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DEVELOPMENT OF CONCEPTUAL TECHNIQUE BY USING INTEGRATED APPROACHES

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Abstract

In order to be a competent player in the market, the product should arrive into market within a short of time and reasonable price. In order to shorten the time to reach the market, most of the manufacturers develop the technique to reduce the assembly cost at the early stage of the design phase. This could be achieve by reducing the part numbers which would reduce the assembly time and assembly cost as well. Design for assembly is one of the techniques that could be adopted by the manufacturers in order to reduce the assembly cost. The objective of this paper is to present the develop methodology which is based on integrated design for assembly technique with other design process. This integrated technique using the philosophy of Theory Inventive Problem Solving (TRIZ), Axiomatic Design (AD) and Boothroyd – Dewhurst DFA. It is aim to provides guidelines for the designer to design a product at the early design phase. The AD is aimed to identify the user needs. The user needs then, are translated into functional requirements and design parameters. At the design parameters, the TRIZ methodology is applied in order to produce several redesign alternatives. The best alternative is then, will be evaluating in terms of design for assembly. The case study is implemented on the table fan. It shows that, by using the develop methodology; the table fan would able to be assemble with lesser time.

Keywords : Axiomatic Design, TRIZ and Design for Assembly

1. Introduction

As the product life cycle is become shorter, the manufacturers are burden with the pressure to accelerate the product output so that it could reach in the market with in a short period of time[1]. Furthermore, the traditional manufacturing concepts applying the *thrown – over – the wall* system consequence no coordination among the product designer, manufacturing engineer and the shop floor or process engineer. Hence, it is too late to changing the design which resulting the cost uplift and time consuming at the end of the process.

In order to prevent the late design changes at the end of the process, the manufacturers create; adopt the design techniques to identify and evaluate quantitatively the design effectiveness at the early phase of the design stage before the product enters in to the process. One of these techniques is Design for Assembly (DFA).

DFA is important manufacturing tools that apply to reduce the cost attributable to the manufacturing. It is often regarded as a repository of manufacturing best practices that are to be used like off-the-shelf answers to the product designers' difficulties about the solutions that they have to select for further development [2]. However , the selection of solutions is a crucial issue in product development, because it usually defines the design and manufacturing processes of the product. There are three well known commercial DFA tools that available in the market. One of the tool is the Boothroyd – Dewhurst DFA methodology(B – D's DFA) [3].

The B – D's DFA can be applied to either manual or semi – auto or automatic assemblies. This methodology consist of the reference tables that consider the ease of handling, insertion as well as the relevence to the assembly [4].Axiomatic Design (AD) is a systematic model for engineering that addresses the decision making process in engineering design issues [5], [6]. It base on two axioms that are the independent axiom and the information axiom, and, four domains (customer domain, functional domain, physical domain and process domain) that mapping among them.

These two axiom in AD is aim to maintain the independence or freedoom of finding the information in the functional domains. The second aim is to reduce the information content in order to achieve the design goal while maintainig the function of the product [2]. Through trial and error in the mapping process, the AD helps the designer in structuring and understanding the design problems. There by, it helps the designer in analysis and synthesis the design qualitatively.

However, in order to avoid the trial and error and reduce the mapping time among the domains in AD, the Theory Inventive Problem Solving (TRIZ) is applied. TRIZ, a problem solving methodology from

Russia, is a structured approach that consists od a series of tools to help designers to avoid trial-and-error in design process and solve problem creatively. In TRIZ , the problems are codified, classified and solved structuredly [7]. There are three premises on which the TRIZ theory may be viewed: (i) the ideal design with no harmful functions is a goal; (ii) an inventive solution involves wholly or partially eliminating a contradiction and (iii) the inventive process can be structured.

The present paper aims to show how the integrated of AD and TRIZ can contribute to improve this condition, as it can provide an unbiased support to collaborative decision-making in DFA.

The paper is arranged as follows: Section 2 introduces the fundamentals of AD, TRIZ and DFA, Section 3 exhibits a developed worked, Section 4 contains a case study and its discussions, and finally, Section 5 presents the conclusion.

