# CONCEPTUAL DESIGN OF THE ERGONOMIC CHILD RESTRAINT SYSTEM FOR INFANTS IN THE AIRCRAFT USING TRIZ METHOD

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## ABSTRACT

*Positive trends in the statistics of infants travelling by air generated a momentum for the industry to develop an excellent Child Restraint System for infants in term of safety, as well as comfort, convenience and usability for infants and their traveling companion. This paper presents a conceptual design of an ergonomic Child Restraint System for infants in aircraft to maximize comfort, convenience and usability using a total design technique consisting of the TRIZ methodology solution. A market survey was conducted at the early stage to discover the needs and requirements of the end user. The product requirements for the Child Restraint System was also defined. The methodology was followed by the 'brainstorming' technique to generate preliminary ideas in between the implementation of the TRIZ methodology solution. Three conceptual designs were generated for selection. The weighted evaluation method used to determine the final design of an ergonomic Child Restraint System for infants. The final concept was analyzed and fabricated as a prototype for further validation.*

***Keywords: Child Restraint System; conceptual;design; TRIZ method***

## I. INTRODUCTION

The contribution of aircraft passengers traveling with infants between 0 – 24 months of age towards the airline industry currently increases. This group of travelers chooses air transportation as their main medium of travel from one place to another. As long distance travelers, besides the safety requirement, the comfort of infants becomes the main concern as well as the comfort, convenience and usability factors of the travelling companion. The rules and regulations for the Child Restraint System in aircraft is still an ongoing debate. The current Child Restraint System in this industry is limited due to the specified regulations.

In most parts of the world, infant passengers on a regular basis travel with the aircraft without being restrained in a way that afford them a level of safety equivalent to an adult passenger in the event of a survivable crash [1]. Compared to adult passengers, infants are not assigned to a specific restraint device that restrict them to the aviation safety standard. It is well acknowledged that this situation is currently being debated and researched. However, besides safety as a main concern, comfort, convenience and usability also play a big role in providing maximum comfort in a journey for the infants, the traveling companion and other aircraft passengers. In fact, the comfort and convenience of a journey in aircraft are widely offered to adult passengers without infant, but are rarely considered for the infant and their traveling companion.

## II. CHILD RESTRAINT SYSTEM (CRS)

Current situation shows that there is no widely available Child Restraint System for an infant that is compatible with the typical aircraft seats. The most widely used Child Restraint System in the aircraft is the bassinet provided by the airlines. However, it is only for lap-held baby aging six months and below. In addition, the use of bassinet is only allowed during cruise and strictly prohibited during takeoff / landing and in any emergency situation [2]. Even though, as suggested by CASA (2014), the bassinet may provide a comfortable position for infants under six months, it restricts comfortable experience directly for older infants and the traveling companions.

In some cases, some airlines permit the use of the Automotive Child Restraint System on their aircraft, but some do not [3]. Improper use of the Automotive Child Restraint System may increase usability and safety issues in aircraft [4][5][6], increasing the level of uncomfortableness of infants and their traveling companions because they cannot use the device to ease their long haul flight journey.

Other than that, infants may be carried lap-held during the long haul flight using a supplementary loop belt provided by the airline management. This supplementary loop belt was designed by attaching the loop belt to the adult passenger's lap belt. However, the use of the supplementary loop belt is only permissible for Europe and Asia countries, while prohibited for Canada and US [7]. This rejection is due to a few studies on the ineffectiveness of the supplementary loop belt since it could maximize the danger towards infants in the case of survivable crash [2]. Besides, in the aspect of comfort, the mother will experience difficulty because of the static position, while holding the infant in a long period of time without any supporting device. This long period of inactivity may produce improper seating posture for the mother and will affect the level of comfort.

Since airline carriers need to serve their customers by considering the cost and the service load, a simple yet effective design is needed. In addition to safety requirement, it is important to offer a comfortable flight journey for infants and their traveling companions.

In the implementation of the conceptual design of infant's Child Restraint System in the aircraft, the application of Teoriya Resheniya Izobreatatelskikh (TRIZ) Method was applied. This method was proven to be effective in the revolution of new ideas in improving the existed design in certain aspects.

