Design and analysis ergonomic adjustable baby chair

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Abstract. Baby chairs are important equipment in the early stages of child care. An ergonomic, comfortable, and safe baby chair is the most important point that is expected by a customer. An ergonomic and safety baby chair will provide better comfort for the baby since the higher need for affection and emotional bonds. The research aimed to investigate and develop an ergonomic baby chairs design with considering comfort and regulatory safety standards. The initial step was product design scoring based on customer voice using simple decision matrices. Optimization of the structure material selection parameters was carried out by using a numerical simulator based on the factor of safety. The research shows that a baby chair need to have safety features such as castors with brake, 5-points restrain system, adjustable or recline seat, detachable tray. Durability features are also important, such as high tensile strength, wear and impact-resistant material, and lightweight aluminium structure. As a result, a hollow aluminium pipe with a diameter of 26 mm for the chair structure is the most economic choice with a factor of safety 4.8.

Keywords: baby chair, comfortable baby chair, safety baby chair

1. Introduction

A baby chair is an equipment that is needed in the early stages of child care that not only needs to be focused on its functions but must also provide comfort and safety to the baby. Products that meet these two criteria will add value view of consumers and make it a superior product compared to competitors. In product design related to humans, anthropometry is very important because it can be considered as the basis of ergonomics [1].

To make a baby chair comfortable needs to be guided by the use of anthropometry data to fulfil its function and purpose. Therefore, anthropometric measurement data is needed to help achieve comfort levels [2]. Anthropometry also be further defined as studies relating to body dimensions such as body size, shape, and strength. Currently a baby chair in terms of design is still less ergonomic so it makes the baby uncomfortable.

The safety factor is one of the problems of baby chairs on the market and one of the contributors to the high level of children injured. Powell [4] states that the annual injury rate in children under 3 reaches 53 per 10,000 children. Data from the National Electronic Injury Surveillance shows that around 402,479 cases of injuries in groups of children under 3 years from 2003-2010 were related to baby chairs [3]. Furthermore, additional data from another study also stated that there were about 40,650 cases of injury in emergency room units in hospitals the United States related to seats in the age group of children under 3 years in the period 1994-1998 [4].
Due to the number of cases of children injured caused by product design unsafe and less comfort, thus needing a safer design by providing a safety strap to prevent the baby doesn't fall and adding comfort features on the backrest, armrests, and seat. The comfort features that need to be given to the product design by addition of foam and fine fabrics. The basis of adding these features is supported by an empirical study conducted by C. Salvador [5] that states that children want the comfort of a chair with additional pads.

Product development is needed to provide variations and additional features needed to create a safe and ergonomic baby chair to prevent the baby from getting injured. The majority of baby chair in the market only focuses on one of the criteria; safety or comfort. Therefore, this research aims to investigate and develop an ergonomic baby chairs design with considering both comfort and safety aspects within the regulatory safety standards.

2. Materials and methods
The product design has several steps. The initial step is simple Quality Function Deployment analysis based on consumer voice. Second step is material selection. Third step is designing the baby chair based on Australian standard AS 4684-2009 and Malaysian baby anthropometry. The last step is optimization of the structure material selection parameters was carried out by using a numerical simulator based on the factor of safety. Figure 1 shows the detail of research steps in order to carry out the problem.

![Figure 1. Research Steps](image)

Quality Function Deployment is a consumer-oriented approach to product innovation. It guides designer teams through the conceptualization, creation, and realization process of new products. The voice of the consumer is getting from in a variety of ways, such as interviews, market surveys, focus groups, customer specifications, direct discussion, field reports, etc. [8]. The most important in product design to consider consumer needs and translating into product specification, collection consumer voices is a step to get the initial concept. In the selection of technical parameters that correlate with consumer's needs using simple decision matrices by scoring. The result show as presented in Table 1.
Table 1. Product Design Scoring

| Technical parameter | Weight (point) | Harness / strap | Casters with brake | High tensile plastic | Adjustable & recline | Detachable | Fabric / foam | Weight | Size | Shape | Wear & impact resistance |
|---------------------|----------------|----------------|--------------------|----------------------|-----------------------|------------|--------------|--------|------|-------|-------------------------|
| Safety              | 5              | +              | #                  | +                    | #                     |            |              |        |      |       |                         |
| Ergonomic design    | 3              | +              | +                  | #                    |                       |            |              |        |      |       |                         |
| Comfortable to use  |                |                |                    |                      |                       |            |              |        |      |       |                         |
| Study & durable     | 3              | +              | +                  | #                    |                       |            |              |        |      |       |                         |
| Not easy broken     |                |                |                    |                      |                       |            |              |        |      |       |                         |
| Multifunction       | 3              | +              | +                  | #                    |                       |            |              |        |      |       |                         |
| High chair, booster, stroller | 3 | +              | +                  | #                    |                       |            |              |        |      |       |                         |
| Feature             | 1              | #              | +                  |                       |                       |            |              |        |      |       |                         |
| Light, fold up      |                |                |                    |                      |                       |            |              |        |      |       |                         |
| Easy to clean       | 1              |                |                    |                      |                       |            |              |        |      |       |                         |
| Total Score         | 50             | 55             | 80                 | 60                   | 60                    | 40        | 30           | 10     | 15   | 45    |                         |

Based on the Table 1, a large until the medium score (80-30) will be applied to the product specification of the baby chair. From this selection criteria show items related to safety, ergonomic, and durability were concerned with baby chair product design.

