Understanding the railway driving activity to design HUD: Recommendations and specificities for future light trains

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Abstract. As new operating modes emerge for rail transportation, an ergonomics and human factors centered study is essential to ensure that the needs of operators are fully taken into account during this evolution. In this paper, we study the possibility of integrating heads-up displays (HUD's) to help design future train cabs for very light trains operating in small rural lines. Multiple studies underline the apparent advantages of using HUD's in transport fields, notably to improve the visibility of certain information or reduce the time when the driver's attention must diverge from the train and its environment. However, implementing such interfaces is not simple, as technological solutions can be difficult to implement and must comply with strict safety standards. While it has been scarcely explored in the railway industry, this paper investigates the known advantages and disadvantages of using HUD's, and presents recommendations for their development, based on both a study of the literature and general observations made in the driver's cab of various types of train operating on small rural lines.

1 INTRODUCTION

To face today's environmental and economic challenges, mobility must evolve. In France, as part of the France 2030 investment plan, a number of projects are being launched to move towards low-carbon, modular and more intelligent forms of mobility adapted to the needs of small territories. The emergence of these new forms of mobility is associated with new operating modes. They include for example road-rail systems or rural tramways. This is the case of the DRAISY project, a very light train created to revitalise small and underused lines, which often implies a line-of-sight driving mode, like a tramway. In this operating mode, DRAISY driving is a cross between train driving and tramway driving, with specific design requirements in terms of ergonomics and human factors. One of the priorities is to enable the driver to monitor the dynamics of the external environment (i.e. outside the cab) while monitoring the instruments reflecting the state of the train (i.e. inside the cab), without inducing distraction or cognitive overload that could lead to risky situations. HUD's have proved their worth in the automotive and aviation sectors in particular because these technologies allow operators to access information without taking their eyes off the road. Indeed, HUD's offer a number of advantages in transport. In particular, they could provide a more effective response to unexpected events [1], improve situational awareness [2, 3], and reduce the level of distraction [4, 5]. However, the disadvantages are also numerous, and the effectiveness of HUD's depends on how they are designed. The design of HUD's requires rigour and the implementation of specific methodologies to test and validate design proposals. In the automotive domain, some works [6, 7] present a methodological approach for designing a driver interface that takes into account drivers' needs. In particular, these studies highlight the importance of considering the driver's driving activity and needs when identifying, organising and categorising the information to be displayed. In the railway sector, work is less widespread, but [5] is also taking into account drivers' opinions and needs to develop a specific symbology for railway HUD's. As French ergonomists, we believe that the design of HUD's depends on understanding the complexity of the activity concerned. The HUD must be designed to support the operator in achieving the safety and performance objectives specific to his activity. In this article, we investigate the possibility of integrating HUD into future train cabs for very light trains operating on small rural service lines. The aim is to make design recommendations based on a study of the literature and our understanding of the activity resulting from observations in the driver's cab. These observations were organised to understand the specificity of driving activity on small rural lines, to gather the needs of drivers familiar with operating on these small lines and to make HUD design proposals.

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2 REVIEW OF HUD IN TRANSPORTATION

2.1 Benefits of using HUD's in transportation

In transport, driving or piloting performance depends on the operators' ability to monitor both inside and outside the driving zone (e.g. cabin or cockpit). Interior monitoring is used to process information relating to system status such as speed, energy consumption, or location, while exterior monitoring is essential to track the environment and its dynamic evolution in order to detect and respond to safety hazards as early as possible. In the aviation or automotive domains, HUD's offer a number of benefits, providing information directly in the field of vision. Indeed, by reducing the frequency of off-road glances , the driver has more time to analyse the road, events, detect obstacles and react more effectively to unforeseen events [1, 8, 9]. Some studies also show that using a HUD could improve situational awareness [2, 3] and reduce workload [4, 5], which are key notions for performance and safety in complex activities. Finally, HUD's could also improve safety by reducing incidents and accidents. This was highlighted by [4] after analysing accident and incident reports on the UK rail network. They revealed that an appropriate HUD in the cab of a train could help prevent up to 10 per cent of incidents and 3 per cent of accidents.

