

Train is a high efficiency mass transportation which is suitable to increase life quality and support of high citizen mobility. The purpose of this paper is to produce some recommendations of improved railway carriage design which are accessible for disabilities, ergonomics and economics. Firstly, the research started with theoretical studies on the product design development, House of Quality (HoQ), visual displays design, anthropometry, and the needs of disabilities. Next step collected data from the open survey and then form the closed survey of 30 respondents who has physical disabilities and visual impairment to understand the passengers' need. The results of voice of customers shown that an easy access of disabilities people in the carriage has the biggest negative gap between reality and expectation for 1.16 and then following by space availability of wheelchair for 1.10, the seat numbering for visual impairments passengers = 0.85, and the ease of emergency aid = 0.71. The HoQ provided analysis of room 1 for customer needs, room 2 for voice of team design, room 3 for relationship matrix, room 4 for benchmarking, room 5 for technical benchmarking, room 6 for correlation matrix, and room 7 for weighted importance and relative importance. The QED results shown that the first rank of relatives importance was distance between seat with score = 0.618, the second was colour on seat numbering and train series = 0.561, and the third was emergency button = 0.439. New design recommendation of carriage design should contain of modified seat layouts, improved wheelchair and aisle space, added guiding blocks, emergency assistance buttons, additional folding chairs, and handrail adjustments. Alternative designs were successfully created and able to increase the seat number of the railway coach

Keywords: house of quality (HoQ), accessible train design, ergonomics, visual impairments

RE-DESIGNING OF RAILWAY CARRIAGES TO INCREASE ERGONOMIC AND ACCESSIBLE: A CASE STUDI OF INDONESIAN RAILWAY

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1. Introduction

High densely populated countries face various transportation system problems. The population density equals with the social's daily mobility [1]. Various kind of mass transportations are supporting the mobility, such as trains, buses, ships and planes. Train is land transportation with good efficiency [2, 3]. Train must be accessible for all parties, including children, adolescents, adults, elderly, and special needs passengers. However, there are often some problems in fulfilling those demands. These problems are still a big and quite complex homework for the developed countries like Indonesia. Transportation policies, railway infrastructure, railway modes, officers and passengers are still the main problem sources. Not only technical factors, but also cultural and ethical factors are a serious concern in order to produce a good transportation.

Research in public transportation accessibility for people with disabilities or with special needs has been carried out for a long time and continues to make significant progress. The main obstacles for people with disabilities are physical factors, infrastructure and passenger behaviour [4]. Therefore, the main solution is improving the understanding of

passengers' physical characteristics. The users, especially with disabilities, still experience problems in transportation, railway system still needs some improvements [5]. A good transport planning can improve services for all people, especially the elderly, children, visually impaired, deafness and disabled [6, 7]. Government regulations on the application of accessible public transportation are needed in order to provide appropriate services for disabled people [8]. There have positive correlation between comfort transportation and human stress [9].

Their needs studies and innovations on the railway carriage accessibility to improve comfort, especially for disabled people, children, elderly and pregnant women. The survey of the railway coaches' accessibility assessment was conducted to 30 passengers consisting of respondents with disabilities and visually impaired. All respondents stated that the railway accessibility needs to be improved. Some of the complaints were: the chairs were too upright, the seat number were unclear, especially for low vision passengers, the carriages number were not clear, there is no armrest, the distance between the seats was too close, and the access for the disabled passengers was difficult. Thus, the survey results conclude that an ergonomic and accessible train layout is not

only critical to maintain each passenger comfort but also tied to the economic value because they determine the passenger willingness to ride the train. Therefore, this research is critical to meet the comfort level as demanded by the train passengers especially the disabled passengers.

2. Literature review and problem statement

The paper [10] presents the results of how importance disabilities factor should be involved continuously as part of passengers right. There were still unresolved issues related to comprehensive research among train facilities, train carriage layout, ergonomics, accessibilities and economics aspect. There are many studies that have discussed the ease with which passengers can access trains for people with special needs, such as blind people, wheelchair users, and others. In addition, several researches related to passenger comfort through developments in the field of ergonomics. The aim of all of them is to be able to increase passenger satisfaction, better transportation life, and of course economically it will benefit the management. The more people who use the train is an advantage that affects many aspects of life, such as congestion, air pollution, and sustainable development. As a step towards the mentioned objectives, this study analyses the importance of accessibility in train.

The need of accessibility for disabilities is an important part in fulfilling their rights, thus their mobility in daily activities can still be done. Accessibility in designing public facilities includes transportation facilities [11]. One of the legal bases for the application of Indonesian Railway accessibility is in the UU RI No. 13 of 1992 concerning on railways article 35 that stated people with disabilities and/or sick people are have right to receive special services in the railway transport system. Accessibility requirements in Indonesia according to the Ministry of Public Works and Housing Regulation No. 30/PRT/M/2006 have to fulfil 4 elements: ease, usability, safety, and independence. However, there is no specific practical method on how to deliver the regulation in public. Therefore, this study provides a blueprint based on the disabled to build the practical method to deliver the corresponding regulation.

