Integrated AHP-TRIZ Innovation Method for Automotive Door Panel Design

M.U.Rosli [#1], M.K.A. Ariffin [#2], S.M. Sapuan[#3], S.Sulaiman[#4]

[#] Department of Mechanical and Manufacturing, Faculty of Engineering,
Universiti Putra Malaysia, 43400 UPM Serdang, Selangor,
Malaysia
[1] uzair_rosli@yahoo.com.my
[2] khairol@eng.upm.edu.my
[3] sapuan@eng.upm.edu.my
[4] suddin@eng.upm.edu.my

***Abstract*—This research is intended to improve the 'Theory of Inventive Problem Solving' TRIZ methodology by integrating with the Multi Criteria Decision Making (MCDM) tool; Analytical Hierarchy Process (AHP). This integration works as a support tool to assist the TRIZ practitioners or design engineers. AHP is employed to rank ideas generated by TRIZ in order to select the most ideal idea further to next stages. This integration was analyzed and validated by a study case of door panel of a sedan car. Both front and rear door panels are covered in this study. A survey of interior's problems and customer's preferences had been conducted in order to identify the criteria and weights for AHP evaluation processes. Basically, there were 10 ideas triggered by TRIZ contradiction and principle approach. The ideas were refined and ranked through AHP's Expert Choice software. Several ideas had been combined and finalized as one ideal improved design. Applying AHP into problem solving method of TRIZ results in avoiding cost waste and increasing the design efficiency during the product design and development processes.**

Keyword-Analytical Hierarchy Process, TRIZ, Integration, design improvement

I. Introduction

Innovative design has become the core value in most companies in new product and process development. The forceful rate of the money-making environment and revolution in technology implies that the prospect for innovative design is accelerating and an organized and structured support system for the process is greatly needed in order to achieve a particular product with engineering optimization. Engineering optimization generally means the trade-off parameters are balanced. On that basis, the current research in design phase focuses on how to apply enhanced systematic innovative design approach. To date, the clash of performance parameters issue related to manufacturing field have been handled by many researchers by applying the approach of design trade-off. The issue of a systematic incompatibility or conflict design problem faced by the engineer when trying to solve a design problem becomes an ordinary old issue. Normally, the design engineer always finds an approach to compromise with this kind of contradictory situations and limits the creativity on performing innovative design tasks when the design engineer modifies certain parameters of the system, the other parameters are directly interrupted. From the idea of utilizing the trade-off parameters as a focus for systematic innovation in the product design, the approach of TRIZ, the Russian acronym for the 'Theory of Inventive Problem Solving' has recently come out.

The innovation of TRIZ is now being developed and extensively practiced throughout the world [1]. Approximately over millions of patents have been analyzed to build the knowledge base which is mostly on mechanical design. As shown in Fig. 1, problem solving approach is traditionally to move from a specific problem directly to find a specific solution. However, there are a number of cases where this approach did not work due to contradictions or conflicts in order to prevent the generation of good solutions. As stated earlier, the final solution using the normal problem solving usually ended up in the form of compromise or finding the 'balanced spot'. Instead, TRIZ strategy was different from a normal problem solving process which works towards resolving contradictions or conflicts while providing an inventive solution.

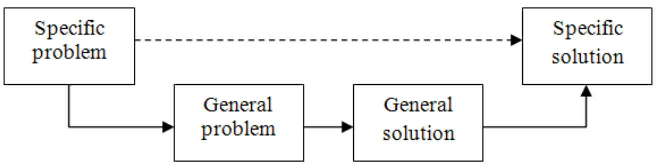


Fig.1. TRIZ problem solving process

The components of TRIZ include the contradiction matrix, 40 inventive principles, Algorithm of inventive solving (ARIZ), substance-field analysis modeling, scientific effects and laws of evolution. The foundation of TRIZ such as 40 contradiction principles and the matrix are the effective tools that assist in constructing the contradiction and analyzing it. The approach has been applied to various design problem-solving such as the development of automated gripping devices for micro parts [2], development of energy efficient lighting of fluorescent tube [3], innovative energy-saving design method of products [4], energy efficient notebook computer development [5] and design of inherently safer chemical processes [6].