2.2 Dangers and disadvantages when using HUD's

However, certain notable disadvantages have been identified. First of all, it appears that advantages of HUD's may depend on the workload situation and the degree of uncertainty. In fact when performance is measured under high workload conditions and there is a high degree of temporal uncertainty (i.e., the external target is unexpected), cognitive capture by a HUD is likely to occur [10] (i.e. the degradation of responses to external targets as a result of processing information from a HUD image). Moreover and because the information is projected into the field of view, there is a risk of interference between the symbols displayed on the HUD and the real environment as well as a risk of masking relevant objects while driving [11]. HUD's can also cause distraction or cognitive overload if the information displayed is too numerous, unnecessary or poorly designed [9, 12, 13] and some issues remain related to daylight and nightlight readability, display adjustment, refresh rate, track curvature, vibration and display readability from different positions [4]. Finally, the performance of HUD's also depends on how they are designed (e.g. icon, symbology, choice of colours or text, etc.). This makes their design a major source of dangers. Using a HUD wisely requires in-depth thought about what is displayed, how and when. Thus, some authors have put forward recommendations or methodologies for designing HUD's. In the automotive sector, some guidelines for the design of HUD graphical interfaces are based on three main levels: characterisation of vehicle information, allocation of information, and structure of HUD information [6, 7]. Nevertheless, and despite the difficulties, recent studies suggest that train drivers are ready to use HUD's [14]. However, to ensure that they are properly adapted to their needs, it is important to take the operator's point of view with a special emphasis on their activity and the context in which it is performed.

3 THE PLACE OF HUD IN THE DEVELOPMENT OF INNOVATIVE INTERFACES FOR LIGHT TRAIN OPERATIONS

3.1 Context and objectives

The French railway sector is moving towards low-carbon, intelligent, networked and modular mobility. To meet these new challenges, the DRAISY project aims to develop new rail mobility solutions adapted to the specific characteristics of small rural lines as well as to current economic and ecological issues. Within the consortium, made up of SNCF, LOHR, GCK Battery, Stations-e, the technological research institute Railenium is contributing to the design of the driver's cab focusing on ergonomics and human factors. DRAISY is a very light train, fully powered by an electric battery and specially designed to meet the needs of the territories. With a length of 14 metres, DRAISY is designed to accommodate 80 passengers, including 30 seated. Although DRAISY will be travelling on a railway infrastructure, driving will rely more on a line-of-sight driving principle, similar to a tramway. This special feature creates a new way of driving, somewhere between train driving and tramway driving, with high perceptual requirements. The future cab and driving instruments must be designed to support the future driver in achieving the performance and safety objectives specific to this new driving activity. Our first objective was therefore to define this new driving activity on the basis of (1) a study of the literature characteristic of train driving, tramway driving and tram-train driving and (2) observations in the cab in reference situations as close as possible to the operation conditions of the future light train. Our second objective was to identify, on the basis of the activity understanding, the essential information for driving very light trains and to propose initial design recommendations specific to this new mode of operation.

3.2 Understanding future light train driving activity and information needs

The literature reveal that in the context of train driving, driver performance is governed by cognitive and perceptual factors [15]. Driving a train is primarily a visual task involving the integration of various sources of information from both outside and inside the cab [16, 17]. Although monitoring the screens in the cab is important to determine the train's speed and control status, one of the driver's major responsibilities is to monitor the environment outside the cab to detect and react to unexpected events. Visual monitoring outside the cab is therefore just as important as visual monitoring inside the cab, if not more important [18]. Outside the train cab, the driver has to use and integrate information mainly from signals and signs positioned at the edge of the line. Inside the train cab, the sources of information include automatic train control, the route book and timetables, the rules and various types of safety messages [17]. In trams, visual perception is even more important due to the line-of-sight driving mode. Under this operating mode, the tram must be able to stop before a stationary obstacle at its intended operating speed using the service brake. Furthermore, in rail driving, situational awareness is also considered as a key concept for safe train operation and loss of situational awareness is the leading cause of driver error [15, 19]. Maintaining situational awareness, which is based on the perception of the elements that compose the environment, is one of the most important cognitive functions of the driver [18]. In train driving, situational awareness would be based on the perception of the following elements: track characteristics, current speed, current position, railway signalling, fixed and changing physical elements (e.g. level crossings, milestones, work zones, etc.), trespassers and obstacles, workers, other trains, operating limits, train characteristics. The observations in the cab and discussions with drivers allowed us to analyse the behaviours, conducts, cognitive processes, and interactions implemented as well as drivers needs in 4 operational situations: providing passenger service / ensuring communications / driving the train between two stations / managing level crossings or road crossings (i.e. operational situations transferable to the future DRAISY driving activity).

