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Redesign Wheelchair Using The Failure Mode and Effect Analysis Method

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ABSTRACT

Background: The research aims to identify potential hazards, then assess and determine mitigations to avoid the risks of accidents resulting from the use of wheelchairs, as well as to reduce the incidence of accidents among elderly wheelchair users.
Methods: The FMEA method is a series of procedures used to identify potential risk hazards, followed by assessment and prevention measures to ensure that these hazards can be prevented or minimized. The research uses data from field observations and interviews.
Result: The results of the calculations indicate that the three highest RPN values reveal that the potential risk of accidents with the largest RPN value is "Head hanging," which poses a risk of neck nerve compression with an RPN value of 192. The second is "Hand caught in the wheel," which presents a potential danger to the area around the hand that could impact the fingers of the rim with an RPN value of 120. The third is "Foot hanging," which carries the risk of the foot being scratched or pinched while seated and could be greater when the wheelchair is in motion, with an RPN value of 112.
Conclusion: These three highest RPN values serve as priority recommendations for actions to reduce the RPN values.

1. Introduction

At an age where the lower part of the body is affected, the elderly can no longer walk with agility and cannot carry out their activities independently. Human health behavior is influenced by how individuals perceive health issues, view the benefits of treatment or preventive measures, and recognize their need to take specific actions (1). The elderly are a group of the population aged 60 and above who undergo the aging process and need to adapt to various functions and environmental stress due to a decline in bodily capabilities (2). In Malaysia, out of 2,594 people interviewed, 21.1% complained of rheumatism; among women, 23.8% and 17.8% more frequently, while among men, 64.8% reported knee pain (3). In this regard, wheelchairs are essential as a mobility aid that is very important for individuals with physical limitations, providing independence, assistance, and improving quality of life

A wheelchair is a mobility aid for individuals with leg disabilities that assists people such as those with physical limitations, patients in hospitals who are not allowed to engage in physical activities like normal, the elderly, and other disabilities (4). According to (5), using a wheelchair provides people with disabilities benefits such as improved quality of life, health levels, and economic conditions.

In previous research, the development of a wheelchair with a portable backrest mechanism has proven to be very efficient in minimizing the negative impacts of immobilization in preventing the onset of pressure sores and back pain (6). The height adjusters for the footrest and armrest have the advantage of providing users with ample access to mobilize on the wheelchair and can be adjusted to fit each individual's body ergonomics (7).

However, the manual wheelchairs that are commonly available still have shortcomings depending on who is using them. For example, musculoskeletal disorders indicate health issues that occur in the body's movement apparatus, such as muscles, tendons, the skeletal system, cartilage, ligaments, and nerves (8). Complaints related to the musculoskeletal system are issues arising from the skeletal muscles that a person experiences, ranging from very mild complaints to the onset of damage, which is commonly referred to as MSDs or injuries in the musculoskeletal structure (9) (10). This study will involve elderly individuals as users of manual wheelchairs, which will be determined through the results of a FMEA analysis (11) (12). Involving the elderly in research is important because their body postures vary from one another. In addition, many wheelchairs available on the market are not specifically designed for various activities or certain environmental conditions, such as rough surfaces or stairs, which can limit the mobility of users (13).

This research aims to develop an innovative wheelchair design that is suitable for body posture conditions. By utilizing the FMEA (Failure Mode and Effect Analysis) method, a user-centered design approach for wheelchairs aimed at the elderly is developed. The use of the FMEA method is expected to result in modifications to wheelchairs by identifying plans and recommended actions for wheelchairs as a preventive measure against injuries by finding potential risks in manual wheelchairs (14). The FMEA method requires three elements that help determine recommended actions: Severity level, Frequency of occurrence, and Detection. Through observations, interviews, and questionnaires conducted at one of the shelters located in Palembang. It is hoped that by understanding the potential risk of injury for users, preventive measures can be created by modifying the existing elements of the wheelchair.

2. Method

FMEA is a technique for evaluating the potential failures of design systems, procedures, or services to generate corrective actions (15). According to Puente (2002), as cited by (16), FMEA is a method used to examine the causes of defects or failures that occur during the production process, evaluate the priority of risks that lead to workplace accidents, and assist in taking actions to avoid problems identified as hazards of workplace accidents.

Risk Priority Number = Severity x Occurance x Detection

The stages of activities for conducting this research can be generally described as consisting of the preparation stage, data collection stage, data analysis stage, results and discussion stage, and the concluding stage.

The preparation for research consists of several stages, namely preliminary study, problem identification, research objectives, and problem limitations. The preliminary study involves conducting a literature review related to previous research or studies that have been conducted as references, particularly concerning the risk analysis of the Failure Mode and Effect Analysis method. (17). Identify the problem with the aim of discovering or identifying potential injury risks for users of manual wheelchairs. The respondents of this study are individuals who use manual wheelchairs and are elderly, approached holistically regarding elderly users of wheelchairs.

