Elevate Design-to-Cost Innovation Using TRIZ

Zulhasni bin Abdul Rahim and Nooh Abu Bakar

Abstract Design-to-cost (DTC) is a powerful concept to adopt in reducing cost at design level. The concept brings the cost parameter to the same level with the design or technical parameter. The ultimate goal of DTC is to design a product that effectively meets the planned target cost before the product is launched. Therefore, DTC consists of tools which assist the organization to achieve its goals. However, the effectiveness in achieving its goals is quite challenging as there are a number of conflicting issues in the process of driving down the cost toward the target cost. The best and most common tool of the DTC concept is a trade-off. A trade-off allows designers to tune their designs and seek ultimate points of optimization between conflicting product requirements. This directly hinders the designer from pushing the cost further down or achieving the targeted cost as it is only looking for a compromise as its solution. A framework called design-to-cost innovation (DTCI) is introduced to overcome these challenges. A case study is shared to discuss the application of the DTCI framework as compared to the optimization approach. The application of TRIZ tools in DTCI managed to achieve 75.3 % in weight reduction as compared to 22.1 % from the optimization approach, which indirectly reduces the material cost of the system. The outcome of DTCI brings a higher value to cost reduction initiatives by eliminating trade-offs and improving product innovation.

Keywords TRIZ • Design-to-cost • Cost reduction • Optimization • Automotive

1 DTC and Its Constraints

The first DTC concept was introduced in the military industry by The Department of Defense (DoD), United States of America. The concept was applied through DoD Directive 5000.1 named "Acquisition of Major Defense Systems" way back in 1971. The initial objective of this directive was to quantify the design parameter in the form of cost parameter. This established the cost element from the design

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parameter which gave impact to development cost and product cost. Later, another directive was created, DoD Directive 5000.28 named "Design-to-Cost" to improve the adoption of new concepts as guidelines which later become a policy. The most significant change in the new directive was highlighting cost control toward preestablished target cost throughout the design and development process of the product. At that time, the only approach which supported the product developer to achieve the given target cost was by adopting a trade-off between cost and other critical deliverables such as product performance, product design parameters, development time, or product quality.

The practical trade-off approach adopted by the DoD was considered as the most feasible method to achieve the target cost which was focused on finding a balance point between conflicting goals in product design and development (Tyson 1989). In other words, practical trade-offs would seek a compromise between the product design parameter and product cost parameter to prevent the final cost of the product to go beyond the targeted cost (Rahim and Bakar 2013). This forced the DoD to explore more effective methods or tools for support to achieve the target cost. Furthermore, they needed a tool which provided a specific analysis on the design and cost parameters in order to assist them in controlling the product cost from going beyond the target cost and eventually fail the project (Montgomery and Carlson 2011).

Subsequently, value engineering (VE) was adopted as a tool to reduce the dependency on trade-offs by analyzing between design and cost parameters. Wichita (1975) stated that VE was able to provide a significant improvement to DTC by incorporating clauses in the project's contract. Wichita (1980) conducted several case studies on the application of VE in DTC projects to develop weapon systems, which in his opinion was successful. However, the study recommended that trade-offs were still a component of DTC projects followed by the VE method to achieve target cost (Zulhasni and Nooh 2015).

The vertical improvement of DTC effectiveness to achieve target cost was not merely by introducing VE into the processes. Several tools have been proposed throughout the four phases of DTC based on a comprehensive DTC framework by Gilb and Maier (2005). The DTC framework comprises the following phases in sequence: preparation, design, evaluation, and implementation. Figure 1 shows the tools proposed in the DTC processes based on the framework by Gilb and Maier.

A common tool used in the preparation phase is the Pareto analysis, which focuses on prioritizing improvement areas for DTC projects. In the design phase, tools such as VE analysis and brainstorming are used to generate ideas to achieve the target cost. In the evaluation phase, the DTC project would encounter problems which may become constraints to its goals. Common problem-solving tools are used in this phase, such as "5-Why analysis" (Gilb 2011). However, there is less options for the DTC project in solving problems as it marches toward the implementation phase. In this phase, there is only one common alternative left for the DTC to execute the project, which is using the trade-off analysis. This tool distinctly proposes a compromise between conflicting needs, especially in terms of the cost parameter (Williamson 1994).

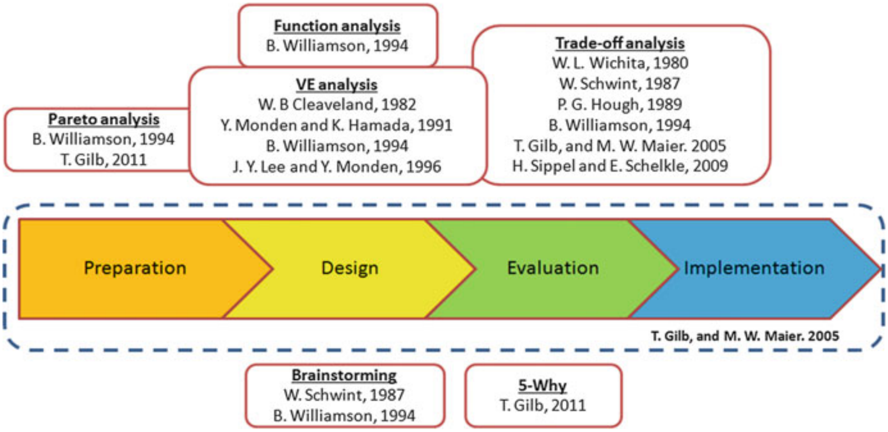


Fig. 1 Application of tools in DTC processes based from Gilb and Maier's framework

There is also a horizontal improvement that is focused on creating better value compared to the DTC. A new concept called "Cost as an Independent Variable" (CAIV) was introduced to the DoD in 1995. The CAIV concept highlights cost as a fixed variable, while performance and schedule are allowed to vary (Boudreau 2006). In other words, the focus on compromise is transferred to performance and schedule. Meanwhile expecting the product of the project is affordable. However, this concept is not feasible when the project is extended to a longer schedule. This is because the operational cost is still active and therefore, the total development cost would increase. It would have a similar impact on the compromising performance to achieve target cost, which inevitably ends up with poor customer satisfaction (Zulhasni et al. 2015).

