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Identification of design requirements for ergonomic long spinal board using quality function deployment (QFD)

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Abstract

Emergency Medical Services (EMS) is a basic medical acts carried to an accident victim with the purpose of sustaining life and preventing a decline in body condition before the victim finally getting further treatment from medical personnel. One evacuation tool of first aid commonly used is Long Spinal Board (LSB). This tool is set up as an emergency stretcher boards made from wood or polymer with a flat surface that is used to perform the evacuation of the injured spinal cord. The basic principle of the LSB use is to immobilize the position of the spine so that the secondary injury on the spine due to swing, clash, or shocks that occurred during the evacuation process can be minimized. However, the existing LSB has several disadvantages, both in terms of user comfort, and also the effectiveness and efficiency of the evacuation process when done. A recent study found the LSB use can cause pain, discomfort, and respiratory disorders to the patients. Furthermore, the LSB can blockage the flow of oxygen in the tissue capillaries at the placement of strap. Therefore, it is important to improve the design of the LSB with the aims to achieve mobility and better equipment compatibility when used, so that the evacuation process can be done more effectively, efficiently and safely. This study identifies the design requirements of ergonomic LSB using Quality Function Deployment (QFD). QFD is an effective design method to integrate ergonomics needs and comfort into LSB design because it explicitly addresses the translation of customer requirements into engineering characteristics. Preliminary survey was conducted through direct observation of the actual use of LSB that exists today and interviews with volunteers from the Indonesian Red Cross of West Sumatera. Data gathered was translated into questionnaire and answered by 47 participants from medics, Red Cross, Ambulance Unit Medical Officer and rescue team of Padang, West Sumatera. Then it was clarified and used in the House of Quality matrix. The QFD analysis of the LSB revealed that the selection of LSB main board materials, the application of LSB strap systems, as well as the addition of LSB features were receiving the highest overall weighting, which means that improving the design of those criteria would lead to higher customer satisfaction.

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Keywords: Long spinal board; Ergonomics; Quality Function Deployment; Design requirement

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1. Introduction

Emergency Medical Services (EMS) is a basic medical actions undertaken to accident victims quickly and precisely in order to maintain life and to prevent a decrease in body condition or disability before the victim finally getting further treatment from medical personnel. One method of first aid and evacuation of casualties commonly studied and practiced is the method of evacuation using a tool called Long Spinal Board (LSB). This tool is shaped like an emergency stretcher boards made from wood or polymer with a flat surface that is used to perform the evacuation of the injured spine. The basic principle use of LSB is immobilize (limiting the space) position of the spine so that the injury to the spine due to swing, clash, or shocks that occurred during the evacuation process can be minimized.

Integration between the cells of the central nervous and spinal cord contained within the structure of the spine and the brain makes these nerves sensitive if exposed to damage or injury. This means, damage to the central nervous system will lead to defects that will affect the structure of the body that are directly related to damage nerves. Injury or damage to the central nervous system on a larger scale can result in permanent paralysis and death. National Spinal Cord Injury Statistical Centre (NSCISC) collected epidemiological data in the United States from 2010-2012 on the cause of injury to the spinal nervous system. The data shows that the most common cause of traumatic injury to the spinal nervous system, among others, due to motor vehicle accidents by 36.5%, fell from a height by 28.5%, an intentional act of violence by 14.3%, sports by 9.2%, and other unknown causes by 11.4% [1]. Mortality (risk of death) in patients with traumatic spinal cord injury is estimated at 48% in the first 24 hours, and approximately 80% died at the case [2]. This shows that the effective and efficient handling should be done to reduce the risk of injury to the victim's death at times critical. One thing that should be kept in saving lives is the victim first aid and evacuation itself, by knowing the proper technique in moving the victims to a safer area to minimize secondary injury that occurs as a result of the evacuation process itself.

However, in practice, the existing LSB has several shortcomings, both in terms of user comfort and also effectiveness and efficiency of the evacuation process when done. In fact, a recent study found that the use of LSB can cause pain, discomfort in patients, and respiratory disorders. Furthermore, LSB can decrease tissue perfusion (blockage of the flow of oxygen in the tissue capillaries) at the points given pressure (in this case the placement of ropes or strap), which will lead to the occurrence of decubitus wound, the wound caused by blockage of blood flow on certain body parts [3].