In this design, some materials used like a Polyoxymethylene (POM) which has a high tensile strength, low friction processing plastic, outstanding wear properties in both wet and dry environments. POM is one of the materials that usually used for complicated applications because of its tight tolerances. Another material polycarbonate (PC) is tough, plastic material with outstanding strength, stiffness, and impact resistance. Moreover, nylon is a type of material that usually used to replace wheels, bushings, and metal bearings, and eliminate the use of external lubrication because of its durability and its superior bearing. Furthermore, this material can reduce weight, minimize operating noise, and decrease wear on mating parts. Besides, metal alloy (Aluminium & steel) used for chair structure and also used for joint systems, screws, nuts, bolts, rivets. Fabric (polyester, foam, cellulose) materials usually used for manufacturing baby chairs that require free of hazardous materials that may harm both the occupant and the environment.

Material selection is important to make sure products have good quality, uncomplicated to produce in manufacturing, and must consider economic aspects. Definitely standards related baby chairs are accommodated when selecting material and product design.

This product refers to Australian standard AS 4684-2009 when creating baby chair product design, there are several items implemented such as a chair for a baby up to 3 years of old, safety restraint system 5-point or a full-body harness for maximum prevent baby fall from the chair, at least two have brake when using 4 castors to avoid sloping floor. Stability means chair must not tip over when pulled forward, backward and sideways by a specified force, the purpose of this requirement is to test the chair's resistance to falling over if an occupant leans forward, pushes off a nearby surface, or the chair is otherwise pushed [7].

Based on anthropometry measurement height and weight of Malaysian children from birth to 6 years old [6] shown in table 2, the maximum chair load is set up to 21 kg for babies 3 years old. Table 2 lists the descriptive statistic from the previous study.
Table 2. Descriptive Statistics (means ± standard deviations) of Height and Weight for Studied Subjects from Birth to 6 Years Old (n=15474)

| Gender       | Age (years) | Number of subjects | Height (cm) (Mean ± SD) | Weight (kg) (Mean ± SD) |
|--------------|-------------|---------------------|-------------------------|-------------------------|
| Boys (n=7882) | At birth    | 38                  | 50.05 ± 4.41            | 3.06 ± 0.47             |
|              | 0.5         | 3729                | 60.27 ± 6.12            | 5.75 ± 1.54             |
|              | 1.0         | 1625                | 73.53 ± 4.20            | 8.76 ± 1.25             |
|              | 1.5         | 577                 | 78.42 ± 4.87            | 9.62 ± 1.45             |
|              | 2.0         | 499                 | 85.74 ± 5.42            | 11.13 ± 1.66            |
|              | 2.5         | 320                 | 89.30 ± 4.97            | 11.74 ± 1.87            |
|              | 3.0         | 317                 | 94.43 ± 5.59            | 13.24 ± 2.56            |
|              | 3.5         | 221                 | 97.26 ± 7.67            | 13.71 ± 2.71            |
|              | 4.0         | 216                 | 101.45 ± 6.59           | 15.13 ± 3.34            |
|              | 4.5         | 130                 | 104.02 ± 5.85           | 15.37 ± 3.43            |
|              | 5.0         | 78                  | 107.90 ± 6.72           | 17.85 ± 4.86            |
|              | 5.5         | 83                  | 109.86 ± 7.94           | 18.35 ± 4.57            |
|              | 6.0         | 49                  | 113.98 ± 7.37           | 20.33 ± 4.82            |
| Girls (n=7592) | At birth    | 52                  | 50.01 ± 2.60            | 3.09 ± 0.46             |
|              | 0.5         | 3680                | 59.14 ± 5.88            | 5.36 ± 1.39             |
|              | 1.0         | 1482                | 72.32 ± 4.03            | 8.21 ± 1.09             |
|              | 1.5         | 553                 | 77.85 ± 5.22            | 9.21 ± 1.44             |
|              | 2.0         | 495                 | 84.30 ± 5.05            | 10.57 ± 1.58            |
|              | 2.5         | 306                 | 88.20 ± 4.34            | 11.33 ± 1.81            |
|              | 3.0         | 294                 | 93.45 ± 5.80            | 12.87 ± 2.57            |
|              | 3.5         | 224                 | 97.22 ± 5.72            | 13.69 ± 2.88            |
|              | 4.0         | 167                 | 101.18 ± 5.67           | 14.94 ± 2.85            |
|              | 4.5         | 111                 | 104.11 ± 5.63           | 15.39 ± 3.16            |
|              | 5.0         | 79                  | 107.26 ± 6.94           | 16.65 ± 3.49            |
|              | 5.5         | 70                  | 111.73 ± 8.09           | 18.62 ± 3.70            |
|              | 6.0         | 79                  | 113.40 ± 7.35           | 18.67 ± 3.67            |

Note: Adapted from Malaysian growth centiles for children under six years old by Bong et al [6].