The vertical and horizontal improvements of DTC are still tied to the trade-offs as their final decision-making in pursuing the target cost. However, in 2000, Esaki claimed making the first attempt to introduce TRIZ in DTC, together with other concepts such as quality function deployment (QFD) and the Taguchi method (Esaki 2005). Figure 2 shows the evolution of the DTC concept derived by Esaki (2005).

The main possible reason for the new method such as TRIZ to become a part of the DTC concept is to overcome the dependency of trade-offs in the main processes. This opens up a new improvement in the overall DTC concept if TRIZ is to be significant to break away from trade-offs. However, the search for literature on a proposed framework(s) and case studies on implementing TRIZ in DTC has yet to be found (Bakar and Rahim 2014). This creates motivation to pursue the possibility of the DTC in adopting TRIZ in its framework and processes. The next section will discuss some investigations conducted on how TRIZ was adopted in cost reduction initiatives, which was similar to the DTC concept. Subsequently, TRIZ was applied in the DTC concept through several case studies using a new framework called design-to-cost innovation (DTCI).

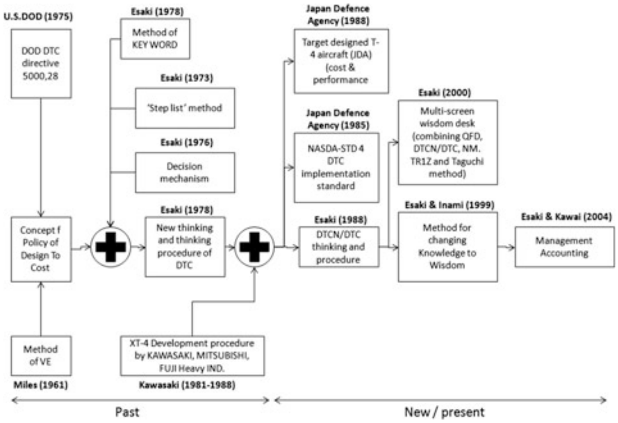


Fig. 2 The evolution of DTC concept (Esaki 2005)

2 TRIZ in Cost Reduction

Most TRIZ practitioners are aware and may agree that TRIZ is an arch enemy of trade-offs (Hipple 2012; Linstone 2011). One of the main reasons for the existence of the TRIZ methodology is to break away from the compromise or trade-off. Without TRIZ, most people would do their best and focus on optimization until they reach the ultimate limit (Hipple 2012; Cascini et al. 2011). Most probably people at this stage are unable to think of better solutions and instead propose more complex solutions (Rahim and Nooh 2014). Furthermore, what they require deploys unnecessary resources to maintain high levels of optimization. This includes cost as one of the main bottom-line for any industry.

Cost is the problem of all industries and things get more severe when the competitive environment becomes hostile. Almost all industries are struggling to improve their cost at every level of the business process. Regardless of how cost reduction is done, most business owners only want to see huge profits and zero losses. They would use whatever methods or approaches to find the ultimate solution reduce cost, including employing TRIZ methodology (Sheu and Hou 2011).

Many tools from level 1 to level 3 are taught within the scope of knowledge governed by the International TRIZ Association, or known as MATRIZ. The purpose to divide to three levels is to ensure that TRIZ practitioner is able to adopt the complexity of the methodology. Level 1 tools are "function analysis," "cause effect chain analysis," "ideality," "trimming," "engineering contradiction," "contradiction matrix," and "40 inventive principles." In level 2, the tools are "physical contradiction," "Su-field analysis," "76 standard inventive solution," and "S curve analysis." The rest of the 14 more tools are allocated in level 3 that are mostly known as modern TRIZ tools. However, there is no specific tool that focused on solving cost problems explicitly (Stratton and Mann 2003). Most of the applications of those tools are used to indirectly reduce cost-related problems. For example, in the application of Contradiction Matrix, there is no "Cost" listed as worsening or improving parameters, neither is "Cost" listed as a part of inventive principles (Domb 2005).

Cost is considered as subjective and is dependent on the context of the moment. In cost reduction initiatives, there are many conflicting factors caused by identified cost element(s). This cost element may have a direct, inverted, or exponential relationship with the technical parameters of TRIZ. Furthermore, some inventive principles are capable of providing effective solutions while some do not. For example, in the context of meeting customer level of affordability, segmentation of product variants may solve the problem. However, merging many variants of a product may reduce the number of its resources, which could impact on cost reduction. So, which solution is better? Create segmentation to expand the market or merge to reduce resources. This, of course, creates another contradiction to solve.

Furthermore, the buzzword in the twentieth century competitive industry is innovation. The industry is pushing new technology to the market; at the same time the market is pulled by customer demands for better products from the industry. This automatically imposes a greater challenge to the industry to ensure that they survive in the competition. There is a misconception by industries regarding innovation that it always requires a huge investment and incurs great risk to the organizational performance. This hinders industries from pursuing innovation, and instead they choose to conduct business as usual, hoping that they would survive any competition coming their way.

In investigating how other TRIZ practitioners carry out cost improvement activities, a literature review was conducted on areas of cost reduction. Most TRIZ practitioners are focused on the product design area as it brings a huge impact and delivers significant results in cost reduction. Domb and Kling (2006) suggested that the focus on cost improvement must begin from the cost of the root cause(s). Domb (2005) recommended several TRIZ tools as in Fig. 3 which was considered as effective to solve cost problems.

