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Ergonomics product development of over bed table for bedridden patients

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ABSTRACT
The ergonomic design is very important parameter for many products. When designing a human control product, the ergonomics factors should be satisfied to make a product which will not harm the user. Considering ergonomic factors in the design process are really important. This paper presents a design methodology for developing an ergonomics product. The ultimate goal of this research is to design and to produce a new type of over bed table for bedridden patients. A survey has been conducted and the Quality Function Deployment (QFD) was developed. A virtual ergonomic analysis has been implemented in Jack SIEMEN® using virtual human models and anthropometric data.

KEYWORDS
QFD; conceptual design; ergonomics analysis and simulation; design for manufacturing

1. Introduction

The over bed tables are widely used in majority of hospitals around the world. Those are used to help disable or injured patience but the most of the available products does not meet the basic standards of ergonomics. We can see human operators facing long term problems such as repetitive task injuries after being engaged in operating certain machinery. Therefore the main aim of ergonomics is to help these operators or users by producing products which fit their capabilities so that none of the users will face any injuries when using them. In order to fit the job according to the person, measurements (Anthropometry) relevant to the human body are very important. Therefore when designing a product, according to the capabilities and limitations of the user, ergonomists mainly consider anthropometry so that the product can be designed without any flaws using the correct materials, dimensions, shape, weight and so on. The objective of ergonomics is to achieve the best possible match between a product and its users in the context of the work task to be performed. Human factors are involved in several steps of product life (design, manufacture, etc) and the capability to keep them into account effectively is a key point for a winning product on the market. Therefore many researchers have been focusing on the ergonomic factors of hospital bed, computer desk and mobile workstation for healthcare [2] [4] [7] [8] [10]. Ergonomics design and maintenance operation through virtual human models are studied in [3] [9].

Fig. 1 shows a flow chart for ergonomics product development of Over Bed Table. There are many activities to be carried out for the product development. They are comparing existing tables, identifying mechanisms, cost estimation, conducting survey, development of QFD and analyzing the anthropometric data for generating conceptual, parametric and assembly models. Structural model and virtual ergonomic models are implemented for manufacturing parts. In this paper we will discuss mainly the development of the Quality Function Development (QFD) and Virtual Ergonomic Analysis. This paper is organized as follows. Section 2 describes the details of the development of the Quality Function Deployment (QFD) and Ergonomics Analysis. Section 3 shows the results and discussions. Finally, Section 4 presents our conclusions.

2. Development of the quality function deployment (QFD) and ergonomics analysis

QFD is a tool for improving the development cycle and manufacturing products that better match customer needs [1]. QFD accomplishes these goals through the use of a design tool that is known as "House of Quality" (HOQ).

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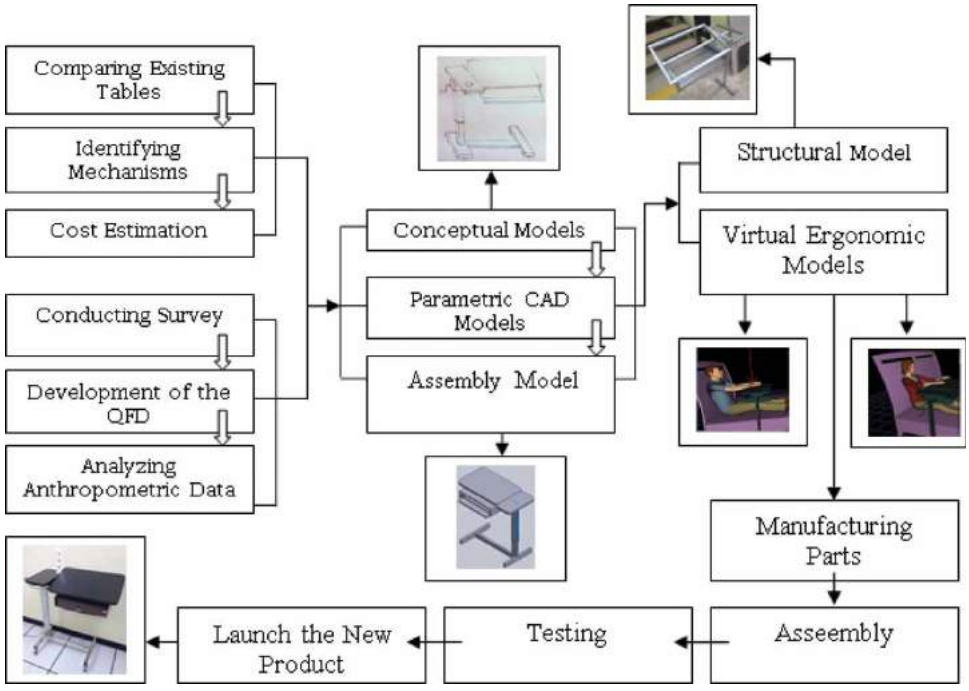

Figure 1. A flow chart for ergonomics product development of over bed table.