After revealing the general path for possible solution for the problem using the TRIZ approach method, based on the practitioners knowledge and experiences, there might be a number of ideas triggered and generated. The practitioners need to evaluate, revise and refine in order to find the ideal and most appropriate solution. The imprecise solution decision for further step might imply the final design including the time taken and cost. In order to perform the task of evaluation which may involve the multi-criteria selections, the Analytic Hierarchy Process (AHP) is considered among the effective method seem as the ideal method for the task.

AHP is one of the most widely used methods to assist in selection of alternatives with the basic idea of pair-wise comparisons conducted using a nine-point scale in order to select the best alternatives. Flexibility, intuitive appeal to the practitioners and its ability to check inconsistencies are the main advantages that makes AHP ahead compared to other tools [7]. Moreover, the straightforward pair-wise comparison of data input with less mathematical calculations makes the evaluation processes of AHP an ideal technique. In AHP applications, the decision makers are assigning the values based on the relative importance of alternatives prior to their upper parent component in the decision hierarchy and the judgements is based on their own experience and knowledge. The step is then repeated to obtain the relative contributions of alternatives to accomplish each objective. As a result, the set of weights which represent their contributions or the priorities to the objectives is presented.

Vaidya et.al [8] reported that AHP can be applied in decision situations of planning and development, evaluation, priority and ranking, benefit–cost analysis, allocations and decision-making. Shirmohammadi et.al [9] applied AHP for evaluating different maintenance organizational structures prior to the several objectives of a maintenance department. Chi-Cheng Huang et.al [10] employed the AHP in the selection of government sponsored technology development projects. Al Khalil [11] utilized AHP approach to pick the most appropriate project delivery method. Yuen [12] utilized the AHP approach to select the most appropriate operator prioritization among the various prioritization candidates. Wong et.al [13] applied AHP in MDCM analysis to select the intelligent building systems where AHP performing the task of prioritize and assign the weightings for the perceived criteria in the general survey.

II. TRIZ

In 1946, a former Soviet Union scientist named G. Altshuller was developed a set of tools, methods and strategies based principally on the concept of resolving contradictions. It was built over the study of four hundred thousands of the world's most successful patents. From the analysis of patent data, several different solution systems have been derived and realized that quite a lot of the solutions focus on contradictions or trade-offs in identifying innovative solutions. Generally, the TRIZ theory is aiming to have the ideal design with no harmful functions. TRIZ is believed to be a way for inventive solution eliminating a contradiction and the inventive brainstorming process can be structured in several steps [14].

In engineering field, contradiction arises in an engineering system if an improvement in one characteristic might affect another characteristic to degrade. As a solution, attempting to compromise or reach the balance as what the designers typically do, does not really solve the problem. Instead, TRIZ tries to identify improving versus worsening characteristics towards resolving the contradiction arises and generating the ideal solution to desired functions or effects without any harmful or negative effects as given in Equation 1:

$$Ideality = \frac{\text{All useful functions or effects}}{\text{All harmful functions or effects}} \quad (1)$$

Emphasizing on improving the functionality, one may argue that this is quite similar to Value Engineering (VE) approach. However, VE does not identify harmful functions and their relationships to other functions and VE also does not have extensive patent database, or physical and engineering parameters that TRIZ does [15]. TRIZ, as well, quickly offer solution or solution paths when the core problem is identified. The constituents of TRIZ include 40 inventive principles, the contradiction matrix, scientific effects and Algorithm of inventive solving (ARIZ), substance-field analysis modeling, and laws of evolution. Commonly, the matrix is the most favoured tool which is built by matrix contradictions and 40 principles. Engineering contradictions can be found in many engineering issues where compromise of trade-off is needed to balance an improving parameter and worsening engineering parameter exist concurrently. There are 39 engineering parameters in TRIZ such as the weight of object, speed of object, complexity of object and shape. The 39×39 matrix contains the most probable principles for solving design problems as shown partly in Fig. 2.

	Worsening Feature				
	Weight of moving object	Weight of stationary object	Length of moving object	Length of stationary object	Area of moving object
	1	2	3	4	5
Weight of moving object	+	-	15, 8, 29,34	-	29, 17, 38, 34
Weight of stationary object	-	+	-	10, 1, 29, 35	-
Length of moving object	8, 15, 29, 34	-	+	-	15, 17, 4
Length of stationary object		35, 28, 40, 29	-	+	-
Improving Feature	Suggested Principles				

Fig.2. Part of contradiction matrix

Generally, The TRIZ founder has divided the contradiction into three classes as administrative contradiction, physical contradiction and engineering contradiction. However, in this research, the administrative contradiction is not included due to the fact that the administrative contradiction normally arises from the management field.