Isaka (2012) proposed cost cutting in redesigning products to develop simpler products using "Trimming" in the 8th TRIZ Symposium in Japan. The trimmed system was expected to create new problems to be solved to achieve cost improvement results. Furthermore the focus of TRIZ tools in cost reduction initiatives has expanded to other improvement concepts. Ikovenko and Bradley (2003) advanced an integrated TRIZ under Lean Thinking Tools in the 2004 ETRIA Future Conference. The objective of integration was to harness the advantages and potential which could be effectively used in organizational methods like Lean. The strongest TRIZ tools applied in Lean were "Trimming" and "Flow Analysis."

Besides conceptual studies, there were also several case studies which used TRIZ in cost reduction initiatives. Cho et al. (2004) shared their application of TRIZ in reducing material cost in a Samsung camcorder product. The main TRIZ tools used in their product were Function Analysis, Technical Contradiction, and Su-Field Analysis. The most interesting outcome of the cost reduction activities was their success in securing three new patents for the technological innovation.

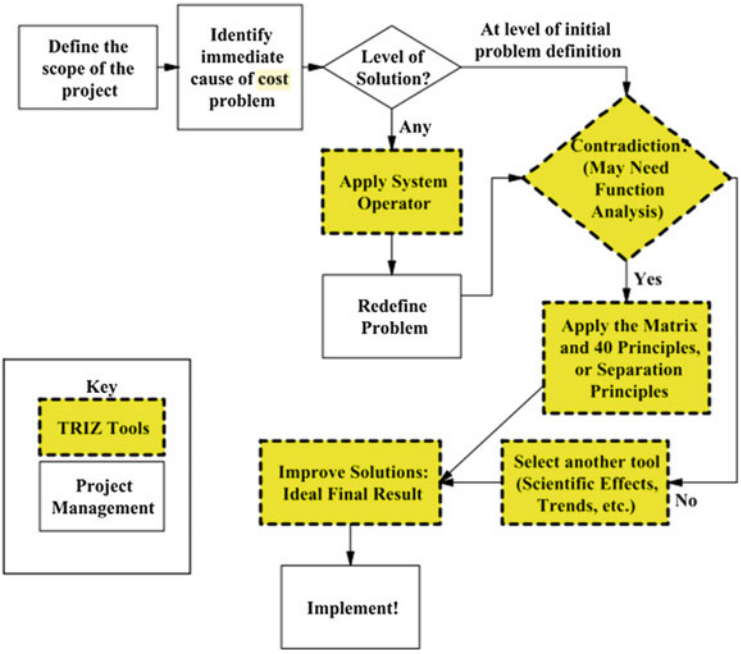


Fig. 3 Flowchart for cost problem using TRIZ (Domb 2005)

There were some studies on the application of TRIZ tools which provided significant improvement to the current DTC which moved away from using trade-offs. Table 1 shows a summary of previous research on TRIZ applications in cost reduction and area of complement in the DTC process.

The common tools used and the approach adopted by TRIZ practitioners in cost reduction can be seen in Table 1. One of the strategic approaches is by integrating TRIZ tools into other concepts. Each context of TRIZ tool application varies depending on the objective of the cost reduction initiative. The following section describes a new framework of DTC which integrates TRIZ tools in order to achieve better cost reduction performance without trade-offs and also improves the level of innovation.

3 DTCI Framework

A framework is created based on the inherent contradiction of current DTC in product design and innovation. A new version of the DTC framework called DTCI framework was developed using the framework by Gilb and Maier (2005) as a base. The framework consisted of four phases: system prioritization, idea generation, idea evaluation, and implementation. The unique part of integrating the TRIZ

Table 1 A summary of researches on TRIZ related to cost improvement

No.	Authors and year of publication	DTC area of improvement	TRIZ tools	Integration of TRIZ
1	Ikovenko and Bradley (2003)	Idea generation	Trimming	Integration success
2	Mann and Domb (2003)	Trade-off and evaluation	Contradiction	Harmful function
3	Sawaguchi (2000)	Brainstorming	Inventive principles	High-value ideas
4	Stratton and Mann (2000)	Idea generation and evaluation	Trimming	Engineering needs
5	Domb and Kling (2006)	Technical cost element	Contradiction	Integration
6	Domb (2005)	Prioritization	Inventive principles	Manufacturing success
7	Isaka (2012)	Design simplification	Trimming	Simplification
8	Mann (2002)	Idea generation	Function analysis	Business area
9	Martin (2010)	Prioritization	Trimming	Lean and TOC
10	Wu (2004)	Design improvement	Inventive principles	Taguchi method
11	Li (2010)	Trade-off	Contradiction	Technology acceleration
12	Mann and Domb (1999)	Design improvement	Function analysis	Customization
13	Ball (2014)	Simplification	Trimming	N/A

method is that it is divided into three categories. The first category is addressing the cost problem of the existing system. For example, components caused high defects based on warranty claims. The second category is developing a new system to improve the cost of the old system, due to changes in a stakeholder's requirements or meeting the target cost. The third category is developing an advanced system which improves the level of product innovation or which is related to developing patents. Figure 4 shows the DTCI framework with an integration of TRIZ tools.

All DTCI initiatives are strategically prioritized based on the product or components of cost analysis. This focus is on a specific system which applies TRIZ tools for improvement. The solution developed is evaluated from three dimensions: technical, commercial, and management. Solutions which meet the requirements of the evaluation process would proceed to the implementation process. Meanwhile, solutions which do not meet the requirements would either be improved further or reserved for future strategic product development.

