Visualizing Running Time Constraint for Driver Adaptation to Punctual Train Operation

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Abstract: Since train drivers need to make operational decisions based on their own knowledge and capability to be aware of various domain constraints like safety, schedule adherence, and passenger comfort, their operational performance and quality may fluctuate depending on their level of driver expertise. The present paper proposes a configural display for inexperienced drivers that makes visible the dynamic constraint for schedule adherence, which is an ecological interface aiming at supporting the compliance of the regular running time. The display visualizes the train status on top of dynamically changing speed boundaries that represent the “running time constraint”. The skill-fostering aspect of this driver assist display is empirically investigated by comparing it with an optimal-profile display which gives more specific operational guidance as the ideal speed profile for punctual operation. As a result, it is indicated that, while both of the displays can enhance inexperienced drivers’ operational performance, the constraint-based display is distinctive for giving drivers much more opportunities to adapt themselves to variable work conditions.

Keyword: Ecological Interface; visual display; train driving; driver adaptation

1 Introduction

Train driving involves a variety of domain constraints such as safety, schedule adherence, passenger comfort, and so on. Train drivers are therefore making dynamic decisions based on their own knowledge and capability to be aware of those constraints. Such higher dependence on the individual’s ability can be considered as one of those factors that may cause fluctuations in operational performance and quality, especially across different levels of driver expertise.

Several studies to date, such as Askey et al.[1], Einhorn et al.[2] and Naweed et al.[3], have investigated train driver assist displays targeted at high-speed locomotives. Askey et al.’s “advisory display”[1] provides a high-level decision support by advising the driver of the optimal speed profile that satisfies all of speed and schedule constraints with the minimum fuel expenditure. As Naweed et al.[3,4] discussed, giving specific operational guidance like the advisory display changes the nature of the skill, changing the train driving into a display-based pursuit-tracking task. While leading to much higher operating performance and reducing complex decision-making components, the advisory display was found to increase the head-down time of inexperienced drivers[1], which will bring a new risk factor in the system disturbing their vigilance to the external environment. In addition, it is also concerned that drivers may get robbed of opportunities to improve their own skill not only for speed regulation but also for the overall management of train operation.

In the present paper, the authors propose a configural display for inexperienced train drivers that makes visible the dynamic constraint for schedule adherence, which is an ecological interface[5-7] aiming at supporting the compliance with the regular running time, i.e., punctual train operation. The display visualizes the train status on top of dynamically changing speed boundaries that represent the “running time constraint”. Since the constraint-visualization display does not provides any decision cues that enable stable performance by following them blindly, it is expected that this property of the display encourages the drivers to learn their own operational strategy from results of their independent decisions. This skill-fostering aspect of the display is empirically investigated by comparing it with a sort of advisory display.

2 Constraint-Visualization Display

Figure 1 shows the overall picture of the constraint-visualization display that was developed in the present
study. The display consists of three different graphical charts connected to each other.

The central chart provides the main view that presents the current train speed together with two horizontal lines representing the upper \(v_U\) and lower \(v_L\) speed boundaries. The two boundaries are estimated dynamically from the operational condition of the train with respect to its route schedule as graphically described in the other two charts.

The left chart visualizes how to calculate the lower-speed boundary that must be exceeded so as to make the train to arrive at the destination (i.e., the next station) within the remaining duration of time. Figure 2 presents this chart separately, illustrating the mechanism to calculate the boundary speed \(v_L\) depending on the current system state. In the chart, the horizontal axis represents the remaining time until the scheduled arrival time at the destination \(t_r\) while the vertical axis represents the distance from the current train location to the destination \(x_r\). The quadratic curve in magenta shows the imaginary state trajectory the train would make if it decelerated at a constant rate to stop at the destination on time. In our implementation, the train’s maximum deceleration in the case of the emergency brake was employed to draw this curve. The current system state \((t_r(x), x_r(t))\) is expressed by the red dot in the chart, from which a line segment is drawn tangent to the deceleration curve. The lower-speed boundary \(v_L\) is given by the gradient of this line segment. The horizontal line in blue, which is knotted with the tangent line at the point of time that is shifted one unit of time from the tangent line’s intercept on the horizontal axis, shows the derived speed boundary. Figure 2 also illustrates how \(v_L\) changes depending on a transition of the system state. As shown in the figure, going faster than the lower-speed boundary will decrease the boundary indicating the increased leeway for punctual operation, and vice versa.

