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SYSTEMATIZATION OF ERGONOMIC AND INCLUSIVE PRINCIPLES FOR DESIGNING INTERIORS OF AUTONOMOUS VEHICLES

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Abstract

The use of authonomous vehicles (AVs) offers possibilities for providing improved passenger experience and comfort as well as independent travel for persons with different types of impairments. This paper provides an analysis of ergonomic principles related with vehicle interiors, as well as principles of inclusion. This is done with the goal to withdraw key recommendations that need to be applied in the design process. Those recommendations are systematized as a list divided in several categories and organized in a manner that is easily understood and applicable in the vehicle interior development. In addition, this paper presents the design process of a self-driving shuttle interior in order to illustrate the practical application of the provided lists of ergonomic and inclusive principles and highlight their importance.

Key words*: ergonomics, inclusive design, human-centred design, autonomous vehicles, vehicle interior design*

1 INTRODUCTION

Vehicle ergonomics is a daunting interdisciplinary task which requires the application of knowledge from various disciplines. On one hand, it deals with physical constraints of users that need to be taken into consideration when designing the space, which is where following anthropometric measurements is the most useful approach, and on the other hand there are biomechanical, sensory and cognitive limitations that are also crucial to know when attempting to achieve comfort, convenience and safety [1]. These limitatations are even more specific when addressing the needs of persons with impairments. This complexity is why a common approach used by designers in the development is the “humans as a systems component”. In this approach the human is considered to be a part of the vehicle interior system that is being designed and in this way the users’ performance, preferences and perceptions can be captured and evaluated [2].

AVs with highest levels of automation eliminate the need of a driver and therefore exclude the need to apply one segment of the ergonomic recommendations and constraints related with the driving tasks. However, the engagement of passengers in various non-driving-related activities during the ride opens up the possibility for re-thinking the design of the interior space which is a process that imposes new ergonomic challenges. Therefore, researchers investigate possible driving scenarios to establish optimal passenger positions [3]; methods for virtual development of interior concepts based on flexible virtual models to support vehicle packaging, seating positions, passenger view and safety-relevant aspects [4]; simulations using the Wizard of Oz method to understand human behavior and passenger-vehicle interactions in highly automated driving [5, 6] etc. Moreover, experts in the field of human-factors of automated driving elaborate that the new ergonomic challenges for self-driving cars are related to the vehicle-passenger interactions, such as: determining the interaction when the attention of the user needs to be captured, for example during possible transitions of control between vehicle and user; determining the interaction between AVs and conventional cars and other road users such as cyclists and pedestrians; and exploring training programmes so that users are instructed how to use automation in a safe and acceptable manner [7]. This means that additional effort needs to be placed in designing the user interface (UI). Designing an accessible UI is equally important as designing the inclusive interior space of the vehice. In order for the vehicle-passenger communication to be successfull regardless of the passengers’ biomechanical, sensory and cognitive capabilities, universal design principles need to be followed when developing the interface of the vehicle [8].
Providing fully ergonomic and accessible self-driving car models is likely to result with a higher employment rate, faciliated individual health management, increased frequency of travel, reduced traveling costs, and other benefits of persons with impairments which will help them maximize their independence [9]. The need for independent travel and participation in social activities is why persons with different types of disabilities are predicted to be the early adopters of self-driving cars, expressing a strong interest in purchasing or using an AV [8].

This paper aims to provide an overview of ergonomic and inclusive principles for vehicle interiors and vehicle UIs and systematize the crucial points that need to be established as standards, or minimum requirements, in the AV interior design process. After elaborating the literature analysis and providing the lists of recommendations, the last section of this paper explains the method for their practical application using a design example.

2 LITERATURE REVIEW IN THE FIELD OF VEHICLE ERGONOMICS

The thorough literature analysis helped to gain better understanding of the key factors that influence vehicle passenger ergonomics and to pinpoint which features need a special design approach in order to provide accessibility for all. The review is based on the following main categories: seating, ingress/egress, controls and displays, and fearures for inclusion.

2.1. Seating

Research on this topic is mainly focused on the comfort of sitting in vehicles in the context of preventing factors that can cause body pain or injury. The conclusions include specific and useful data on the correct sizing of the seats, guidelines for defining the shape of the seats and the materials used to allow optimal temperature, air and humidity circulation, as well as guidelines for defining the angles of inclination to ensure proper body support and position of the skeletal joints closest to their neutral state. For example, Reed, Schneider and Ricci emphasize the fit, feel and support seating parameters (fit – linear dimensions related with anthropometry (Fig. 1); feel – related to stimuli located in the skin; support – related to body angles intended to influence the posture (Fig. 2)) [10].