3.3 Expected roles of future HUD's for light train operations

From the previous analysis was extracted some necessary information for driving that can be support by the HUD.

For passenger service, the driver must be able to identify upcoming stopping points and perceive the external elements relative to that stopping point (i.e. location of the station building, location of the pedestrian walkway, length of the platform, location of the electric charging point; presence or absence of signs indicating the stopping point); adapt the stopping point to the composition of the train and the characteristics of the external environment; perceive the track state; perceive users in the platform so as to be able to anticipate behaviour and react accordingly. The driver also needs an easy access to the current time, the expected waiting times, as well as the advance or delay. Once on the platform, the driver must ensure that the train is perfectly immobilised to avoid any drift until perceiving and/or receiving departure authorisations. When the train is running between two stations, drivers need to be able to perceive signals and signs in the distance and the information transmitted by these elements, monitor speed, check the speedometer and speed instructions, perceive the outside environment, detect obstacles, monitor the time regularly, know the exact duration in minutes of the advance or delay in order to comply as strictly as possible with time constraints, control energy, know the train's location and ensure that the direction given corresponds to the planned route and the service to be carried out. For communications, the driver must be able to detect a radio call (whether in motion or stationary), quickly provide the caller with all the information concerning the train (its status, number and location), and quickly detect warning signals. Finally, when approaching a level crossing, the driver must be aware of other road users (front, rear, side) so as to be able to anticipate their behaviour and react accordingly, detect whether the level crossing is open or closed, and identify the level crossing signs specifying the type of infrastructure to be crossed. Based on this analysis, our expectations are that:

- HUD must not obstruct the essential elements of the environment: signals, signs, rail condition, station and crossing elements (e.g. barriers, buildings, platform, ...), planned and unforeseen events.
- HUD shall not be a distraction and shall not interfere with the detection of radio calls, emergency signals or unexpected event (e.g. trespassers, obstacles).
- HUD must be suitable for sitting, standing and non-central positions. In addition, a person may join the driver in the cab, particularly for the execution and validation of the line study practical course (i.e. a teacher or manager).
- HUD could be able to display any information essential to achieve the safety and performance objectives specific to rail driving which are:

1. Time management: display of current time, advance time, delay time, estimated and actual waiting times;
2. Speed management: display of actual speed, target speed, actual speed in relation to the selected target speed, actual speed in relation to the speed limits applied on the track section;
3. Train management: display of actual train location and train composition (i.e. single unit or multiple unit);
4. Energy management: display of battery charge level, remaining range in kilometres and time;
5. Station stop management: display of the next stop; the planned service; specific characteristics of the stop that could generate risks, such as the presence of a set of points or a pedestrian crossing;
6. State of the external environment management: display of current weather (i.e. outside temperature, rain, wind, freeze, etc.), line profile;
7. Rail rules management: display of signs and signals approaching;
8. Train immobilisation management: display of feedback confirming that the train has stopped properly during stops;
9. Planned events management: display of fixed elements on approach, such as speed restrictions and level crossings;
10. Unforeseen events management: display of temporary approach events such as work zones, display of a dynamic moving element highlighting external objects of interest such as obstacles;
11. Communication management: notification of radio call or communication.

4 SUGGESTIONS FOR DESIGNING INTERFACES FOR RAIL TRANSPORTATION

4.1 General recommendations and symbology

Although the use of HUD's is less widespread in the railway sector than in the aviation and automotive fields, there are rigorous studies supporting the design of HUD's for trains [4, 5, 20, 21]. Based on these studies, we extracted the following 6 design recommendations families : information displayed, symbols, colours, text, screen layout and user options and preferences.