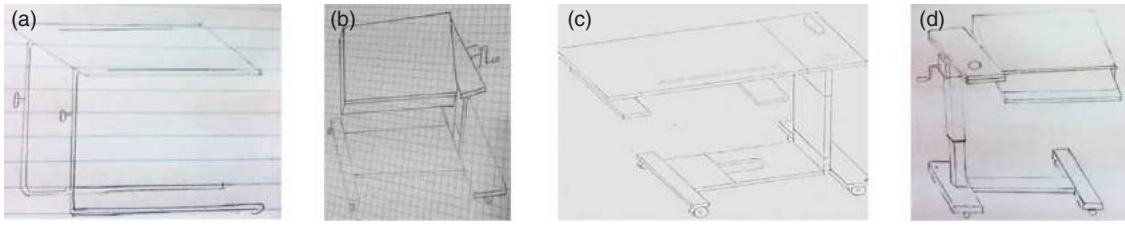

Figure 2. Conceptual Models: (a) Concept 1, (b) Concept 2, (c) Concept 3, and (d) Concept 4.

2.1. Concept generation

Authors, we would like to develop a new design of the over bed tables with our point of view on the exciting tables available in the market. Before coming up to a final conceptual model, we sketched out the several drawings with different ideas, identified the pros and cons of these sketches and finally we could decide the preliminary design model. Define the parameters and functions that are essential to include in the design stage. They are

– High adjustability
– Portability
– Ergonomic factors
– Drawer
– Movability
– Simplicity
– Tilting table top

After brainstorming sessions, our research team had drawn 4 or 5 designs separately with defined design parameters and functions, as shown in Fig. 2. Then we drew a final design which containing the most valuable ideas of each members. In the early moments of our project, the main focus of design was to make it simple, portability and height adjusting functions, shown in Fig 2 (a). Then the caster wheels were added to increase the portability and the table top height was adjusted by using a mechanical handle. In the last stages of conceptual design we included a drawer and many other minor features for our over bed table as shown in Fig 2 (d).

2.2. A survey

In attempting to meet the patients need, a survey was conducted about 20 patients in private sector hospital to determine the basic requirements and the current issues are faced by patients regarding over bed tables. Moreover the survey was used to determine factors in order to conduct a Quality function deployment (QFD). The survey dealt with narrower questions which are concentrating

on the customer requirements. The questions related to customer requirements were as follows,

– Design
– How well it works
– Height adjustability
– Table top inclination
– Size
– Ease of use
– Portability
– Cost
– Lamp
– Power supply
– Anti-sliding edges
– Storage space
– Impact on environment
– Material
– Mechanism

The main purpose of carrying out a survey is to understand the customer needs and identify the major difficulties that users are facing with the existing products in the market. The survey questionnaire are included the above factors and customers have to rate from 1-5 for each factor. The average data of each factor will be used as the data for the QFD. Survey results are shown in Fig. 3.

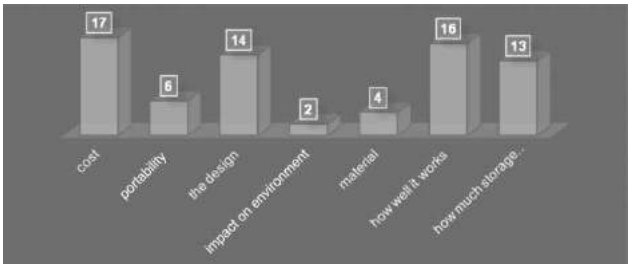

Figure 3. Survey results.

The outcome of survey depends on how analytical ability of survey. For data collection a sample size was calculated mainly. It was divided into two main categories: Probability samples and non-probability samples. Probability sampling is a method that sub-populations within a general population are recognized and included in the sample selected in a balanced way.

2.3. A development of QFD

The basic structure of a Quality Function Deployment is shown in Fig. 4. Customer requirements were identified through the survey that was carried out in the hospital together with 20 patients those who used over bed tables and the hospital staff who had quite a good

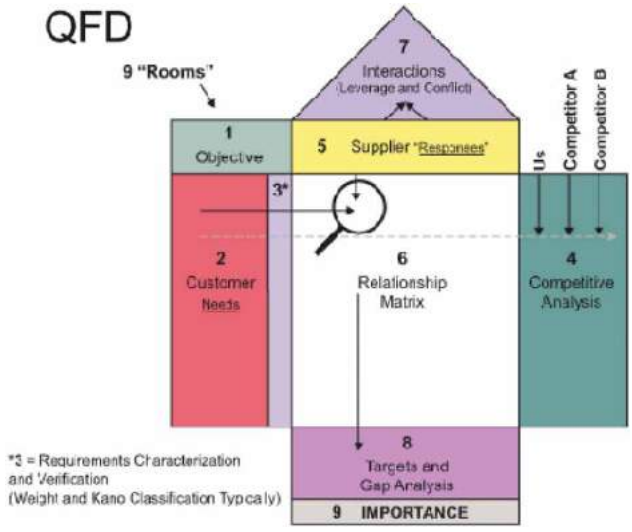

Figure 4. Basic structure of QFD [11].