By observing the facts, it can be concluded that it is necessary to redesign the existing LSB. It aims to achieve mobility and better equipment compatibility when in use so that the evacuation process can be performed more effectively, efficiently and safely. By doing this, it is expected that the risk of death of patients with traumatic injuries to the victim's spine can be minimized, and thus increase the comfort and safety of both victims and rescuers when evacuation is done.

Regarding the methods for designing the new product development, Quality Function Deployment (QFD) is a significant methodological approach to enhance customer satisfaction and reduce the product costs and development cycle time. It is also a crucial tool to increase time and resources saving throughout all stages – design to production planning [4]. QFD has been profitably applied by industries around the world [5-7]. Hence, this study used QFD method to investigate the customer and technical requirements for designing ergonomics LSB.

2. Research method

2.1. Preliminary study

Preliminary study was conducted by a direct observation to the actual use of the existing LSB. It was also carried out using interviews with volunteers from the Indonesian Red Cross of West Sumatera, assuming they have a good understanding of the accident evacuation process as well as having experience in the LSB use. The interviews were conducted to know in general how customers respond to the existing LSB on the market today as well as the characteristics of the customers towards the desired LSB in the future. The interview is a preliminary stage that serves as a reference in designing the research questionnaire. It is also a method to get an initial picture of consumer expectations for designing an ergonomic LSB.

Based on these preliminary studies it is known that it is necessary to redesign of the existing LSB. It aims to achieve better equipment mobility and compatibility when used so that the evacuation process can be performed more effectively, efficiently and safely.

2.2. Participant

There were 47 participants from medics, Red Cross, Ambulance Unit Medical Officer and rescue team of Padang, West Sumatera. They were involved in answering the survey questionnaires. The participant's criteria are people who have ever used the Long Spinal Board. The data was collected from April to June 2014.

2.3. Data collection

The primary step in the product planning process is determining the user or customer requirements. According to Bergquist and Abeysekera [8], the information about what the customer requirements and their priorities can be gained through various marketing methods, e.g. questionnaires, interviews, and brainstorming techniques. This study collects data through a survey method, by using questionnaire. It aims to investigate the participants' opinions and ideas related to the products that will be developed.

The survey questionnaire was developed based on the data from the initial interviews. It also refers to the dimensions of quality according to Garvin [9]. The criteria include performance, features, durability, and aesthetics. It is added by the price aspect as proposed by American Society for Quality Control (ASQC). The questionnaire aims to investigate the customer requirements and desires related to the notebook soft case. It covers a range of topics including personal backgrounds and customer requirements to the design of notebook soft case. Scale used for the design of the questionnaire is a Likert rating scale with a range of 1-5 for the assessment is not important (1) to very important (5).

2.4. Data analysis

The collected survey questionnaires were tested for their validity and reliability using SPSS software V.22. Then, the collected data were processed using QFD design through House of Quality (HoQ). The primary chart used in QFD is the House of Quality (HoQ). According to the HoQ, customer requirements are translated into technical requirements, and subsequently into part or component characteristics, the process operations, and production requirements associated with the manufacturing process. Therefore, accuracy of customer requirements input is critical for applying the HoQ with success [10].

HoQ consists of several activities supported by various tables and matrices. The basic idea is to translate customer requirements into the product design characteristics in order to increase customer satisfaction [11-13]. The procedures of QFD design in this study are divided into the following steps:

a. Determine the customer requirements and the customer important ratings
b. Translating customer requirements into measurable technical requirements
c. Determine the relationship between the customer requirements and the technical requirements
d. Determine the interactions between the technical requirements
e. Determine the priority of the technical requirements
f. Setting engineering targets for the design.

3. Result

3.1. Interview and questionnaire

The process of customer requirements identification is the first step conducted for designing a product. The process begins with preliminary study by a direct observation and interview with volunteers from the Indonesian Red Cross of West Sumatera. This initial study successfully investigated the advantages and disadvantages of the

existing LSB and suggestions for improvement in the future. Table 1 shows the summary of investigation results which illustrates the existing LSB conditions.

Table 1. The Existing LSB Conditions.

