The Integration of DFX Principles with TRIZ for Product Design – A Case Study of Electric Scooter

Tien-Lun Liu(✉), Yi-Chen Li, and Ji-Ze Xiao

Department of Industrial Engineering and Management, St. John's University,
499, Section 4, Tam King Road, Tamsui District, New Taipei City 25135,
Taiwan, R.O.C.
`tliu@mail.sju.edu.tw`

Abstract. In order to improve product development, enterprises need to strengthen product lifecycle management (PLM) and collaborative design capability. For the description of product design we have proposed a four-level structural classification scheme, which includes Design Intentions, Design Requirements, Design Parameters and TRIZ Engineering Parameters. This study is based on the classification scheme, and introduces the concept of Design for X (DFX) and then discusses the design principles from four different perspectives including manufacturing aspect, customer aspect, maintenance aspect and environmental aspect. We deliberate the meaning of these aspects and further establish their relevance with the TRIZ 48 engineering parameters. An electric scooter design is presented to illustrate the application.

Keywords: Design for X · TRIZ · Product design · Electric scooter

1 Introduction

In current product development, enterprises often need to cooperate as a project team, or even need to work with other enterprises to accelerate the development process. This paper explores the problems of industrial innovation, and tries to combine the TRIZ method to integrate the related operations in product design. TRIZ is mostly used at the conceptual design stage to generate design concepts and solve problems. Therefore, the main purposes of this study are as follows:

1. To assist collaborative design and provide better understanding for team members to communicate each other more efficiently during product development process.
2. To combine the characteristics of TRIZ into the product design and then help resolve design problems through TRIZ methods when needed.

J.-S. Pan et al. (eds.), *Advances in Smart Vehicular Technology, Transportation, Communication and Applications*, Smart Innovation, Systems and Technologies 86,
https://doi.org/10.1007/978-3-319-70730-3_16

2 Literature Review

2.1 Design Collaboration

Fan (2014) depicted that how to assure the designate processes are easy to follow-up and clearly to understand is the key to success. If have to build the collaborative development working environment, better to do it at the earliest phase. It's a hard requirement to reach every aspect of agreement from different departments to functions. While agreements define the quality of a project, thus all project success elements including guidelines, priorities, communications, or endorsements must be unambiguously identified at project kick-off and agreed upon related parties. Clearly defining the ways to execute jobs help teams from confusing or arguments during issue managements. This research is considered on the base of the collaborative platform for the product development due to the different backgrounds of the team members. The design requests from the various departments in the process of product development are integrated, and the product design information is then compiled and analyzed to achieve the goal of the project.

2.2 Design for EXcellence

In the spirit of collaborative development, there is a very important concept to product design - early involvement in the product life cycle, which results in a "Design for X (DFX)" methodology. Since the 1970s, many DFX ideas have been proposed by experts and scholar. Kuo et al. (2001) pointed out that DFX covers Design for Assembly (DFA), Design for Manufacturing (DFM), Design for Disassembly (DFD), Design for Environment, DFE) and Design for Quality (DFQ) and so on. The main purpose of DFX is to hopefully fulfill different design considerations in the product life cycle, thereby enhancing the product capabilities. It may also refer to "DFX" as "Design for eXcellence" for representing the achievement of a variety of design goals. This study takes DFX as the initial design intention and hopes to integrate the design requests from various departments.

2.3 TRIZ

The TRIZ theory is a systematic innovation approach, which was mainly established by Russian scientist Altshuller (2000) in 1946. TRIZ is abbreviated from Russian and interpreted in English as "Theory of Inventive Problem Solving". TRIZ theory was concluded methodically via analyzing more than twenty hundred thousand patents, and inferring the resolving techniques involved in these patents. There are several problem defining methods and solving tools in TRIZ, including System Operator, Ideality, Resource, Contradiction Matrix, 40 Inventive Principles, Separation Principles, Substance-Field Analysis, Patterns of Evolutions, ARIZ, etc.

The concept of Contradictions is one of the fundamental philosophies in TRIZ. Contradictions existing in the problem imply potential opportunities to innovation.

