Design of an Infant Incubator for Cost Reduction and Improved Usability for Indian Health Care Centers

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Abstract

India is 2nd most populated country in the world and the birth rate is very high. According to market survey’s, in India every year 26 million infants are born. Out of 26 million 2.6 Million infants are prematurely born with low birth weight (lbw). These LBW infants are generally kept in chambers referred to as “incubators” which are housings with controlled temperature and humidity. Since from the time incubators are introduced in the hospitals, the survival rate of premature babies have significantly raised up. Thus incubators are highly important device in Intensive Care Unit’s (ICU) at hospitals. This study is to design an Infant incubator with improved usability targeting low budget hospitals. To solve the problem, various data is collected, referred and documented from various websites, books and journals. Product study is carried out at a local hospital. Market study is carried to know about the available models. Leading model in the market is selected as benchmark product. Based on literature review, product study, market study and other analytical design techniques, Product design specification (PDS) is generated. Based on the PDS, five concepts are developed. Final concept is selected based on Pugh’s method of concept selection. From the study the finalized concept has superior usability features compared to that in the present market.

Key Words: Infant Incubator, Low Budget Hospitals, Cost Reduction

Nomenclature

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICU</td>
<td>Intensive Care Unit</td>
</tr>
<tr>
<td>LED</td>
<td>Light emitting Diode</td>
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Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>QFD</td>
<td>Quality Function Deployment</td>
</tr>
<tr>
<td>PDS</td>
<td>Product Design Specifications</td>
</tr>
</tbody>
</table>

1. INTRODUCTION

Over the recent years, technology in medical field has tremendously advanced giving birth to modern devices which are generally expensive. However in developing country like India, since the economy is low compared to that of developed countries, the cost of the medical devices has to be kept low.

Preliminary study says, reason for the underutilization are, The complexity of design of the standard incubators, standard available incubators are difficult to maintain and the staff find the incubators too complicated to use and only Special trained technicians are capable of repairing the incubators and they are not readily available. Further a large portion of low weight infants die in transit to hospitals since there is no adequate means to transport these infants in a temperature controlled environment. There are small players in the market, who cater to the low budget hospitals, but they are proven to be bit expensive and often the designs are ergonomically poor. Therefore there is a need of incubator which caters the need of low budget hospitals thereby saving millions of premature baby’s life by ensuring them the safety and reliability. The goal of this study is to come up with a cost effective solution with improved usability.

2. LITERATURE REVIEW

Literature review was done to know the background of the product, understand the product advancement, Product introduction, classes in the area of infant care and to find the gap opportunity.

2.1 Background

First Infant incubator was invented in the year 1860. Tanier, a Frenchman, observed premature babies dying within couple of days after birth. He realized that the world needed a way to prevent babies from death. Infant Incubators are now used in all hospitals in the world.

2.2 Product advancement

Since 1860 to 2012, it has been 152 years from now that the incubators were invented. Over this period lot of advancements have taken place. In early 1860’s, the incubators helped infants from saving their lives. Slowly over the time, it was found that most of the babies were dying due to lack of basic safety features. From then safety of the infants was a major concern. To address the safety issue, incubators were revisited, redesigned to accommodate various safety features. Currently the incubators are well sophisticated and reliable.

2.3 Product Class

According to the literature survey, the three major classes of Incubators are:
- High technology incubators
- Mid technology incubators
- Low technology incubators

A vast review is carried out on the incubator class and technology in the coming section. Due comparison is
also made to understand the difference between various classes and to know the advantages, disadvantages and features associated with it.

Figure 1 is pictures taken from Ramaiah hospital during Product study.

- The device works on the principle of Forced convection
- A fan enables the air to suck from the environment and discharge it into the chamber
- Induction heating coil is the source of the heat which warms the air. The warm air is circulated in the chamber
- Baby gets continuous warm air
- The temperature is constantly measured by two probes. One probe measures the temperature of the chamber while the other measures the temperature of the body of the baby.
- The basic and crude method to humidify the air is by allowing the water in the path of the flowing air.