There are recommended application tools in the DTCI framework within those categories, as shown in Fig. 5. Certain tools are suitable for a specific objective and context in solving a cost problem on an existing system, developing a new system, or exploring an advanced system. However, this does not restrict the application of other tools in other categories that is not listed as recommended tools. There are also other new TRIZ tools used in the DTCI framework which are not mentioned in

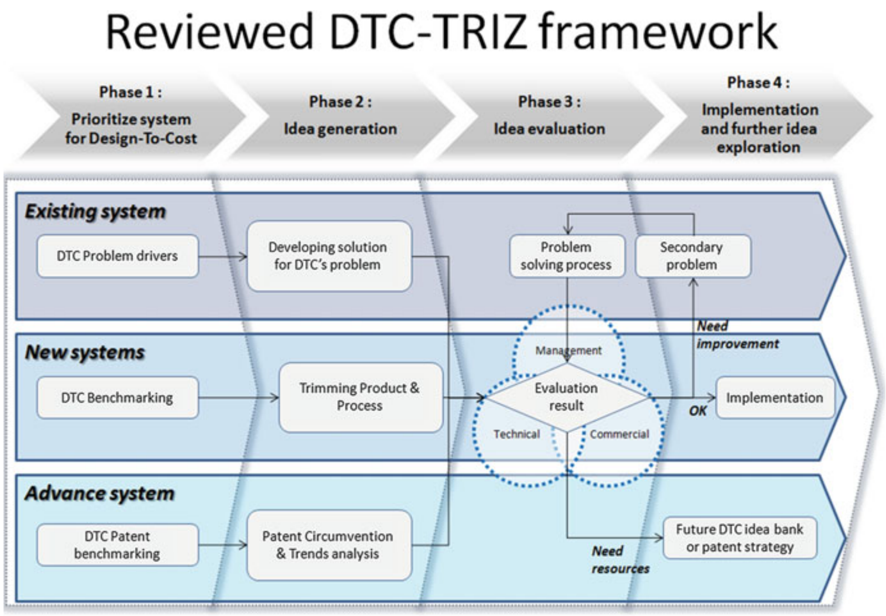


Fig. 4 DTCI framework

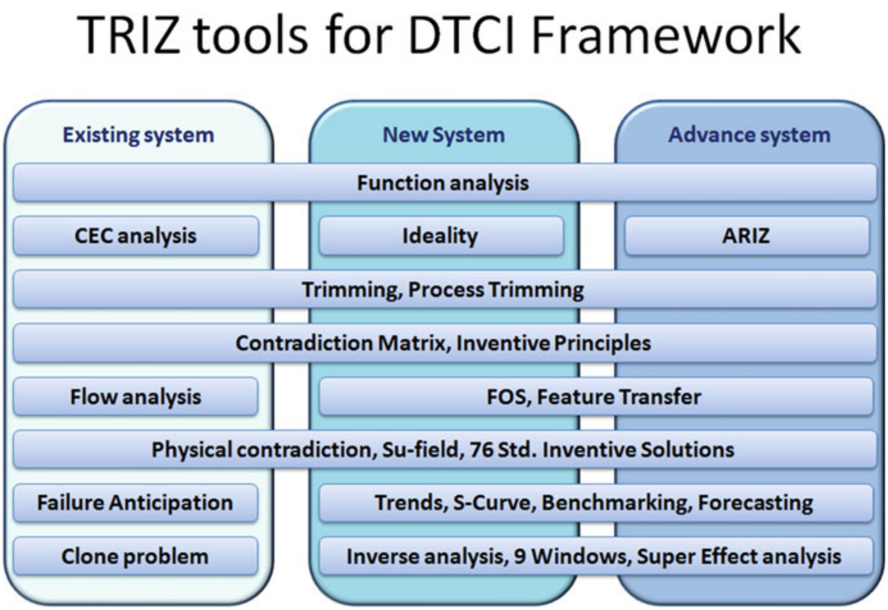


Fig. 5 Recommendation list of TRIZ tools in DTCI categories

the list such as patent circumvention and patent strategy, which consist of a combination of other TRIZ tools with a legal perspective.

The next section looks at some case studies on each DTCI category and the focus to enhance DTC to achieve better target cost and to improve the level of product innovation.

4 DTCI Case Studies

The DTCI framework is an elevation of the current DTC with the application of TRIZ tools and focuses to break away from being too dependent on trade-offs. Another expected outcome of DTCI is to embrace innovation in product design so as to achieve the cost reduction objective. There are several published projects concerning case studies on the application of DTCI in the automotive industry at the systems and component level (Rahim et al. 2015). However in this chapter, a case from one of the projects is presented on problem solving by way of a comparison study between a common optimization method and the TRIZ method.

4.1 Project Case: DTCI in Existing Design Optimization

A wiper system is selected for improvement through a cost engineering analysis. The wiper system has a number of limitations such as the issue of reliability and material cost. On top of this, the engineering team was intent on improving the design of the wiper system and reducing the weight of its components. Figure 6 shows the wiper system mounted on a car.

A cross function team was assembled. It consisted of members from engineering design, procurement, quality, and manufacturing including suppliers. The activity started with a component analysis, before it progressed to developing an improved design concept through current engineering optimization activity. After that the same system was analyzed using TRIZ methods and another design concept was developed for a comparison study. The focus outcome from both the design concepts was a comparison on component cost improvement, functionality, and key focus on reducing the weight of the wiper system.

The heaviest component in the wiper system was the wiper bracket. It weighed about 1.5 kg, which was considered too heavy for the total system. It was made from thick cast iron and went through the casting process to obtain its solid and rigid features. The features were required as this component was considered as the most critical component in the wiper system mechanism. If the weight of the bracket was reduced, it would directly reduce the material cost. However, the weight reduction must not reduce the reliability and performance of the wiper system. This was considered as a good problem statement for TRIZ to solve the

Fig. 6 Original wiper system in the current model

contradiction. Meanwhile, conventional methods began to seek trade-off points between weight reduction, cost reduction, and performance through design optimization.

In a product design optimization process, computer-aided engineering (CAE) would be used to analyze the current wiper system for weight improvement. Figure 7 shows the overview process of design optimization for the design concept of the wiper bracket.