2.1. Engineering contradiction

A contradiction happens when an improvement of one of the system parameters will then lead to deterioration of other parameters. Generally, a contradiction arises from mutually exclusive demands that may be placed on the same system. The worsening of another characteristic can take on many forms such the example illustrated in Fig. 3. In order to improve the characteristic or parameter of the product, Components A performs Function A, but it may change a previous useful function of Function C into an unsatisfactory function or cause an undesired harmful function of Function D onto the product. Or else, the product in turn triggers a harmful function of Function B onto component A. There may also be effect in a normal useful function of Function E to an excessive useful function on another component (component B) [16]. In these scenarios, although one parameter improves, there are consequences in terms of other impacted parameter which worsen. This then stands as an engineering contradiction which needs to be resolved in order for the engineering system to move towards ideality. In order to resolve an engineering contradiction, the designers need to identify the significance of contradictions and use the contradiction matrix to identify potential inventive principle of problem solving. The classical examples of contradiction includes the product gets stronger which means good but the weight increases conversely and the vehicles has high acceleration but uses more fuel.

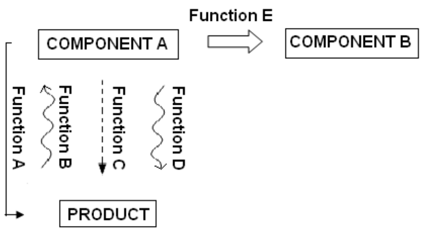


Fig.3. Engineering contradiction example

2.2. Physical contradiction

Physical contradiction happens when one object has contradictory and opposite requirements which create a contradiction at two extremes of one features such as area, speed, duration and so on. Examples of cold and hot, moveable and stationary, light and heavy, big and small, etc are the typical physical contradictions. Dissimilar with contradiction matrix, this contradiction is more focused and can result in better solutions. The physical contradictions can be solved through the methods of separation in space, time, relation and system level of satisfaction and bypass. For instances, when pouring hot filling into chocolate shells in chocolate making, the filling should be hot to pour fast, but it should be cold to prevent melting the chocolate. Another example is in computer field, software should be simple, but should be complex with many features and options.

III. AHP

The analytic hierarchy process (AHP) is a process based on mathematics and psychology developed by Saaty [17] in the 1970s. In other words, it is an ordered technique for organizing and analyzing complex decisions and has been broadly studied and refined since then. AHP assists decision makers to find one that best suits their objective and their understanding of the problem, rather than prescribing a appropriate decision. It provides a complete framework for structuring a decision problem, displaying and quantifying each element, involving those elements to overall objective and evaluating alternative solutions.

A nine-point scale is used to conduct the pair-wise comparisons for each level prior to the goal of the alternative selection. This process differentiates the relative importance, performance or likelihood of two elements with respect to another element in the level above as well as represents the participants' judgments or preferences among the alternatives such as equally important, moderately more preferred, strongly more preferred, very strongly more preferred, and extremely more preferred to the others as shown in Table 1.

In general, AHP practitioners define the unstructured problem and determine clearly the objectives and outcomes followed by decomposing their decision problem into a hierarchy structure with decision elements such as criteria, sub-criteria and alternatives which each can be analyzed independently. The elements of the hierarchy may come from any aspect of the decision problem such as tangible or intangible, well or poorly understood, roughly estimated or carefully measured or anything at all that applied to the decision. Once building the hierarchy was done, with respect to their impacts on an upper parent element in the hierarchy, the decision makers start to evaluate the stated elements by comparing them one at a time through the pair wise comparison matrix (size of $n \times n$) by utilizing the relative scale. During the comparisons, the decision makers can use concrete data about the elements, but they typically use their judgements about the elements' relative meaning and importance [18]. After all the pairwise comparison completed, the pair wise comparisons need to be synthesized where the average of normalized column (ANC) method was used [19]. The AHP converted each element of the hierarchy to numerical values that could be compared and analyzed over the entire range of the problem to provide the numerical weight or priority, allowing diverse elements to be compared to one another in a rational and consistent way. This capability differentiated the AHP from other decision making techniques. Then, the consistency analysis would be performed in order to calculate the consistency of judgment by calculating the value of consistency ratio (CR). The judgement matrix was acceptable if CR below 0.1 or 10%, otherwise it was considered inconsistent and the decision maker was allowed to review and improve the judgement. Hierarchical synthesis was used to weight the eigenvectors by the weights of the criteria and the sum of overall weighted eigenvector entries regarding those in the next lower level of the hierarchy. Finally, numerical priorities or ranking were presented for each of the decision alternatives. These numbers represented the alternative's relative ability to achieve the objective for selection at the top of hierarchy.