3. Results and discussions
The result of product design based on consumer needs, created with CAD and 3D model software is shown in Figure 2. The baby chair presented with safety features are castors with brake, and restrain system 5-point, ergonomic features are adjustable or recline seat, detachable tray, and foam wrapping by fabric. Durability features are high tensile, wear and impact-resistant material, and lightweight aluminium structure.

![Figure 2. 3D Model Baby Chair](image)

Simulation static analysis was conducted by SolidWorks, and found the maximum stress this product is $4.182 \times 10^6$ N/m$^2$, and the maximum displacement $7.426 \times 10^{-1}$ mm. The Factor of safety
(FOS) is 6.8. The load used in this analysis is 250 N, spread out 4 positions on the chair as shown in Figure 3. In addition, the product shows feasible to use POM & metal alloy (solid aluminium rod diameter 25 mm) but the factor of safety value too high that shows excessive strength. The FOS needs to be reduced related considering the cost. Further simulation needed to find the most economic structure material.

![Figure 3. Maximum Stress Simulation](image)

Structure material chosen is aluminium based material, because it needs to keep lightweight and durable. In selection kind of aluminium to make a lower-cost, a systematic approach needs to select the suitable aluminium. First, it is required to consider criteria the related factor of safety (FOS) due to mandatory items, process manufacture impact for production cost & consumer need about lightweight. Determine aluminium type base on the size that is prevalent in the worldwide market and suitable with baby chair CAD design, the best selection is the aluminium hollow pipe diameter of 26 and 33 mm. Then the choices are narrowed down by the method of elimination, the highest score selected for the design. Score define by the strength of the correlation between material and criteria, score calculation by multiply criteria weight, and correlation value. Table 3 shows simple matrices scoring for baby chair structure material.

**Table 3. Structure Material Scoring**

| Criteria               | Weight (point) | Material | A | B | C |
|------------------------|----------------|----------|---|---|---|
| Factor of safety       | 5              | O        | X | O | A |
| Easy to manufacturing  | 4              | X        | O | O | O |
| Lightweight            | 4              | X        | O | O | A |
| Cost                   | 3              | X        | O | O | A |
| Total Score            | 68             | 102      | 98 |

A : Solid Aluminium rod Ø 25 mm  
B : Aluminium hollow pipe Ø 26 mm, thickness 2.87 mm  
C : Aluminium hollow pipe Ø 33 mm, thickness 3.38 mm

Correlation:  
Strong (7)  
Moderate (5)  
Weak (3)
The result of the baby chair structure is an aluminium hollow pipe diameter of 26 mm selected due to highest score rank. This selection will make a lower cost than before, more lightweight, but still keep factor of safety (FOS) acceptable. The fact will show in Table 4.

**Table 4. Factor of Safety Related Structure Material**

| Material type                      | Mass (gram) | 100 N | 150 N | 200 N | 250 N |
|-----------------------------------|-------------|-------|-------|-------|-------|
| Solid Aluminium rod # dia 25 mm   | 4800        | 17.0  | 11.0  | 8.8   | 6.8   |
| Aluminium Hollow pipe # dia 26 mm | 3030        | 12.0  | 8.0   | 6.0   | 4.8   |
| Aluminium Hollow pipe # dia 33 mm | 4288        | 18.0  | 12.0  | 8.8   | 7.1   |

The benchmark result for each material showed (Table 4), the factor of safety (FOS) achieved 4.8 with a maximum load of 250 N for aluminium hollow pipe diameter 26 mm. The total pipe structure weight 3030 grams. It is lighter than the others. These results meet all the criteria specified above.

![Factor of Safety Simulation](image)

**Figure 4. Factor of Safety Simulation**

The value of FOS 4.8 was quite enough compared to the normal set value (Figure 4). Usually, the FOS set value around 1.5 - 2.0 for the economical aspect. For safety aspect value 4.8 is an advantage of baby chair products, and more resistant to variations in load.
Figure 5 shows the resulting load versus FOS, increasing load will decrease the FOS for all material. It means product specification for maximum load or weight capacity can adjust higher than before for FOS value over 2.0. In other words, this product can be used by babies over 3 years old. This is also one of the product advantages that can be offered. So, the most economical structure material is an aluminium hollow pipe with a diameter of 26 mm.

4. Conclusion
The paper presents baby chairs that meet safety, ergonomic, and durability design, selection criteria based on scoring concepts which concern consumer expectation. From this screening method, the material is chosen with specified properties that meet all criteria requirement. Product design refers to Australian Standard AS 4684-2009. Anthropometric data used is particularly suitable for Indonesian babies. The maximum load is confirmed after passing a static load analysis on the chair model. The factor of safety results more than the expectation because of our concern for safety. Finally, this product design can adapt to commercial products that meet all requirements of the consumer.

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