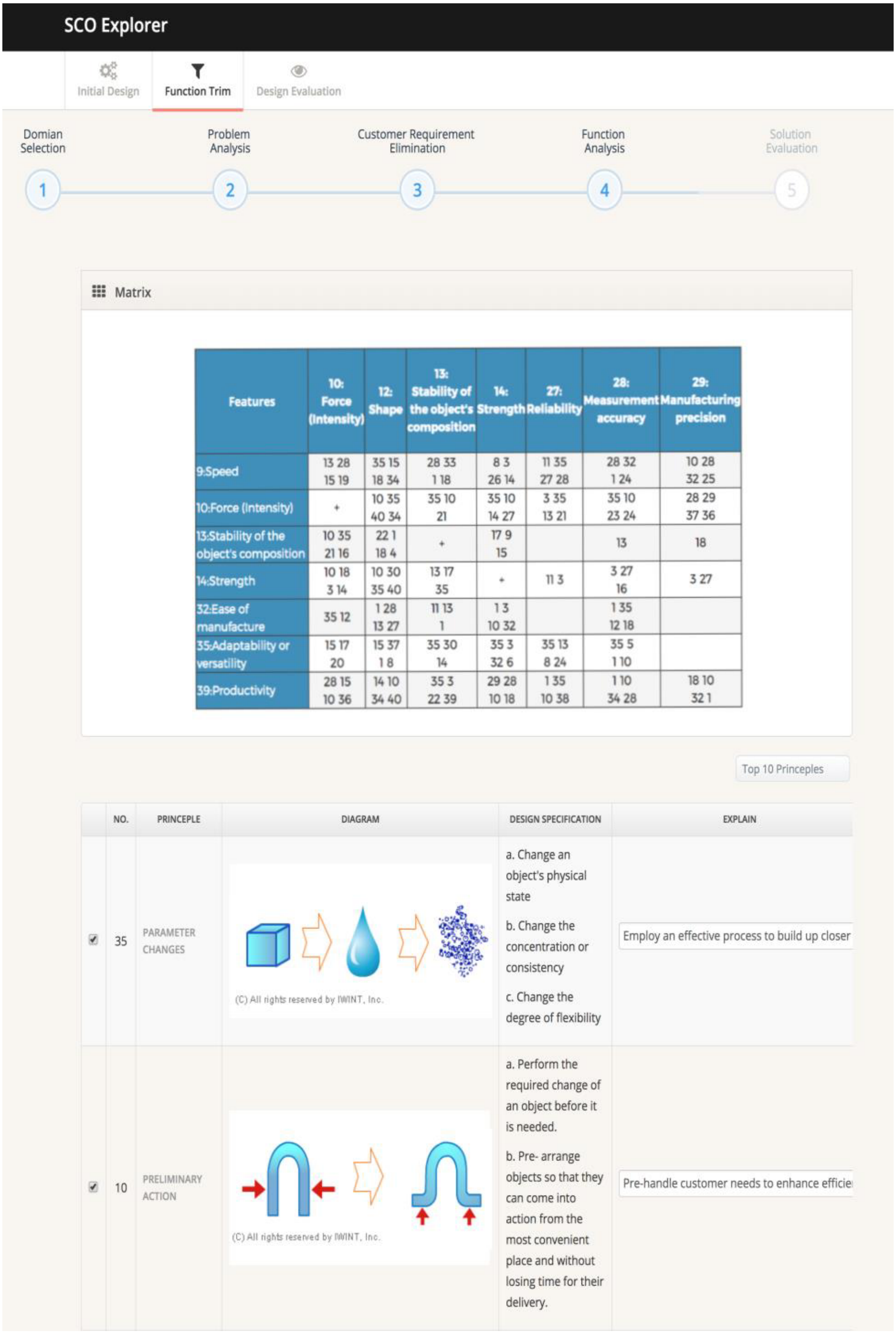


Figure 2. Screen shot of phase 1 in SCO explorer



Features	10: Force (Intensity)	12: Shape	13: Stability of the object's composition	14: Strength	27: Reliability	28: Measurement accuracy	29: Manufacturing precision
9:Speed	13 28 15 19	35 15 18 34	28 33 1 18	8 3 26 14	11 35 27 28	28 32 1 24	10 28 32 25
10:Force (Intensity)	+	10 35 40 34	35 10 21	35 10 14 27	3 35 13 21	35 10 23 24	28 29 37 36
13:Stability of the object's composition	10 35 21 16	22 1 18 4	+	17 9 15		13	18
14:Strength	10 18 3 14	10 30 35 40	13 17 35	+	11 3	3 27 16	3 27
32:Ease of manufacture	35 12	1 28 13 27	11 13 1	1 3 10 32		1 35 12 18	
35:Adaptability or versatility	15 17 20	15 37 1 8	35 30 14	35 3 32 6	35 13 8 24	35 5 1 10	
39:Productivity	28 15 10 36	14 10 34 40	35 3 22 39	29 28 10 18	1 35 10 38	1 10 34 28	18 10 32 1

Figure 3. Screen shot of phase 2 in SCO explorer

We can finally design system modules with the concept of customized cloud manufacturing (CMfg) as the “Transparent-screen based smart meal-ordering service”. It consists three major modules: (1) interactive meal menu, (2) meal order service, and (3) business intelligence of sales and customer relationship modules. An interactive display menu module can be implemented to provide a new ordering interface with a transparent-screen. This module can provide customers with information about the food nutrition, ranking and comments about the meals. The Meal-order service module allows customers to order meals via a new ordering system embedded in the kiosks. The new “business intelligence sales and customer relations” module can be implemented to solve unclear information about a restaurant's sales status with the integrated web-POS system.