Concerning the information displayed, [20] proposed to display only crucial information so as not to crowd the screen and display information continuously. [13] point out that the number of items of information displayed should be less than 6, and that important information should be in the centre, while information that is less important for the activity can be located on the sides. By way of example, [21] proposed a HUD for locomotive including speed display, in-cab signals, moving elements to draw attention to external objects of interest and a box displaying messages for upcoming events. By consulting three locomotive engineers, [5] ranked in order of criticality the information to display in a HUD for passengers trains, referred to as: current train location/signals, speed indicator, stops, approach, upcoming temporary speed restrictions, resume, fault/error message, cab signal, equalising reservoir, main reservoir, brake pipe pressure, headlight/auxiliary light position, time of day, effort, rear, delay in block, critical curve ahead, grade, radio communication notification, throttle, bell, flow, upcoming station, distance counter, condition brakes, quiet zone, stopping distance, current weather conditions. Concerning the symbols, we can read in [5] that icons and symbols have been found to be more powerful than text and become even more effective when accompanied by text [22]. They also cite [23] who is exploring the structural elements of symbols and highlighted the most important characteristics: continuity, closure, symmetry, simplicity, and unity. They highlight that symbols being realistic and resembling the actual objects tend to be more effective (Horton, 1994) but symbols that are too realistic or detailed are not ideal because of the complexity of the background on which they will be displayed. [3] advises that each symbol must serve a direct purpose and convey critical information. The motto is "if you doubt, leave it out". It is also suggested that a pilot using a HUD should have the opportunity to "unclutter" the display, with a minimum of at least two levels of reduced symbols available. Finally, it is recommended that symbol layout be based on learned habits (i.e. action sequences; frequency).

In HUD design, it is important to pay attention to colours because this is one of the fastest processed cues in the visual system and because reaction times differ according to colour [24]. Because the external environment is always changing, [24] suggest that the colour of symbols should be evaluated according to their environment, and could have different modes to be better seen in different environments. For example, for avionic systems, red colour can be used for warning, prohibition, activation, limit state ; orange colour for prompt, caution, alarm and green colour for sart up, normal operation or standard mode. However, in the railway domain, it is strongly advised that colour choices for HUD symbols be consistent with those currently used in railway operations (e.g., use ERTMS DMI colours) [20]. Based on the work of [22], we can read in [5] that text labels are useful to accompany an unknown icon, text labels should be brief (i.e. no more than 2-3 words). It is best to use a clear and simple sans serif font and avoid using bold, italics, underlining or colour differences to underline words. Finally, a larger typeface should be used as criticality increases. About the display layout, [20] suggests that the HUD should be presented at the lowest possible part of the windscreen and in the middle, should not interfere with wayside signals or instructions and should be below the horizon and in the middle. Based on studies analysing the visual strategies of train drivers, it is shown that drivers are primarily interested in a relatively small area of the visual scene located far in front of the train at the junction between the end of the tracks and the sky. Installing a HUD that covers this area would deliver maximum value. Regarding user preferences, [20] and [3] suggest that the operator should be able to unclutter the screen in less stressful situations, customise the display according to preferences, customise the number of items displayed on the screen, hide screens when necessary, and adjust brightness and contrast, particularly when entering and exiting low-light areas such as tunnels.

4.2 Suggestions of HUD's for railway operations

Taking into account the previously identified recommendations, we propose in this part potential solutions for HUD interfaces that could contribute to some of the functions listed in part 3.3. These solutions are only theoretical to illustrate the recommendations, as further investigation is still necessary to identify what should be experimented in the context of this project and not all of them may be applicable. The elements that vary the most require frequent attention from the driver, who must constantly stop monitoring the environment to read the time or the speed of the train, for example. Thus, displaying the speed through a HUD could help being aware of the train speed and complying to speed instructions at all time while maintaining the ability to perceive signals and events in the environment. Fig. 1 presents an example of how the train's current speed could be displayed on a HUD. As this information is important and directly linked to train control, it could be placed directly in the centre and at the bottom of the field of view. If possible and when it makes sense, this space could be used to provide even more information that affect the activity, such as weather variations, the track's steepness if critical or alerts when overspeeding for example, as illustrated in Fig. 1. In addition to speed management, time management is an important part of the activity with a lot of possible fluctuation. In Fig. 2, we propose another interface that displays: (1) the current time as the main

Figure 1: Speedometer with additional indicators for the weather, steepness or overspeeding

