



Article

Teleoperation of Highly Automated Vehicles in Public Transport: User-Centered Design of a Human-Machine Interface for Remote-Operation and its Expert Usability Evaluation

Carmen Kettwich ^{1, *}, Andreas Schrank ¹ and Michael Oehl ¹

¹ German Aerospace Center (DLR), Braunschweig, Germany; {Carmen.Kettwich; Andreas.Schrank; Michael.Oehl}@dlr.de

* Correspondence: Carmen.Kettwich@dlr.de

Citation: Kettwich, C.; Schrank, A.; Oehl, M. Teleoperation of Highly Automated Vehicles in Public Transport: User-Centered Design of a Human-Machine Interface for Remote-Operation and its Expert Usability Evaluation. *Multimodal Technol. Interact.* **2021**, *5*, 26.
<https://doi.org/10.3390/mti5050026>

Academic Editors: Shadan Sadeghian Borojeni and Philipp Wintersberger

Received: 13 February 2021

Accepted: 3 May 2021

Published: 5 May 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Supplementary Materials

Table S1. Overview of features liked (complete)

Feature Liked	N	Typical Utterance
<i>Design</i>		
Division of Screens	4	"I like how the information is distributed across several monitors"
Clarity	2	"I liked the interface very much, it is very clear and logically structured"
Display of Relevant Information	2	"I was not disturbed by unnecessary notifications"
Number of Menu Levels	1	"There aren't too many submenus"
Adjustment of Menus	1	"The menus adjust depending on the situation, normal operations or disturbed operations"
Integration of Disturbance Notification and Map View	1	"There was a link between incoming notifications and the map view"
Selection of Singular Vehicles	1	„You can choose shuttles individually by entering their number“
<i>Details Screen</i>		
Shuttle Details	1	"I like the way details about the shuttle are presented"
<i>Disturbances Screen</i>		
Steps to Overcome Disturbance	4	"The process is logical, practicable, and pretty clear"
Communication Link	2	"You can directly get in touch with other people"
Presentation of Disturbances	2	"Whenever something was not in order, the details about it were presented with an exclamation mark"
Disturbances Screen	2	"I appreciate that the central screen is reserved for incoming disturbance notifications"
Distribution of Tasks for Processing Disturbances	2	"Accepting a task makes clear who is responsible for what"
Communication Link to Passengers	1	"I can directly address the passengers in the cabin"
Acceptance of Disturbance Notification	1	"It is innovative that you can accept the disturbance notification"
<i>Map Screen</i>		
Focus on Current Vehicle	1	"I can focus on a single vehicle on the map"
<i>Touchscreen</i>		
Waypoints	2	"Setting waypoints is useful to get the shuttle away from the road"
<i>Video Screens</i>		
Video Images	5	"The video images are very helpful"

Table S2. Overview of features missed (complete)

Feature Missed	N	M Importance	Typical Utterance
<i>Shuttle Details</i>			
Relevant Information about Disturbances	2	4.50	"It would be better to focus on important things"
Less Screens	2	4.50	"There should not be more than five monitors"
More Intuitive Design	1	5.00	"The presentation should be more fluent and intuitive"
Distribution of Information on Screens	1	5.00	"You don't need to dedicate a whole screen to some of the features"
Display of Vehicle Type	1	5.00	"Maybe the type of the vehicle could be displayed"
Display of Technical Systems	1	5.00	"An extension by a display of technical facilities would be helpful"
Flexible Expandability	1	5.00	"I would embrace the option to flexibly extend the interface by additional features"
Display of Occupancy	1	3.00	"I would appreciate to be shown a percentage of seats currently occupied"
<i>Disturbance Ticker</i>			
Prioritization of Disturbances (Using Color-Coding)	3	5.00	"Priority should be given to passenger emergency calls"
Visual Highlighting of Incoming Notifications	3	4.67	"Incoming notifications should be visually highlighted"
Auditory Highlighting of Incoming Notifications	2	4.50	"I want to hear a sound when a notification comes in"
Interactions between Disturbances Concerning Different Vehicles	1	5.00	"I want to see if and how a disturbance of one shuttle has an impact on another one"
Direct Order of Substitute Vehicle	1	5.00	"I want to be able to directly order another vehicle to replace the malfunctioning one"
One Click Only to Accept Disturbance Notifications	1	4.00	"Accepting and processing the disturbance should be combined so I only need to click once"
Direct Setup of Bypasses	1	4.00	"Setting up a bypass spontaneously enables me to deal with accidents"
Display of Time Passed since Reception of Disturbance Notification	1	3.00	"I want to see when the disturbance entered the system so I know for how long it has been there to assess its priority"
<i>Map View</i>			
Clear (Colorful) Display of Trajectory	2	4.50	"Highlight the trajectory by making it bold or using colors. The dashed lines are not clear"
Selection of Single Vehicles Via Context Menu	1	5.00	"I want to be able to directly access a single shuttle from the map"
Clearer Display of Destination	1	5.00	"It is not clear where the shuttle is headed to"