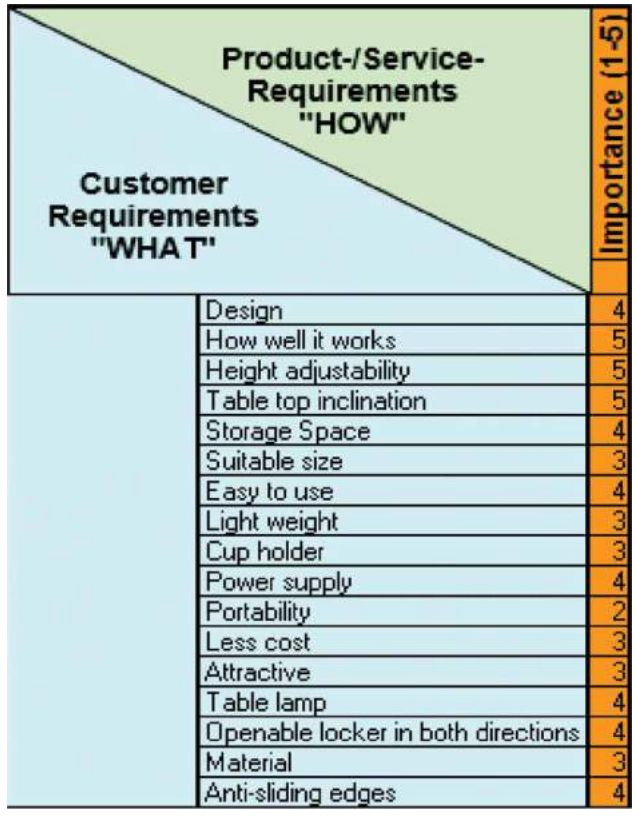

Figure 5. Customer requirements.

knowledge about this product. The customer graded for each requirement in a survey therefore the customer importance factor was tabulated. For example, all the customers were asked to grade (rate from 1–5) for the one of the customer requirements, design factor, that was included in the survey and the number from all the surveys were summed up and then the average importance

factor was calculated. In the same way, the average importance factor of other customer requirements was obtained, shown in Fig. 5.

The next step was to run the competitive analysis and it was done by comparing the new conceptual model with the exiting model in the hospital. The hospital staffs were asked orally and graded to compare our conceptual model with the existing model. After interview process, the average value of each customer requirement of two models were tabulated and compared.

Fig. 6 depicts the competitive analysis of our table with the existing table in the hospital. According to the customers, the conceptual model was ahead in most of the aspects. The grade for our table is denoted in square while the hospital table is shown in triangle.

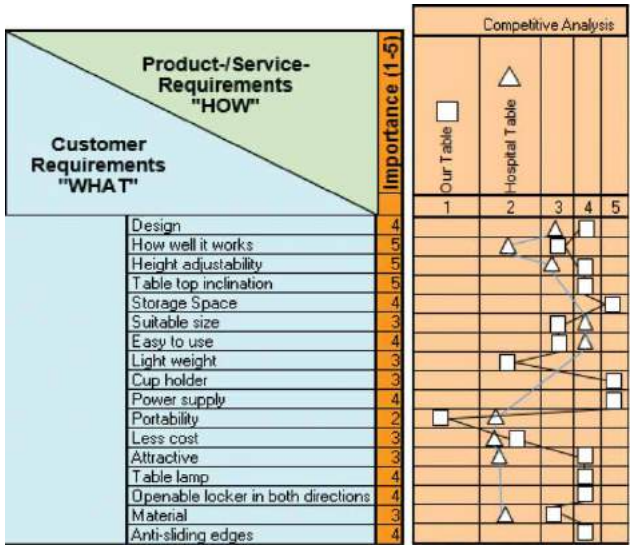

Figure 6. Competitive analysis.

After executing the competitive analysis, technical requirements are also known as the supplier responses which are taken into consider as important factors for the final design to build a high quality product. Basic requirements of the model were multi-functional, safe, stable, convenient, ergonomic, durable and reliable.