## III. TEORIYA RESHENIYA IZOBREATATELSKIKH ZADATCH (TRIZ) METHOD

TRIZ or "Teoriya Resheniya Izobreatatelskikh Zadatch" is a tool developed by Genrich Altshuller in 1940s to solve most engineering problems innovatively [8]. Altshuller gathered approximately one hundred people by screening over 200,000 patents, from which he extracted 40,000 innovative patents to develop TRIZ. From their research, Hishihama and Hamada (2009) were convinced that TRIZ function and attribute analysis successfully identified the problems that were difficult to solve by conventional methods in designing a safety seat for children [5].

Fig. 1 represents the resulting TRIZ conceptual scheme to idealize the process that took place. Initially, the designer would be presented with the original design problem. Then, the designer would generate the TRIZ problem based on the design problem. Later, the TRIZ solution would be obtained and the design solution would be identified.

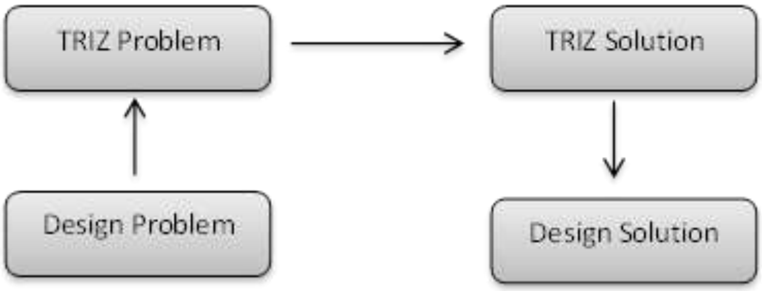



**Fig.1:Conceptual scheme of TRIZ [Product Redesign Using TRIZ and Contradictive [9]**

In the application of TRIZ method, three aspects were applied to improve these three features: products, services, and systems. The aspects are referred to as learning by repeating patterns of problem solutions, using scientific effects, and applying the general TRIZ patterns [10]. According to Natraj et al. (2002), to solve contradicting problems, a number of prior methods had been employed to aid the new design process [11]:

(1) Inspiration method: The designers who depend upon this method may be able to enhance a design. However, they can never be sure that they will be able to find the right solution to a design problem. In addition, this method is seen as very subjective for most problems.

(2) Trial and error method: The designers who hinge on the trial and error method can spend a great deal of time and resources in exploring design options, even though this approach is thought to be a conservative method. In addition, the outcomes may not be complete with inexperienced designers.

(3) Brainstorming method: The brainstorming approach is one of the most common methods employed in the industry. During 30-40 minutes discussion, a leader guides a group to voice out their ideas without hesitation. This method provides the chances and likelihood for designers to hear other people's ideas, nevertheless the designers may also be influenced by others.

## IV. DESIGN METHODOLOGY

This section will discuss the overall design methodology to come out with the conceptual designs of the ergonomic child restraint system for infants in commercial aircraft

### 3.1 Market Survey Stage

The design process started with a market survey on Child Restraint System for infants in the airline industry. The market survey included survey on patents, journals, technical reports as well as websites from various airlines and others regarding the existing Child Restraint System for infants. Besides that, focus group interviews were also conducted in order to document the targeted passengers experience and the view of the targeted passengers regarding the existing Child Restraint System. The information gathered is important in the design process. The focus group served as a useful tool to explore various key issues on the use of Child Restraint System for infants in aircraft [12]. Participants discussed experiences and difficulties associated with the usage of Child Restraint System. The reviewed topics included issues on comfort, convenience and usability factors on infants and their travel companions.

### 3.2 Product Requirement Stage

The design process was followed by the product requirement stage. This stage was performed as an output of the market survey and was used as a reference and guideline to generate ideas on the new design [13]. The requirement of the product mainly focused on the performance of the Child Restraint System, material, size, reliability, weight, strength, safety, incurred cost and finally, the design itself. These performances were developed based on their importance to Child Restraint System on aircraft.