Furthermore, this research requires the necessary data, including primary and secondary data. The primary data, which comes from original sources that serve as the research data, is collected through observation, interviews, and questionnaires in this study. To understand what accidents and potential injuries could occur in the elderly care facility. An interview with a manual wheelchair user about their daily activities, experiences, issues, or complaints during the use of the wheelchair, as a representation of the manual wheelchair experience. The results of the questionnaire yielded data on severity (S) ranking of severity, Occurrence (O) ranking of occurrence, and Detection (D) detection for each potential risk. (14). Sources of research data obtained indirectly, such as books, notes, existing research, whether published or unpublished.

Failure Mode and Effect Analysis is a technique used to find, identify, and eliminate potential failures, problems, or errors that occur in systems, designs, and processes before they reach the

consumer (Stamatis, 1995). The data processing stage begins with calculating the values of severity, occurrence, and detection, referred to as S, O, and D. After the calculations, a Risk PriorityNumber (RPN) will be produced. The data processing involves assessing the risk level of workplace accidents using the FMEA method by multiplying the values of S (severity), O (occurrence), and D (detection), which will yield the RPN value.

After that, the RPN values will be sorted, which will then be identified as high-level events, mid-level events, and low-level events. The identification at the data processing stage aims to determine the types of accidents, how often they occur, and their prevention as a solution to the problem. After obtaining high-level data, I then conducted interviews and discussions with staff employees and team members. The next step is to determine the mitigation or propose plans and actions that will be taken as measures to reduce the RPN value.

3. Result

At this stage, the researcher evaluate damage caused by failure based on S parameter criteria .The researcher also conducted brainstorming assisted by each member For evaluate how muchbig impact from each failure mode . For do this , they using historical data , experience or skillresearchers and team For help they assess it . Determination severity value as following accordingto (McDermott et al., 2008) :

1. **Severity scale,** researcher use scale usually it revolves around from 1 to 10.

Table 1. Scale severity

Mark	Description	Impact
10	Extreme	Death or serious injury
7-9	Critical	Injury
4-6	Currently	Minor injury
1-3	Light	No impact

2. **Category impact ,** category the impact on research This is safety .
3. **Value based on impact and validation ,** determining mark based on the impact thathas been identified with do discussion and validation with team from various aspect field .

Next, just like the previous stage, researchers and teams use the O parameter criteria to assess how often the possibility of a failure or incident on the research object can occur. Ensure sufficient data is obtained to assess the frequency of possible failures that can occur. Occurrence is a determination to measure how often failures can occur.

1) **Scale** , the scale applied ranges from 1 to 10.

Table 2. Scale occurance

Mark	Description	Frequency
10	Very often	> 1 time in a day
7-9	Often	1 time in Sunday
4-6	Sometimes	1 time in a month
1-3	Seldom	< 1 time in a year

2) **Historical data** , historical data analysis serves as a reference point in the form of a pattern and behavior.
3) **Probabilistic approach** , the use of models where there are possible outcomes with varying degrees of certainty or uncertainty.

Just like other parameters, In chapter 3, the D parameter criteria are used by researchers. For evaluate or measure capacity For control failure modes . They consider all over aspect aspect control , as well as indicator related additions with the process being evaluated . Measurement ability system For detect before happen as following :

1) **Scale** , scale detection used range from 1 to 10

Table 3. Scale detection

Mark	Description	Ability detection
10	Very often	Not detected
7-9	Often	Detected with probability low
4-6	Sometimes	Detected with probability currently
1-3	Seldom	Detected with easy

2) **System analysis detection** , evaluation system like do testing , inspection andcontrol quality
3) **Effectiveness detection** , efficiency how much effective detection .

After determining the assessment of potential and danger by brainstorming with the team and staff at the orphanage where the data was taken, the S, O, and D results were obtained as follows.

Table 4. Risk assessment

Potential	Danger	Risk assessmesnt		
		S	O	D
Head hanging	Nerves neck squeezed	8	4	4
Hands in to fingers	Injured hand	5	2	5
Back bent	Nerves squeezed	7	4	2
Hand	Scratched / abraded hands	4	2	2
Legs dangling	scratched / pinched foot	6	4	3
Hands affected wheel	Scratched / injured hands	8	2	5
Legs affected wheel	Scratched / pinched feet	5	4	1

Potential refers to the ability or capacity of something to develop, produce, grow, or provide benefits. It includes positive possibilities that can be achieved or utilized. The opposite of danger refers to the possibility or risk of loss, injury, or other negative impacts, including threats that can occur as a result of an action or situation.