Advantages	Disadvantages	Suggestions
• LSB is the easiest, inexpensive, and efficient tool for use in the treatment of spinal cord injury. • It can be used on land and water. • LSB material made of plastic does not interfere with the scanning process using X-Ray.	• LSB can cause discomfort, pain and respiratory distress in victims. • Strap system may decrease tissue perfusion because it blockages the blood flow to certain body parts. • LSB main board size is large and heavy so it can reduce the mobility of saviour. • Strap system has not really able to make sure the victim is bound well. • There is no device that allows LSB is rigidly mounted in Ambulance.	• The design of strap system that allows the immobilization more focused on the side of the victim's body. • Board design follows the body contours for improving the convenience of use. • The design of the LSB main board allows rescuers to move more freely.

Based on the investigation results about the existing LSB obtained from interview, a questionnaire was developed to gain reliable data about customer requirements with respect to customer satisfaction. It also refers to the Garvin's quality dimensions namely performance, features, durability, aesthetics, and the price aspect as proposed by American Society for Quality Control (ASQC).

3.2. QFD design

3.2.1. Determine the customer requirements and the customer important ratings

The identification of the customer requirements was conducted by distributing developed questionnaires to 47 participants. The answers were weighted in order to obtain the measured value. The collected questionnaire data were tested for validity, reliability and adequacy. The results show that all data obtained were valid, reliable and sufficient for the next analysis. Table 2 shows the customer requirements and customer important ratings for redesign of LSB.

The results from the questionnaire survey in Table 2 revealed information on the average weighting of ergonomic demands of LSB. The table shows that of the 22 items of questions posed to the participants, 10 items are considered important for the LSB design. This information was used directly in the QFD analysis as a basis for translating the customer requirements into technical characteristics expressed in the technical terms.

3.2.2. Determine the technical requirements

Technical requirements used to represent the voice of developers. Determination of the technical requirements was done by consultation and discussion with experts in the respective products related to material and manufacturing. On the other hand, the engineering characteristics related to the medical treatment method for spinal cord injuries were obtained through consultation with an Orthopaedic and Traumatology surgeon.

Table 2. Customer Requirements and Customer Important Ratings.

No.	Customer Requirements	Customer Important Ratings
1	The materials are able penetrated by X-ray	4.36
2	The strength of the strap to resist the body movement	4.28
3	LSB strap is powerful	4.20
4	LSB material is easy to clean	4.20
5	The speed of strap installation	4.18
6	LSB material is stainless	4.16

No.	Customer Requirements	Customer Important Ratings
7	LSB ability in resisting the body weight	4.10
8	LSB handle is made anti-slip	4.08
9	LSB does not have sharp edges or angled	4.04
10	LSB ability in resisting the body movement especially the spine	4.02
11	The comfort during use	3.84
12	The LSB main board can be folded so it is easy to carry	3.84
13	Head Immobilizer is installed permanently on the LSB board	3.64
14	LSB strap is not easily broken	3.50
15	Strap are given foam pads to reduce the blockage risk of blood flow	3.46
16	The ease of strap installation	3.44
17	LSB main board has a lot of socket which can be used to install the additional devices such as waist and ankle safety	3.42
18	Fold in the LSB board (if point 1 applied) made under the tail bone so that it is still able to withstand the spine movement	3.42
19	The shape and the size of the LSB designed, do not change the evacuation procedures	3.20
20	The price is affordable	3.18
21	Strap design can withstand the head movement	3.00
22	There are variations in the LSB colour	2.86

The technical requirements are presented below:

- Material selection of high density polyethylene and polyurethane as the material for the LSB main board
- Material selection of nylon as the material for the LSB strap
- Installation mechanism of LSB strap
- Modifications of the LSB strap design
- Modifications of the LSB main board design
- Extra features on the LSB main board
- Color variations on the LSB design
- LSB handle are textured or coated with rubber
- The selection of manufacturing methods

3.2.3. Determine the relationship between the customer requirements and the technical requirements

The process of determining the relationship between the customer and technical requirements was done through discussions with the engineering experts and the Orthopaedic and Traumatology Surgeon. The relationships were represented by several categories such as strong (• = 9), moderate (o = 3), weak (Δ = 1), and there is no relationship (0). For example, the relationship between the variables " LSB ability in resisting the body weight" with the variable "Material selection of high density polyethylene and polyurethane as the material for the LSB main board". The relationship between them is expressed "strong" because High Density Polyethylene and Polyurethane is a thermoplastic material that is not only strong but lightweight so the selection of this material will have a major influence on the ability of LSB to withstand the load from patient's body.