The design process was then continued with the conceptual design stage consisted of the brainstorming method and TRIZ method. The brainstorming method was used as a tool to generate the conceptual design [14], while, TRIZ method served as the problem solving process based on logic and data, and not on perception. The ideas from the two combined methods based on the product requirement were then described in a Morphological Chart to ease visualization.

Finally, after the three main processes, the final concept was selected based on the weighted objective method and the design was then revealed using a Computer Aided Design in the last stage. Fig. 2 shows the total design model developed during the development of a new ergonomic Child Restraint System for infants in an aircraft.

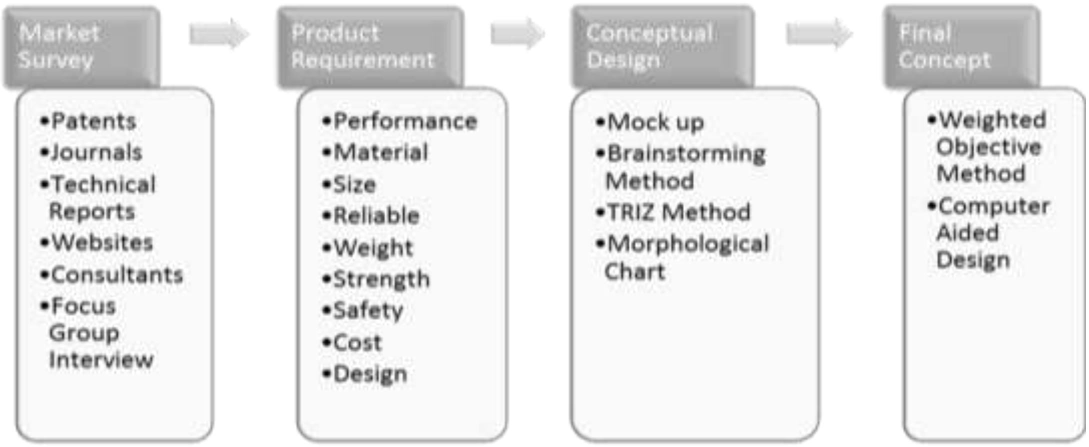



**Fig. 2: The Total Design Process Of The Child Restraint System For The Infants In Aircraft**

### 3.3 Conceptual Design Stage

During the development of the conceptual design, the product requirement of the Child Restraint System becomes the main guideline and reference. Throughout the design process, the brainstorming method was used to generate as many relevant ideas without any limitation. The first brainstorm session was conducted with two experts in the industry regarding the acceptable restriction of the design according to the airline industry rules and regulations. The second brainstorm session was conducted with four individuals who were encouraged to develop their ideas extensively.During the second brainstorming session, the application of TRIZ method was injected for more innovative solutions. The method has proven to be practical to the design team to come out with the boundless creative ideas [10].

The TRIZ method started with the analytical stage: in the beginning, the situation was analyzed, the object and the functionality were identified, and the main useful function of the system was identified. From the analysis, the problems that need to be solved were identified. After that, the next phase was to identify the contradiction. In a design scenario, there can be many contradictions and the core of the problem should be identified first. To identify those problems, the documented data collection from the market survey were used to generate the ideas and the problems.

For an improved design of the Child Restraint System for aircraft, the main problems are listed in a table of the good and the bad effects, as shown in Table 1.