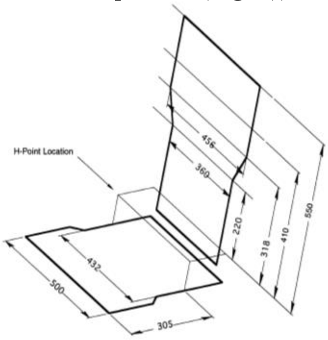

Fig. 1 *Fit seating parameters [10]*

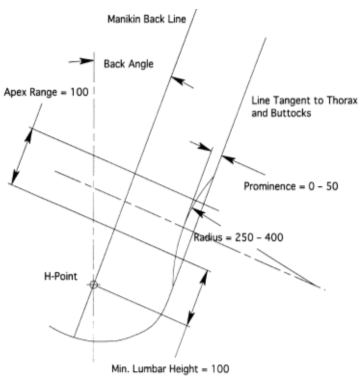

Fig. 2 *Support seating parameters [10]*

Modern vehicle manufacturers have the vision of developing seats that provide added value to passengers and create a whole new sitting experience whilst also providing maximum safety. This does not only mean designing the seats with various angles of adjustment and options for rotation, but also smart seats that: can "memorize" previously selected position preferences; have options for heating or cooling; massage; have airbags with adjustable thickness; equipped with speakers for playing music; even capable of tracking the passengers' psycho-physiological state in order to make fast adjustments if uncomfortable sitting is identified [11, 12].

For example, the Faurecia group and the company ZF are working on a collaborative project for the development of new models of power seats. The online publication of SAE International explains that this type of seat has electronically powered 60-degree recline position and 15-degree swivel, and it combines the seat, safety seat belt, and airbags in one package in order to provide maximum safety in each possible chosen sitting position [13].

2.2. Ingress/egress

One vehicle feature that is actually part of the design of the vehicle exterior, but needs to be taken into account as closely related to the general perceived ergonomics of the interior, is the design of the door opening. The shape and sizing of the door opening affects the comfort of ingress/egress. Multiple researchers are devoted to the analysis of the factors that influence this process. Results emphasize that the key parameters that determine the ingress/egress ergonomics are the height of the roof and the seat placement (distance from the front seats to the dashboard and from the back seats to the front seats) [14]. Other parameters that need to be taken into consideration are: the height of the floor, the height of the seats, the width of the rocker, and the angle of the door opening that dictates the foot passage space (Fig. 3) [2]. Some researches investigate the influence of the door opening shape on the perceived comfort during entering and exiting. Studies involving users from different statures and commercial vehicle models with different contours of the door opening conclude that the geometric contours are rated as more comfortable to use in comparison to more rounded shapes with a higher angle of inclination of the windshield and a lower roof (Fig. 4) [15]. Of course, the larger width of the opening has better ergonomic properties as well.

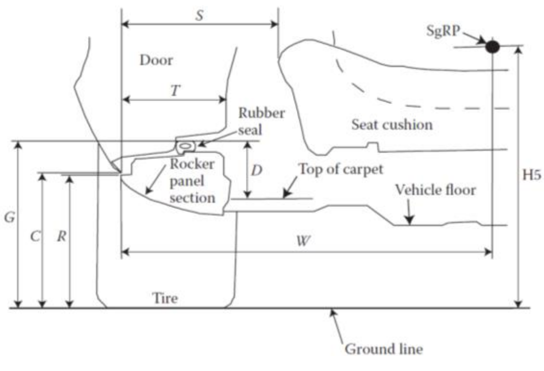

Fig. 3 *Dimensions relevant for ingress/egress comfort [2]*

Fig. 4 *Comparison between a door opening rated as most comfortable (left) and least comfortable (right) during ingress/egress in a research involving 9 city cars while investigating the relation between the door opening contour and ingress/egress ergonomics [15]*

AVs have a greater possibility to provide maximum ingress/egress ergonomics due to several reasons listed below.

- The interior volume is liberated from the installation of a standard steering wheel and driving controls which may not be present in the AV or may be designed as retractable when the car is in a full autonomy mode.
- The seats in AVs have more freedom of translation and rotation, which means that when the door opens, the seat can be moved aside for easier entry and accommodation of passengers.
- There are several options for door-opening methods, allowing wider ingress/egress space. AVs for shared rides usually have larger dimensions and are designed in the form of shuttles where sliding doors are typically used. Sliding doors, combined with seats positioned to face each other, leaves free space in the central part for an ergonomic ingress/egress.

2.3. Controls and displays

The placement of controls and displays in the vehicle interiors is a process that requires the combination of anthropometric data, standards and regulations (SAE, ISO). The physical measures of individuals in a sitting position should be considered. In order to determine the comfortable reach zones, the main dimensions of male and female persons belonging in the 5th and 95th percentile in a sitting position are needed [16]. These dimensions are important not only for optimal sizing of the seats, but also for the correct placement of all controls. Authors also define the most ergonomic body angles when sitting in a vehicle which dictate the placement and shaping of all other components nearby the occupant (Fig. 5) [17, 18].

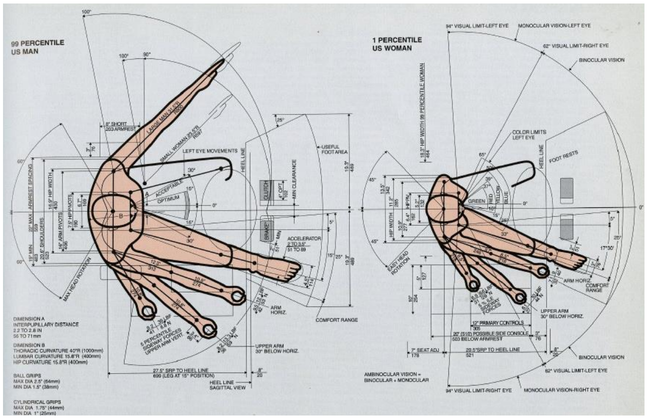

Fig. 5 *Reach zones for locating control areas [17]*

Researchers also provide information regarding the most comfortable angles of head movement which help to position the controls and displays in locations where they can be operated by minimum head and eye movement of the user, reducing neck flexion, extension and bending, and increasing the efficiency of use [2, 17, 18]. Minimizing the operation effort can also be solved by applying Fitts' Law according to which to reduce the difficulty and time to use a control (touch target) the ratio between the distance to the target and the width of the target needs to be reduced [2]. This means that one option is to place the control closer, and another one is to increase the size of the control.