3.2.4. Determine the interactions between the technical requirements

The interactions between the technical requirements were design to identify the design conflict and complementary characteristics [14]. It is also useful to see how a technical requirement affects the other technical requirements. There are five types of relationships used in this matrix [15]. They are strong positive relationship (√√), medium positive relationship (√), no relationship (no symbol), medium negative relationship (X), and strong negative relationship (XX).

An example of the relationship between the technical requirements is "Material selection of high density polyethylene and polyurethane as the material for the LSB main board" and "Modifications of the LSB main board design". The relationship between those requirements is categorized as a strong positive relationship. It means that the selection of materials for the LSB main board and the modifications of LSB main board design will influence and support each other in order to create more flexible and efficient of LSB main board in use. Thermoplastic

material tends to be more easily processed and shaped so that the modifications to the LSB main board can be more dynamic and easy to do.

3.2.5. Determine the priority of the technical requirements

The process of determining the priority value of each technical requirement was done by summing the results of multiplying the customer important ratings with the score of the relationship between the customer requirements and the technical requirements. Figure 1 shows the matrix of customer requirements, customer important ratings, relationship between the customer requirements and the technical requirements, the interactions between the technical requirements, and the technical requirements' priority (the House of Quality 1).

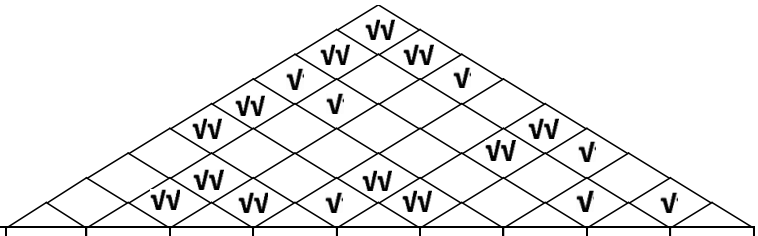
4. Discussion

Customer important ratings show that the highest requirements in the LSB design according to the customers are the selection of LSB main board materials, the application of LSB strap systems, as well as the addition of LSB features. The variable that gets the highest rating is "The materials are able penetrated by X-ray" with the rating value of 4.36 or classified as "important". This is because the victim suffered should be immobilized well until the scanning process using X-rays is completed. The transfer of the victim without immobilization tool will increase the risk of secondary injury.

Polyethylene and Polyurethane is the best option to be used as the LSB main board material because of its ability and endurance. Those materials can also answer the fourth rating "LSB material is easy to clean" and the sixth rating "LSB material is stainless". It is because the Polyethylene and Polyurethane are the thermoplastic materials with small pores so it does not absorb water and can survive at the extreme temperatures.

In terms of strength, Polyethylene especially High Density Polyethylene (HDPE) has good strength because it has a high density equal to 0.941 g/cm3, with an average tensile strength of 32 MPa [16]. It can answer the customer requirement on the seventh rating "LSB ability in resisting the body weight". Therefore, for the parts which have the important function as weight-bearing on the LSB main board such as the bottom frame, hinges, connecting pegs, and side handles are made using rigid HDPE material, while at the top of LSB main board, HDPE used as outer shell with polyurethane on the inside. Thus it can reduce the overall weight of the LSB, but will not effect on its strength.

The next highest customer requirements are related to the strap system. It includes "The strength of the strap to resist the body movement", "LSB strap is powerful", and "The speed of strap installation". It shows that the selection and application of the strap system which is strong and has quick installation are important for the customers. Therefore, ECS strap system with nylon will be used to design the strap in the product. ECS Straps are a crossing restraint system for both adults and children and can be used on a variety of transport devices such as boards and vacuum mattresses. The sliding of the cross-sectional belts upon the longitudinal one and its extension will allow a better fit to the patient's body. All these features make the ECS-straps an innovative and versatile device for any kind of immobilization operation [17]. This system makes a bond not only relies on a single point, so the risk of rope cut off is smaller. By implementing this system, the emphasis on the body will be split between two segments of the rope so that the risk of blood blockage is also smaller.