2. A Review of DFA, Axiomatic Design and TRIZ

2.1. Design for Assembly(DFA)

DFA is a systematic methodology that reduces manufacturing costs by reducing the total number of individual parts in a product and redesigning the remaining parts in the product for ease of handling and insertion [4]. The DFA is a two-step process. The first process is to evaluate the assemblability of the individual parts as to whether the parts are easy to assemble or not. The second process is to evaluate the theoretical minimum number of parts that should be in the product.

In the first process the rating system, such as the DFA Toolkit are use to evaluate each individual part with respect to [4]:

1. Graspability—to check that the part is easy to be grasped or not during the period of assembly.
2. Orientability—to check if the part is easy to be oriented or not when it is being assembled.
3. Transferability—to check whether the part is easy to be transferred to the work position or not.
4. Insertability—to check if the part is easy to be inserted into the correct position or not when it is being assembled.
5. Securability—to check whether the part or the product is secure or not after the part has been assembled.

At the second process, theoretical minimum number of parts is evaluated by the part redundancy criteria. The following three questions about each part were asked: (1) does it move relative to adjacent parts, (2) do adjacent parts need to be made of a different material, and (3) does the part need to be separate to permit assembly or disassembly? A "no" answer to all three questions recognizes that there is a high probability that the part can be eliminated through redesign. Elimination of extraneous parts always improves assemblability. If the assembly contains sub-assemblies treat them as "parts" and assign an identification number to each item, then analyze the sub-assemblies later with the above method.

2.2. Axiomatic Design (AD)

According to AD, a design process can be describe into four design domains that are the customer, the functional, the physical and the process domains.

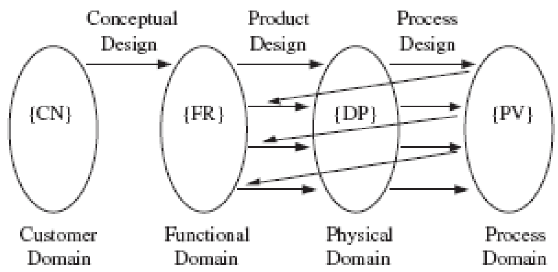

Figure 1: Domains of the Design and ZigzaggingProcess

As illustrate in Fig. 1, the design object is described in the customer domain by the customer needs vector, {CN}, in the functional domain by the functional requirements vector, {FR}, in the physical domain, by the design parameters vector, {DP}, and in the process domain by the process variables vector, {PV} [8]. The design assignments must consider the ''input constraints'', and consist of passing from a design domain to the adjacent domain. Passing from the customer to the functional domain is named as ''conceptual design''; from the functional to the physical domain,is known as ''product design''; and ''process design'' means moving from the physical to the process domain. The transitions are accomplished through mapping, as shown in Figure 1.

The design process is developed from top to bottom, beginning at the system level and continuing through to the detail levels until the point that the design object is clearly represented. A zigzagging, is used to systematically decompose the entire system into smaller design objects by going back and forth (see Figure 1) between at least two contiguous design domains [5],[8],[9]. The zigzagging process is based on the independent and information axiom.The Independence Axiom aim to maintain the independence of the functional requirements. In the independence Axiom, the number of DPs should be equates to the number of FRs . A design solution is ''uncoupled'' if the design matrix is diagonal, and it is classified as ''decoupled'' if the design matrix is triangular. Both uncoupled and decoupled are acceptable. However, if the design matrix is neither diagonal nor triangular, then the corresponding design solution is ''coupled'' and is regarded as ''poor design''. On the other hand, the information Axiomis aim to minimize the information content of the design. The information content of a design solution is closely related to the probability of fulfilling the design goal or goals.

2.3. TRIZ

"TRIZ" is the acronym for Theory of Inventive Problem Solving (TIPS) was developed in 1946, and is now being developed and practiced throughout the world. TRIZ began with the hypothesis that the universal principles of invention that are the basis for creative innovations that advance technology, and that if these principles could be identified and codified, they could be taught to people to make the process of invention more predictable. TRIZ can be divided into analytical and knowledge based tools. The former ones look for the correct approach to the problem, and the latter ones give useful ideas to solve the problem. These tools are [10]:

- Principles (contradictions) - used to solve the contradictions, i.e. the design trade-offs. Contradictions can be technical or physical. Technical contradiction occurs when, trying to improve a design aspect (or parameter), another one gets worse. To eliminate the contradiction, the contradiction matrix is used. The input data to enter into the matrix are the contradicting parameters, and the outputs are the inventive principles to eliminate the contradiction [11]. Physical contradiction are those that involve a characteristic that is in contradiction with itself. To eliminate the contradiction, the effects and principles are used. These effects can be physical, chemical or geometrical.
- Ideality – the ideal product can perform its function without existing. The objective is to push the system towards increase in benefits and reduction of cost and other harmful effects of the system [12].
- Evolution of the Systems – a generic technology evolution trends that determine the evolution of all technical systems [13].
- Standards (S-fields transformations) – rules for solving commonly occurring inventive problems.
- ARIZ – an acronym for the *"Algorithm for Inventive Problem Solving"*. It is a logical structured process that incrementally evolves a *complex problem* to a point where it is simple to solve[14].

3. Methodology

The integrated methodology is illustrated in Figure 2. It is divided into 3 processes. The first approach is to identify the customer needs and seek and identify the coupled design matrix. The second approach is to seek and solve the contradiction in the coupled matrix. The final process is to review the design from DFA perspective.

As illustrated in Figure 2, the methodology starts with gathering the information that relate to the current product. The gathered information of the current product is then are translated into the customer perspective in order to identify the customer requirement of the current product. The identified customer requirement is then, through zigzagging process, are translated into the functional requirement of the product. The functional requirements are then, mapped to the design parameters in order to identify the coupled matrix. If the coupled matrix is found, then it will enter into second process.

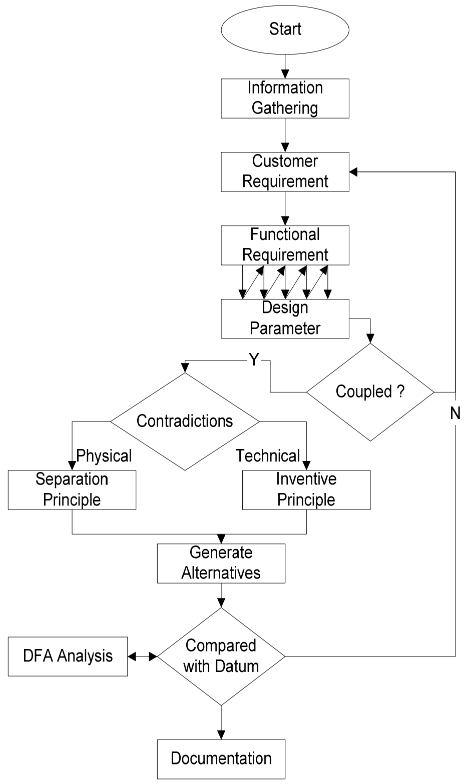

Figure 2: Integrated methodology

At the second process, the coupled matrix is analyzed to seek for either the technical or physical contradictions. If the matrixes possess the technical contradiction the inventive principle is use. On the other hand, if the matrix contains the physical contradiction, the separation principle is used. After that, the alternative designs are generated and evaluated based on the principle use in the second process. The final process is to determine the assemblability of the proposed design and compared to the current design. If the proposed design has design efficiency lower than the current design than it will be iterate back to identify customer requirement process

4. RESULTS AND DISCUSSION

The methodology applies the Proton Wira Car Seat as a case study. The table fan constructs of 6 components of the sub – assemblies that consists of 127 parts. The details of the results will be discusses in this sub – section. The explode view of the current Proton Wira car seat is illustrated in Figure 3.

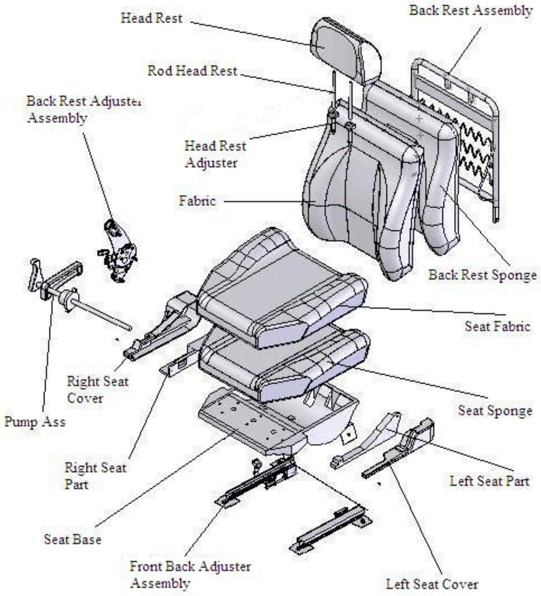

Figure 3: Explode view of the Proton Wira car seat

4.1. Part Information

The part information gathered the information of the parts in terms of the material, quantity, the assemblies structure and time of the current product. The part information of the 'Back Rest Assembly', one of the components of the Proton Wira car seat is shown in Table 1.