Fig. 7 clearly explains the technical requirements that were considered in the quality function deployment (QFD). Next step was to identify the relationship between the customer and technical requirements. This was done by using the technique of relationship matrix. Both customer and technical requirements were analyzed for the existing relationships. The relationship matrix was very important since it provided us with the necessary information in order to calculate the final absolute importance.

Fig. 8 shows the relationship matrix that was produced for the over bed table. Different symbols were assigned with different values. For an example the black color circle mentions that a high relationship was existed between the particular customer requirement and the technical requirement. Likewise all the possible relationships between the customer requirements and the technical requirements were identified. The next step was to analyze the direction of improvement of the QFD house as shown in Fig. 9. It could be enabled to identify the requirements should be increased or decreased. For example to identify the requirement of weight, it should be reduced the weight of the product so that the customer can handle it easily. We finally work towards the direction of improvement of each factor and it will help the product with a better quality at the end.

After that the roof of house of quality (Fig. 10) was drawn in order to identify the positive and negative correlations of the technical requirements. This particular section in the QFD is where the term House of Quality comes from since it makes the QFD look like a house with a roof. Though the correlation matrix consumes a very small amount of space in the House of Quality, this roof does a great help to the design engineers in the next phase of a comprehensive QFD project. A basic analysis was done as to how each of the technical requirements affects each other, whether in a positive manner or a negative manner. The main idea of the roof is to identify the negative correlations between technical requirements and to eliminate those physical contradictions.

Figure 7. Technical requirements.

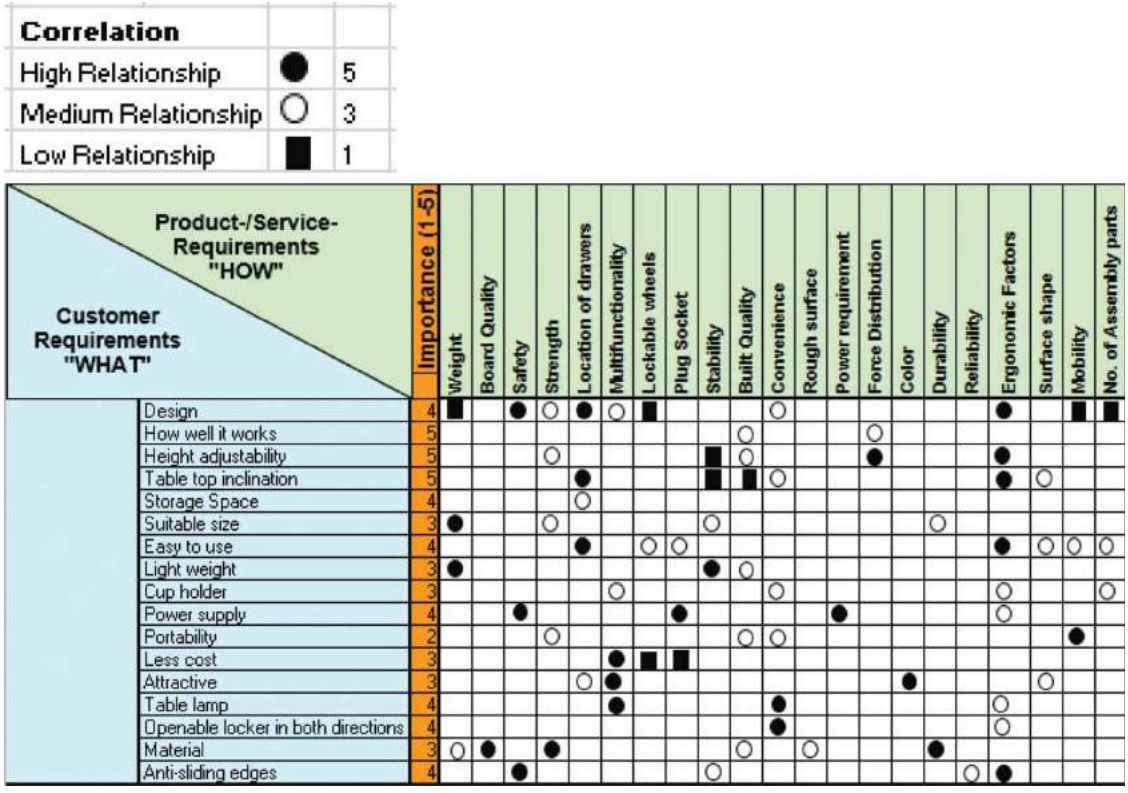

Figure 8. Relationship matrix.

Figure 9. Direction of improvement.

Next step was to benchmark (Fig. 11) our conceptual model with the existing table in the hospital. After doing the benchmarking, we were able to identify that our product was ahead of the existing table in many ways. Next step was to identify the goals (Fig. 12) of the table with respect to the technical requirements of our product.