Based on the optimization process using CAE, some minor changes were proposed for the existing design of the wiper bracket. The limitation to the changes was the allowable maximum stress applied on the bracket during operational mode. The reduction in weight was achieved by 22.1 %, which was equivalent to 0.332 kg from its current weight. Figure 8 shows the changes performed through CAE optimization.

The next method was using TRIZ as a weight optimization initiative. First, the system was modeled using function analysis to investigate the level of function which existed in the current wiper system. Figure 9 shows the function analysis performed on the wiper system. In the context of weight reduction, the wiper bracket carried excessive functions in holding other components. From an engineer's viewpoint, the excessive weight of the wiper bracket was to attain rigidity in holding other components and to have it mounted on to the body structure. This

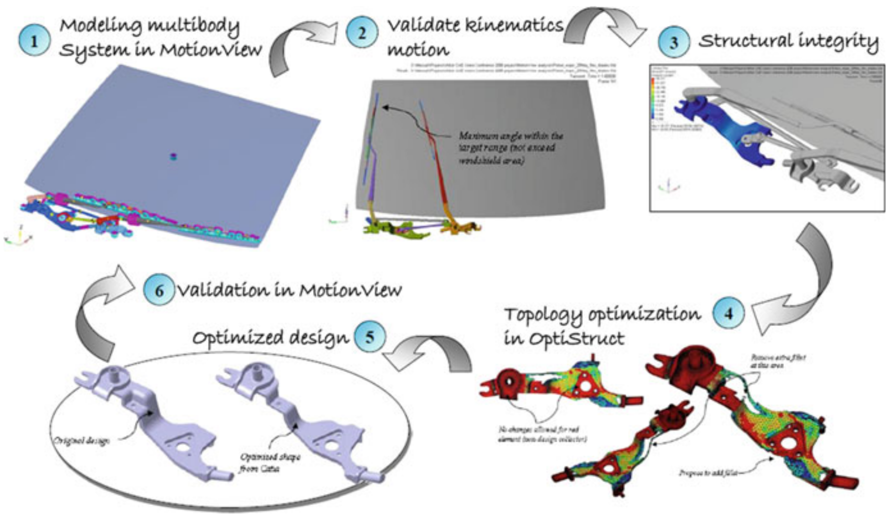
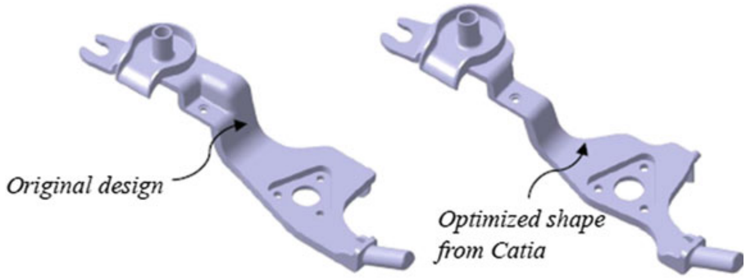


Fig. 7 Optimization process on weight reduction for wiper bracket



Design	Mass (kg)	% reduction
Original	1.504	-
Optimized	1.172	**22.1%**

Fig. 8 Comparison of optimization analysis and weight improvement

understanding is considered as psychological inertia to overcome the contradiction between weight and rigidity.

The contradiction was reviewed through 39 engineering parameters. The improving parameter comprised weights of stationary object (#2), whereby the stationary wiper bracket was fixed on to the body structure. Meanwhile, the worsening parameters were force (#10), stress (#11), stability (#13), strength (#14), reliability (#27), and ease to manufacture (#32). The worsening parameters were highlighted by the subject matter expert (SME) in the cross function team. Figure 10 shows inventive principles extracted from the contradiction matrix.