Modern vehicle models have reduced amount of buttons and offer displays and touch panels for providing all the necessary controls and commands. However, displays and touch panels bring additional ergonomic challenges.

Attention should be paid to the placement and size of the touch zones as the fingers have a larger touch area, but also eliminating glare and issues with reduced visibility due to prints or scratches.

Guidelines [19] for the touch panels include the appropriate angles of inclination and distance from occupant for ease of use. However, the tendency of people to unconsciously tilt towards the screens [20] reduces the ergonomic properties of electronic devices by causing the neck to bend, which places additional strain on the neck and shoulder muscles bringing the body into an unnatural position.

Virtual reality (VR) and augmented reality (AR) play an important ergonomic role in this field as technologies that do not require physical screens and replace them with flexible digital solutions. In addition to windshield projections with VR and AR, the latest technologies support the development of smart surfaces (Fig. 6) in the form of displays integrated with the aesthetics of the interior (https://www.yfai.com/en/smart-surfaces), or the development of multifunctional, intelligent platforms for the instrument panel (Cockpit Intelligence Platform (CIP)) [21].

In addition, the use of voice controls and personal assistants has a significant impact on interior comfort. Voice controls and sound notifications facilitate the vehicle-passenger interactions because they enable spontaneous communication without wasting time on locating touch commands.

Fig. 6 *XIM18 concept model featuring functional interior surfaces, Yanfeng, 2017 (image source: https://www.yfai.com/en/the-next-living-space)*

2.4. Inclusion

To understand the needs of users with impairments, it is important to consider the most common types of disability. The American Intelligent Transport Association [22] states three main impairment categories: vision impairment, hearing impairment, and mobility impairment. Persons belonging in the first category face greatest difficulties to move independently as they must have full faith in the aid-devices that help them to move through space. Non-visual methods of communication are important to them, as well as devices that help them orient themselves in space and detect obstacles. For persons belonging in the second category, it is important to convert all sound signals into visual and textual modes of communication. Persons belonging in the third category have requirements regarding the physical characteristics of the space because they use mobility-aid devices such as wheelchairs, crutches, canes, walkers etc. and often have problems with road obstacles, ingress/egress and accommodation.

According to these facts, the difficulties of persons with reduced vision and hearing can be reduced mainly through a different approach of designing the vehicle UI, while reducing the difficulties of persons with mobility impairments requires adaptations of the physical space.
In order to adjust the interior space according to the needs of persons with mobility impairments it is important to consider the measurements of the individual together with the aid-device (Fig. 7). Anthropometric measurements of persons with mobility impairments include scalar data that helps determine the interior clearance and positioning of control units in the reach zone of the occupant [17].

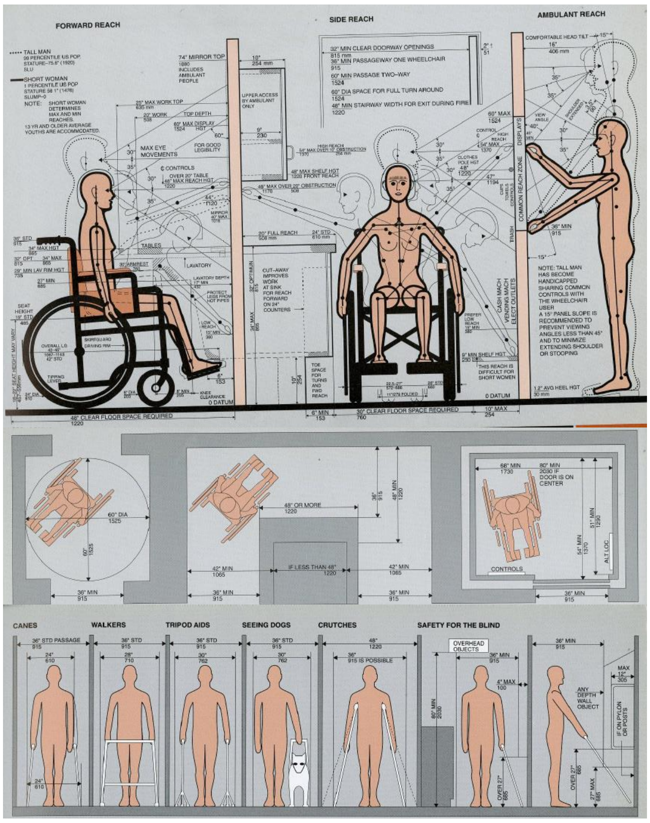

Fig. 7 *Basic measurements that need to be considered to adjust the space for persons using mobility-aid devices [17]*