Table 1: Part information of the Back Rest Assembly

No	Part Name	Qty	Total Assembly Time (s)	Material base
1.	Back Rest Main Rod	1	6.50	Steel
2.	Centre Wire	3	25.62	Steel
3.	**Adjuster Holder**	**2**	**51.78**	**Steel**
4.	Head Rest Adjuster	2	21.30	PVC
5.	Right Supporter	1	12.35	Steel
6.	Left Supporter	1	7.15	Steel
7.	Centre Bar	1	6.33	Steel
8.	**Plastic Centre Wire**	**6**	**50.70**	**Plastic**
9.	**Centre Wire Holder**	**6**	**74.16**	**Steel**
10.	Bottom Support Rod	1	6.33	Steel
11.	Back Rest Sponge	1	14.00	Cotton Gauze
12.	Fabric	1	8.50	Velour

From Table 1, it can be concluded that there are 29 parts with different material. All fasteners are made by the same steel base materials. The base part consumed the assemble time more than other parts. The current base part is illustrated in Figure 4.

From Figure 4, the current design of the back rest assembly consists of main rod, center wires, adjuster holder, head rest adjuster, bottom support rod, left and right supporters, center bar, back rest sponge and the back rest cover fabric. The total parts numbers are 29 and the total assembly times to assemble these components are 286.87 seconds. From Table 1, it can be conclude that the adjuster holder, plastic center wire and its holder is a contribute 61.62% to the total assembly time of the back rest assembly. This component will be analyze using the Axiomatic Design techniques in the section 4.2

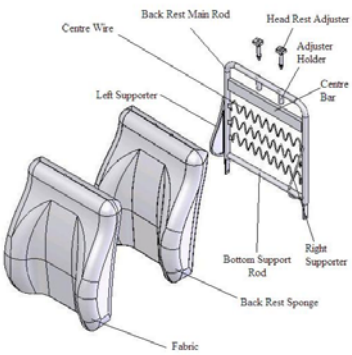

Figure 4: Current design of the back rest assembly

4.2. Axiomatic Design(AD) Analysis

In AD analysis, the customer information is identified. The identified customer information is then mapped to the functional domain and finally to the design parameters domain. The mapping results is illustrate in Table 2.

Table 2: Mapping results in AD

CR Domain	FR Domain	PV Domain
CR1 Minimize service	FR1 Improve the service in terms of product design efficiency; (CR1); FR1.1 Minimize number of parts FR1.2 Minimize number of fasteners and their component FR1.3 Minimize assembly steps and extra operation	PC 1 Means to reduce number of parts PC 1.1 integrate the screws, and nuts (FR1.2); (FR1.3); (FR1.1) PC1.2 means to minimize the application of fasteners; (FR1.2); (FR1.3); (FR1.1) PC1.3 Increase the area of center wire (FR1.1); (FR1.2); (FR1.3)
CR2 Facilitate Safety features	FR2 Increase safety features of the back rest; (CR2) FR2.1 Adjustable head rest FR2.2 Cover the components with soft and absorbable material	PC2 Means to provide the safety feature to the back rest assembly (FR 2) PC2.1 Provide head rest adjuster to adjuster holder (FR2.1) PC2.2 cover back rest main rod and center wire with sponge (FR2.2)
CR3 Minimize Vibration	FR3 Minimize vibration between body and back rest (CR3) FR3.1 Provide protective cover FR3.2 Maintain connection between center wire and its holder	PC3 Means to Minimize vibration between body and back rest(FR3) PC3.1 cover back rest main rod and center wire with sponge (FR2.2); (FR3.1) PC3.2 Means to cover the center wire at both ends (FR3.2); (FR3.1)

The data from the Table 2 is transferred into the matrix form in Table 3.