Contradictions are classified into two different categories. One is technical contradiction and the other is physical contradiction. A technical contradiction is defined as two different engineering parameters conflict each other in the problem; for instance, a car needs to be fast but energy-saving. A physical contradiction means an engineering parameter conflicts by itself, such as a car needs to be longer for better space but also needs to be shorter for easy parking. Contradiction Matrix is formulated to deal with technical contradictions, and the Separation principles are developed to solve physical contradictions.

3 Four-Level Structural Classification

In our previous research (Liu et al. 2016), authors discussed product design requests from project team members and made connection to TRIZ engineering parameters according to their characteristics and attributes of the design. In such a way the TRIZ contradiction analysis can be applied once encountering conflicts. The classification hierarchy was developed into four levels, which are Design Intention, Design Requirement, Design Parameter and Engineering Parameter, as explained below:

- First level - Design Intentions (DIs): The concept of DFX is applied as the first level to comprehend each collaborative team member's aim on his/her design demands. The typical DFXs used in this level are Design for Manufacture (DFM), Design for Assembly (DFA), Design for Customer (DFC) and Design for Environment (DFE). However the DFXs can be expanded if necessary.
- Second level - Design Requirements (DRs): These are explicit requests from the team members to state their purposes on DFXs. The design requirements should be concrete and meaningful.
- Third level - Design Parameters (DPs): These are the product specifications which are typically related to the parts or components. DPs are usually quantifiable.
- Fourth level - Engineering Parameters (EPs): The definitions of EPs are the same as discussed in TRIZ theory. However the 48 engineering parameters proposed by Mann (2003) are applied instead of 39 in classical TRIZ as shown in Table 1.

Founded on the four-level structural hierarchy a more comprehensive scheme for the multi-disciplinary design requests is constructed. A basic conceptual example is illustrated in Fig. 1. By arranging the design requests in such a way, the cross-functional team members can understand what and why the product design is deliberated from different viewpoints. Particularly linking to TRIZ engineering parameters, the design conflicts may be examined in more details and possibly resolved through the contradiction matrix and inventive principles. Therefore the efficiency of collaborative product development could be improved to achieve the effectiveness of product design quality.

Table 1. The 48 engineering parameters in TRIZ (Matrix 2003)

1	Weight of moving object	25	Loss of substance
2	Weight of non-moving object	26	Loss of time
3	Length of moving object	27	Loss of energy
4	Length of stationary object	28	Loss of information
5	Area of moving object	29	Noise
6	Area of stationary object	30	Harmful emissions
7	Volume of moving object	31	Other harmful effects generated by system
8	Volume of stationary object	32	Adaptability/versatility
9	Shape	33	Compatibility/connectivity
10	Amount of substance	34	Trainability/operability/controllability
11	Amount of information	35	Reliability/robustness
12	Duration of action of moving object	36	Repairability
13	Duration of action of stationary object	37	Security
14	Speed	38	Safety/vulnerability
15	Force/torque	39	Aesthetics/appearance
16	Energy used by moving object	40	Other harmful effects acting on system
17	Energy used by stationary object	41	Manufacturability
18	Power	42	Manufacturing precision/consistency
19	Stress/Pressure	43	Automation
20	Strength	44	Productivity
21	Stability	45	System complexity
22	Temperature	46	Control complexity
23	Illumination intensity	47	Ability to detect/measure
24	Function efficiency	48	Measurement precision