Aside from adjusting the physical dimensions and providing additional features for easier ingress/egress such as ramps and handles, another important safety aspect for accommodating persons with mobility impairments, particularly wheelchair users, is equipping the vehicle with improved occupant-protection systems. Such systems include: auto-docking wheelchair devices, three-point lap/shoulder-belt restraint systems with vehicle-floor-anchored pivoting bars, additional support in the knee area and in the back-neck-head area [23].
Regarding the development of an inclusive UI, there are numerous recommendations for the design of the general layout, wireframe, graphical elements, typography, color combinations and types of messages. The visual interface must be simple and intuitive and its' appearance needs to be useable by persons with visual impairments such as visual acuity loss, tunnel vision, central vision loss, night blindness, color blindness etc. Available guidelines in literature for accessible design of the visual UI include [24, 25, 26, 27, 28]:

- using a structure corresponding to the users' mental models;
- avoiding cosmetic graphics;
- offering text and icon alternatives for conveying messages; using filled icons instead of outlined;
- using an AAA contrast between the text and the background;
- avoiding red-green/blue-yellow color combinations;
- limiting the number of colors to a minimum;
- using sans-serif fonts such as Ariel;
- using a minimum font size of 12pt;
- using a ratio of 3:5 between the width and height of the characters;
- providing sufficient white space around buttons etc.

Another crucial aspect of the UI is to provide multiple ways for input and output of information. Multimodality is commonly used as a term related with inclusion and interfaces. Using a combination of visual, sound and tactile modes of communication makes the interface useable for persons with different types of impairments. Sources [29] state that for persons with reduced sight the combination of tactile and visual signals is less effective than using these signals in a combination with sound messages as well. There are additional recommendations regarding the characteristics of the sound and tactile messages which are included in the final systematization of principles. For example, it is important to provide an option for volume adjustment, the volume of the sound notification needs to correspond to the urgency of the message, all ambient sounds need to be minimized, an option for reviewing the content through short audio plots of each section can be provided, allowing the voice commands to be expressed and given to the system in multiple ways etc. [30, 31].
However, multimodality as a concept needs to be used with caution and filtering of the messages is needed in order to avoid cognitive overload of the users. In that sense, one research [29] emphasizes the following three rules for establishing a good system-user communication:

- quality (sharing true information);
- quantity (never sharing more/less than necessary);
- relevance (sharing only relevant information) and manner (short and concise messages).

3 SYSTEMATIZATION OF PRINCIPLES

The conclusions from the conducted research resulted in the systematization of principles for ergonomics and inclusion as a basis for designing interiors of AVs. The principles are specific guidelines which need to be used as minimum design standards in the AV design process and they are divided into 2 categories: general guidelines for dimensioning the interior and the components with which it is equipped; and guidelines for designing the UI in order for it to be maximally inclusive. All systematized lists of guidelines and recommendations are provided in this section (Table 1, Table 2).

Table 1 Guidelines for designing the AV interior

Characteristic	**Optimal dimensions and recommendations**	
Type of vehicle	For shared rides, 4 - 5 passengers	
Wheelbase distance	Min. 3200 - 4000 mm	
Interior width	Min. 1600 - 2000 mm	
Door type	Opening	Automatic side sliding
	Shape	Rectangular
Door dimensions	Width	Min. 720 - 915 mm
	Height	1400 mm
Type of ramp	Fold-out housed in the doorway or in-floor tucked into the floor	
Ramp dimensions	Width	760 mm
	Length	132 mm
	Angle	10 °
Seat configuration	Adjustable backrest angles, adjustable seat height, adjustable lumbar support, back-forth translation, left-right rotation, complete seat folding for freeing interior space	
Seat dimensions	Seat width	432 - 500 mm
	Seat depth	450 - 500 mm
	Backrest width	456 - 483 mm
	Backrest height	550 - 635 mm
	Lumbar support height	150 - 300 mm (adjustable)
	Lumbar support radius	250 - 400 mm
	Backrest angle	At least 10 - 20° (up to 60°)
	Foam thickness	Min 70 mm
	Foam density	30 kg/m3 (with additional cushions in the thigh-contact area)
	Seat position adjustment	112 mm vertical 178 mm horizontal
Seat movement	Translation	800 - 1000 mm
	Rotation	15°
Safety systems	3-point seatbelt incorporated in the seat Additional seatbelts in each position for fastening wheelchair users Wheelchair docking system	
Additional comfort features	Folding armrests placed at height of 200 mm from the seat with adjustable positions Option for dividing the space between passengers Folding tables placed at a distance of 300 - 325 mm from the SgRP and at a height of 100 mm from the central line of the passengers' thigh bone	

Table 2 Guidelines for designing the AV UI

Characteristic	**Optimal dimensions and recommendations**
Types of control devices	Touch screens (tablets or smart surfaces) and a HUD
Positioning of control devices	Touch screen should be placed not closer than 208mm sideways from the central line of the passenger in a seated position and not further from additional 127mm (central line + 208mm + 127mm) HUD messages should be at an eye level, with a height of about 700 – 800 mm from the seat, displaying information in the maximum angle range of comfortable head and eye movement - 0° to 30°