3. DATA COLLECTION

3.1 Market Study

The market study plays a vital role in the product design process as it helps to understand the different types of product and various competitors available in market. This was carried out by direct interaction with the various dealers, manufacturers available in the market as well as study through internet. There are various infant incubators produced by various manufacturers in the market like GE, Cello, Dreager and various other local manufacturers. These incubators are available in wide range of features and are designed for various market classes. Referring to the Figure 1, 26million babies are born every year. Ten percent out of 26million babies are born with low weight 1.8M babies need incubators in India alone. Thus it is evident that Infant incubators play a major role in saving the baby. Since India is a developing country, middle class families contribute most of the population and design has to be made such a way that cost should not become a matter of non-procurement. [3]

3.2 User Study

3.2.1 Introduction

The role of User study is vital while designing an Incubator and to develop newer concepts as per the customer requirements. These customer requirements are found out by Gembba or user study and by a set of questions; this would help in finding out user interactive solution

3.2.2 Gembba study

Gembba study was been conducted to identify the basic requirements, essentialities, aspirations and expectations while the product is in use by the end user. Initially many hospitals, local health care centres were visited (Figure 2), in order to understand how they use the product. Ten Nurses, four doctors and compounders were interviewed about their perceptions of the difficulties caused while using the product.

Fig. 2 User Research

From GEMBA study, many usability issues are identified from the existing incubator. Refer figure 3, They are listed in the next page.

Height adjustment:
In the existing product, there is no provision for height adjustment, forcing the user to use as it is designed. It is built for 95th percentile; a user who belongs to 5th percentile cannot use the product. Refer to figure 3.

![Fig. 3 Usability issues](image)

**Monitor:** Difficult to read the numbers since the display and text below the display is quite small. There are many LED lights creating ambiguity.

**Handle:** Handle is essential to move the incubator from one place to another. In Most of the existing products handles are not provided. Refer fig 3

**Port hole:** Diameter of the port hole is not sufficient. Based on the ergonomic factors, the diameter should be 100mm. Refer Fig 3

**Shelves:** Most of the incubators are accommodated with open shelves to store required medicines. But during transportation, medicines often fall down.

A set of questions had been prepared and the user feedback was received from health staff and patients, the answers given by them have been noted and while the same is considered while designing the product. Majority of the answers were almost similar. The graph is shown in figure 4.

![Fig. 4 Customer interaction](image)

### 3.2.4 Customer voice

- High cost
- Lack of modularity
- More number of parts creating confusion
- Handling is difficult
- Inter hospital transportability is not up to the mark
- Not possible to monitor the baby in sitting position
- Low cost incubators - No vertical height adjustment

In order to design the incubator according to customer needs, customer voice which is derived from the user questionnaire has been converted into technical voice.

**Table. 2 Customer voice to technical voice**

<table>
<thead>
<tr>
<th>S. No</th>
<th>Customer voice</th>
<th>Technical voice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cost</td>
<td>Reduce part count/Manufacturing options</td>
</tr>
<tr>
<td>2</td>
<td>Modular</td>
<td>Design for assembly</td>
</tr>
<tr>
<td>3</td>
<td>Handling</td>
<td>Ergonomic design</td>
</tr>
<tr>
<td>4</td>
<td>Transparency</td>
<td>Castor wheels handle</td>
</tr>
<tr>
<td>5</td>
<td>Durability</td>
<td>Material</td>
</tr>
</tbody>
</table>

### 3.2.6 Data obtained from user and product study

The concepts are to be further designed with considering the points observed from the Gemba [4] and product study. The vital points to be considered while designing the product are as follows,

- Affordable price
- Modularity, Ease of handling
- Reliability, durability

### 3.3 QFD Matrix

The QFD matrix is prepared from the data obtained from the user study. The customer voice is converted into technical voice to obtain the features of the concepts. Table 4

<table>
<thead>
<tr>
<th>Customer Requirement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating comfort</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ease of access</td>
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<td>0</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
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<td>Transportability</td>
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<tr>
<td>Storage need</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple and Host Monitor</td>
<td>3.5</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Easy maintenance</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Reduce part count</td>
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<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Summary of QFD: Top priority is given for the features, least is for the weight.

### 3.4 Final Product Design Specification

The final product design specifications are fixed by obtaining the major factors from the QFD. Those are the factors to be considered while designing the product.

Table. 4 shows Final PDS for the incubator which includes various features with quantified specifications.
Table 4 Final product design specification

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Factors</th>
<th>Final Product Design Specification</th>
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<tr>
<td>1</td>
<td>Price</td>
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</tr>
<tr>
<td>2</td>
<td>Canopy width</td>
<td>900 mm</td>
</tr>
<tr>
<td>3</td>
<td>Canopy height</td>
<td>600 mm</td>
</tr>
<tr>
<td>4</td>
<td>Canopy depth</td>
<td>600 mm</td>
</tr>
<tr>
<td>5</td>
<td>Mattress size</td>
<td>600 mm (w) X 600 mm (L)</td>
</tr>
<tr>
<td>6</td>
<td>Height adjustment Range</td>
<td>300 mm</td>
</tr>
<tr>
<td>7</td>
<td>Weight</td>
<td>80 kg</td>
</tr>
<tr>
<td>8</td>
<td>Height mattress to hood</td>
<td>350 mm</td>
</tr>
</tbody>
</table>