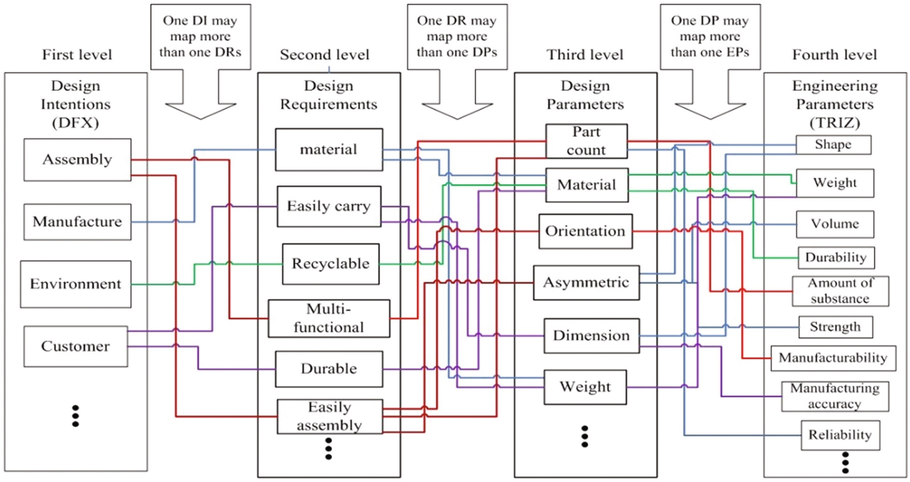

Fig. 1. The four-level structural classification

4 Case Study

An electric scooter design is applied to demonstrate the proposed methodology as we consider the DFXs for four different design purposes - manufacturing, customer, maintenance and environmental protection. In order to understand the applicability of the four-tier architecture, this section will assume two design situations of the electric scooter. The first situation is considered as the design requirements without setting any premise of the design and the second situation is discussed for the design integration on the scooter frame.

4.1 The Situation Without Premise

The assumption of this situation is that the departments do not have any design premise at the beginning. As the product project proceeds, the team members put forward their design requests based on their backgrounds. For examples from the manufacturing point of view, it is desirable that the parts of the scooter frame can be reduced in assembly, and the degree of adhesion between the hulls is improved. In the maintenance point of view, the motor needs to be easily repaired and the battery can be easily picked up when replaced. As for a customer's viewpoints, a good battery capacity and long travelling distance are preferred as well as handling the battery can be lightweight and convenient. In addition, the storage space should be larger. From the environmental point of view, the scooter should be energy-saving and the battery has to be recycled. To sum up the design requests from different aspects, the corresponding four-level data structure is shown in Table 2.

Table 2. Four-level data structure of design requests from different aspects

DFX	Design requirement	Design parameter	No. engineering parameter
Manufacturing	Reduce the number of parts	Frame Outer shell	10. Amount of substance 41. Manufacturability 45. System complexity
	Reduce part variation	Outer shell	41. Manufacturability 42. Manufacturing precision
Maintenance	Good accessibility	Battery	16. Energy used by moving object 36. Repairability
	Easy detection of diagnostic accuracy	Motor	46. Control complexity 47. Ability to detect/measure 48. Measurement precision

(*continued*)

Table 2. (*continued*)

DFX	Design requirement	Design parameter	No. engineering parameter
Customer	Suitable size and space to use	Storage space	9. Shape 34. Operability/controllability 40. Other harmful effects acting on system
	Reduce the physical burden	Battery	16. Energy used by moving object 24. Function efficiency
	Increase battery capacity	Battery	7. Volume of moving object 10. Amount of substance 40. Other harmful effects acting on system
	Long travelling distance	Battery Motor	12. Duration of action of moving object 24. Function efficiency 27. Loss of energy
Environment	Reduce energy consumption	Motor	27. Loss of energy
	Designed to be recyclable or reusable	Battery	25. Loss of substance 31. Other harmful effects generated by system

After examining the four-tier structure in Table 2, we can find that the immediately improved design parameters and request conflicts. The battery and the motor are significant targets to be focused. Furthermore, possible conflicts can be identified. For instance, the customer wants a bigger battery capacity, but the battery capacity is usually proportional to the volume and weight of the battery such that will impact the storage space of the scooter. Therefore after checking the Contradiction Matrix in TRIZ, we can find several inventive principles as shown in Table 3 for improvement directions. Note that there are total 40 inventive principles in TRIZ, the details can be found in Ref. ?.

Table 3. Contradition analysis for battery

Improving engineering parameters	Worsening engineering parameters	Suggested inventive principles number
10. Amount of substance	12. Duration of action of moving object	35, 40, 34, 10
	31. Other harmful effects generated by system	1, 35, 30, 31
	40. Other harmful effects acting on system	35, 9, 21, 22

The suggested inventive principles of this scenario are numbered 1, 9, 10, 21, 22, 30, 31, 34, 35, 40, and the most frequently appeared principle is 35 - *parameter change/changing properties*, which may be sought as the first attempt for solution.