Customer Requirements	Customer Important Ratings	Material selection of high *density polyethylene and polyurethane* as the material for the LSB main board	Material selection of nylon as the material for the LSB straps	Installation mechanism of LSB straps	Modifications of the LSB straps design	Modifications of the LSB main board design	Extra features on the LSB main board	Color variations on the LSB design	LSB handle are textured or coated with rubber	The selection of manufacturing methods
	Engineering Characteristics									
LSB ability in resisting the body weight	4.10	•	o	o	o	•	Δ		o	•
LSB ability in resisting the body movement especially the spine	4.02	•	•	•	•	o	o			o
The strength of the straps to resist the body movement	4.28	o	•	•	•	o				o
The ease of straps installation	3.44	Δ	o	•	•	o	Δ			
The speed of straps installation	4.18	Δ	Δ	•	•	o	Δ			
The comfort during use	3.84			Δ	•	•	•			
The materials are able penetrated by X-ray	4.36	•	•			o	o			o
The LSB main board can be folded so it is easy to carry	3.84	o				•	•			Δ
Fold in the LSB board (if point 1 applied) made under the tail bone so that it is still able to withstand the spine movement	3.42	o				•	•			Δ
Straps design can withstand the head movement	3.00					•	•			
LSB main board has a lot of socket which can be used to install the additional devices such as waist and ankle safety	3.42	•		Δ	o	•	•			Δ
LSB handle is made anti-slip	4.08	o		o					•	Δ
Straps are given foam pads to reduce the blockage risk of blood flow	3.46		o	•	•		Δ			Δ
Head Immobilizer is installed permanently on the LSB board	3.64	•		o	o	•	•			•
The shape and the size of the LSB designed, do not change the evacuation procedures	3.20	o	o	•	•	•	•			
LSB material is stainless	4.16	•	Δ	Δ		•	•			•
LSB strap is powerful	4.20	o	•	•	•	o	Δ			•
LSB strap is not easily broken	3.50	o	•	•	•	o	Δ			•
LSB material is easy to clean	4.20	•	o	Δ	Δ	Δ	Δ		Δ	Δ
LSB does not have sharp edges or angled	4.04	•		o	Δ	o	o			•
There are variations in the LSB color	2.86	o	o		Δ	Δ	Δ	•	Δ	Δ
The price is affordable	3.18	•	•	Δ	Δ	Δ	Δ			•
Priority Values		**411.84**	**283.98**	**338.90**	**354.84**	**399.88**	**327.06**	**25.74**	**56.08**	**304.64**
% Priority		**0.16**	**0.11**	**0.14**	**0.14**	**0.16**	**0.13**	**0.01**	**0.02**	**0.12**

Fig. 1. House of Quality 1.

In terms of feature development, customers require "LSB handle is made anti-slip" with rating value of 4.08; "The LSB main board can be folded so it is easy to carry" with a value of 3.84, and "Head Immobilizer is installed permanently on the LSB board" with a value of 3.64. These features are then implemented in the design. To the side grip on the LSB main board, the handle is made with circular shape so that rescuers can grasp LSB perfectly. The texture on the grip is also made rougher so that the slip risk is smaller when gripped. At the top of the LSB are also added Head Immobilizer features integrated on the main board in order to the victims' head can be detained without any additional devices so the evacuation process can run faster. The LSB main board was designed can be folded into two parts to increase the rescuers' flexibility when carry it. All components including hinges player in the crease and Head Immobilizer made from the same material as the LSB main board. So it can still be penetrated by X-rays but does not reduce the strength and resilience of the LSB main board.

In ergonomic side, the LSB should be designed in such a way to accommodate the two sides of the interests of users at once, such as safety and comfort of the victims as well as the flexibility and speed of the rescuers who make the evacuation process. The use of anthropometric variables was also adjusted to the dimensions of the Indonesians, so it is expected that this product really assist the efforts to reduce traffic accidents and disasters in Indonesia.

5. Conclusion

QFD method aims to design more targeted products in accordance with customer desires. QFD translates customer requirements into the form of product attributes to meet the customer requirements. This research has used the QFD method until HoQ phase 1 to identify the customer and technical requirements for redesign the ergonomics LSB product. The results indicate that the selection of LSB main board materials, the application of LSB strap systems, as well as the addition of LSB features are very important to design an ergonomic LSB. The next phase will discuss about parts deployment until production planning. Thus, the ergonomic LSB can be designed in accordance with the conditions and the latest technology.

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