<table>
<tr><td rowspan="1">Content of messages</td><td colspan="2">Quality – only true information
Quantity – never sharing more or less than necessary
Relevance – the shared messages must be relevant
Manner – fast and precise communication without delay
Sharing information according to priority based on the focal activity and end goal of the passenger
The number of interactions should be as little as possible</td></tr>
<tr><td rowspan="3">Use of multimodality</td><td>Visual communication</td><td>Touch screens and HUD</td></tr>
<tr><td>Sound communication</td><td>Voice control
Personal assistant</td></tr>
<tr><td>Tactile communication</td><td>Seat vibrations</td></tr>
<tr><td>Color and contrast</td><td colspan="2">Use of color to share a message (example: red - stop, orange - warning, yellow - attention, green - security, blue – information)
Use of dark and light color combinations to achieve contrast
Use of complementary colors instead of adjacent colors in the color wheel
Use of strong contrast between the background and text - at least 4.5: 1 (AAA), or 3: 1 (AA) for text with 24px or 29px bold font
Suggested color combinations with AAA contrast: #18183f and #25c34a, #39f491 and #470655, #73f0ad and #080bb0
Use of patterns and textures to emphasize contrast
Mmaximum number of colors used - 2 to 3 (or shades of one color)
Without the use of red-green and blue-yellow combinations
Conveying messages not only through color, but in combination with text, symbols, sound
Monochromatic variant should be available</td></tr>
<tr><td>Structure</td><td colspan="2">Use of Gestalt principles
Consistent layout
General organization that fits the mental models of the users (expected positions of content)
Content divided into sections that are clearly delineated - menu, map, buttons, info header and footer
Central placement of the most important information
Constantly available navigation elements
Clearly defined clickable zones and an explanation of how they are used - through the appropriate shaping of buttons in combination with symbols
Sufficient space between clickable zones - min. 20px - 30px for large buttons (example 500x100px on a 10-inch tablet with a resolution of 1920 * 1200 Full HD)
Use of an image blur test (min. 25% using the Cambridge Impairment Simulator) to check that the arrangement of the elements is clear - the following positions should be recognizable: the positions of the most important information (start / stop, map, menu, etc.); selection buttons; success / failure signals; warning messages</td></tr>
<tr><td>Graphic elements</td><td colspan="2">Use of text-symbol-form-color combination to convey information
Use of universally recognizable icons (example: exclamation mark - danger / warning, left - back arrow, right - forward / click arrow, padlock - lock, letter "I" - information, hand - stop, etc.)
Use of full icons instead of outlined
Use of the icons as standalone, without placing them in a circle / square
Use of images relevant to the text
Without the use of graphic elements that are purely cosmetic
Limited number of navigation elements - one map</td></tr>
<tr><td>Text</td><td colspan="2">One type of font
Sans-serif, non-decorative font
Recommended fonts: Roboto, Calibri, Arial
Minimum font size 12pt
Recommended height of the characters according to viewing distance: distance 35 cm - height 22 mm, distance 70 cm - height 50 mm, distance 1 m - height 70 mm, distance 1.5 m - height 70 mm
The required ratio between the thickness of the outlines and the height of the characters is between 1: 8 and 1: 6 for black letters on a white background and between 1:10 and 1: 8 for white letters on a black background
The required ratio between the width and height of the characters is 3: 5</td></tr>
</table>

	The recommended minimum distance between characters is the width of one outline The recommended minimum distance between words is the width of one character Use of universal words Use of short text in active speech Use of text alternatives for images (which describe the substance, not the content of the image), for people who use screen readers Use of text links to an external URL source in the usual form - underlined

4 APPLICATION

The combination of the guideliness discussed above can be used to generate ergonomic and inclusive AV interior design solutions. The parctical application of the systematized recommendations in the design process can be organized in several steps.

Step 1. Defining the vehicle characteristics.

The first step is to define the type of AV to be designed and the characteristics of the potential users. It is required to determine the shape and size of the vehicle which means defining if it is a SUV, mini van, station wagon, shuttle etc. This leads the whole design process and helps to define the wheelbase distance, interior width and number of passengers that can be accomodated. Based on this information, one segment of the exterior features can be defined as well, such as the type of door, its' dimensions and way of opening. The possibility for incoroprating elements that faciliate the ingress/egress can also be considered at this point. In addition, the characteristics of the potential users need to be clearly stated. This dictates the choice and application of the information provided in the tables such as: the additional comfort features, types of safety systems, types of control devices, overall interior appearance etc. Figure 8 shows a preliminary concept of an interior generated for an inclusive autonomous shuttle for shared rides. The first sketch helps to determine the main interior dimensions.

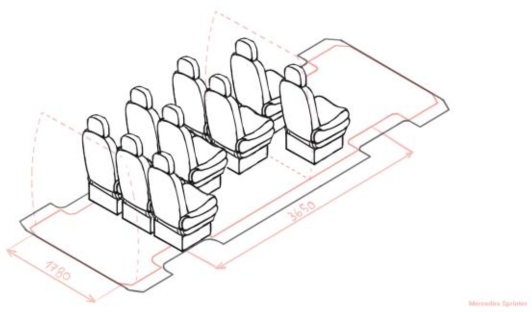

Fig. 8 *Defining the main interior dimensions of an autonomous shuttle for shared rides*

Step 2. Defining the seating positions and seat dimensions.