4.2 Frame Integration Design

The scooter frame and the outer shell are assembled together, and then the frame will be manufactured in one forming. This way can reduce the number of parts and enhance the reliability of the frame as well as reduce the gap between the parts to achieve better appearance for customers. Nevertheless from the manufacturing aspect, the number of parts is reduced, the technical requirement of the frame manufacturing becomes higher. Parts reduction may help maintenance, but the integrated component needs be replaced entirely once damaged. As from the environmental aspect, the material usage is simpler, however the waste may increase if replaced as a whole. In addition the more complex manufacturing process may cause more pollution. In this situation, the corresponding four-level data structure is shown in Table 4.

Table 4. Four-level data structure of frame integration design

DFX	Design requirement	Design parameter	No. engineering parameter
Manufacturing	Reduce the parts count	Frame	10. Amount of substance 45. System complexity
		Outer shell	
	Easy manufacture	Frame	41. Manufacturability 44. Productivity
Maintenance	Simplify the product and maintenance	Frame	10. Amount of substance 36. Repairability 45. System complexity
Customer	Good quality and appearance	Frame	35. Reliability/robustness
		Outer shell	35. Reliability/robustness 39. Aesthetics/appearance
Environment	Raw material type is single	Frame	10. Amount of substance 33. Compatibility/connectivity 40. Other harmful effects acting on system
		Outer shell	
	Simplify manufacturing process	Frame	25. Loss of substance 27. Loss of energy

Frame integration is mainly to decrease body parts of the scooter, but the manufacturing process may become difficult and harmful to the environment, resulting in the conflict between DFM and DFE. Similarly by querying the Contradiction Matrix in TRIZ, we could find the corresponding inventive principles to look for possible solution as shown in Table 5.

Table 5. Contradition analysis for frame integration design

Improving engineering parameters	Worsening engineering parameters	Suggested inventive principles number
10. Amount of substance	41. Manufacturability	10, 2, 35, 1
	44. Productivity	1, 13, 3, 35, 36
	27. Loss of energy	35, 7, 18, 19
45. System complexity	41. Manufacturability	3, 12, 1, 28, 26
	44. Productivity	16, 12, 29, 8
	27. Loss of energy	35, 28, 13, 10

The suggested inventive principles of this scenario are numbered 1, 2, 3, 7, 8, 10, 12, 13, 16, 18, 19, 28, 35, 36, and the more frequently appeared principles are 35 (*Parameter change/changing properties*), 1 (*Segmentation*) and 12 (*Equipotentiality*). These inventive principles may be applied to solve the conflict problem.

5 Conclusion

This model may be applied to a cloud-based product development platform to aggregate the design requests from collaborative team members. Through the proposed hierarchical product design contents, members of the product development team can effectively express their intentions of the design, and communicate each other better to reduce the gap between different professional fields. Combined with TRIZ engineering parameters, the conflicts inbetween may be resolved by contradiction analysis in TRIZ. The product quality and time to market can then be improved effectively.

References

Altshuller, G.: The Innovation Algorithm: TRIZ, Systematic Innovation and Technical Creativity. Technical Innovation Center, Inc. (2000)

Fan, C.S.: A study on a product development and collaborative design process improvement of a transnational company—take the D company as an example. Master Thesis, National Taiwan University (2014)

Kuo, T.C., Huang, S.H., Zhang, H.C.: Design for manufacture and design for X: concept, applications, and perspectives. Comput. Ind. Eng. **41**(3), 241–260 (2001)

Liu, T.L., Li, Y.C., Li, M.L.: A framework of cloudbased collaborative platform to integrate product design requests and contradiction analysis. In: Proceedings of 2016 International Conference on Advanced Materials for Science and Engineering (ICAMSE), pp. 475–478 (2016)

Mann, D.L., Dewul, S.: Updating the TRIZ contradiction matrix. In: 5th Annual International Conference of Altshuller Institute for TRIZ Studies (2003)