Table 3: Mapping matrix for finding the coupling type

	PC1.1	PC1.2	PC1.3	PC2.1	PC2.2	PC3.1	PC3.2
FR1.1	X	X	X				
FR1.2	X	X	X				
FR1.3	X	X	X				
FR2.1				X			
FR2.2					X		
FR3.1					X	X	
FR3.2						X	X

From Table3, it can be concluded that the FR1.1 up to FR1.3 are coupled with PC1.1 up to PC1.3. The complete matrix mapping from Table 3 can be convert into mathematical equation as illustrated in equation 1, 2 and 3.

$$\begin{Bmatrix} FR1.1 \\ FR1.2 \\ FR1.3 \end{Bmatrix} = \begin{bmatrix} X & X & X \\ X & X & X \\ X & X & X \end{bmatrix} \begin{Bmatrix} PC1.1 \\ PC1.2 \\ PC1.3 \end{Bmatrix} \cdots (equation\ 1)$$

$$\begin{Bmatrix} FR2.1 \\ FR2.2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} PC2.1 \\ PC2.2 \end{Bmatrix} \cdots (equation\ 2)$$

$$\begin{Bmatrix} FR3.1 \\ FR3.2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ X & X \end{bmatrix} \begin{Bmatrix} PC3.1 \\ PC3.2 \end{Bmatrix} \cdots (equation\ 3)$$

From the *equation 1* up to *3,* it shows that the equation 1 is a coupled design, equation 2 is a uncouple design and equation 3 is decouple design. The couple designs in equation 1 means that, in order to improve the design efficiency, the designers at first, must consider reducing the number of parts base on the DFA guidelines. The second consideration, the designer must consider to provide the safety related features at the back rest assembly. And finally, the designers also need to consider how to minimize the vibration at the back rest area. However, from AD perspectives, the design of FR1 is violating the independent axiom. This can be improved by changing the PC1 elements in the PC1 domains to eliminate the coupling.

From Table 3 and equation 1, it can be conclude that the identified matrix are coupled when the FR domain and PV domain is zigzagging. However, from Table 2, the PC 1.2 and PC 1.3 have an obvious contradiction and the TRIZ technique is applied to identified as the technical contradiction. Hence, the inventive principle is applied in TRIZ.

4.3. TRIZ Analysis

TRIZ analyze the contradicted parameters that are the PC2.2and 3.1 in the AD. The selected principle is the inventive principle because the contradiction is the technical contradiction. In order to improve the design efficiency, the parameter 6 which quote '*increasing the area of non – moving object'* (please refer to attachment 1) is selected as a parameter to be optimized. The improved parameter, parameter number as well as the suggested inventive principle is shown in Table 4.

Table 4: Inventive Principle used

Increasing the area of non – moving object (Parameter 5)		
Without damaging the parameter of ….	**Parameter Number**	**Inventive Principle used**
Repairability	34	16
Manufacturability	32	16,40

From Table 4, the area of non – moving object has to increase without damaging the parameters 16 and 40. Therefore, 3 Inventive Principles need to be considered before changing the area of non moving object. These Inventive Principles are stated in Table 5.

Table 5: Inventive Principles for Car Seat

No	Principle
16	Partial/overdone action
40	Composite Materials

From Table 4 and 5, the Inventive Principle number 16 is selected. The optimized suggestion is to provide partial or overdone action to the back rest assembly. It is suggested that '*If 100 percent of an object is hard to achieve using a given solution method then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve'*. in order to increase the area of the back rest center wire assembly.

4.4. Proposed design

Based on the recommendation given by the TRIZ inventive principles, the proposed design is illustrated in Figure 5. According principle number 16, using 'slightly less' or 'slightly more' of the same method, to solve the problem.