Research that discusses access for people with disabilities is the scope of infrastructure that must be considered, including: pedestrian clearways, steps and stairs, ramps, lifts, platforms, information, ticket machines, toilets, etc. [12]. It is also important to understand the perception of disability as a train passenger, such as information models, visual displays, and others [4]. Visual displays must pay attention to the level of color contrast and size, for example for low vision disabilities [13]. Complaints about the existing carriage design need to be considered in an effort to continuously improve [14]. The importance of the good experience of persons with disabilities while riding the train for the basis of repair [15]. A lot of research related to disability and trains is how the assessment process is carried out, such as assessments with multidimensional criteria [16]. Other studies have further prepared the ability of passengers with disabilities through educational modules to support mental and intellectual abilities in understanding train boarding procedures [17]. Different from the previous study, this study let the passenger with disabilities guides the solution in participative manner.

In the field of ergonomics, it is very widely implemented for train innovation. Knowing the needs of passengers to

be able to improve services is important in carrying out innovation [18]. Ergonomics for people with disabilities was crucial to improve accessible train carriage design, e.g. seat, door, etc. [19]. Moreover, the other research expands to provide queuing system innovation of trains platform to reduce the potential virus spread through participatory ergonomics [20]. The importance of analysing ergonomic risks while driving by trains that tend to sit for long periods of time, such as the emergence of the risk of Musculoskeletal Disorder [21]. Improving the utilisation of train ergonomics also very importance to increase passengers satisfaction. Rula/Reba analysis used to design ergonomics for train seat, door dimension, and train luggage position [22]. Thermal comfort as part of environment ergonomics was employed to increase passenger satisfaction, including six parameters of environment temperature, mean radiant temperature, relative humidity, air speed, metabolism, and cloth insulation [23]. The train design needed to pay attention to air flow in order to produce a small aerodynamic noise, using the principle of streamline flow [1]. Train vibration has strength in relation to human comfort and it can be used to predict maintenance time [24]. Passenger posture and behavior impacted on train passengers during operating the mobile phone [25]. All the researches were not yet tried to combine comprehensively all the ergonomics approach to design the train carriage layout and train facilities as disabilities passenger needs. Therefore, this study uses the voice of passengers with disabilities to select the critical design parameter to improve and the new features to add to the existing train carriage design.

3. The aim and objectives of the study

The aim of the study is looking for the best design for carriage seat layout based on ergonomics, economics, and accessible targets.

To achieve this aim, the following objectives are accomplished:

- finding the voice of customer related to ergonomics and accessible experiences as a train passenger. It included the disabled needs for ergonomics and accessible layout design;
- building a HoQ to explore technical benchmarking analysis and weighted importance factors;
- redesigning the existing layout based on HoQ results and disable needs in carriage layout.

4. Materials and methods

Based on current researches and theories, it can be written down that the hypothesis of the research are disability needs will provide redesign of train carriage layout more detail and more complex and Redesigning of train carriage layout will reduce the total number of seats. Disability in general is limitation in body function or structure, loss of sense ability, and difficulty in carrying out work or duties and dealing with the problem in their daily life [26]. Disability is a complex phenomenon that reflects the interaction between a person's body functions and the functions of the community where it lives. The new disability understanding is expected to see people with disabilities as humans who have limitations and disabilities yet still have the potential and beneficial to their surroundings. The design planning is the main factor and basis reference in improving the acces-

sibility and ergonomics of railway coaches. To simplify the product manufacturing process, the design needs to be done in the form of sketching and 2D/3D modelling. Good and detailed design can increase user satisfaction and reduce errors from the production process, thus designing is essential and important before the manufacturing process begins. The design as a systematic process that involves idea or concept formation, concept development and evaluation, creation and testing or implementation of services [27]. Conceptual design begins with «problem analysis» and «problem statement» prior to the conceptual design stage in the design process [28]. Problem analysis is a small activity but an important stage of the overall design process [29].

There are several phases in product design, there are information phase, the creative phase, and the analysis phase [30, 31]. The information phase aims to understand all aspects related to the product to be developed. This information should be collected as accurately as possible. The information collected are include initial product images, criteria for consumer desires for the product and its priorities, and product specifications. The creative phase aims to present alternatives that can fulfil the required function. One of the steps that must be taken is by determining the priority of the design using the Quality Function Deployment (QFD) matrix. The analysis phase aims to analyse the alternatives that have been made and make recommendations on the best alternatives.