| The Good Effect/Improving Factor | The Bad Effect/Worsening Factor |
|---|---|
| (1)Infant can have their own seat. By creating new available spaces in front of the parent. (Length of moving object (3)). | Will involve the use of existing confined space. (Area of moving object (5)). |
| (2)The design is strong enough to support infants up to 13kg. (Strength (14)) | The mechanism must have a good attachment / adjustable at the base structure. Strong base. (Reliability (27)). |
| (3)Ease parents' labor in loading/unloading their child by using a simple mechanism. (Ease of operation (33)). | The users/parents may be the person who can contribute to the complexity. (Device or system complexity (36)) |
| (4)Restraint infant during travel while allowing free movement in normal condition facing their mom using a simple mechanism. (Reliability (27)). | The users/parents may be the person who can contribute to the complexity. (Device or system complexity (36)) |
| (5)Can be stored easily and reused whenever required by having a simple design and structure. (Ease of operation (33)) | The users/parents may be the person who can contribute to the complexity. (Device or system complexity (36)) |
| (6)Provide comfort during travel for lap-held mom when they do not have to hold the baby all the time. (Adaptability or versatility (35)) | Will involve the use of existing confined space. (Area of the stationery object (6)) |
| (7)Can secure the infant in all phases of flight, while located as near as possible to the mom. (Reliability (27)) | The structure could affect the mom's comfort. (Shape (12)) |

**Table 1. The Good And The Bad Effects Of The Newly Proposed Design.**

Based on the good and bad effects described by the problem, the design of an ergonomic Child Restraint System for infants with improved feature parameters consisted of the length of moving objects (3), strength (14), reliability (27), ease of operation (33) and adaptability and versatility (35). The worsening features consisted of the area of the moving object (5), area of the stationary object (6), shape (12), reliability (27) and finally, device or system complexity (36). The detail of the contradiction matrix is shown in Table 2. The shown contradiction matrix was constructed from the problems indicated earlier, which was matched with the improving and worsening factors. From the contradiction matrix study, the improving and worsening factors were identified.

Based on Table 1, the idea of giving infants their own seats in front of their travelling companions led to the improving factor for 'length of the moving object (3)', but, it would involve the use of existing confined space that lead to the worsening factor for 'area of the moving object (5)'. These parameters brought to the 40 inventive principle solutions of '#15 dynamics', '#17 another dimension' and '#4 asymmetry'.

The idea of implementing a strong device to support infants below 13kg was included under the improving factor of 'strength (14)' but, prior to that, the device must have a good basic structure included under the worsening factor of 'reliability (27)'. This parameter proposes '#11 beforehand cushioning' and '#3 local quality' as solutions.

The usability and convenience issues of easing parents' labor in loading/unloading their infant when using the system were included under the parameter of 'ease of operation (33)'. However, in order to achieve that, the users or parents might contribute to the complexity of the operation, which can be referred to as 'device or system complexity (36)' parameter, resulting to the solution of '#32 color changes', '#26 copying', '#12 equipotentiality' and '#17 another dimension' from the 40 principles.

The study of the fourth design problem on the need to restrain the infant during travel, while allowing the infants to move freely in normal condition facing their parents in the aircraft could be classified under the parameter of 'reliability (27)'. On the other hand, the users or parents might be the person to contribute to the complexity of the process for those design mechanisms, and was classified under the parameter of 'device or system complexity (36)'. The 40 principles indicated that '#13 the other way round', '#35 parameter changes' and '#1 segmentation' as the proposed solutions.

Another problem stated in designing the Child Restraint System was to design a system that can be stored easily and reused whenever required by the parents. This problem can be classified under the parameter of 'ease of operation (33)'. However, the users or parents might be the person to contribute to the operational complexity classified under the parameter of 'device or system complexity (36)'. The 40 principles solution stated were '#32 color changes', '#26 copying', '#12 equipotentiality' and '#17 another dimension'.

The design also focused on the need to provide comfortability for lap-held parents so that they do not have to hold their babies at all time. The parameter used to describe this issue was 'adaptability or versatility (35)'. Conversely, the idea would require the use of existing space to accommodate the device, which described the parameter for 'areas of the stationary object (6)'. The outcome indicates that '#15 dynamics' and '#16 partial or excessive actions' were the best solutions of 40 principles.

The last problem that needs to be solved for the design necessity was the ability to secure the infant in all phases of flight as near as possible to the mom. This problem was classified under the parameter of 'reliability (27)'. However, overcoming this problem might affect the comfort of the travelling companion because of the design, which could be categorized under the 'shape (12)' parameter. From the contradiction matrix, the proposed 40 principle solutions were '#35 dynamics', '#1 segmentation', '#16 partial or excessive actions' and '#11 beforehand cushioning'.