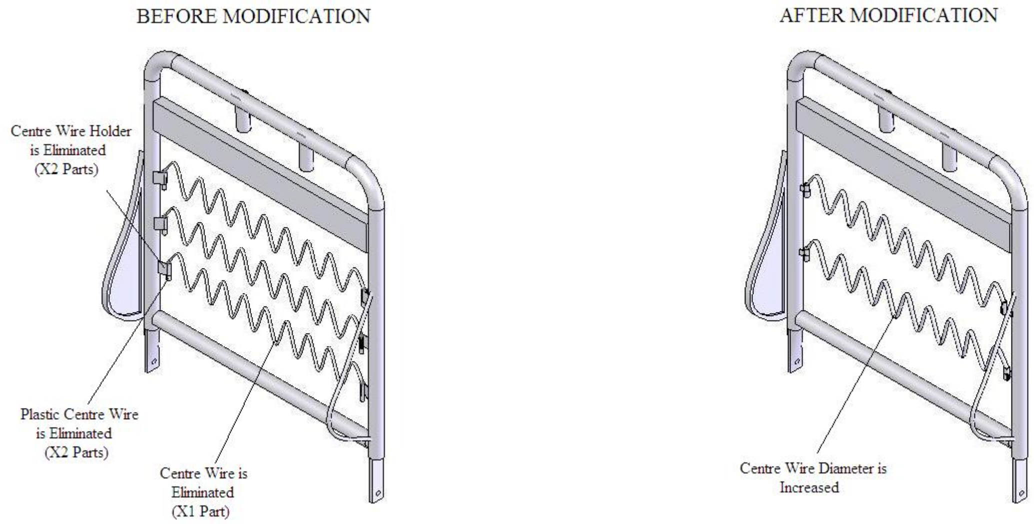

Figure 5: Proposed Design

From Figure 5, base on the inventive principle number *35*, the center wire holder and the plastic center wire in the middle are eliminated. The diameter of the center wires is increase to support the body. Hence, the total number of part is reduced from 29 to 24.

4.5. DFA Analysis of the modified design

The proposed design of the base is design based on the recommendation from the inventive principle in TRIZ. The design is later; being is analyzed in the terms of the assemblability by using the Boothroyd – Dewhurst DFA techniques. The results of the analysis and comparison between before and after modification of the table fan, is summarized in Table 5.

Table 6: DFA Analysis Before and After Modification

Item	Original	Modified	Difference	Improvement
Total Number of Parts	29	24	5	17.24 %
Theoretical Minimum Number of Parts	13	12	1	
Total Operation Time (s)	286.67	236.51	50.16	17.5%
Design Efficiency (%)	13.6%	15.22%	1.62%	

From Table 6, it shows that by applying the developed integrated approach, the total parts number is decrease from 29 to 24 parts. This contributes to 17.5% of the total assembly cost reduction. The total operation time is reduced from 286.67 seconds to 236.51 seconds. The design efficiency is improved from 13.6% to 15.22%.

5. Conclusion

In this paper, the concept of the TRIZ, AD and DFA were reviewed from the engineering design perspective. The pillar of each techniques philosophy were selected and integrated in order to produce the integrated method by the aim to evaluate the design from both qualitative and quantitative perspectives. Thus in this paper, it can be concluded that:

1. TRIZ and Axiomatic design is one of the methods that able to guide the designer on how to redesign a product systematically and qualitatively while the DFA considers the redesign from the quantitative perspective.
2. Integration of axiomatic design, TRIZ and DFA is able to aid the designer to generate the creativity in the assembly design

3. DFA set the guidelines on how to design a product with minimizes assembly cost. The aim of this method is to increase design efficiency, in order to produce an efficient and economic design.

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Attachment 1: Contradiction Table 1