Final step was to tabulate the absolute importance for each of the factors. This was done by multiplying the values of the relationship matrix columns by the importance factor and summing it up for each technical requirement. By doing this we were able to identify the most import requirements for the customer and therefore we were able to give the priority to the most important factors so that we could come up with a high quality product.

2.4. Analyzing anthropometric data

Ergonomic factors such as the best reading angles, writing angles, lighting positions, mobility, height adjustment techniques and table tilting techniques were analyzed with the best ergonomic methods for the users. Also the location of drawers, how they should be built, how the power supply should be provided to the table were considered. Considering ergonomic factors were really important with the correct anthropometric data. Using anthropometric data by [6], Tab. 1 was calculated by considering the Thai male and female's dimension. Different sizes in anthropometry are described with the aid of percentiles.

Our aim was to calculate the minimum height if the table height of a bed usually varies from 20–25 inches.

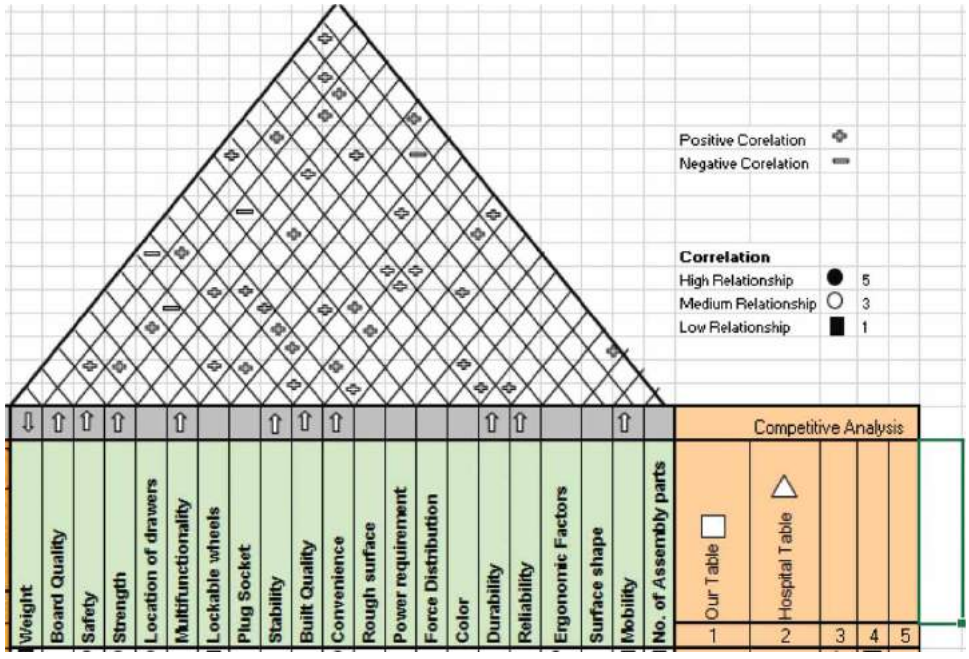

Figure 10. Roof.

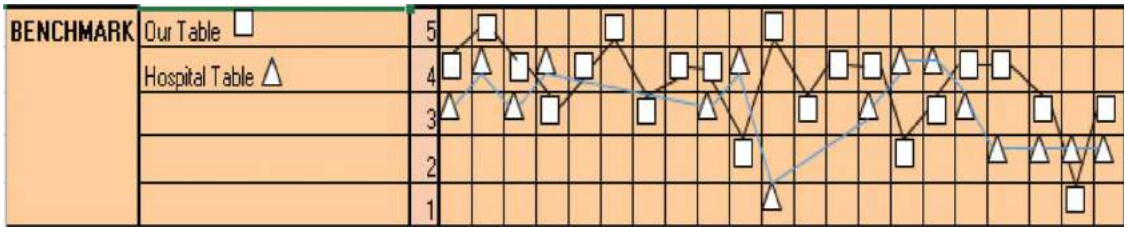

Figure 11. Benchmarking.

A hospital bed would have a minimum height of 20 inches with the mattress while the standard height of a bed used at home has a height of around 25 inches [5].

- Maximum height from ground to drawer of the table = 97.5 cm
- Minimum height from ground to drawer of the table = 60 cm

Therefore the minimum height from ground to the drawer was decided after calculating 1st percentile of Southern Thai females:

Seated Knee height = 43.96 cm

Seated Popliteal height = 36.66 cm

Thigh height = would be the height difference between the knee height and the popliteal height.

Figure 12. Goal.

Table 1. Calculated parameters for over bed table.