TABLE I
Relative Scale of Pairwise Comparison

Intensity of relative importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed

IV. THE PROPOSED APPROACH

In this paper, organized product design approaches, TRIZ and AHP as depicted in Fig. 4, were employed as an integrated methodology for the new optimized product design. By breaking up the complex design problem into a contradiction matrix as well as incentive principles, TRIZ provide various design suggestions. AHP was performed by decomposing the structure of decision process into a hierarchical sequence in order to find out the relative importance of each alternative design through pairwise comparisons. However, TRIZ does not rank the ideas like AHP does and might be a few of the ideas were chosen to take further. Hence, AHP would be utilized as a selection method for the ideas generated by TRIZ approach.

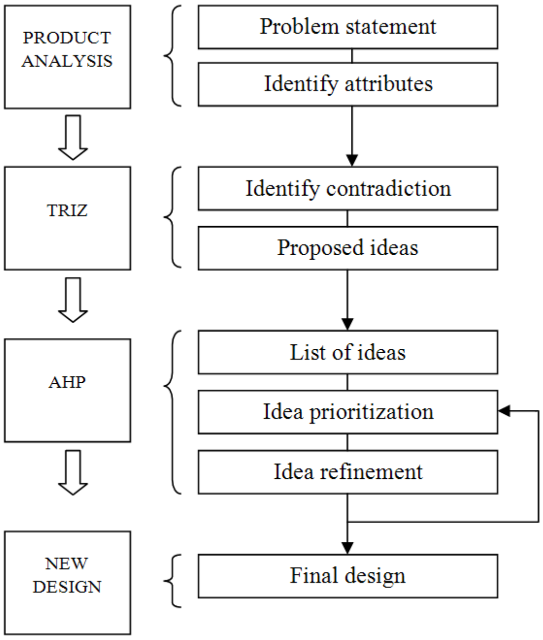


Fig.4. Proposed approach of framework

Step 1: Product analysis

Product analysis included identifying the problems of existing product. A number of survey questionnaires were needed in order to identify the current customer demand and market trends of the current product.

Step 2: Identify the attributes for evaluating the idea alternatives

After analyzing the product, the attributes or criteria for evaluation process must be identified and established. The attributes or criteria were based on a survey questionnaire in order to determine the customer's preferences of particular product. The chosen attributes or criteria were ended up with the percentages or weight that useful for AHP processes.

Step 3: Identify contradiction

The specific problems were generalized into 39 TRIZ's parameters by identifying the improving parameter and worsening parameter that might be occur. This conflict was converted to contradiction matrix and feasible inventive principles would be proposed. The suggested inventive principles were then might be adopted to stimulate redesign ideas.

Step 4: Propose idea based on the related inventive principles

The designer started to generate ideas based on the inventive principles suggested by the 39×39 contradiction matrix. Based on information and experiences of TRIZ practitioner might be just one or two principles could be used out of maximum four suggested principles from contradiction matrix. If none of principles had potential to develop solution idea, the designers were allowed to explore to all of the 40 principles. The generated ideas were resulted in a set of concepts.

Step 5: Construct the hierarchy of AHP and perform judgement of pairwise comparison

The hierarchy of AHP was constructed. The highest level in the hierarchical structure was the target which was to rank the list of generated ideas. The second and third levels were with the set of chosen criteria and sub-criteria, which were previously done by a survey. The last level comprised the lists of ideas by TRIZ solution. Pairwise comparison and judgement were performed by utilizing Expert Choice software; a multi-attribute decision support software tool based on the AHP methodology [20]. The weights of criteria were based on survey results and the judgements for the idea evaluation were based on the experiences and knowledge by using the relative scale of pairwise comparison as depicted in Table 6.