The QFD concept was first introduced in Japan in 1969, and developed as a system in 1972 known as the Hinshitsu Tenkai System. QFD is very useful, especially when you are going to create new products/services, it also be used to review and improve existing products/services. QFD has two main understandings, translating customer or user needs so that the product has the desired quality characteristics (design stage) and describing the identified quality characteristics so that control points in production are maintained (production stage). QFD is not entirely new. According to the basic meaning and function [32, 33], described the various attributes of a product (goods/services) and service (service) desired by the customers into the functional components of the organization, it is believed that many parties can help the companies to improve customer satisfaction. The implementation of QFD consists of six stages [34]:

- 1) identification of customer needs;
- 2) identification of technical characteristics;
- 3) preparation of the relationship matrix;
- 4) the distribution of the expected quality;
- 5) technical comparison;
- 6) compile a correlation matrix.

The QFD implementation includes four phases: firstly, the product definition phase [35, 36]. The Product Definition phase begins by collecting the voice of the customers and translating customers' wants and needs into product specifications. This stage involves competitive analysis to evaluate on how effectively a competitor's product meets customer's wants and needs. The initial concept design was based on specific product performance requirements and specifications. The second stage is the product development stage. During the Product Development Stage, critical parts and assemblies are identified. Critical product characteristics are derived and translated into key parts and characteristics or assembled specifications. The functional requirements or specifications are then defined for each functional level. The third stage is development process. During the development

process stage, the manufacturing and assembling processes are designed based on product and component specifications. The process flow is developed and critical process characteristics are identified. The fourth or final stage is the quality control stage. Prior to the production launch, the QFD process identifies the critical parts and process characteristics. Process parameters are determined and appropriate process controls are developed and implemented. Furthermore, each inspection and test specification is developed. Full production is begun after completing a process capability study during prototyping.

The research design used in improving the accessible layout of railway carriages is quantitative research with a descriptive approach. Quantitative research methods can be defined as methods based on sampling and data collection. This study also used a descriptive approach to describe the object of research by describing the research results. Interview and surveys method were carried out on 30 respondents with visual impairments and physical disabilities to find out the voice of customers on the railway services, especially the accessibility to enter and mobilize inside the railways coaches. Visually impaired respondents filled the survey by the help of research companion. There were 12 wheelchair users, 8 walking stick users, 2 other people and 3 people with severe visual impairment, 6 people with mild visual impairments. The respondent age range was 19–57 years old, the spread of age range was not only among the college students, but also the elderly with various occupation backgrounds. Respondents aged <40 years were 22 people and respondents aged ≥40 years were 8 people. Fig. 1 shows the research stages in redesigning a train carriage layout thus it becomes more accessible and ergonomic by using HOQ as a data processing framework and designer ideas. The results of the HOQ will be used as the basis of making improvements design with an ergonomics approach.

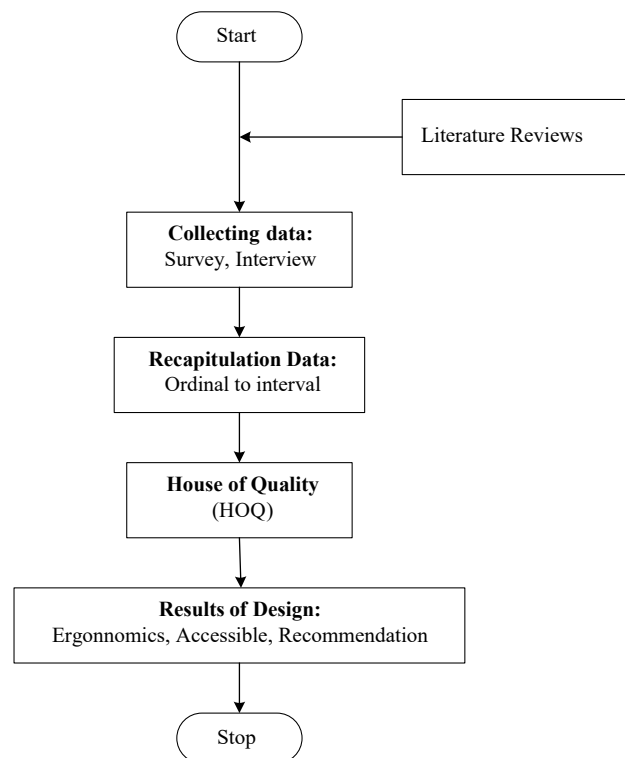


Fig. 1. Research stages on the redesigning an ergonomic and accessible carriage layout

Railway carriage data and human physical data were collected in the form of primary and secondary data. Primary data including data obtained directly from the research field such as documentation of train passenger seats, and measurements of train seat dimensions. Secondary data included technical drawing data for passenger train seats, layout dimensions of special carriage for disabled passengers, and Indonesian anthropometric data. Dimensional data of disabled was obtained from several previous studies that have been carried out as a reference because the data collection is still relevant to the current research. Moreover, the data also obtained from determined standard sizes, such as standard sizes of wheelchairs and walking sticks. Anthropometric data processing was carried out using Indonesian Anthropometry which has 36 body dimensions.