Following This is table RPN assessment , obtained with multiply Severity (S), Occurance (O), Detection (O) potential values risk with method FMEA

Table 5. Results of FMEA Method

No	Activity	potential	Danger	Risk potential assessment			RPN	Mitigation
				S	O	D		
	Sit	Head hanging	Nerves neck squeezed	8	6	4	192	Elevation backrest and cushions on the back neck
		Shoulder no balance andhand caughtwheel	Sore and scratched consequence backrest hand	5	2	5	50	Backrest A little morehard or bearing more thick
		Back bent	Nerves squeezed	7	4	2	56	Suitable bearings withback
		Hand	Scratched / abraded hands	4	2	3	24	Expansion cushion on the backrest hand

Categorization criticality , for example high , medium and low. example categorization can arranged with to count highest and lowest RPN values , with examples of parameters S, O, and Dwith scale rank 1 to 10. So the highest RPN value is 10 x 10 x 10 = 1000 and the value lowest 1 x 1 x 1 = 1 arranged in category as following :

Table 6. Categorization danger

RPN	Category
501 - 1000	Tall CurrentlyLow
251 - 500	
1 - 250	

Researcher perform Cut-off point for category > 200, category while it is ranging between 100 and 199, and categories low ranging between 1 and 99. The RPN value is the number over 200 will considered need analysis more further and action corrective (19). Cut off point was carried out For make it easier determine priority handling and control For every potential failure . Whenthe RPN results are low so still will done action recommendations to be more reduce RPN valueand even until No There is impact . With existence ranking criticality or priority researcher can quick determine with ranking category medium and high must done action recommendation as handling and control .

4. Discussion

Based on from results RPN calculation above can be known that potential risk accident with largest RPN value is " Head "hanging " that is own danger nerves neck squeezed with RPN value is 192.Then furthermore is “ hand” caught wheel ” at the time chair wheel walk own potential dangerousin part around potential hand about fingers rims or wheels at the time that can just happen when user chair wheel miscalculation movement hand with The RPN value is 120. And the third is “ dangling legs ” has danger of scratched feet or squeezed when sitting position and chair still wheelsand Can more big when chair wheel walk with RPN value of 112. With third highest RPN valuemake priority action recommendation as action For reduce RPN value .

Figure 1. Ordinary wheelchair

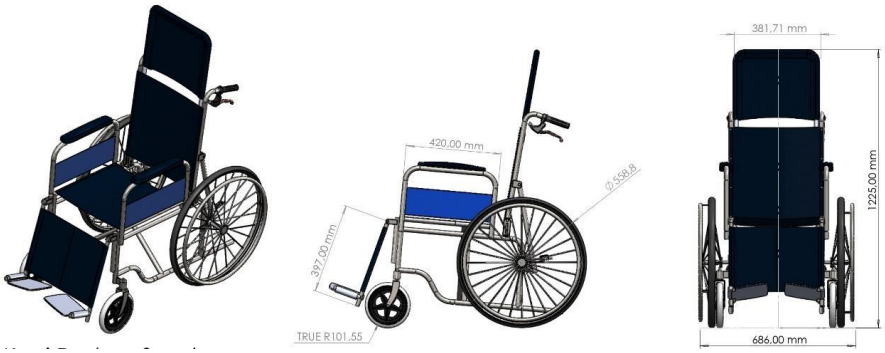

Figure 2. Design recommendations wheelchair

Based on results implementation modification For potential subtraction RPN value of 192 has been done on design plan recommendation that is , to give backrest head external or accessories extrasthat are usually sold apart or called with not included in purchase chair Wheels . Backrest solutionhead expected will provides comfort to the neck and head area at a time For lighten up load on theneck that supports heavy head .

And implementation a plan worth RPN 120 in the form of design is modify the framework that is below backrest hand in the form of a plate or pieces functioning iron as divider between user withwheels , on the chair wheels . With extend the iron plate framework chair wheel until closed perfectexpected for the event squeezed , rubbed or enter to fingers rims chair wheel can handled with good . Which is based on the results interview between to 4 respondents who have done previously.

And potential with RPN value of 112 in the form of design modification part lower or foot part with extend footrest on chair the wheel that the user's feet expect can free put your feet down without must think about gap big one on the chair footrest wheels . With so user whose feet shapedalmost resemble letter X number avoid from friction floor or caught wheels at the moment chair wheel walk .

5. Conclusion

Conclusion based on from results and discussions that have been done , then can concluded as following :

1. Based on FMEA analysis can known that based on results observation and interview found seven risk accident to the user chair wheels , three of them including danger extreme .
2. In the condition walk increase mark potential risk to the hands and feet, namely to the hands will face potential risk hand about bars or fingers rims chair wheels and on the feet will experience friction on the floor and potential risk caught wheel front . Condition This applicable before mitigation or proposal results study Not yet implemented .
3. Based on results data analysis can known that three failure modes with largest RPN value sequentially , which has disturbance health of the body's organs during sitting activities . ThirdThe highest RPN value , namely “ head " hanging " with value 192, hand caught wheel” withRPN value of 120, “legs dangling ” with value 112, will planned recommendation repair For third highest tier RPN value.
4. Based on results evaluation results analysis . Recommendation actions on the three highest RPN value that is designing modification chair suitable wheels with need users , namely modification addition part addition or accessories chair wheel external on the part on chair wheel , framework and parts lower chair wheel like footrest and footrest
5. Give mitigation or proposal in the form of A recommendation design that is backrest head thatcan removed and installed back , close all the framework that is below backrest hands shapedlike iron plates or chrome. And modification part lower with extend backrest from lower kneeuntil almost about footrest , at the same time extend footrest with Meaning For overcome dangling legs and club-shaped legs almost resemble letter X.

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