Anthropometric factor	Dimensions (cm)
Ground to drawer height	
-Maximum	97.5
-Minimum	60
Knee height	43.96
Popliteal height	36.66
Thigh height	7.3
Standing elbow height of 1st percentile Thai female	90.63
Hip height of 1st percentile Thai female	69.76
Hip to shoulder height 1st percentile (Thai female)	20.87
minimum height from ground to table top when tilted	72
The angle of inclination after considering the best ergonomic factors	15degrees
Forward grip reach 1st percentile (Thai female)	62.91
Table max grip reach	35.56

$$43.96\text{cm} - 36.66\text{cm} = 7.3\text{cm} = 2.92\text{inches}$$

Therefore the minimum height of the bed plus the height of the thigh of a 1st percentile Thai female came up to (20+2.92) = 22.92 inches

Therefore the minimum height from the ground to the drawer was decided to be 25 inches with an allowance height of 2.08 inches.

Next step was to decide on the minimum height from the ground to the table top. This was calculated using the following data.

Standing elbow height of 1st percentile Thai female = 90.63 cm

- Hip height of 1st percentile Thai female = 69.76 cm
- Hip to shoulder height 1st percentile Thai female = 90.63–69.76 = 20.87 cm
- Elbow height while on a 20 inch tall bed = 50 cm + 20.87 = 70.87 cm = 27.852 inches

Therefore the minimum height from ground to table top when tilted was decided to be 72 cm = 28.8 inches

Next step was to calculate the minimum distance that we should place the handle, power base and other accessories in order for the person to reach all these with convenience.

- Forward grip reach Thai female 1st percentile = 62.91 cm = 25.164 inches
- Table maximum grip reach = 35.56 cm = 14 inches

2.5. A skeleton of new design

A prototype was built in order to confirm all the specified features and requirements from the survey and customer inputs via the QFD. Building a prototype was indeed advantageous as all the requirements were able to be visualized. Special considerations were given to the maximum tilt angle and the storage compartments as these were very critical in the design. Prototype is an early representation of the final model and built with exact dimensions to conduct a proper analysis of the mechanical parts. It can visualize the key features and communicate the insights. It also gives a certain opportunity to spot out the flaws and correct them to improve the product at the early stage so that these initiatives help to reduce the costs of development at the final stage. Force analyses using Computer Aided Analysis (CAE) tool are not discussed in this paper.

Figure 13. A skeleton of new design

2.6. Virtual ergonomics models and analysis

In designing the over bed table, anthropometric measurements of Thai population was considered as the product was designed in Thailand for the Thai population. Anthropometric data for a certain population is based on size and described as percentiles. The common feature in design is based on designing to the 5th percentile of female and 95th percentile of male [10]. In general the 5th percentile female value represents the smallest value in a population and conversely the 95th percentile male represents the largest value in a population. Generally design considerations can be made the range from the 1st percentile female to 99 percentile male. Fig. 14 shows the Thai Population database for creating the virtual human models for performing ergonomics JACK SIEMENS analysis. The SolidWorks CAD model of the over bed table and virtual Thai human model are