5. Railway carriage redesign results

5.1. Customer needs of ergonomics and accessible train carriage

The first step in designing the railway carriage is by knowing the voice of the customer. Table 1 shows the results of the customer assessment recapitulation on existing condition and expectations through a questionnaire to 30 respondents with disabilities. From the table, it can be reported that there were 9 statements of needs from respondents to design train

carriages to be more accessible, including an easy access to in and out for disabled people with a negative gap of 1.16 from expectations, then availability of wheelchair storage=1.10, visually impaired-friendly seat number=0.85, ease of emergency aid=0.71. There was one passenger assessment stated that the existing conditions are better than expected, it was the disability-friendly aisle design=-0.26.

Voice of Customer (VoC) as shows in Fig. 2 needs to be firstly categorised because the HoQ design of this study would develop some of train products. Thus, the HoQ result can prioritise the development features of each product. Voice of team design or technical response consists of seat formation, distance between seats, wheelchair space area, number of wheelchair handles, wheelchair safety material, wheelchair storage space dimensions, door width, entrance ramp design, aisle dimensions, handrail dimensions, seat and carriages numbering colours, and emergency buttons.

From the Fig. 2 it can be explained that the seat design will affect the comfort of seats. The front distance of the seats has a big correlation to the comfort of seats because one of the qualities of a comfortable seat is the appropriate front distance. The wheelchair space area has a small correlation with the seat comfort level because the wheelchair securement length would stretch adjusted on the length of available distance. However, the securement stretch is easier to adjust according to the available space, thus the relationship is weak.

Table 1

Closed questionnaire result on assessing the existing toilets and their expectations

No.	Customer needs	Importance average	
		Existing	Expectation
1	Comfort of the train seats	2.615	3.227
2	Wheelchair securement availability	1.852	2.499
3	Wheelchair storage availability	1.852	2.940
4	Walking stick storage availability	1.852	2.232
5	Easy of access to in/out for disabled passengers	1.594	2.755
6	The door design suitability for disabled passengers	2.615	2.940
7	The aisle design suitability for disabled passengers	2.755	2.499
8	The ease of seat and carriage series number for visually impaired passengers	1.908	2.755
9	Ease of emergency aid	1.448	2,159



Fig. 2. Voice of Customers for an accessible railway carriage design

5. 2. HoQ for Improving train carriage design

HOQ is a framework of product designing process known as QFD [37, 38]. The HoQ has several parts; they are customer needs, planning matrix, technical response, relationship, technical correlation, and technical matrix [38]. The arrangement of the HOQ components is shown in Fig. 3. The HoQ for room 1 to room 4 is a summary of the voice of the customer which has been explained in the research objectives in the first part. Room 5 in the HoQ contains technical benchmarking or comparison of technical capabilities between existing products and expected products. For example, the seat formation in the existing carriage is a 2-2 formation joining and facing each other and the disabled seats are the same as general passengers, while the ideal expected value is a single seat formation facing the aisle, and disabled seats are made special. The distance from the seat to the front seat on existing products is 500 mm with changes as expected of 600–700 mm. The wheelchair space area for existing products is 1150×1000 mm, which is expected to be 1300×1000 mm. The number of wheelchair safety for existing does not exist to 4 (according to the number of wheels in the wheelchair). Furthermore, there is a need for a place to store sticks, seat numbering with the right color, and an emergency button which previously did not exist at all.

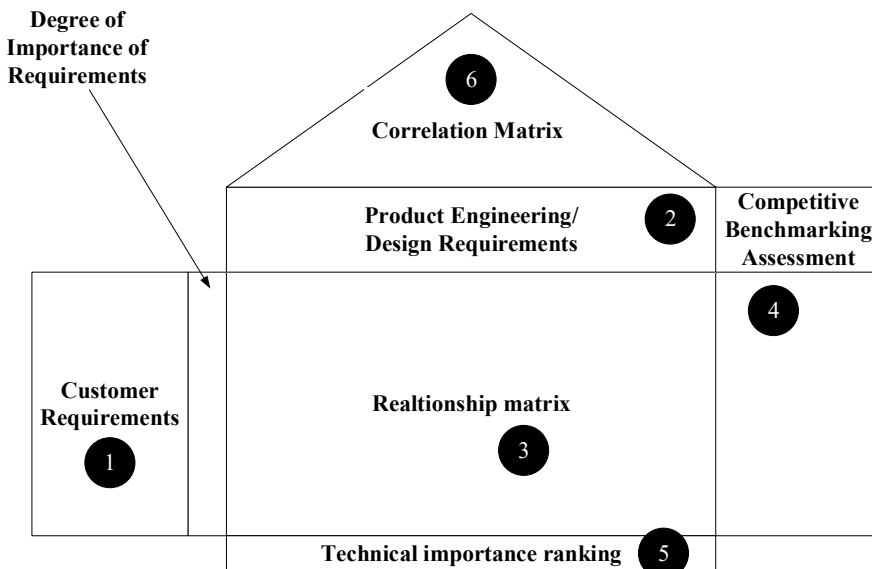


Fig. 3. The main components of HoQ [32]