Step 6: Idea priority ranking

After the consistency calculation for all level was completed, further calculation of the overall priority vector was carried out to sort or rank the list of generated ideas. The overall priority vector was obtained by multiplying the priority vector for the listed ideas by the priority vector of the criteria. In the ultimate phase of evaluation, weight vectors for the individual levels of hierarchy were evaluated using the methodology given in the ranking. The ideas were ranked based on their weights.

Step 7: Refine and finalize the improvement idea

From the list of generated ideas, the designer refined the list by combining, altering and rejecting some of the ideas. The ideas were refined until the ideal one was decided for further step.

Step 8: Final concept

The designer proposed the final improvement ideas based on the input of suggested principles from the previous step and illustrated by sketching approach.

V. THE STUDY CASE

The procedures in previous section of the proposed model's efficiency was analyzed and evaluated by a case study of door panel of Proton saga BLM model as depicted in Fig. 5(a) and 5(b).

Fig.5(a). Front door

Fig.5(b). Rear door

5.1. Product description

In general, a vehicle door is used to open and to provide access to the opening, or closing to secure. It is hinged partition and attached by other mechanisms such as tracks, in front of an opening which is used for entering and exiting a vehicle. There are two types of door namely manually operated, or electronically which is normally found on minivans, high-end cars and modified cars. The boot lid which is usually found in saloon or sedan and coupé types of vehicles is not counted as a door by definition because it is meant for a separate storage compartment. From the observation of Proton Saga BLM door panel, it serves the common function as other car's door such as visor's control button, arm rest, door lock and small compartment for magazine and bottle.

5.2. Systematic product design approach integrating TRIZ and AHP

In previous section, integration between TRIZ and AHP used as a systematic product design approach has been presented. The following research steps were carried out using the steps previously depicted in Fig. 4.

Step 1: Product analysis

In order to identify the problem faced by users specifically in the door panel, a survey questionnaire has been conducted. The results stated several common problems such as power window malfunction and sound proof problems. In Malaysian culture, most of the groceries were come in plastic bag which needed to be hooked. Hence, a function of a hook was needed to be considered especially for the rear door for back passengers. Apart from that, the items placed in compartment made a messy atmosphere. Since that this study aimed for functionality and space efficiency optimization, the power window and sound proof problems were excluded. Besides, adding extra function also would be considered.

Step 2: Identify the attributes for evaluating the ideas alternative.

A survey questionnaire has been conducted to identify the customer preferences when they were buying a car in term of ergonomic, quality and functionality. The results of this survey assist the criteria evaluation process of AHP especially the weight determination. The criteria and sub-criteria were shown in Fig. 6.

Step 3: Identify contradiction

Based on the problems listed in product analysis step, those specific problems were then generalized into term of 39's TRIZ parameter in order to build a contradiction matrix as shown in Table 2. For the problem of 'messy compartment atmosphere', the physical contradiction have been applied since that it is dealing with single parameter contradiction.

TABLE III
Generalization of Problem to TRIZ's Parameter Term

Problem	Improved	Degraded	Solution principles
No hanging stuff function	Add function #39 productivity	Design will be complex #36 Complexity	12 - equipotentiality 17- another dimension 28 – mechanic substitutions 24 - intermediary
		Space consuming #6 Area of stationary object	10–preliminary action 35–parameter changes 17-another dimension 7 –nested doll
		Inconvenience passenger # 30 Object affected harmful factors	22-blessing in disguise 35–parameter changes 13-other way round 24 - intermediary

TRIZ of Physical contradiction (satisfaction)

The compartment should be present to store the items such as magazines and bottle but must be present to create an aesthetic interior environment. Suggested inventive principles for satisfaction are:

36 phase transition

37 Thermal expansions

28 Mechanics substitution

35 Parameter change

38 Strong oxidants

39 Inert atmosphere

Step 4: Propose idea based on the related inventive principles

The principles proposed by contradiction matrix were reviewed and one or more principles that seem to have potential to trigger solution idea were selected. Based on the principle/s, a number of ideas were then proposed as shown in Table 3. Before going further to conceptual design stage, the lists of ideas should be revised and refined.