Based on the analysis made in the Contradiction Matrix, the most frequent solution principles were summarized in Table 3.

| **WORSENING FACTOR** | Area of the moving object (5) | Area of the stationery object (6) | Shape (12) | Reliability (27) | Device or system complexity (36) |
|---|---|---|---|---|---|
| **IMPROVING FACTOR** | | | | | |
| Length of the moving object (3) | 15, 17, 4 | | | | |
| Strength (14) | | | | 11, 3 | |
| Reliability (27) | | | 35, 1, 16, 11 | | 13, 35, 1 |
| Ease of operation (33) | | | | | 32, 26, 12, 17 |
| Adaptability or versatility (35) | | 15, 16 | | | |

**Table 2. The Contradiction Matrix For Worsening And Improving Factor**

| 40 PRINCIPLE | DETAIL | DESCRIPTIONS |
|---|---|---|
| #17 | Another dimension | -Tilt or reorient the object, lay it on its side<br>-Use another side of a given area |
| #15 | Dynamics | -Divide an object into parts capable of movement relative to each other / Folding mechanism for better movement and adjustment. |
| #16 | Partial or excessive actions | - 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 |
| #35 | Parameter changes | -Change the degree of flexibility<br>-Reduce the parameter of the Child Restraint System frame without effecting the infant's comfort<br>-Change other parameters/(the change in seat pitch may give more comfort on the travelling companion) |
| #1 | Segmentation | -Divide an object into independent parts (independent main frame, independent fabric support, independent support system)<br>-Make the object easy to assemble or dissemble (Rapid release /easy to use when in need or when to store) |
| #11 | Beforehand cushioning | - Prepare emergency means beforehand to compensate for the relatively low reliability of an object (auto release the infant seat main frame from its base support for any situation e.i. Emergency, to stand up) |
| #32 | Color changes | - In order to improve observability of the components that are difficult to see, use colored or luminescent elements (there will be different luminescent color on the push/release button for easy observe/visibility) |
| #26 | Copying | - Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies |
| #12 | Equipotentiality | - If an object has to be raised or lowered, redesign the object's environment so the need to raise or lower is eliminated or performed by the environment (travelling companion may adjust their seat recline for max comfort) |
| #4 | Asymmetry | -Change the shape of the object to suit external asymmetry (ergonomic features) |

**Table 3.Summary Of The Finalize TRIZ 40 Principles Solutions**

Resulted from the output of the TRIZ methodology, the brainstorming session was constructed in beneficially mode. 3 designs were generated as conceptual design. Table 4 depicts the detail concepts.

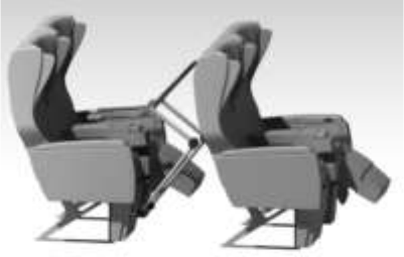
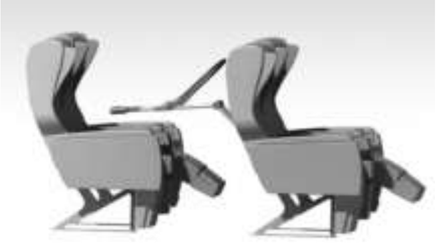
| Design | Conceptual Design | Descriptions |
|---|---|---|
| 1 |  | - The system is attached to the additional base structure, located/mounted under the passenger's main seat.<br>- Have several segmentations.<br>- The restraint device seat frame consists of several recline positions.<br>- The system consists of retractable support arms to hold and store the whole system. |
| 2 |  | - The system can be attached to the table tray arm mechanism.<br>- The restraint device seat frame can be inserted whenever needed, and pull out when not in use.<br>- There will be a minor modification on the table tray part.<br>- Have several segmentations.<br>- The restraint device seat frame consists of several recline positions. |
| 3 |  | - The system is attached to a strong support on the passenger seat armrest.<br>- The restraint device seat frame consists of several recline positions.<br>- Have several segmentations.<br>- The system is designed for take off/landing/emergency situation.<br>- Emergency release button for evacuation.<br>- The frame can be rotated according to the mother's need.<br>- Asymmetry design. |

**Table 4: The Description Of Conceptual Design Of An Ergonomic Child Restraint System For Infants In Aircraft**

## IV. FINAL CONCEPT EVALUATION

Later, the different conceptual design was evaluated based on the weighted objective method, which were primarily centered on the product requirement constructed earlier as shown in Table 6.