The right chart in the constraint-visualization display, on the other hand, visualizes how to calculate the upper-speed boundary the train speed must be kept
below to stop at or pass through the destination safely. Figure 3 presents this chart illustrating the mechanism to calculate the boundary speed $v_U$. The horizontal axis represents the train speed ($v$) while the vertical axis represents the position on the route ($x$). The current train state is expressed by the red dot in this position-velocity state space. The quadratic curve crossing the point of destination shows again the imaginary state trajectory in the case that the train gets to the destination with its maximum deceleration. The $v$ value of the destination is set to zero if the train is supposed to stop there and to a designated speed limit if the train is to pass through the destination. The boundary speed $v_U$ is derived from this curve by looking at the $v$ value of the curve at the current position of the train $x(t)$. If the derived speed is higher than the speed limit for the traveling section of track, the latter is employed for the upper-speed boundary to be displayed. In the chart, the resultant upper-speed boundary is represented by the horizontal line in crimson. Similar to $v_L$, $v_U$ changes dynamically depending on the system state, especially when the train is approaching close to the destination. Figure 3 illustrates such a change in the display configuration in which the horizontal line of $v_U$ moves downward increasing the pressure for deceleration.

From the configurational display, the driver can easily identify necessary actions to comply with the running time constraint in one glance. As shown in Fig. 4, the central chart of the display can signify different operational conditions through its aspect. If the train speed is between the two boundaries (Fig. 4a), it tells that it is in a good condition towards arriving at the destination on time. If the train is running below the lower-speed boundary (Fig. 4b), it represents that the train would be late for the designated arrival time although it is still recoverable. If the train speed is shown above the upper-speed boundary (Fig. 4c), it represents that the train had better decelerate in order to avoid running over the designated stop position. If no adequate action is taken while the system is in these recoverable conditions, the display will get the aspect in which the lower boundary line goes above the upper boundary line (Fig. 4d). This aspect signifies the condition where the arrival on time is already impossible, suggesting that the driver needs to choose options other than managing to keep the schedule, such as driving the train reasonably fast below the speed limit.

Basic performance of the constraint-visualization display was already tested in our former studies [9-11] and it was confirmed that the display is beneficial for inexperienced drivers to achieve the punctuality. On the other hand, as described above, the constraint visualization provides no decision cues that enable stable performance by following them blindly. This property of the display can encourage drivers to develop their own operational strategy from results of their independent decisions. The display is therefore expected to give more opportunities to drivers to adapt themselves to variable work conditions.

3 Experiment

Advantages of the proposed display are empirically investigated by comparing it with another display that gives more specific operational guidance like the advisory display. The experiment was designed focusing on the driver’s independent performance as a result of their learning through the use of the driver assist display.

3.1 Setup

A driving simulator experiment was conducted to evaluate the driver assist displays. Figure 5 shows the experimental setup utilized for this study. As the train simulator, openBVE ver. 1.4.2 was used together with Pony Canyon’s game controller Master Controller II
for Train Simulator and a 27-inch Widescreen LCD monitor. The view from the driver’s perspective including instruments in the cab was rendered on the upper half of the monitor while the additional, driver assist display was presented on the lower half.

Participants operated a West Japan Railway 223-5000 series suburban train whose route was from Kojima station to Chayamachi on Seto-Ōhashi Line. On the route, the maximum speed limit was set to 130 km/h between Kojima station and Uematsu and to 95 km/h between Uematsu station and Chayamachi. The schedule was designed so that the train runs the route for 470 seconds in total. Considering they were not professional drivers, the power notch level 0 (coasting) and 5 were only available for the participants in addition to 7 brake notches.

3.2 Optimal-Profile Display

Another driver assist display was prepared for comparison purposes, which visualizes a sort of optimal speed profile that was generated from a train “run-curve”. Run-curve is a pair of position-velocity and position-time trajectories that describe the train dynamics along its journey and extensively used for railway operation such as route planning and train scheduling[8]. The trajectories are computed by considering vehicle dynamics and speed limit constraints along the route in question. In order to compose the optimal-profile display, the position-velocity trajectory of the acquired run-curve is utilized.

Figure 6 shows the configuration of the display, in which a run-curve is plotted with the train speed as the vertical axis and the train position (i.e., distance from the start station) as the horizontal axis. The red dot represents the current system state and the vertical line represents the ideal train position the run-curve supposes at each moment of time. The display gives drivers a very explicit, easily understandable instruction of how to operate the train. Points of inflection on the speed profile apparently show the optimal timings for the next operation. If the train follows the profile perfectly, it means that the train is actually operating on schedule.

Equivalent approaches of the optimal-profile display have been made by Askey et al.[1] (“advisory display”) and Naweed et al.[3] (“driver-tracking mode”). Naweed et al. discuss that such displays translate the key proponent of train driver expertise into the onboard computer and reinvent train driving as a tracking task.[3][4]. This reduction of the task components for human drivers can enhance and homogenize the driving performance very efficiently. Basic performance of the optimal-profile display has been empirically examined in our previous studies[10][11].