TABLE IIIII
Evaluation of principles

Principles	Relevance		Proposed ideas
	Yes	No	
12 - Equipotentiality		√	
17- Another dimension	√		Multi-storey compartment
28–Mechanic substitutions			
24 - Intermediary	√		Collapsible '*Teh tarik*' or groceries hook.
10 –Preliminary action		√	
35 –Parameter changes	√		Drawer compartment
7 –Nested doll	√		Small compartment on arm rest
22-Blessing in disguise		√	
13-Other way round	√		Flexible cover/door for compartment
36- Phase transition		√	
37 -Thermal expansions		√	
38 -Strong oxidants		√	
39 -Inert atmosphere		√	

Step 5: Construct the hierarchy of AHP and perform judgement of pairwise comparison

The hierarchy of AHP was constructed as shown in Fig. 6. Specifically, the overall target of this hierarchy was to 'rank the generated ideas'. The second level represented the main criteria affecting the generated ideas. The main criteria were classified into three aspects namely ergonomic, functionality and quality. The sub-criteria were presented in the third level. Finally, at the lowest level of the hierarchy, the idea alternatives were identified. The AHP Expert Choice was utilized to perform the pairwise comparison as shown in Fig. 7.

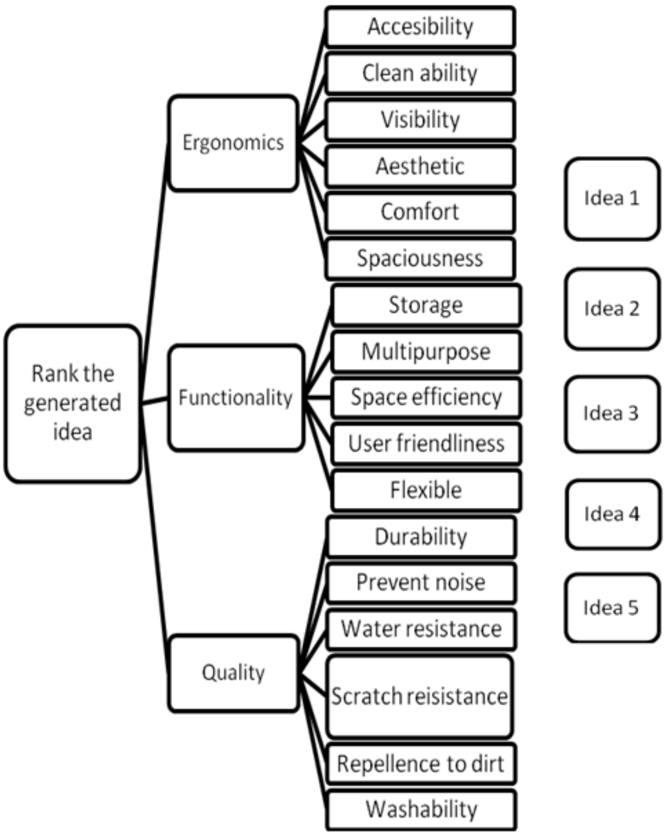
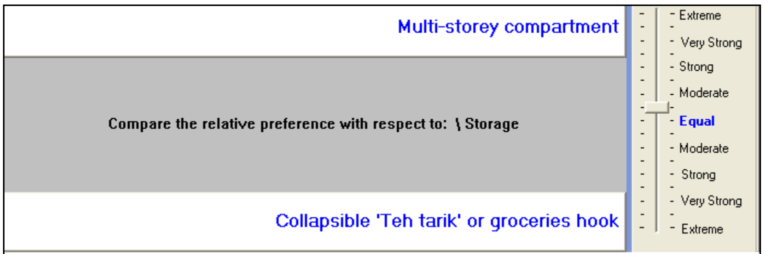


Fig.6. The hierarchy model for problems ranking.



	Multi-store	Collapsible	Drawer co	Small com	Flexible cov
Multi-storey compartment		2.0	2.0	2.0	1.0
Collapsible 'Teh tarik' or groceries hook			2.0	1.0	2.0
Drawer compartment				1.0	2.0
Small compartment on arm rest					1.0
Flexible cover/door for compartment		Incon: 0.04			

Fig.7. Pairwise comparison with respect to 'Storage' criteria

Step 6: Idea priority ranking

After carrying out the pairwise comparison with respect to each criterion as well as consistency ratio, as shown in Fig. 8, it was found that collapsible groceries hook scored 0.211, flexible cover/door for compartment (0.204), small compartment on arm rest (0.203), multi-storey compartment (0.196) and drawer compartment (0.185). The results were then reviewed and refined.