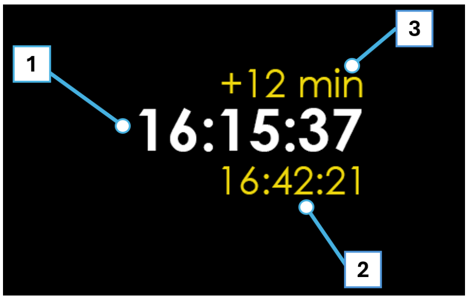

Figure 2: Current time indicator featuring estimated time of arrival and delay

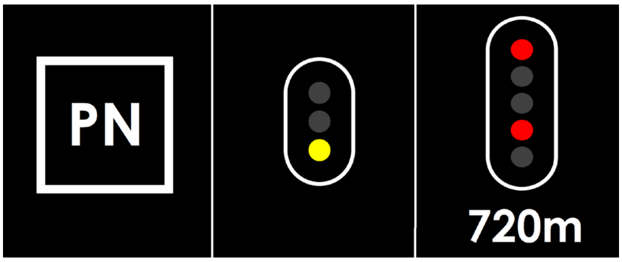

Figure 3: Example of upcoming signals and signs that can be displayed on a HUD

Figure 4: Preview of HUD within the train cab

information; (2) the estimated time of arrival to the next stop; and (3) the estimated advance or delay compared to the expected objectives. In the example of Fig. 2, the train is expected to arrive about 12 minutes late to the next objective. They are displayed in yellow to alert about the difference compared to the objective and suggest, if possible, an action from the driver. However, these choices are for illustrative purpose only and may be adjusted for actual experiments. Indeed, although the colour choice is important for the readability and efficiency of the information [24], they must also respect strict safety standards for digital interfaces that restrict the use of certain colours. For example, in France, the green colour is prohibited from digital interfaces to not be confused with side signalling.

To assist the driver in maintaining a high level of situational awareness during the activity, we could consider using an interface to display temporary information, such as upcoming events or signs. In Fig. 3, a "PN" sign reminds the driver of the upcoming level crossing ("passage à niveau"). This could also be extended to wayside light signals such as distant warning signals or stop ("Carré") signals. Additional information could be provided, like the estimated distance to the next sign or signal, as shown in Fig. 3. Although this redundancy of information may be beneficial to the driver to maintain situational awareness, it is not yet clear whether such information can actually be integrated this way and further tests remain necessary. Indeed, potential problems of adding several HUDs of this kind must be considered, such as the increase of visual clutter or the risk of overtrust in the HUD interfaces [25], which could reduce the driver's attention towards the environment. As with the colours used, the choice of elements that can be displayed or doubled on HUD's must also be confronted with safety standards, which may limit certain suggestions depending on the criticality of the information or the display quality and refresh rate of the screens used. Fig. 4 suggests how these interfaces could be presented on a HUD. All of them are placed on the outer edge of the field of view, to avoid obstruction.

While plenty of other solutions could be implemented, further study is necessary to determine the most critical and beneficial choices for future train driving interfaces. In this example, the information is displayed directly over the glass windscreen. However, the actual technology that should be used has not been determined yet as multiple parameters must still be investigated. For example, if the information is displayed on the windscreen, it is imperative to ensure that it is not negatively affected by variations of lights. This could possibly be done through an adaptive luminance and darkness from the interface. Alternatively, the HUD's could be displayed separately from the windscreen, being projected on isolated glass panels. Ultimately, the technology must comply with strict safety requirements, for instance in terms of electromagnetic compatibility or vibration resistance. Thus, multiple barriers remain as developing HUD for railway transport is still challenging and represents a heavy investment that may not yet be relevant.

4.3 Experimentations

Following on from this initial work, future tests are planned. The first step will be to set up a working group of railway experts (e.g. driving experts, safety experts) to discuss these first prototypes. The aim will be to compare points of view and gather opinions in order to come up with an improved version of the HUD that takes into account driving and safety requirements. This improved version of the HUD will then be tested on a train simulator developed by Railenium. The aim of the simulator tests will be to understand how the HUD impacts (1) perception of the external environment through the detection of elements essential to driving, (2) situational awareness, (3) driving performance, in each of the activity phases previously identified as being transferable to DRAISY driving (driving between two stations, ensuring passenger service, communication, managing level crossings or road crossings). To do this, we will compare performance with and without HUD. Tobii occulometric glasses will be used to compare the visual strategies implemented by drivers with and without HUD.

5 CONCLUSION

The work presented here is part of the French DRAISY project, which aims to design a very light train, where the line-of-sight driving mode may be more important than in the regular train driving activity and which is more adapted to the needs of small territories. This implies new operating modes and new ways of driving. In order to support the driver in the realisation of his future activity, the development of technologies must take into account the driver's needs and the complexity of the work activity. Based both on the study of the literature on HUD's and the realisation of observations in the cabs of trains operating on small lines in France, we have realised X design proposals for HUD's adapted to future very light trains such as DRAISY. Future work will focus on testing and validating of this first proposal on a train simulator.

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