The second step is defining the seating configuration. Based on the number of passengers the necessary number of seats can be arranged in the interior following the provided guidelines for required clearance, legroom, distance between passengers, reach zones etc. The seats can be shaped using the information provided in the table where the optimal dimensions for achieving maximum ergonomics are stated. Once the seats are designed and placed, options for their translation and adjustment of positoons can be considered, again following the given recommendations. Following those recommendations is a safe approach since it will result with a layout that is not only ergonomic but also follows universal design principles and is inclusive. Figure 9 shows sketches in the early design stages of the AV shuttle where the possible seat positions, rotations and folding options are considered.

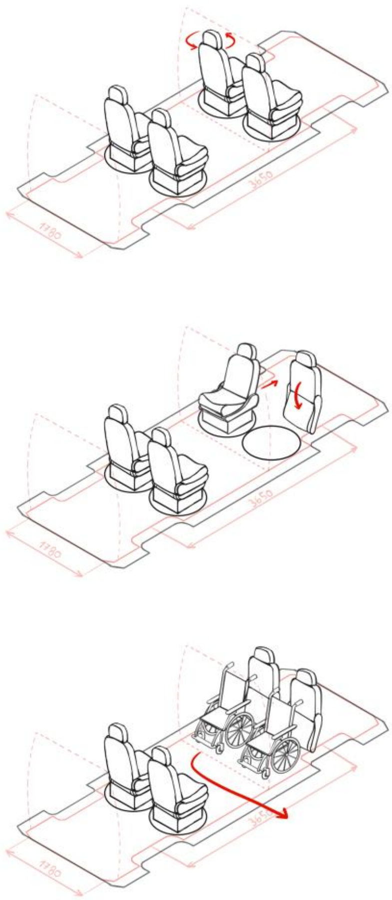

Fig. 9 *Defining the seating configuration of an autonomous shuttle for shared rides*

Step 3. Defining reach zones and positioning interior features.

The next step in the procedure is positioning all additional interior elements based on anthropometric measurements and comfort reach zones. This step also includes the positioning of safety systems such as seat belts, air bags and wheelchair docking systems. The systematized guidelines contain information regarding the placement of armrests, folding tables, controls, displays etc., which can be used directly in the design process. Figure 10 illustrates the first concepts where ideas for the locations of the additional features are generated.

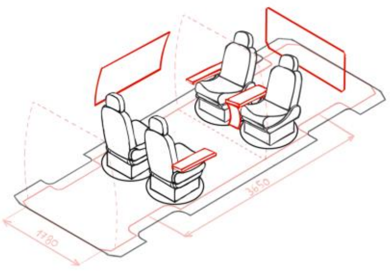

Fig. 10 *Defining the positions for the interior elements of an autonomous shuttle for shared rides*

Step 4. Defining interior details.

After all the elements have been arranged in the interior, the remaining details should be designed, such as the overall style, used colors, materials, textures, lights (Figure 11).

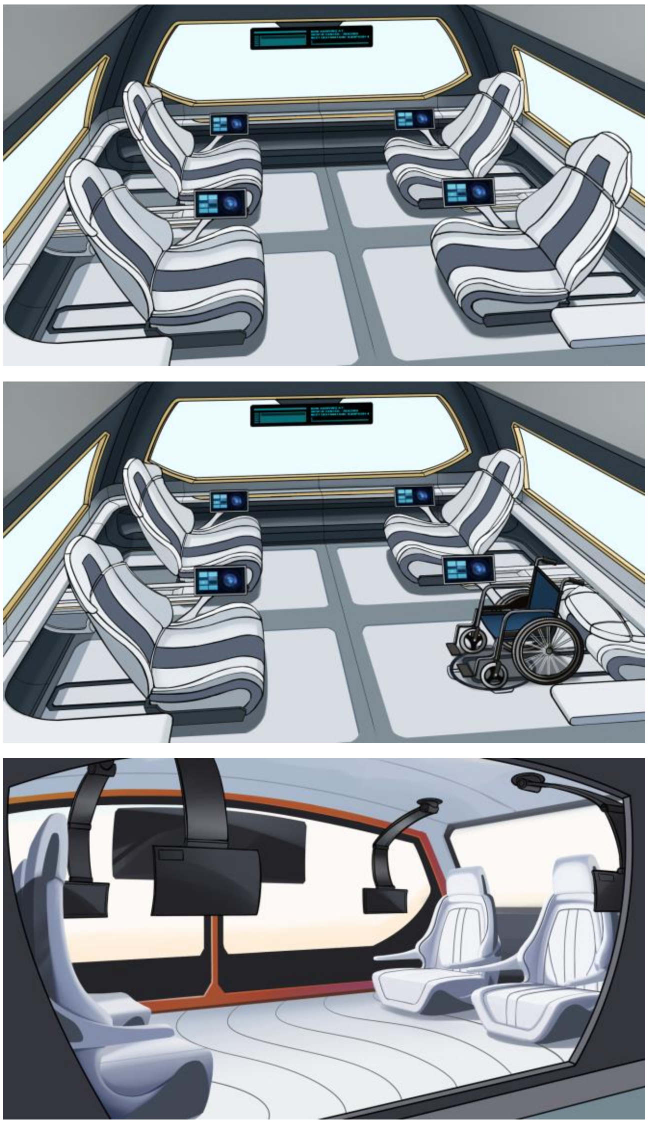

Fig. 11 *Interior design variants of an autonomous shuttle for shared rides*

Step 5. Defining possible vehicle-passenger interactions and developing the UI.