The HoQ contains the correlation matrix, which is the correlation between the matrices of the voice of the design team. The correlation matrix consists of a strong positive correlation, a positive correlation, a negative correlation, and a negative strong correlation. For example, the voice of the design team 1.1.1-2 has a strong positive correlation, because of the wider the distance from the front seat, the more optimal the seat design, but still within the required anthropometric limits. Voice of the design team 1.2.2-6 has a strong negative correlation, the larger the dimensions of the wheelchair space, the narrower the wheelchair space will be. Weighted importance and relative importance (RI) are very significant in the HOQ stage to prepare the development of railway coaches. The main priority for disabled facilities is precise measurements of wheelchair space (RI=0.25), dimensions of wheelchair storage space (RI=0.22), followed by dimensions of walking stick storage space (RI=0.18). The in and out access will be prioritized

by width of the door (RI=0.38) and followed by the aisle design (RI=0.35). Before carried out the designing of train seats, disabled facilities, access to in/out, and train carriages navigation, it is necessary to determine the train carriages interior layout in order to clarify the boundaries of the designed space.

5. 3. New design of train carriage layout

Seats as the main facility of train carriages have different shapes, materials, and dimensions for each different type of train. However, there are several things need to be considered in determining the seat design, especially in making priority seats. Priority seats must be placed as close as possible to the entrance so that they are easily accessible for the user, including people with disabilities [39]. In addition, it is better to provide space for wheelchairs to be brought closer to priority seats. The OSJD-ERA Contact Group (2015) specifies a minimum amount of wheelchair space based on the length of train carriages as described in Table 2. Train carriages in Indonesia are generally less than 30 m, thus one wheelchair space is sufficient. According to existing research, train carriage layout design is still open to explore to find more comfortable for disable people. The research provided the best lay out design that involved some aspects of ergonomics, economics, and accessible for disable people, especially for wheelchair.

Disabled means having physical and/or mental disorders that can be a limitation for it to carry out proper or normal activities. Some criteria of disabled people include physical disabilities, visual impairments, deaf or hard of hearing, speech impairments, and mental health disabilities. Physical disability is a disabled person with physical limbs such as paralysis, bone/joint impairments, muscle impairments, or incomplete limbs. Mobility aid commonly used by disability people are wheelchairs and auxiliary crutches. Anthropometric dimension data is required in designing accessible infrastructure [40]. The wheelchair user group data is to consider the dimensions of smallest span population. Fig. 4 shows the standard wheelchair size used by disabled people [41]. This size is very important as a consideration in designing an accessible train layout.

Table 2

Determination of Wheelchair Space Number (OSJD-ERA Contact Group (2015, p.57) [39]

Unit Length	Number of Wheelchair Spaces by Unit
<30 m	1 wheelchair space
30–205 m	2 wheelchair spaces
>205–300 m	3 wheelchair spaces
>300 m	4 wheelchair spaces

Visual impairments is an abnormality of the visual system that can be categorized into three types, total blindness, low vision, and light perception. People with low vision and light perception can be categorized as mild visual impairments. Assistive devices commonly used by visually impaired people

are a walking stick. In public facilities, a guiding block is usually available as a path for visually impaired people with two patterns, a line (meaning straight) and a dot (meaning stop). In addition, people with visual impairments use Braille letters in the form of raised dots for reading. The reflection of accessible facilities is by providing a guiding block [38].

Fig. 5, *a* shows the existing layout for disabled railway coach, there is a disabled carriage in each series of railway coaches. Meanwhile, Fig. 5, *b* shows the recommended layout, which each railway carriage has a disability service. The layout in general had several changes according to the technical response results from HOQ. The diffable space previously 1150 mm (only dimensions of wheelchair space without seat space) was changed to 1690 mm (including dimensions for seats), located behind the toilet wall. The front distance of the seats for general passengers is 500 mm for seats facing each other, was changed to 300 mm for 1 seat, 600 mm for 2 seats facing each other in the middle. The 2-2 seat formation combined facing each other was changed to 2-2 split facing the center of the series. 800 mm aisle width changed to 840 mm. The number of priority seats has changed from 4 pairs of seats (for 8 people) with a maximum capacity for 4 wheelchairs to 1 priority seat with 1 wheelchair space and 2 seats for blind and disabled people that used auxiliary crutches. The total passenger seat capacity has changed from 64 seats to 75 seats. The number of toilets with disabilities has changed from 2 toilets to 1 toilet accessible and 1 toilet for public.

A wheelchair storage area was designed after knowing the wheelchair space area. Some passengers were more comfortable when they were sitting in the passenger seat, so the wheelchair can be folded up. The wheelchair dimension storages have a span of 700 mm, which is the distance of disabled passenger seat to the general passenger seat. Next step was determining the walking stick storage space dimension. The walking stick storage design in Fig. 6, *a* uses a locking system which is safer when exposed to the train vibrations. In addition, the placement of the walking stick storage is 780 mm from the base thus different types of walking sticks can fit into the holder. Therefore, the second alternative was chosen as the train carriage design. The dimensions used are 180×115 mm with a close placement.