Feature to Improve \ Undesired Result (Conflict)		27 Reliability	28 Accuracy of measurement	29 Accuracy of manufacturing	30 Harmful factors acting on object	31 Harmful side effects	32 Manufacturability	33 Convenience of use	34 Repairability	35 Adaptability	36 Complexity of device	37 Complexity of control	38 Level of automation	39 Productivity
1	Weight of moving object	3, 11, 1,27	28,27, 35,26	28,35, 26,18	22,21, 18,27	22,35, 31,39	27,28, 1,36	35,3, 2,24	2,27, 28,11	29,5, 15,8	26,30, 36,34	28,29, 26,32	26,35, 18,19	35,3, 24,37
2	Weight of non-moving object	10,28, 8, 3	18,26, 28	10,1, 35,17	2, 19, 22,37	35,22, 1,39	28, 1, 9	6,13, 1, 32	2,27, 28,11	19,15, 29	1,10, 26,39	25,28, 17,15	2, 26, 35	1, 28, 15,35
3	Length of moving object	10,14, 29,40	28,32, 4	10,28, 29,37	1,15, 17,24	17,15	1, 29, 17	15,29, 35,4	1, 28, 10	14,15, 1,16	1, 19, 26,24	35,1, 26,24	17,24, 26,16	14,4, 28,29
4	Length of non-moving object	15,29, 28	32,28, 3	2, 32, 10	1, 18		15, 17 27	2, 25	3	1, 35	1, 26	26		30,14, 7,26
5	Area of moving object	29, 9	26,28, 32,3	2,32	22,33, 28,1	17,2, 18,39	13,1, 26,24	15,17, 13,16	15,13, 10,1	15, 30	14, 1, 13	2,36, 26,18	14,30, 28,23	10,26, 34,2
6	Area of non-moving object	32,35, 40,4	26,28, 32,3	2,29, 18,36	27,2, 39,35	22, 1, 40	40, 16	16, 4	16	15, 16	1, 18, 36	2,35, 30,18	23	10,15, 17,7
7	Volume of moving object	14, 1, 40,11	25,26, 28	25,28, 2,16	22,21, 27,35	17,2, 40,1	29, 1, 40	15,13, 30,12	10	15, 29	26, 1	29,26, 4	35,34, 16,24	10, 6, 2,34
8	Volume of non-moving object	2,35, 16		35,10, 25	34,39, 19,27	30,18, 35,4	35		1		1, 31	2, 17, 26		35,37, 10,2
9	Speed	11,35, 27,28	28,32, 1,24	10,28, 32,25	1,28, 35,23	2,24, 35,21	35,13, 8,1	32,28, 13,12	34,2, 28,27	15,10, 26	10,28, 4,34	3,34, 27,16	10, 18	
10	Force	3,35, 13,21	35,10, 23,24	28,29, 37,36	1,35, 40,18	13,3, 36,24	15,37, 18,1	1,28, 3,25	15, 1, 11	15,17, 18,20	26,35, 10,18	36,37, 10,19	2, 35	3,28, 35,37
11	Tension, pressure	10,13, 19,35	6, 28, 25	3, 35	22, 2, 37	2, 33, 27, 18	1, 35, 16	11	2	35	19, 1, 35	2, 36, 37	35, 24	10,14, 35,37
12	Shape	10,40, 16	28,32, 1	32,30, 40	22,1, 2, 35	35, 1	1,32, 17,28	32,15, 26	2, 13, 1	1, 15, 29	16,29, 1,28	15,13, 39	15, 1, 32	17,26, 34,10
13	Stability of object		13	18	35,24, 30,18	35,40, 27,39	35, 19	32,35, 30	2,35, 10,16	35,30, 34,2	2,35, 22,26	35,22, 39,23	1, 8, 35	23,35, 40,3
14	Strength	11, 3	3, 27, 16	3, 27	18,35, 37,1	15,35, 22,2	11,3, 10,32	32,40, 28,2	27,11, 3	15, 3, 32	2, 13, 28	27, 3, 15, 40	15	29,35, 10,14
15	Durability of moving object	11, 2, 13	3	3,27, 16,40	22,15, 33,28	21,39, 16,22	27, 1, 4	12, 27	29,10, 27	1, 35, 13	10,4, 29,15	19,29, 39,35	6, 10	35,17, 14,19
16	Durability of non-moving object	34,27, 6,40	10, 26 24		17,1, 40,33	22	35, 10	1	1	2		25,34, 6,35	1	10,20, 16,38
17	Temperature	19,35, 3,10	32,19, 24	24	22,33, 35,2	22,35, 2,24	26, 27	26, 27	4, 10, 16	2,18, 27	2,17, 16	3,27, 35,31	26,2, 19,16	15,28, 35
18	Brightness		11,15, 32	3, 32	15, 19	35,19, 32,39	19,35, 28,26	28,26, 19	15,17, 13,16	15, 1, 1, 19	6, 32, 13	32, 15	2, 26, 10	2, 25, 16
19	Energy spent by moving object	19,21, 11,27	3, 1, 32		1,35, 6,27	2, 35, 6	28,26, 30	19, 35	1,15, 17,28	15,17, 13,16	2, 29, 27,28	35, 38	32, 2	12,28, 35
20	Energy spent by non-moving object	10,36, 23			10, 2, 22,37	19,22, 18	1, 4					19,35, 16,25		1, 6