Access
1. Doors: 1
2. Wall: Single
3. Hand ports: 4
4. Tray withdrawal: Front

Controller
1. Air Temperature: 20 deg C to 30 deg C
2. Baby Temperature: 34 deg C to 38 deg C
3. Heater power output: 450 Watts

Alerts
1. Main power failure: Yes
2. High air Temperature: Yes
3. Skin temperature: Yes

General Specifications
1. Humidity capacity: 50% to 70%

5. CONCEPT GENERATION & SELECTION

5.1 Introduction
Generation of Ideas and concepts is done during this stage. Further to this process, Final concept is selected based on Pugh’s method.

5.2 Idea Generation
The center of the map is the subject “Infant incubator”. It is branched out to 5 main aspects related to the Incubator. These five sub branches are further branched out into minor characteristics, features and attributes.

Figure 5 shows mind mapping for Infant incubator with various sub branches and branches. This was done to proceed further with conceptualizing the generated idea. Outcome of mind mapping tree is taken as input to generate concepts. [5]

5.3 Visual Theme Board

Figure 6 shows visual theme board for Infant incubator. Derived from the mood board, images of incubator is collected to convey the target mood. Based on the theme of medical device, the infant incubator styling is taken care at the concept generation stage.

5.4 Concept Generation

5.4.1 Introduction
Concept generation for incubator is evolved from the ideas that are generated. Basically ideas generated from mind mapping method are wage but concepts are workable solutions. During this stage, various concepts have been generated for the stated problems.

5.4.2 Ergonomics for Infant incubators
Anthropometric considerations are very important for designing any medical product. Incubator concepts have been generated with Indian anthropometric data.
5.4.3 Concept-1

- State of the art Canopy design [6]
- Vertical adjustment is achieved by lifting the hood and locking at desired height
- Ergonomic monitor
- Simpler frame design with 2mm thick sheet metal
- Estimated cost – Rs 38000
- Provision for storage racks

5.4.4 Concept-2

- Improved aesthetics
- Fixed working height
- Storage racks to store medicines
- Optional storage racks
- Bed tilting up to 10 deg.
- Estimated cost Rs, 55000
- Frame – 2mm thick cold rolled sheet

5.4.5 Concept-3

Concept 3 is shown in figure 9, the features of this concept is listed below:

- Conventional design
- Separate handle for opening/closing the canopy
- Bed tilt mechanism
- Frame – 2mm thick Cold rolled sheet
- Rigid Base member.
- Estimated cost – Rs 42000

This shape is similar to conventional incubators; bed tilt mechanism is incorporated for ease of access for doctors while operating the baby

5.4.5 Concept-4

Fourth concept is shown in figure 10. This concept is developed for low cost with minimum features. Other product features are as follows:

- Simpler design
- Minimum part count
- Rectangular Tubes – Light weight, readily available
- Working height is fixed.
- Estimated cost – Rs 27000
Concept four is less expensive compared to all other concepts, but has minimum safety features.

### 5.4.5 Concept-5

Concept 11 shown in figure 11 is conceptualised entirely different from the existing incubators. Features:

- Vertical height adjustment: Able to adjust the working height without any external means.
- Simpler frame design – cast iron and thermoformed plastic
- State of the art canopy design [6]
- Ergonomic monitor
- Reduced part count
- Conventional design is replaced with new handle design.
- Curvy shape
- Estimated Cost – Rs, 40000

All above characteristics contribute towards cost reduction and increased usability.

### 5.5 Concept selection

Final concept is selected using Pugh’s method. Refer Table 5

<table>
<thead>
<tr>
<th>S</th>
<th>= Same as the datum</th>
<th>+</th>
<th>= Superior as the datum</th>
<th>-</th>
<th>= Worse than the datum</th>
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<tr>
<td>1</td>
<td>Ergonomic design</td>
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<td>5</td>
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<td>2</td>
<td>Features</td>
<td>-</td>
<td>5</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Cost</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Max. user capacity</td>
<td>D</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>5</td>
<td>Thermostat</td>
<td>A</td>
<td>-</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Height adjustment</td>
<td>T</td>
<td>-</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Technology</td>
<td>U</td>
<td>5</td>
<td>5</td>
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<tr>
<td>8</td>
<td>Conveiling design</td>
<td>M</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>Press and safety</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>10</td>
<td>Material</td>
<td>-</td>
<td>5</td>
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<td>11</td>
<td>Ambience</td>
<td>-</td>
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<tr>
<td>12</td>
<td>Quality</td>
<td>5</td>
<td>-</td>
<td>5</td>
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<tr>
<td>13</td>
<td>Noise</td>
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<td>6</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

5 generated concepts have been compared with GE incubator, and ranking has been given. Out of 5 concepts, 1st concept has bagged superior ratings and is selected as final concept.