Railway carriage entrance design was 800 mm and 900 mm for the doors of railway carriage series. The aisle was designed with a size of 840 mm which was 40 mm wider than the existing design. It is because of the seat size that has been determined by Indonesian Anthropometry is smaller than the existing design, leaving more than 40 mm for the aisle width. An overview of the aisle, outer door, and inner door was presented. Handrail height is 730 mm from the floor adjusted to the elbow height in a sitting position for wheelchair users or can be calculated through Indonesian Anthropometry, which combines the dimensions of elbow height in a sitting position (250 mm) and popliteal height (400 mm) and add an allowance. Apart from disabled spaces, hand rails are also available in the door and bathroom area as shown in Fig. 6, *b*.

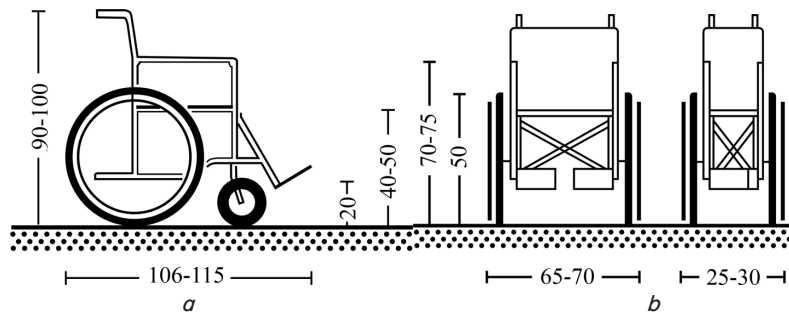


Fig. 4. Dimensions of a standard wheelchair used by the disabled [41]: *a* – side view; *b* – front view

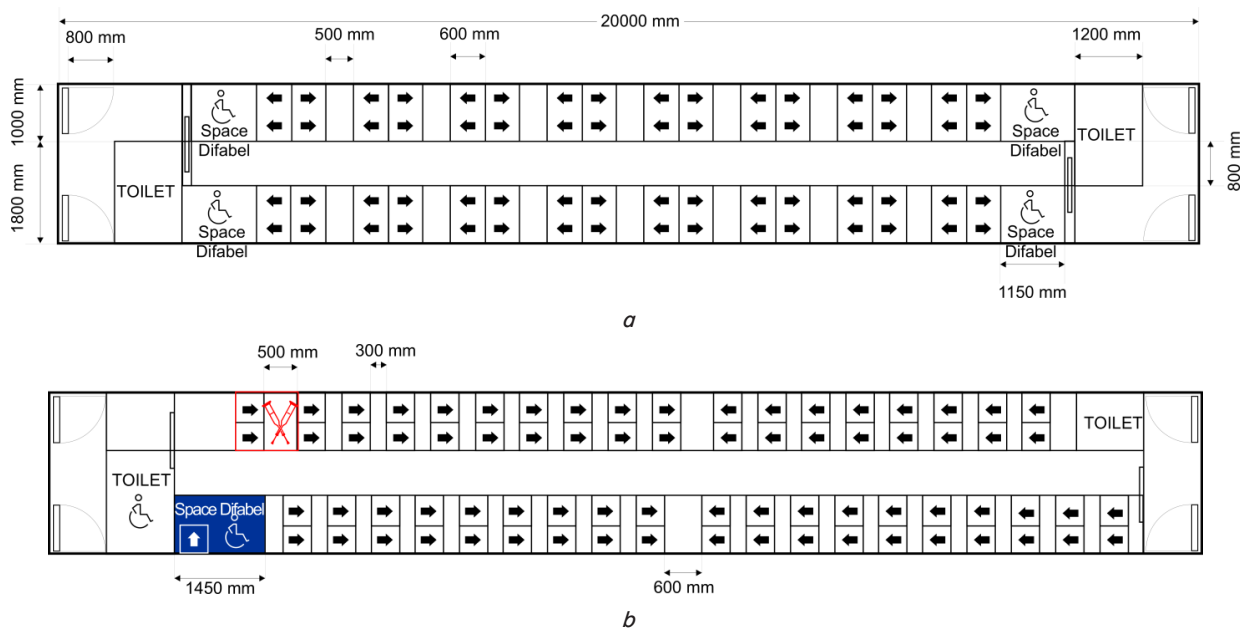


Fig. 5. Carriage design for increasing accessibility: *a* – existing train layout design; *b* – the proposed design based on the HoQ

The new design provides the navigation hints for the passengers with low vision. According to the interview results, the low vision passengers tend to count the seats they passed to find out their seat according to the ticket when entering the coach. The answer to that is by providing a seat-map as shown Fig. 7. Thus, the passengers who will enter the train carriage will know where the exact position of the seats.