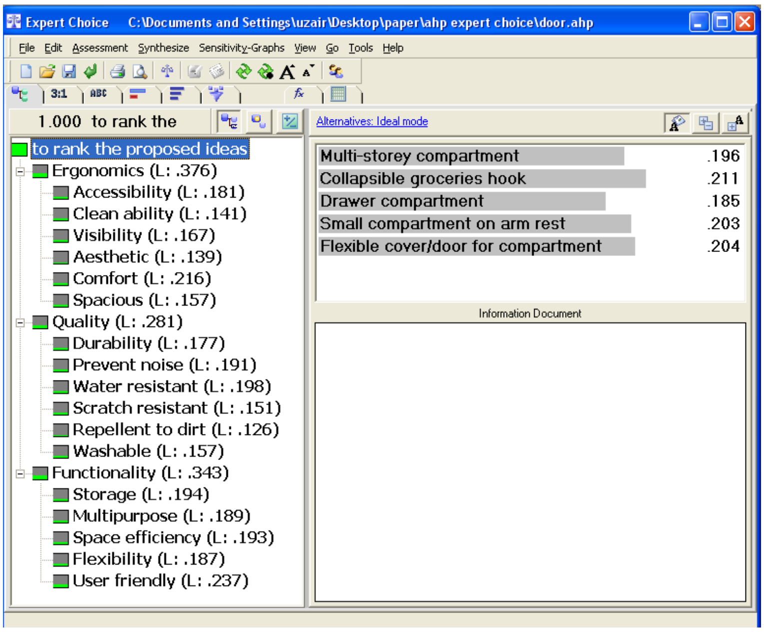


Fig.8. Results of AHP

Step 7: Refine and finalize the improved idea

From the observation and refinement of the result, it was decided to combine the top three of the ideas namely collapsible groceries hook scored, flexible cover/door for compartment, small compartment on arm rest. The three ideas were then refined for final improved concept.

Step 8: Final concept

The final improved design concept has been prepared by sketching and it is depicted in Fig.s 9 and 10.

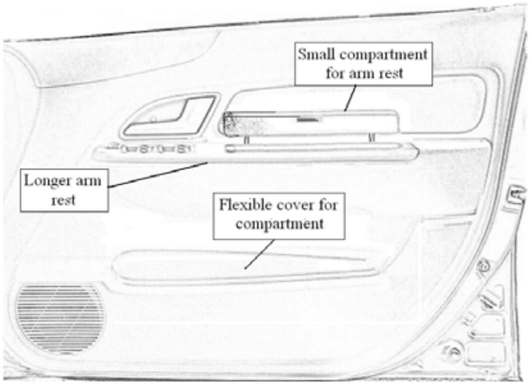


Fig.9. Improvement of front door

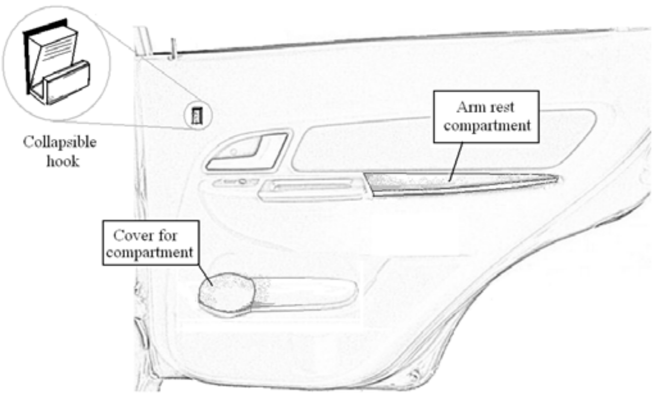


Fig.10. Improvement of rear door

VI. CONCLUSION

In rapidly moving industry nowadays, the needs of an organized system or framework of decision making and problem solving process has become a crucial issue. The extensively used problem solving method of TRIZ and AHP was applied to rank the developed ideas by TRIZ method. The integration of TRIZ and AHP was explored in this paper. The results stated that the generated ideas of each selected principle can be reviewed and combined in order to optimize the improved concept design. This study illustrates how effective the AHP method as a support tool for TRIZ methodology. It was suggested that the TRIZ methodology could be strengthened by utilization of other selection tools such as QFD, FMEA or TOPSIS.

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