Display of Street Names	1	4.00	"I want to see the names of the streets in the environment"
Color-Coding of Disturbances by Priority	1	4.00	"Color-codes could help to see how serious a disturbance is"
Larger Segment of Map	1	4.00	"The default segment is a bit too small"
Automatic Tracking of Trajectory	1	4.00	"Automatically track the trajectory of the shuttle"
Display of Number of Passengers at Pick Up and Drop Off Points	1	3.00	"Mark how many people want to get on and off the shuttle"
<i>Touchscreen</i>			
Legend of Symbols Currently Displayed	1	5.00	"Which symbols mean what? Legends like that would be useful for currently displayed elements"
<i>Camera View</i>			
Moving Cameras	3	4.00	"Being able to control the cameras, for example move them or zoom in, would be a meaningful improvement"
Less Screens	2	4.00	"One monitor is enough"
Camera Showing Vehicle from Outside	2	3.50	"Having a bird-view outside camera would help avoiding the blind spot"
Camera with 360° View Inside the Vehicle	1	5.00	"A dome camera on board would help the detect problems in the passenger cabin when no passengers are on board"
Camera View Below the Vehicle	1	5.00	"Looking below the vehicle could help detect damages on the shuttle's bottom"
Show All Camera Images Simultaneously	1	4.00	"I want to see every camera image that is available for a shuttle without having to switch views"
Change Segment of Camera Images	1	4.00	"I want to be able to move the map around"
More Intuitive Use	1	3.00	"The interface could be more intuitive to use to avoid changes between the screens"
Selecting Cameras from Map View	1	3.00	"For example, choosing the camera from the map view by clicking on the vehicle"
Show Most Information on Central Screen	1	3.00	"70 percent of information should be presented on a central screen"
<i>Further Features Missed</i>			
Manual Teleoperation	1	5.00	"I want to have the option to remote-control the vehicle manually"
Documentation of Previous Trajectories	1	5.00	"It would be useful to be able to document trajectories"
Distinction between User Roles	1	5.00	"I think logging in with different roles, such as disposal or passenger information responsible, could help"
Display of Previous Trajectories	1	5.00	"It would be useful to be able to review trajectories from the past"
Division of Responsibilities by Area	1	5.00	"You can divide the area into subareas, so everyone is responsible for their area"

Color-Coding of Reasons for Disturbances	1	4.00	"It would be helpful to use different colors for different reasons for disturbances"
Direct Communication Link to Passenger Cabin	1	4.00	"I would like to be able to talk into the passenger cabin of a single or multiple shuttles"
Changing Trajectories	1	4.00	"I need to be able to change the path the shuttle follows"
Abort Ride	1	4.00	"I want to be able to stop the ride"

Table S3. Overview of missing information parameters (complete)