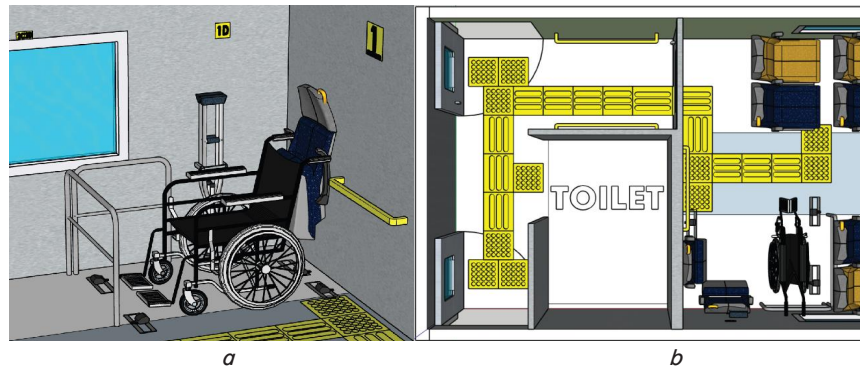


Fig. 6. Accessible innovation for new design: *a* – placement and space for wheelchairs; *b* – guiding blocks directing to the toilet and exist door

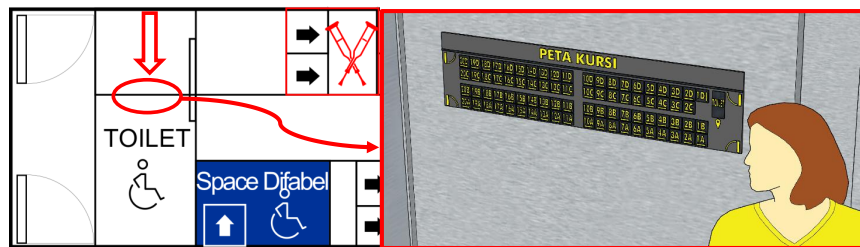


Fig. 7. A seating map placed in the toilet to make easier for disabled passenger to return to the seat

In addition to the survey results the team design has a suggestion to increase the overall accessibility. Moreover, the information obtained from the seat map includes the position when the passenger reads the map, the seat number, the direction towards the seat, the location of the toilet, and the location of the door. In addition to the seat maps, recommended accessories for an accessible train are guiding blocks for visually impaired passenger. Guiding block is a tactile ground surface along the road that has two patterns. Lines mean to go ahead, and dot or round patterns mean to stop.

6. Discussion of the new carriage design evaluation

Based on existing research, it is important to combine ergonomics and accessibility aspects in designing train carriage's to be more comfortable and humane. This study results a practical method to adjust the train carriage design accessibility that controllable based on the passenger with disabilities demands. This study applies participative ergonomic approach by listens to the need for accessibility of the passenger with disabilities. The outcome of the design is the train carriage's layout that acceptable by passengers with various kinds of disabilities. Therefore, this study provides a solution to continuously improve the accessibility level of a train carriage.

An initial survey of the experience felt by train passengers shows that there are still many complaints related to the existing layout, including seat comfort, availability of wheel stor-

age, comfort seats, and ease of access. The results of a survey of users (passengers) describe what things need to be improved as presented in Table 1. The HoQ method in 7 rooms can provide the desired design need, which is a meeting between customer desires and the ability of the designer (company) to be able to fulfill them. Knowledge of the needs of people with disabilities, especially people driving wheelchairs, and knowledge of the limitations of the human body's posture were to be the basic design improvement. The company also provides a minimum limit on the number of seats that must be available so that the operational economy can be met.

The design results of Fig. 5, *b* that have been given show several changes, including the distance between the seats, the wheelchair space, improvements to the door dimensions, aisle width, handrail dimensions, layout maps, and others. The resulting new layout design is able to increase the space for wheelchairs by modifying each carriage to provide 1 space compared to the previous 2 spaces. One space per carriage is sufficient to accommodate the average needs of passengers each departing. By selecting one room for disability, it can also increase the number of regular seats significantly. Other accessories such as layout maps (Fig. 6, 7) for the visually impaired and passengers with wheelchair are also innovations that need to be developed by all trains, so that passengers are more independent and have easy access in train carriage.

Navigation or directions are important in designing an accessible train. Things considered in navigation design according to the HoQ result are the seat and train series numbering colour and the emergency button. In accordance with the Web Accessibility Initiative, there are several colour combinations which will be easily seen by users or in this case are passengers, especially people with visual impairments with low vision. The combination of background and foreground has a contrast ratio of at least 4.5:1 or for large text, it has a contrast ratio of 3:1 according to WCAG 2.0 requirements. The existing series number has a ratio below 3:1, thus a new design was carried out, it is a combination of yellow and black. The seat numbers in the existing series have a ratio above 3:1, in order to have a colour element, the seat numbers are equated with the series numbers, using a black and yellow combination. The recommended size for seat numbering of disabled passengers is 100×100 mm and the circuit number is 200×200 mm. Furthermore, in accordance with the HoQ, there needs to determine an emergency button so the officer can help quickly in case of an emergency situation or when there is a disabled passenger needs help.