One special segment of the interior design process is the development of the UI which is not only the design of the visual interface, its' wireframe, the used colors, symbols and characters, but also the development of the information content and multimodality options. For this step, the first thing to do is to consider the possible vehicle-passenger interactions that might take place during the ride in the AV that is being designed. This helps to define the necessary content for the interface. Than, the UI can be fully designed using the ergonomic and inclusive principles from the second table. Figure 12 shows the first version of the UI developed for the autonomus shuttle. The design is based on the discussed UI guidelines and it includes: options for choosing a preferred mode, AAA color contrast, simple layout with minimum information to avoid confusion, combination of text and icons for conveying messages, use of filled icons instead of outlined, large clickable areas etc.

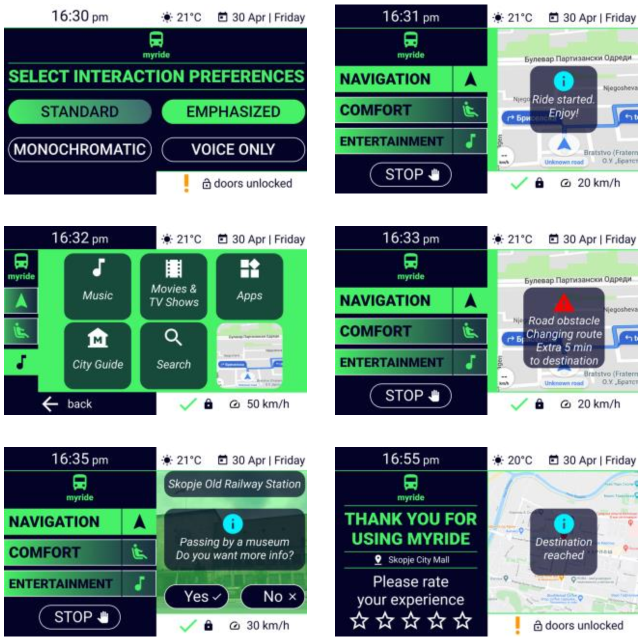

Fig. 12 *UI design of an autonomous shuttle for shared rides*

Step 6. Evaluation.

The final and crucial step in the process is to evaluate the final design. This can be done using software for virtual ergonomics and virtual reality, but it can also be done with real participants using vehicle mockups or driving simulations. Evaluation of the ergonomic and inclusive features will help to assure the interior will meet the needs of the users under all performed tasks. There are numerous evaluation methods for data collection and analysis like observation, communication or experiments [2]. Combining several strategies can provide most reliable results.

5 CONCLUSION

The benefits of the practical application of the sytematized guidelines for ergonomics and inclusion were evident during the design of an autonomous shuttle for shared rides. Firstly, the preparation stage consisted of gathering relevant information was significantly reduced. The design process begun by directly translating the provided data into interior concepts without the need for a thorough research. In addition, the designers that lack expertise in other interdisciplinary fields such as the technical aspects of vehicles or medical data were certain that their developed design fulfills the minimum ergonomic and inclusive requirements.

Further research is needed where the completion of Step 6 will be done. Evaluation will reveal the need for corrections of the systematized guidelines or their increasing with additional data that might have been omitted at this point.

It is hoped that this research will be beneficial to vehicle designers as it aims to simplify the design and development preparation process. Significant aspects of the given systematized principles are adequate not only for fully autonomous AVs, but also for the design of models with different automation modes (0 – 5).