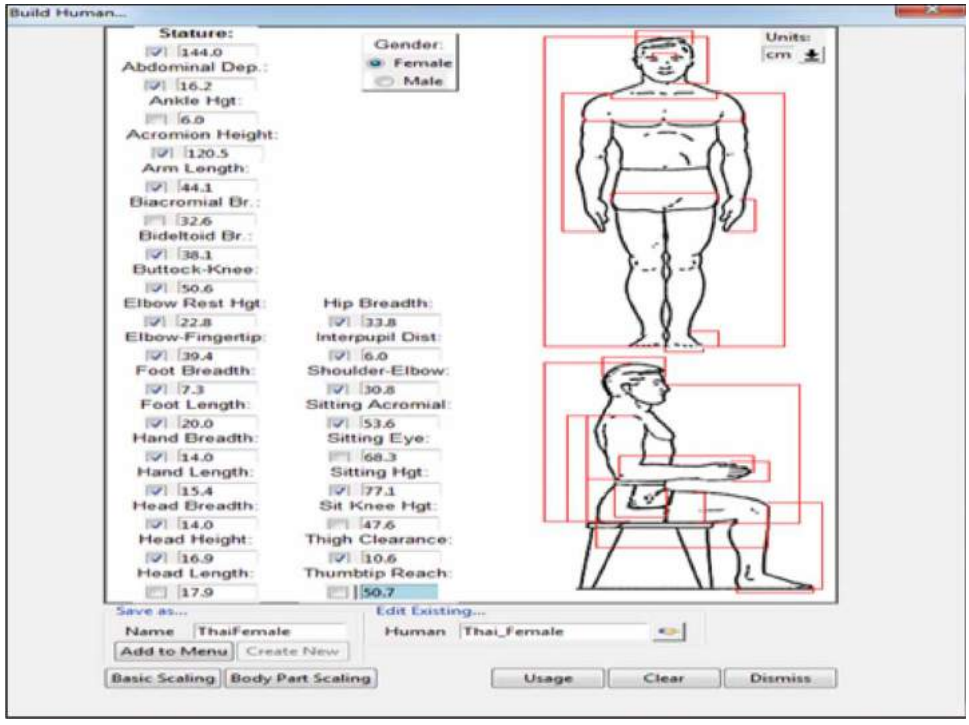

Figure 14. Thai population database for virtual human model

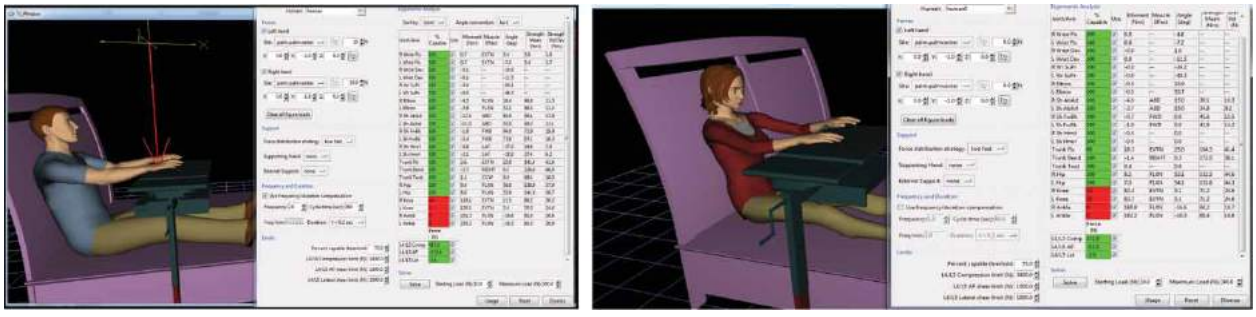

Figure 15. ForceSolver analysis

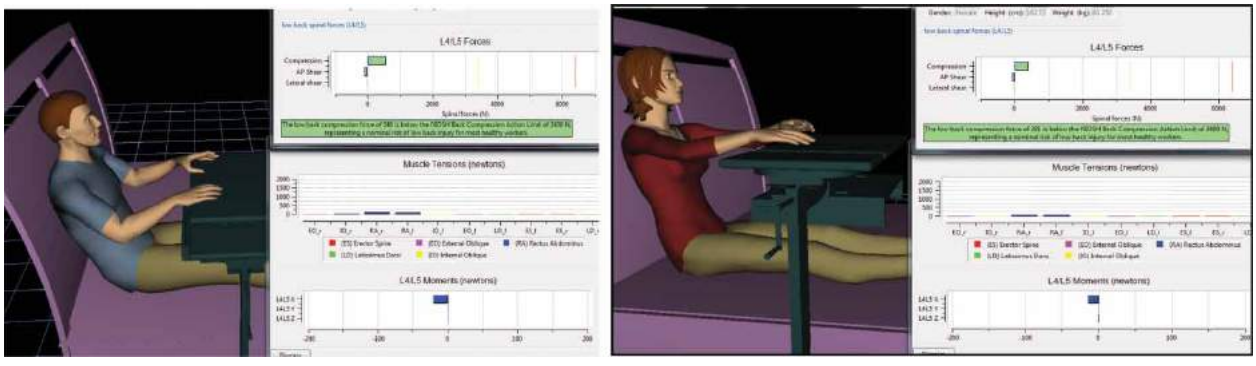

Figure 16. Lower back analysis.

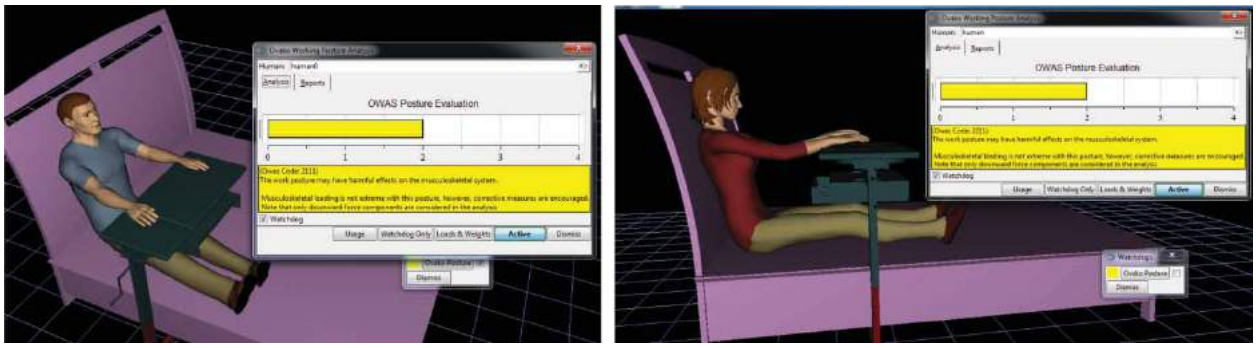

Figure 17. Ovako working posture analysis.