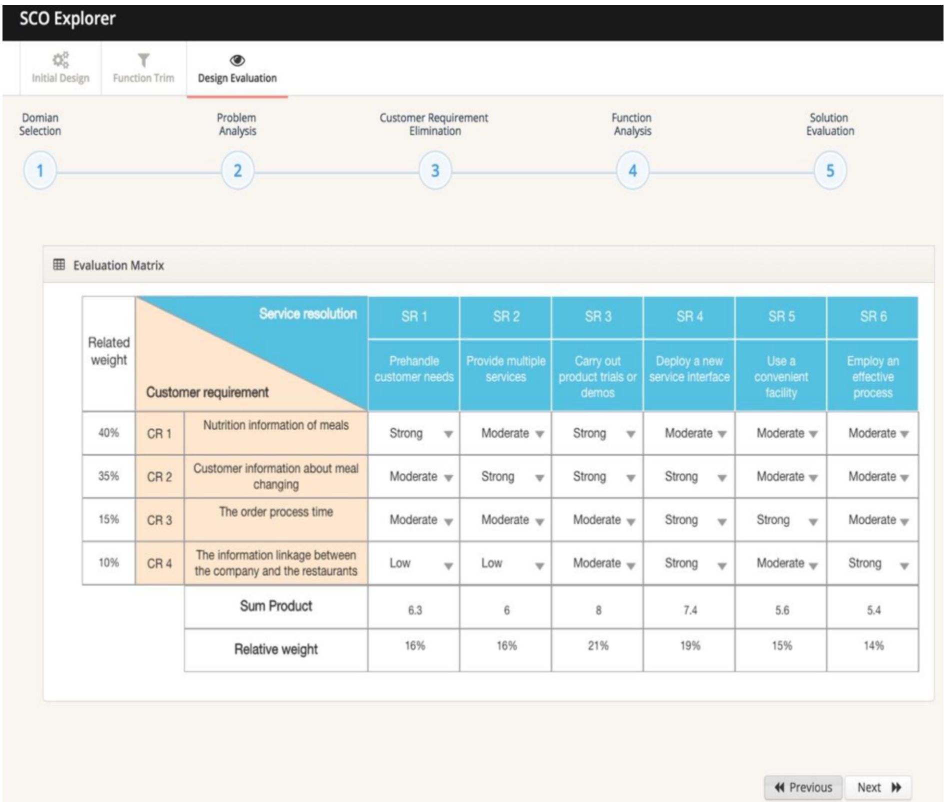


Figure 4. Screen shot of phase 3 in SCO explorer

3. Discussion and Conclusions

This study attempts to resolve the challenges of poor design methodologies and fragile software system architectures. A design approach and computer-aided design system framework for smart PSS development was established and illustrated. The modelized and methodology-based design-aided system contributes to designing the successful innovation systems (Wang et al., 2017). It consists of three design phases. The corresponding user interface and software framework are designed into SCO explorer. The work has carried out the outcomes of each design phase on a case study of a canteen of a high-tech company. The solutions of the new PSS service are also described. The contributions of the paper are consisted of at least two aspects. Firstly, this paper provides a unified framework that can cope with the above challenges that can enrich the literature of the service CAD system (Wang et al., 2017). Secondly, it also brings the practical case study for PSS system design (Lee et al., 2017). In the future work, evaluation with end users of the computer-aided design system can be conducted, focusing on the quality of user interaction with the system (i.e. usefulness and usability) and on the capability of it of supporting collaboration among users (i.e. collaboration effectiveness).

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References

[1] C. H. Lee, C. H. Chen and A.J.C. Trappey, Applying theory of inventive problem solving to develop product-service system, *Proceedings of CSCWD 2017, The 21st IEEE International Conference on Computer Supported Cooperative Work in Design*, Wellington, New Zealand, 2017 , DOI: 10.1109/CSCWD.2017.8066694.

[2] D. Fogli and G. Giovanni, Knowledge-centered design of decision support systems for emergency management, *Decision Support Systems*, Vol. 55 (1) , 2013, pp. 336-347.

[3] W. Yan, C.H. Chen, D. Chang and Y. T. Chong, A stakeholder-oriented innovative product conceptualization strategy based on fuzzy integrals, *Advanced Engineering Informatics*, Vol. 23(2), 2009, pp. 201-209.

[4] Y. H. Wang, C. H. Lee and A. J. C. Trappey, Conceptual Thinking for Collaborative Service Design Engineering Framework, *Proceedings of CSCWD2016, The 20th IEEE International Conference on Computer Supported Cooperative Work in Design*, Nanchang, China, 2016, DOI: 10.1109/CSCWD.2016.7565989.

[5] C. H. Lee, Y. H. Wang, A.J.C. Trappey and S. H. Yang, Applying geo-social networking and the theory of inventive problem-solving in service innovation and evaluation, *Journal of Industrial and Production Engineering*, Vol. 31(2) , 2014, pp. 95-107.

[6] C.H. Chen, K. Sato and K. P. Lee, Editorial: Human-centered product design and development. *Advanced Engineering Informatics*, Vol. 23(2) , 2009, pp. 140-141.

[7] C. H. Lee, Y. H. Wang and A. J. C. Trappey, Service design for intelligent parking based on theory of inventive problem solving and service blueprint, *Advanced Engineering Informatics*, Vol. 29(3), 2015, pp. 295-306.

[8] Y. H. Wang, C. H. Lee and A.J.C. Trappey, Modularized design-oriented systematic inventive thinking approach supporting collaborative service innovations, *Advanced Engineering Informatics*, Vol. 33, 2017, pp. 300-313.