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REFERENCES

1. Marek, C., Siebertz, K., 2015, *Ergonomics for passenger cars*, Chapter 247 of the FISITA Encyclopedia Automotive Engineering, Wiley.
2. Bhise, V., D., 2012, *Ergonomics in the Automotive Design Process*, CRC Press Taylor & Francis Group.
3. Jorlöv, S., Bohman, K., Larsson, A., 2017, *Seating positions and activities in highly automated cars – A qualitative study of future automated driving scenarios*, 2017 IRCOBI Conference, September 13 – 15, Belgium.
4. Hirz, M., Rossbacher, P., 2018, *Integrated approach supporting virtual conception of passenger ergonomics in automated driving cars*, 9th International Conference on Applied Human Factors and Ergonomics – AHFE, July 22 – 26, Florida, USA.
5. Detjen, H., Pfleging, B., Schneegass, S., 2020, *A Wizard of Oz field study to understand non-driving-related activities, trust, and acceptance of automated vehicles*, In Proceedings - 12th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2020, September 21 – 22, Virtual Event, USA, Association for Computing Machinery, https://doi.org/10.1145/3409120.3410662.
6. Ka-Jun Mok, B., Sirkin, D., Sibi, S., Bryan Miller, D., Ju, W., 2015, *Understanding driver-automated vehicle interactions through Wizard of Oz design improvisation*, Proceedings of the Eighth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, June 22 – 25, USA.
7. Kyriakidis, M., De Winter, J., C., F., Stanton, N., Bellet, T., Van Arem, B., Brookhuis, K., Martens, M., H., Bengler, K., Andersson, J., Merat, N., Reed, N., Flament, M., Hagenzieker M., Happee, R., 2017, *A human factors perspective on automated driving*, Theoretical Issues in Ergonomics Science, Taylor & Francis Group, doi: 10.1080/1463922X.2017.1293187.
8. Allu, S., Jaiswal, A., Lin, M., Malik, A., Ozay, L., Prashanth, T., 2017, *Access to personal transportation for people with disabilities with autonomous vehicles*, Undergraduate Coursework, Paper 1, Purde University, https://docs.lib.purdue.edu/ugcw/1.
9. Claypool, H., Bin-Nun, A., Gerlach, J., 2017, *Self-driving cars, the impact on people with disabilities*, The Ruderman White Paper, Ruderman Family Foundation.
10. Reed, M., P., Schneider, L., W., Ricci, L., L., 1994, *Survey of auto seat design recommendations for improved comfort*, Technical Report, UMTRI-94-6, Lear Seating Corporation, Michigan.
11. Tangemann, C., 2019, *Automotive seating innovation: What's next?*, Online Article, Automotive IQ, Available at: https://www.automotive-iq.com/car-body-and-materials/articles/automotive-seating-innovation-whats-next.
12. Pawsey, C., 2017, *The new age of automotive seating*, Online Article, Automotive IQ, Available at: https://www.automotive-iq.com/car-body-and-materials/articles/new-age-automotive-seating.
13. Buchholz, K., 2018, *Seats and instrument panel in Faurecia's autonomous vehicle sights*, Online Article, SAE International, https://www.sae.org/news/2018/03/seats-and-instrument-panel-in-faurecias-autonomous-vehicle-sights.
14. Giacomin, J., Quattrocolo, S., 1997, *An analysis of human comfort when entering and exiting the rear seat of an automobile*, Applied Ergonomics, Vol.28, No. 5/6, pp. 397-406.
15. Angeleska, E., Cvetkovski, A., Dimchova, M., Simonovski, N., Treziovski, D., Sidorenko, S., 2019, *Influence of car door cavity design on ingress/egress ergonomics*, 7th international conference Transport & Logistics, December 6, Nish, Serbia
16. Panero, J., Zelnik, M., 1979, *Human Dimension & Interior Space, A Source Book of Design Reference Standards*, Whitney Library of Design, an imprint of Watson-Guptill Publications, New York.
17. Tilley, A., L., H. Dreyfuss Associates, 1993, *The Measure of Man and Woman, Human Factors in Design*, The Whitney Library of Design, an imprint of Watson-Guptill Publications, New York.
18. Macey, S., Wardle G., 2008, *H-Point, The Fundaments of Car Design and Packaging*, Design Studio Press, China.
19. Swann, M., 2006, *Ergonomics of touch screens*, Ergonomic Solutions International, Surrey.
20. Thomas, B., 2019, *The potential for AR and VR to improve viewing ergonomics*, Blog post, AR post, Available at: https://arpost.co/2019/01/31/the-potential-for-ar-and-vr-to-improve-viewing-ergonomics/.
21. Buchholz, K., 2018, *Seats and instrument panel in Faurecia's autonomous vehicle sights*, Online Article, SAE International, Available at: https://www.sae.org/news/2018/03/seats-and-instrument-panel-in-faurecias-autonomous-vehicle-sights.
22. Bayless, H., Davidson, S., 2019, *Driveless cars and accessibility, Designing the future of transportation for people with disabilities*, The Intelligent Transportation Society of America.
23. Schneider, L., W., Manary, M., A., Orton, N., R., Hu, J., H., Klinich, K., D., Flannagan, C., A., Moore, J., L.,

2016, *Wheelchair occupant studies – Final Report*, National Highway Traffic Safety Administration (NHTSA).

24. W3C, Editors: Allan, J., Kirkpatrick, A., Lawton Henry, S., 2016, *Accessibility requirements for people with low vision*, W3C First Public Working Draft, Available at: https://www.w3.org/TR/low-vision-needs/#visual-impairments
25. Shaheen, S., Niemeier, D., 2001, *Integrating vehicle design and human factors: Minimizing elderly driving constraints*, eScholarship Repository, University of California, Available at: http://repositories.cdlib.org/itsdavis/UCD-ITS-REP-01-06
26. Darvishy, A., Hutter, H., P., 2018, *Recommendations for age-appropriate mobile application design*, Springer, Advances in Design for Inclusion, Proceedings of the AHFE 2017 International Conference on Design for Inclusion, July 17-21, 2017, California, USA.
27. Graham, T., Goncalves, A., 2017, *Stop designing for only 85% of users: Nailing accessibility in design*, Smashing Magazine, Available at: https://www.smashingmagazine.com/2017/10/nailing-accessibility-design/
28. Fulton, G., 2017, *Accessibility basics: Designing for visual impairment*, Envato Tuts+, Available at: https://webdesign.tutsplus.com/articles/accessibility-basics-designing-for-visual-impairment--cms-27634
29. Ferati, M., Murano, P., Giannoumis, G., A., 2018, *Universal design of user interfaces in self-driving cars*, Springer, Advances in Design for Inclusion, Proceedings of the AHFE 2017 International Conference on Design for Inclusion, July 17-21, California, USA.
30. Olofsson, S., 2017, *Designing interfaces for the visually impaired*, Master's Thesis in Interaction Technology and Design, Umea University, Department of Applied Physics and Electronic, Sweden.
31. Batusek, R., Kopecek, I., 1999, *User interfaces for visually impaired people*, Proceedings of 5-th ERCIM Workshop on User Interfaces for All, s. 167-174, GMD Report 74, Dagstuhl, Germany.