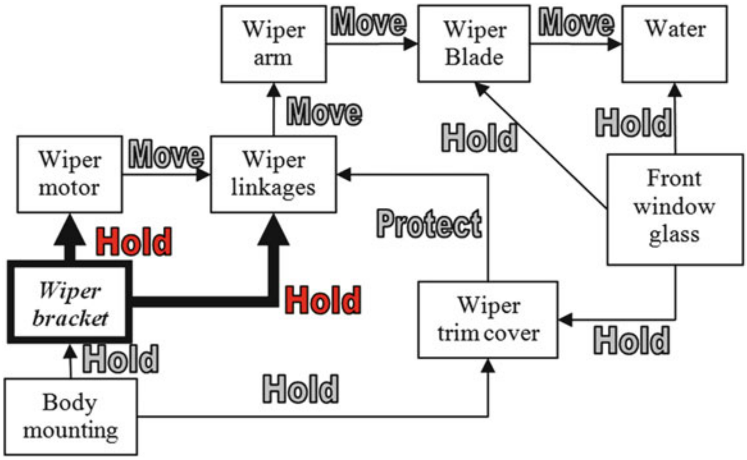


Fig. 9 Function analysis of wiper system

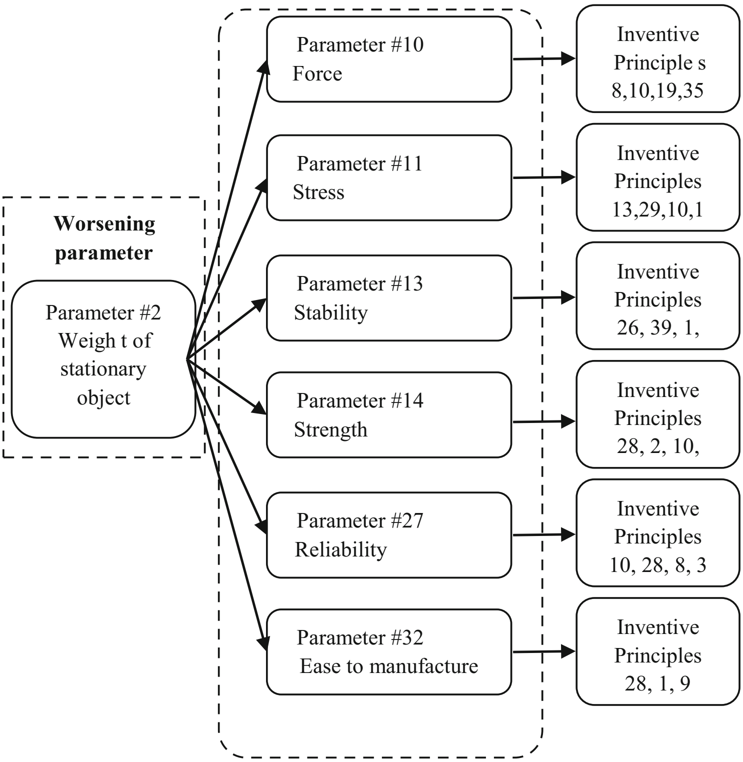


Fig. 10 Contradiction analysis between the studied parameters for weight improvement

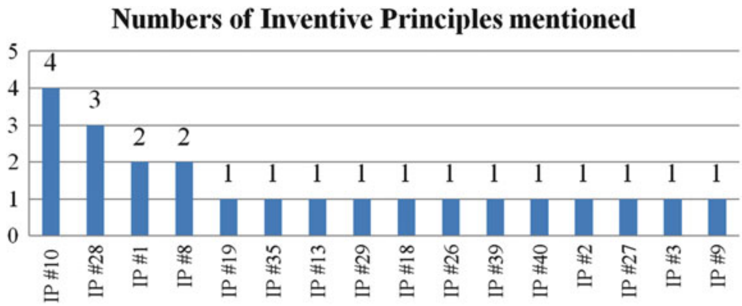


Fig. 11 Pareto analysis of recommended inventive principles for the optimized weight improvement product

The next process was to identify the most common inventive principles recommended to solve interrelated contradictions in reducing the weight of the wiper bracket. Using a simple Pareto analysis, the inventive principles were analyzed to identify the most common concept proposed with regard to similar contradictions. There were four inventive principles that were mentioned more than once. Figure 11 shows the four inventive principles: "Preliminary action," "Mechanics substitution," "Segmentation," and "Anti-weight."

Based on recommendations from many inventive principles, the cross function team was excited to explore all the inventive principles to develop the concept solution. The concept solution was focused on the mechanism of how the function delivered and the technical feasibility of the established concept solution. Table 2 shows the concept solution discussed based on recommended inventive principles and the results of technical evaluation. The technical evaluation result is based on the capability to develop the proposal using existing available resources determine by the DTCI team, experts, and project manager.

The cross function team used their current knowledge and experience to develop the wiper system through the concept of inventive principles. Quite a number of amazing concepts were generated and each of them required some evaluation study on its technical feasibility. However, the development of concepts was quite straightforward due to the team members' basic level of TRIZ knowledge and application. Some members utilized the Internet to extract information to support their proposed concept with facts and figures.

The evaluation process in DTCI also included a commercial study. The concept solutions were mapped to identify the most significant for design improvement using four-by-four matrix cost analysis and technical feasibility; Fig. 12 shows the commercial–technical matrix on the proposed concept solution. The solutions are allocated on the investment cost required and the feasibility of existing resources confirm by the DTCI team and manager.

The most feasible concept solution used the inventive principles: #1 (Segmentation), #35 (Parameter change), #8 (Anti-weight), and #10 (Preliminary action). The activity had made each team member more receptive to developing practical

Table 2 Ideas generated based on inventive principle into the optimization of the wiper system

Inventive principles	Specific improvement	Impact	Technical evaluation results
IP #10 Preliminary action	Use water repellent for front glass window	Not suitable for other than water	Feasible (moderate innovation)
IP #28 Mechanic substitution	High-frequency ultrasound in windshield	Able to delete existing components such as wiper motor	Feasible (radical innovation)
IP #1 Segmentation	Separate the bracket into two pieces	Smaller size bracket	Feasible (minor modification)
IP #8 Anti-weight	A portion of bracket is designed into the trim cover	Reduce metal material	Feasible (minor modification)
IP #19 Periodic action	Pressured air blows the water periodically	Reduce the force to wipe the water, reduce the bracket strength	Feasible (moderate innovation)
IP #35 Parameter change	Use hollow parts to substitute solid parts	Reduce the total weight of parts	Feasible (minor modification)
IP #13 The other way around	Change the position of wiper system to the top of the front glass window	Reduce the force to wipe the water, reduce the bracket strength	Feasible (moderate innovation)
IP #29 Pneumatic and hydraulic	Sucks in water from the glass window Similar solution as IP #19	Eliminate wiper system Similar solution as IP #19	Feasible (radical innovation)
IP #18 Mechanical vibration	Ultrasonic cleaning Same as IP #28	Eliminate wiper system Similar solution as IP #28	Feasible (radical innovation)
IP #26 Copying	Use bracket made of lightweight polymer	Need technical validation and testing	Feasible (minor modification)
IP #39 Inert atmosphere	Introduce a system that changes water into gas	Eliminate wiper system	Feasible (radical innovation)
IP #40 Composite material	Use composite material on metal and plastic parts	Need technical validation and testing	Feasible (minor modification)
IP #2 Taking out	Take out the bracket and use the body structure as support	Eliminate bracket and wiper needs to work Harmonically	Feasible (moderate innovation)
IP #27 Cheap short living object	Not available	The bracket cannot be used within a short period of time	Not feasible
IP #3 Local quality	Make the bracket/body structure part of the linkages to move wiper or Similar with IP #2	Need technical validation and testing	Feasible (moderate innovation)
IP #9 Preliminary anti-action	Glass surface filled with water	Further mechanism to sustain the water on top of the glass	Feasible (radical innovation)