3.1 Procedure

The Research Ethics Committee of Kyoto University Graduate School of Engineering approved this experiment. Twenty two participants (17 male and 5 female, 21.4±1.7 years old) were recruited from undergraduate and graduate students in Kyoto University. They were paid 1,200 JPY per hour for participation. The experimenter provided each participant with instructions about the purpose and procedure of the experiment. All of the participants gave informed consent.

Between-group design was employed in which the participants were divided into two groups of eleven and assigned to either of the two driver assist display conditions below.
A. Constraint-visualization display

B. Optimal-profile display

The participants then went into a practice session in order to get familiar with the train operation on the simulator. In the practice session, participants operated the simulator from Kojima station to Kaminochō 5 times and then drove from Kojima to Chayamachi repeatedly until they satisfied the session termination condition. The practice was terminated when the practitioner was successful in two of the latest three trials in terms that he/she stopped the train within 5 m from the designated stop position and 10 seconds from the designated arrival time. After the practice, the measurement session started.

In the measurement session, each participant performed train driving under all of the following operational conditions in the order counterbalanced between participants.

1. On-time departure
2. On-time departure and the driver assist display disappears after Kaminochō station
3. Twenty-five second delayed departure
4. Twenty-five second delayed departure and the driver assist display disappears after Kaminochō station

The comparative dimension introduced by condition 2 and 4, in which the driver assist display got unavailable suddenly on the way, was intended to examine the drivers’ ability to operate the train independently without depending upon the assist display. The other dimension introduced by condition 3 and 4 was intended to see how differently the drivers respond to variations in departure conditions between the two assist displays. The present paper focuses on the former dimension and thus compares the two driver assist displays with respect only to the first two operational conditions.

5 Results and Discussion

By looking at differences in the driving behavior between condition 1 and 2, drivers’ dependence on the driver assist display will be discussed here. Figure 6 presents each group’s behavioral characteristics under the two different operational conditions in terms of their brake activation timing for stopping at Chayamachi. The group characteristics is evaluated with the average and standard deviation of the position (or running distance from Kojima) when individual drivers began braking, which correspond to the horizontal and the vertical axis, respectively, in Fig. 6.

On the one hand, the graph shows the same tendency between the two assist displays. Both plots of group A and B moved left in the graph from condition 1 to 2, indicating that, irrelevant to the display type, the participants made earlier decisions of activating the brake when the assist display was not available than when available. They made a cautious decision to do with the situational ambiguity imposed by the disabled assistance.

On the other hand, the two groups showed very different tendencies in the within-group variation of the brake activation timing. While group A did not make any changes in this dimension, group B made a large amount of changes in the within-group variation when the assist display got unavailable. Under condition 1, group B was very homogeneous in their brake timing, showing much smaller standard deviation than group A. This is exactly an effect of the optimal-profile display having made train driving a pursuit-tracking task. The users’ enhanced performance, however, easily collapses without the assist display. As shown in Fig. 6, the standard deviation of B-2 became more than 10 times larger than that of B-1. This indicates that group B’s homogenized brake operation was perturbed strongly by the sudden unavailability of the assist display, proving that their operational decision should be much dependent on the information presented on the driver assist display.

![Fig.6 Variation in the position to start braking due to the sudden unavailability of the assist display.](image)

Providing the optimal speed profile can improve the driving performance very efficiently. At the same time, the experimental result suggests that this achievement could not be made by individual drivers’ acquisition
of necessary driving skills, but rather reflecting the substantial transfer of the operational decision-making function from the driver to the speed profile designer. Different from the optimal-profile display, the constraint-visualization display did not entail such vulnerability in the driver’s decision. Group-A drivers demonstrated that they were not perturbed strongly by the halt of the assist display. Because the constraint-visualization display gives no explicit instruction about the use of specific operations and their exact timings, the users need to find some useful visual objects on the route as landmarks to develop their innate decision rules. The constraint-visualization display never provides any decision cues that make sure stable performance by following them blindly. This property of the display can encourage the drivers to develop their own operational strategy from results of their independent decisions. It can be considered as a reason why the display users could demonstrate robust performance against the unexpected unavailability of the display. With the boundary region made visible by the computer, they still have enough opportunities to be engaged actively in train driving.

### 6 Conclusion

The present paper has proposed an ecological interface for inexperienced train drivers that makes visible the dynamic constraint for schedule adherence. The display visualizes the train status on top of dynamically changing speed boundaries that represent the running time constraint. The skill-fostering aspect of this driver assist display was examined by comparing it with the optimal-profile display as focusing on the driver’s independent performance. As a result, it was confirmed that, while both of the displays can enhance inexperienced drivers’ operational performance, the constraint-based display is distinctive for giving much more opportunities to drivers to adapt themselves to variable work conditions than the optimal-profile display.

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### References