Table 2. A comparison of features between the existing and developed model.

	 **An existing model in hospital**	 **A developed model by authors**
Height adjustability	Manual	Automatic
Table top inclination	No	Yes
Portability	Yes	Yes
Cost	Same	Same
Lamp	No	Yes
Power supply	No	Yes
Anti-sliding edges	No	Yes
Storage space	No	Yes

imported to the Jack Siemens and analyzed ergonomics factors by using the ForceSolver, Ovako working posture analysis (OWAS) and Lower back analysis tools. ForceSolver offers powerful alternative to the traditional method of conducting a static strength or low back assessment. In addition to considering posture, we can define task parameters, such as support forces and standing strategy, in order to predict the maximum acceptable force that a human can exert and also hand forces can be analyzed by assigned positions (Fig. 15).

Lower back analysis uses a complex biomechanical low back model to evaluate the spinal forces that act on the lower back under the unlimited number of posture and loading conditions. This analysis was conducted to 95th Percentile of Thai Male Population for bedridden position and 5th Percentile of Thai Female Population for bedridden position (Fig. 16). Ovako working posture analysis (OWAS) evaluates the relative discomfort of a work posture based on the positions and load requirements of the back, arms and legs. It helps to determine the urgency of taking corrective measures. This analysis was conducted to 95th Percentile of Thai Male Population for bedridden position and 5th Percentile of Thai Female Population for bedridden position (Fig. 17).

3. Results and discussions

Tab. 2 shows a comparison of features between two different models. After taking into consideration some of the existing over bed tables today, we have come up with several problems below.

- Difficulty in adjusting the table height according to wish of the user.
- The table top cannot be inclined according to the convenience of the user.

— If it is possible to tilt the table top, there doesn't exist an allocated space where the user can place other components such as a glass of water or a food tray which should not be tilted.
— Anti-sliding edges are not used if the table top can be inclined in order to stop any materials from falling.
— None of the existing over bed tables consists of a power supply where the user can conveniently charge his or her laptop or any other electrical appliance.
— It is not possible to store any immediate goods such as medication due to the lack of a drawer in the design.

If we consider all the above mentioned problems, we cannot see a product which has given solutions to all these problems. In most of the cases we can see tables where the height can be adjusted but the table top cannot be tilted, and if both these features are included there do not exist a drawer to store the immediate goods. Also none of the tables that we took into consideration had anti-sliding edges in order to stop any materials from sliding down the table or a power supply for the convenience of the user. No matter whether you are able or disable, any person would like to make sure that they do not become a trouble to any other person in order to get hold of their personal work. One of the other major issues that we came across when going through the existing over bed tables was that some of the tables do not consist of wheels so that the user can move about the table easily and in some cases there were wheels in order to move the table but these wheels weren't lockable which raised a major issue in the stability of the table.

When designing an ergonomic product there are many guidelines for manufacturers have to consider. The main part is to collect and analyze the anthropometric data of the required population set. Anthropometry is expressed as the measurement of dimensions and proportions of human body. Therefore it is very important prior to the study of ergonomics. In this study, only anthropometric measurements of Thai population was considered for the design of the over bed table. We used Siemens Jack, as a useful ergonomic tool to analyze the ergonomic factors in our design. It allows us to analyze using virtual humans instead of real humans. In the final stage, we automated the height adjusting mechanism to increase the user-friendliness. In this ergonomics analysis study, we did not consider about the user time durations for each positions.

4. Conclusions

The over bed tables are used to help disable or injured persons. However, they face a difficulty when they use a computer, have food, drink and medicine, to read a newspaper or even to brush teeth while staying on the bed. In this paper, we developed a new model for bedridden patients. A methodology has been implemented and applied for our new ergonomics model. An ergonomics model was developed and manufactured using the recommendations of QFD and ergonomics factors by Jack SIEMENS® Ergonomics tool. In this research, anthropometric data of southern Thai population has been applied to develop a new model as our target was for Thai population. A prototype was built and checked for the new design features and functions to avoid any errors when tilting, locating the drawer and etc. Results of our ergonomic analysis verified our developed model that there are no any long term injuries to the lower back or wrist when using our developed table. Un-ergonomics product can lead the user to various types of injuries with the long term use. Therefore, ergonomics factors including anthropometric data should not be neglected when developing a new product model.

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