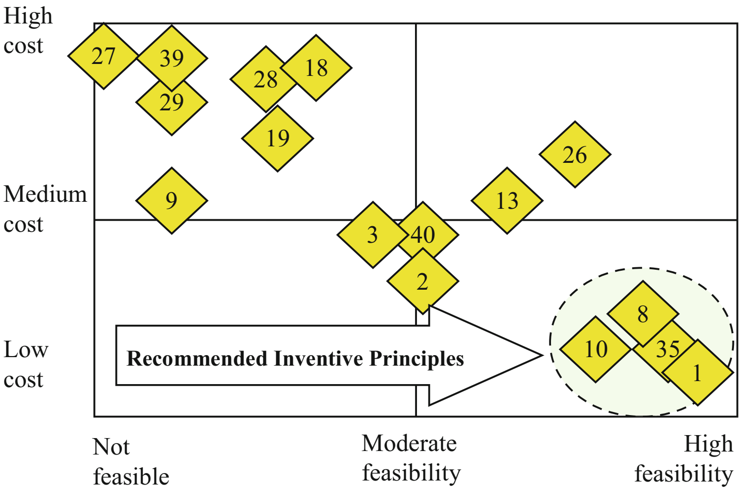


Fig. 12 Recommended inventive principles through technical and commercial evaluations

concept solutions which provided significant impact to their respective scope of work. The wiper bracket was changed to a new design, focused on better weight reduction and lower cost without compromising on its performance. However, the design engineer needed to consolidate and refine the concept into a real practical product which met the target cost and brought new innovation into the wiper system. Other concepts which were considered less feasible to implement due to time taken for development or exceeding the target cost were kept in a database for innovation research and development.

The wiper bracket was segmented into three parts. The middle part which was bigger in size was substituted with a hollow shaft. The rest of the part was modified to integrate with the hollow shaft. Another moving wiper bracket was also redesigned based on a similar concept. Plastic material was introduced into the new system in less critical functions, and metal bush was substituted with a special polymer bush which had better performance and reliability. The rest of the components were transferred to the new system such as the wiper motor, which enabled the cost to be reduced further. The final concept was developed at the prototype level and underwent testing and validation of part performance. Figure 13 shows the existing wiper system and Fig. 14 shows the new wiper system.

The results from this approach achieved 75.3 % in weight reduction, which was equivalent to 1.13 kg from the current design. The result of the weight reduction using TRIZ methodology produced a better outcome compared to the optimization approach which was supported by CAE software. Table 3 shows the weight of the wiper bracket for the existing and the new improved design. The improvement of the wiper system would continue as there were many solutions generated by the cross function team using TRIZ which require a longer time and adequate resources to move forward in product innovation.

Fig. 13 The current wiper link system

Fig. 14 New wiper link system with minor design modification

Table 3 Weight optimization and TRIZ design solution

Level of bracket design	Total weight (kg)	% of weight reduction
Current design	1.504	–
Optimized design	1.172	22.1 %
Adopting TRIZ inventive solution design	0.371	75.3 %

5 Conclusion

The main objective of DTC is to focus on achieving a planned target cost at the initial stage of design. One of the critical steps to achieve effective DTC is to translate a design or technical parameter to a cost parameter. However, in the process of achieving the target cost, there are quite a number of conflicting requirements such as bringing the cost down to a minimum without compromising on the design performance of the product. Currently, there are many methods and improvement concepts used in DTC phases, such as prioritization, idea generation, idea evaluation, and implementation. Among these tools, trade-off will be the most important tool used in DTC to achieve the optimum level of cost reduction against other parameters such as product performance. This chapter has presented a DTCI framework which integrated TRIZ in DTC processes and broke away from being highly dependent on trade-offs. A project case study was discussed. It addressed the cost problem by way of material weight reduction on an existing system. The outcome showed that TRIZ has elevated DTC by producing better value in solving DTC's problem compared to the trade-off method such as optimization. Furthermore, TRIZ has enabled the cross function team of DTC to enhance their product innovation for future development from an existing system, a new system, or an advanced system. The DTCI framework is expected to solve the contradiction between achieving the target cost and enhancing the level of innovation.

References

Bakar, N. A., & Rahim, Z. A. (2014). Design-to-cost framework in product design using inventive problem solving technique (TRIZ). *Journal on Innovation and Sustainability, 5*(2), 3–17. RISUS ISSN 2179-3565.

Ball, L. (2014). *TRIZ power tools: Simplifying* (2014 ed.). http://www.opensourcetriz.com/attachments/Simplifying.pdf

Boudreau, M. (2006). *Using cost as an independent variable (CAIV) to reduce total ownership cost*. Monterey, CA: Naval Sea Systems Command and Naval Postgraduate School.

Cascini, G., Rissone, P., Rotni, F., & Russon, D. (2011). Systematic design through the integration of TRIZ and optimization tools. *Proceeding of the ETRIA World TRIZ FUTURE Conference, Procedia Engineering, 9*, 647–679.

Cho, Y. H., Kim, J. S., & Lee, J. Y. (2004). *Innovation in the material cost of the 8mm camcorder using TRIZ* (pp. 1–17). TRIZCON 2004 Conference Proceedings.

DOD Directive #5000.1. (1971). *Acquisition of major defense systems*. Retrieved 17 August, 2015, from http://www.dtic.mil/whs/directives/corres/pdf/500001p.pdf

DOD Directive #5000.28. (1975). *Design to cost*. Retrieved 17 August, 2015, from http://www.valueeng.org/knowledge_bank/attachments/Application%20of%20VE%20to%20DTC.pdf

Domb, E. (2005, November). *How to deal with cost-related issues in TRIZ*. European TRIZ Association TRIZ Futures Conference 2005, Graz, Austria.