**Table. 5 Pugh’s method of concept selection**

### 6. DETAIL DESIGN

#### 6.1 Introduction

Detailing of final selected concept is done before appearance model preparation. Part and assembly drawing, detail dimensioning was created for making appearance model. Detailing and dimensioning is done to achieve full scale model so that it is similar to 3d model.

**Fig. 12 Final concept**

The incubator is divided into three Sub-assemblies shown in figure 12

- Enclosure assembly
- Frame assembly
- Monitor assembly

#### 6.2 Enclosure Assembly

Enclosure assembly is shown in figure 13

**Fig. 13 Enclosure assembly**

Enclosure assembly consists of following parts

- Enclosure bassinet assembly
- Hood
- Mattress tray
- Mattress
- Handle

#### 6.3 Enclosure Bassinet

**Fig. 14 Bassinet**
Figure 14 shows various parts of incubator placed in the bassinet.

Features:
- Enclosure is a single piece mold construction.
- Material: Thermoformed styrene butadiene
- Parts are fixed on the enclosure with snap fit
- No fasteners added
- For maintenance, only Top cover needs to be removed.

6.4 Hood assembly

Figure 15 is hood assembly. Approach to achieve the objective is listed as follows:

Hood Material and its properties:
- Uline (polyethylene material). 17% less than plexi glass.
- Provides additional features such as UV protection
- This material being thin can be easily transported
- In a rectangular cross section, the air in the corners is useless, as it does not contribute to the convective process, but it is reverse in the case of semicircular cross section.

6.5 Frame assembly

Continuous monitoring is required while the baby is in the incubator. Due to that reason, concerned personnel needs to stand for a long time. However it is possible to sit beside the incubator on chair, but the baby will not be visible and the intent will be lost.

This new frame design is a noble approach allowing parents/health staff to monitor the baby continuously by adjusting the height such a way that the enclosure base rests on the lap there by bringing up intact value of relationship and care. Refer figure 16

Figure 17 shows Nurse monitoring the baby while in sitting position. The frame is tilted to 80 deg. According to Indian anthropometric data [7], the knee height is 567 mm from ground level and the design is also done accordingly.

Figure 18 shows Nurse monitoring the baby while in standing position. According to Indian anthropometric data [7], the Lower position height is 939 mm from ground level and the design is also done accordingly.

6.4.1 Unique idea behind frame design

Figure 19 shows new monitor design. Key features and advantages are listed below:
Unlike old design, the monitor is not embedded in the incubator frame.

Proper grouping of buttons based on looks.

Alignment of buttons for lining up the objects to organize and form groups.

**7. PROTOTYPES**

Appearance Prototype model is made for physical representation and to closely simulate the look of a real product. This model allows an individual to explore the size, and look of the product without simulating the exact function.

The appearance prototype is built using High impact poly styrene, hard foam board, Soft foam board, Polycarbonate, CRS sheet and other miscellaneous materials. Various tools were used for making the model. Some of them are: File-1set, Emery paper, plastic cutting scissors, Cutting blade, engineers square, steel rule, Marking pen, pencil etc.

![Fig. 20 Profile cutting and matching](image)

Finishing process was carried out using Sand paper, Putty, filling powder, primer and special paint used for medical applications. White and blue paints were sprayed for good aesthetics. Figure 20 shows profile cutting of High impact polystyrene for enclosure part (a), Frame strengthening using fabricated mild steel strip(b), profile forming of Frame arm(c) and form, function and fit test of lower part of frame.

![Fig. 21 Part formation](image)

After procuring required materials from market, material was cut to dimension according to the drawing. Few templates were created to achieve exact curves. Figure 20 shows finishing process carried out for the arm. Figure 21 shows enclosure part being cut. Post to cutting operation, a quick check was performed to test form, fit and function of the parts. Primarily, frame parts were assembled to form assembly as shown in figure 22. To achieve 2 positions of frame, to achieve 2 positions of the frame, plunger mechanism was worked out as shown in Figure 22.

![Fig 22 Prototype assembly](image)

**8. CONCLUSIONS**

The purpose of this study was to design an infant incubator for improved usability. This study helped to arrive at customer needs which were later converted into technical voice for the development of quality functional deployment (QFD), based on which final design specification (PDS) was listed.

Five different concepts were generated. Final concept is selected based on Pugh’s method of concept selection. From the study the finalized concept has superior usability features compared to that in the present market.

**9. REFERENCES**