The importance of navigation is even more critical for the passengers with low-vision. The seat map is provided as a solution for miscalculation or error in seat checking by the low-vision's passenger during boarding. For example, a passenger with a ticket 12 B, will approach the first seat number to check whether they entered from seat number 1 or number 20, when the passenger is entering through seat number

20 then he/she will be counted backward while passing through each seat row until finding seat number 12 B. This is because the seat number is too small thus it cannot be seen from a certain distance. The seat map should have embossed (tactile) design in order to make it easier for visually impaired passengers. The embossed design uses the alphabet (not Braille) thus it can be used simultaneously for general passengers.

Also the safety in navigation also taken into the account by proving guiding blocks so that the visual information provided by the new design can easily consumed by the targeted visually impaired or low-vision train passengers. Providing maps or plans with a tactile model in public facilities will help visually impaired people to be more independent in their mobility. Raised pattern design of a plan or map will help people with visual impairments. Moreover, the determination of colour is also very important for people with partial visual impairments (low vision and light perception). Contrasting colours like yellow, neon green, and bright pink on a dark background will be easier to notice (eye-catching).

The findings of this study complete the ergonomics solution for public transport human factor design. The side-by-side comparison of this study previous public transport human factor studies is provided in Table 3. This study outputs an adaptive method to continuously update the accessibility of a train carriage design. In contrast, the study [20] directly manages the situation around the station platform through visual information feedback. This study shares similar concept with study [22] but this study focuses on accessibility for passengers with disabilities. Compared with the human factor design derived from technical parameters by study [23] and [1], this study provides adjustable design control due to clear subjects.

This study has provided a design recommendation to improve rail carriage accessibility for wheelchair bound passengers and visually impaired passengers. The recommendations are the result of the participative ergonomics approach implementation by implementing QFD to specific segment of the passengers which is passenger with disabilities. Hence, this study also provides a practical method to implement an adaptive overall human factor system control through for system redesign based on the VoC.

The limitation that imposed in this study is current adaptive design is not directly adjustable. In the future, it is necessary to develop a more user-friendly layout design with direct feedback, especially for passengers with special needs. One of these developments is innovation in assistive technology by taking advantage of advances in information systems. Hence, the direct real-time engineering control can be applied to monitor overall accessibility of the passengers. Awareness and culture of the surrounding community also need to be improved and fostered so that interactions between normal and disabled passengers can be well established.

7. Conclusions

1. Based on the results of the initial questionnaire to economy train users, there are complaints when using trains with a 2-2 seat formation, join, face each other. Therefore, a new train seat was designed by considering accessibility and ergonomics factors through an anthropometric approach. After collecting data through in-depth interviews by 30 respondents with details of 8 respondents with visual impairments and 22 respondents with physical disabilities, it was found that the need for facilities for the disabled were chairs with a comfortable design, wheelchair space along with wheelchair securement, stick storage, wide doors and aisle, which adapts to the needs of the disabled, handrail, ramp at the entrance, seat numbering and a clear train series along with navigation on the train.

2. Based on HoQ process, there were several changes recommended to improve the accessibility and comfort of train passengers, especially passengers with disabilities. The recommendation was to adjust the layout of the passenger seats facing each other in the same direction with the distance between seats was 285 mm for 1 seat, 600 mm for 2 seats facing each other in the middle. The 2-2 seat formation combined facing each other is changed to 2-2 split facing the center of the series. Aisle width changes from 800 mm to 8400 mm. The number of priority seats has changed from 4 pairs of seats (for 8 people) with a maximum capacity for 4 wheelchairs to 1 priority seat with 1 wheelchair space. The total passenger seat capacity has changed from 64 seats to 79 seats.

3. Accessible should be improved by installing infrastructure for disabilities such as handrails, guiding blocks, seat layout maps for low vision/visually impaired people are also improved, and train seat numbering. Train design recommendations to be more accessible by adding guiding blocks and train series maps in tactile form.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Table 3

Comparisson with other studies

Study	Adaptive	Feedback	Response	Object	Subjects
This study	✓	Voice of Customer	Indirect	Train Carriage accessibility	Train Passengers With Disabilities
[1]	✓	Visual Information	direct	Mass rapid Transit Queue System	Mass Rapid Transit Passengers
[22]	✓	Voice of Customer	Indirect	Jeepney	Jeepney Passengers
[23]	–	Technical parameter	Indirect	Mass rapid transit Station Elevator	Public
[1]	–	Technical parameter	Indirect	Mass rapid transit aerodynamic noise	Public

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