Each product requirement was fixed with the corresponding weight score to specify the importance of each requirement. The relative weight score of product requirement are strength (0.2), reliable (0.1), performance (0.2), safety (0.2), size (0.1), materials (0.05), design (0.05), weight (0.05) and cost (0.05).

During the evaluation session, each design concept was rated with a score (S) of 5 point scale. Each design concept was then rated by the industrial personnel based on the level of importance of the given requirement. The highest point of 5 specifies the product requirement for the specific concept is significant, while, the lowest point shows it is insignificant. Later, each given point is multiplied by the weight to get the relative value (V). Every value of the design concept is summed up to get the total value of each design concept. The total value of each concept was compared and the highest ranking of total value is selected for the final design. Table 5 of the Weighted Objective Evaluation Method shows that the design 3 was selected as the best concept that fulfilled the product requirement specification with a total value of 3.95. Design 3 was selected because it was almost fulfill the requirement of comfort, convenience and usability without neglecting the safety aspect of the ergonomic Child Restraint System for infants in the aircraft.

| | | | **Concept 1** | | **Concept 2** | | **Concept 3** | |
|---|---|---|---|---|---|---|---|---|
| **No.** | **Element** | **Weight** | **S** | **V** | **S** | **V** | **S** | **V** |
| 1 | Strength | 0.2 | 3 | 0.6 | 2 | 0.4 | 4 | 0.8 |
| 2 | Reliable | 0.1 | 3 | 0.3 | 2 | 0.2 | 4 | 0.4 |
| 3 | Performance | 0.2 | 3 | 0.6 | 2 | 0.4 | 4 | 0.8 |
| 4 | Safety | 0.2 | 2 | 0.4 | 2 | 0.4 | 4 | 0.8 |
| 5 | Size | 0.1 | 3 | 0.3 | 4 | 0.4 | 4 | 0.4 |
| 6 | Materials | 0.05 | 3 | 0.15 | 3 | 0.15 | 4 | 0.2 |
| 7 | Design | 0.05 | 2 | 0.1 | 4 | 0.2 | 4 | 0.2 |
| 8 | Weight | 0.05 | 3 | 0.15 | 4 | 0.2 | 4 | 0.2 |
| 9 | Cost | 0.05 | 3 | 0.15 | 3 | 0.15 | 3 | 0.15 |
| | Total Value | | | 2.75 | | 2.5 | | **3.95** |

**Table 5. Weighted Objective Evaluation Of An Ergonomic Child Restraint System For Infants In Aircraft**

## V. CONCLUSION

Three conceptual designs were developed with the Total Design approach as a guideline. The TRIZ methodology was implemented in the early conceptual design stage to develop innovative solutions for the conceptual idea. After the development of the conceptual design, the Weighted Objective Evaluation Method was used to recognize the most appropriate design of the Ergonomic Child Restraint System for Infants in the aircraft. Concept 3 is chosen as the best design that fulfilled both the product requirement and the final solutions on the TRIZ methodology. The design specification on the Concept 3 shown that, this design would benefit the end users; specially refers to infants and their traveling companion. Without neglecting the safety aspect, this design could improve the comfort level on parents and infants, as well as other passengers. This design also may possibly mitigate the convenience and usability issue occurs in current Automotive Child Restraint System used in the aircraft.

By adapting the new mechanism on the system that utilize the existing space in front of the adult passengers using the armrest as the support, this new system can be used in several conditions such as takeoff, landing and in any emergency situation. This design will be used in analysis and prototyping stage for further validation and study.

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