Domb, E., & Kling, T. J. (2006, April). How to reduce cost in product and process using TRIZ. *TRIZ Journal*, Issue. Retrieved 17 August, 2015, from http://www.triz-journal.com/deal-cost-related-issues-triz/

Esaki, M. (2005). *History of methodology of DTC, wisdom of management technology*. http://dtcn-wisdom.jp/

Gilb, T. (2011). Estimation: A paradigm shift toward dynamic design-to-cost and radical management. *ASQ, SQP, 13*, 25–38.

Gilb, T., & Maier, M. W. (2005). *Managing priorities: A key to systematic decision-making*. Proceedings of INCOSE 2005. Available at http://www.gilb.com/tiki-download_file.php?fileId=60

Hipple, J. (2012). *The ideal final result—Optimization: The enemy of innovation*. New York, NY: Springer.

Ikovenko, S., & Bradley, J. (2003). TRIZ as a lean thinking tool. 2004 ETRIA TRIZ Future Conference, Florence, Italy. *TRIZ Journal*. Retrieved 17 August, 2015, from http://www.triz-journal.com/triz-lean-thinkingtool/

Isaka, Y. (2012). *Redesign by reducing the number of parts through TRIZ: Break away from existing designs and enhance competitiveness on cost*. Eighth TRIZ Symposium, Japan.

Li, T. (2010). Applying TRIZ and AHP to develop innovative design for automated assembly systems. *International Journal Advance Manufacturing Technology, 46*, 301–313.

Linstone, H. A. (2011). Three eras of technology foresight. *Technovation, 31*(2–3), 69–76.

Mann, D. L. (2002, May). Case study: The application of TRIZ to economy class aircraft cabin design. *TRIZ Journal*, Issues. Retrieved 17 August, 2015, from http://www.triz-journal.com/case-study-application-triz-economy-classaircraft-cabin-design/

Mann, D. (2002, June). Evolutionary-potential TM in technical and business systems [Issue]. *The TRIZ Journal*.

Mann, D. L., & Domb, E. (1999, May). 40 inventive (business) principles with examples. *TRIZ Journal*, Issues. Retrieved 17 August, 2015, from http://www.triz-journal.com/40-inventive-business-principles-examples/

Mann, D. L., & Domb, E. (2003). *Using TRIZ to overcome mass customization contradictions* (The customer centric enterprise, pp. 231–242). Berlin, Heidelberg: Springer.

Martin, A. (2010, September). TRIZ, theory of constraints and lean. *TRIZ Journal*, Issues. Retrieved 17 August, 2015, from http://www.triz.co.uk/files/triz_toc_and_lean.pdf

Montgomery, P., & Carlson, R. (2011). Control of total ownership costs of DoD acquisition development programs through integrated systems engineering processes and metrics. *Proceedings of Eighth Annual Acquisition Research Symposium, 8*(2), 63–77.

Rahim, Z. A., & Bakar, N. A. (2013). Implementation framework for design-to-cost using TRIZ: Product concept design in automotive stamping process. *American Journal of Economics, 3* (5C), 100–107.

Rahim, Z. A., & Nooh, A. B. (2014). Complexity planning for product design using TRIZ. *Advanced Materials Research, 903*, 396–401.

Rahim, Z. A., Sheng, I. L. S., & Nooh, A. B. (2015). TRIZ methodology for applied chemical engineering: A case study of new product development. *Chemical Engineering Research and Design, 103*, 11–24.

Sawaguchi, M. (2000, July). Effective approaches to solving technical problems by combining TRIZ with VE. *The TRIZ Journal*, Issue. Retrieved 17 August, 2015, from http://www.triz-journal.com/effective-approachessolving-technical-problems-combining-triz-ve/

Sheu, D. D., & Hou, C. T. (2011). *TRIZ-based problem solving for process-machine improvements: Slit-valve Innovative redesign* (pp. 1036–1044). Proceedings of the 41st International Conference on Computers and Industrial Engineering.

Stratton, R., & Mann, D. L. (2000, September). From trade-off to innovation—the underlying principles of TRIZ and TOC applied. System innovation and the underlying principles behind TRIZ and TOC applied to manufacturing. *The TRIZ Journal*, Issues. Retrieved 17 August, 2015, from http://scinnovation.cn/wpcontent/uploads/soft/100921/6-100921120609.pdf

Stratton, R., & Mann, D. L. (2003). Systematic innovation and the underlying principles behind TRIZ and TOC. *Journal of Materials Processing Technology, 139*, 120–126.

Tyson, K. W., Nelson, J. R., Om, N. I., & Palmer, P. R. (1989). *Acquiring major systems: Cost and schedule trends and acquisition initiative effectiveness (No. IDA-P-2201)*. Alexandria, VA: Institute For Defense Analyses.

Wichita, W. L. (1975). *Application of value engineering to design-to-cost contracts* (pp. 315–318). SAVE Conference Proceedings.

Wichita, L. W. (1980). *Design to cost contracts—Implementation of value engineering* (pp. 119–127). SAVE Conference Proceedings.

Williamson, B. (1994). *Design to cost lessons learned* (pp. 242–253). 1994 International Conference of the Society of American Value Engineers (SAVE): SAVE Annual Proceedings 1994.
Wu, T. D. (2004). *The study of problem solving by TRIZ and Taguchi methodology in automobile muffler designation*. Proceedings of the TRIZ Conference, Department of Industrial Management, Tung-Nan Institute of Technology, Taipei.
Zulhasni, A. R., & Nooh, A. B. (2015). Innovative cases of TRIZ application in the automotive industry. *Applied Mechanics and Materials, 735*, 326–330.
Zulhasni, A. R., Nooh, A. B., Sarimah, M., & Yeoh, T. S. (2015). TRIZ business improvement and innovation framework for malaysian small and medium enterprise. *Applied Mechanics and Materials, 735*, 349–353.