Information Parameter Missed	N	M Importance	Typical Utterance
<i>Shuttle Details</i>			
Occupancy	2	4.50	"I want to know how many passengers are in the vehicle"
Previous Stop	1	5.00	"To understand the context, knowing what the stop prior to the upcoming one was can help"
Information on Actions	1	5.00	"A description of the consequences of actions would help"
Destination	1	4.00	"The end of the current ride should be stated somewhere"
Long-Term Trajectory	1	4.00	"I want to see the trajectory beyond the next couple of stops"
<i>Disturbance Ticker</i>			
Clearly Defined Communication Partners	1	5.00	"The description of communication partners should be clear and unambiguous"
Direction of Travel	1	4.00	"The direction of travel is missing"
<i>Map View</i>			
Exact Position with Street Names and House Numbers	2	5.00	"The exact position with street names house numbers should be shown in the map"
Information on Infrastructure and Other Additional Layers	2	3.00	"Elements from the infrastructure, such as cameras on stops, should be visible on the map"
Mark Closed Areas	1	5.00	"I need to determine closed areas in the map, e.g. when I receive notifications from the police"
Code Trajectories	1	5.00	"Driving paths should be coded so they be followed easily, using colors or symbols"
Company Responsible for Bus Shelter	1	5.00	"Show the company that set up and maintains a bus shelter on the map"
Names of Stops	1	4.00	"Show the names of stops on the map"
Aerial Map	1	4.00	"One should be able to see an aerial map, otherwise it's hard to imagine the area"
Details on Field Engineers	1	3.00	"I need to estimate how far away available field engineers are from the place of disturbance, so I can estimate how long it will take them to get there"
<i>Camera View</i>			
View of Vehicle's Bottom	1	5.00	"Seeing the bottom part of the vehicle can help me see if objects below it block the sensors, such as toys"
Time	1	5.00	"I want to see the current time so I can make the system isn't frozen"
Overall System State	1	5.00	"A lamp showing the overall system state would help to make sure that the system is available"
Lateral Cameras	1	5.00	"Cameras on the left and right side of the shuttle could help me become aware of blind spots"
Blind Spots	1	4.00	"Are there any blind spots on the video images?"

Gaps in Video Images	1	4.00	“Do the camera images merge, like in 360 degrees view, or are there any gaps?”
Velocity	1	3.00	“I would like to see the current speed”
<hr/>			
<i>Further Information Parameters</i>			
<i>Missed</i>			
Numbers of Vehicles Available	1	5.00	“How many vehicles are currently available?”
Rate of Vehicle Capacity Used	1	5.00	“What is the percentage of all shuttle seats occupied?”
Number of Shuttles under Maintenance	1	5.00	“How many shuttles are in the maintenance facility right now?”
Process of Handling Vehicles out of Order	1	5.00	“What happens with a shuttle that can’t be used any more?”
General Overview Fleet	1	5.00	“I need an overview over the entire fleet of shuttles”
Degree of Occupancy	1	3.00	“How full is the shuttle?”
Numbers of Vehicles Running	1	2.00	“How many shuttles are out there?”
Color-Code of Vehicle State	1	2.00	“I want to see with one glance if the shuttle is okay, e.g. when it is green on the screen”
<hr/>			

Table S4. Overview of additional improvement suggestions (complete)

Improvements Suggested	N
<i>Design</i>	
Only Relevant Information / Clear Presentation	3
Prioritize / Highlight Particularly Important Information	2
Less Monitors / All Video Images on one Monitor	2
Monitor for Overview	2
Same Structure for All Menus	1
Customizable Distribution of Information Across Screens	1
Integration in Existing Control Center Operations System	1
<i>Details Screen</i>	
No Display of Upcoming Stops	1
Show Actual Departure Times Only	1
Controlling Distribution of Shuttles in Operating Area	1
Exact Position of Shuttle	1
<i>Disturbances Screen</i>	
Only one Click for Accepting and Editing Disturbance Notification	3
Categorizing Incoming Disturbance / Delay Notifications	3
Highlighting / Prioritizing Incoming Disturbance Notifications	3
Improving Check of Prerequisites for Clearance (Making Them Faster / Customizable / Immediately After Each Step in Disturbance Resolution Process)	3
Documenting Prerequisite Checks for Clearance / Disturbances	2
Displaying Further Communication Partners	1
Displaying Further Actions	1
<i>Map Screen</i>	
Showing Driving Path Only After Selecting Shuttle	1
Showing Traffic Density Only If Driving Path Can Be Adjusted	1
Clearer Map with Details Accessible via Context Menu	1
Showing Delays on Map	1
<i>Touchscreen</i>	
Marking Bypasses	2
<i>Video Screens</i>	
Cameras at Every Stop	1
Recording Video Images	1