Predictive aiding in the control of High Speed Trains

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Abstract
As the maximum velocity of trains increases and the speed of human information processing remains constant, computer based decision aids are developed to solve this discrepancy. One of those aids, predictive aiding, helps the operator predicting the future speed of the train. This experiment reveals the influence of predictive aiding on performance and mental load of the human operator, doing two tasks. One task consists of following a predefined speed trajectory and the other task is making train stops as accurate as possible to a prescribed "ideal" stopping point at the station. Experiments were done in a High Speed Train simulator, located at the John Volpe Transportation Systems Center in Cambridge. The simulator is developed in combination with the Human-Machine lab of the Massachusetts Institute of Technology.

Introduction
In order to satisfy the public's need for faster transportation, the maximum speed of trains has increased intensely. Nowadays High Speed Trains reach speeds up to 320 km/h, where as the Maglev (magnetic levitation) systems reach speeds up to 500 km/h. However, as train speeds increase the speed of human information processing remains constant. This discrepancy leads to three effects, which make High Speed Train driving difficult.

First, the allowable reaction time to sudden appearances of obstacles on the track is reduces by the high speeds. Second, when travelling fast all information presented with signals along the track will have to be dealt with in a shorter period of time. As a result the task of filtering relevant information will become more difficult when the filter time decreases. Third, knowledge of the train driver about the track characteristics, landmarks, operating rules and daily changing track properties (work by maintenance crews), will have to be retrieved out of the memory in again less time.

In order to find solutions to counteract these effects S.Askey and T.B.Sheridan started research in August 1993. The objective was to develop computer based decision aids for control of High Speed Trains where the locomotive engineer remains fully in control. In particular, this research sought to design and evaluate decision aids to compensate for limits in signal detection and information processing capacity experienced by locomotive engineers of High Speed Trains. Within this scope three concepts of aiding, preview, predictive and advisory aiding, were proposed.
The idea of *preview aiding* is to compensate for human visual limitations by providing, inside the locomotive cab, necessary information (i.e. track signals) for a distance spanning farther than the longest train’s stopping distance.

The principle of *predictive* aiding is to use a computer model to generate more accurate speed predictions than human operators can generate themselves. Two types of predictive display were designed. One type predicts the speed for the next period of time if the current throttle position is maintained. The other type constantly presents braking curves, indicating the train's future speed when full service or emergency braking was applied.

The third aiding is the *advisory* aiding. It presents an optimal speed profile—optimal in terms of total cost (energy consumption plus weighted schedule deviation).

This experiment was designed to gain insight into the influence of predictive aiding while using both preview and advisory aiding in the display. As a result a display using predictive aiding was compared to the display without predictive aiding. The advisory aiding was implemented with two different speed profiles, one having mainly constant speeds, while the other having more changing speeds. In this experiment the advisory aiding wasn’t a optimal speed profile. The reason for using both speed profiles (trajectories) was to investigate whether the influence of the predictive aiding was dependent on the amount of change within a speed profile. The objective was to have all subjects drive both speed profiles twice, once without predictive aiding and once with, resulting into four test runs. During a test run they were asked to control their speed along the speed profile and to make stops at stations. Arriving at a station they were allowed to discard the speed control task to fully focus on the station stopping.

**Method**

The human in the loop experiments were performed in a High Speed Train simulator located at the Volpe National Transportation Systems Center (VNTSC). The simulator consisted of an out-the-window view, an in the cab instrument display combined thrust and braking lever and some control button panels to control doors, emergency brakes etc. Three interconnected Silicon Graphics computers computed train dynamics, out-the-window view and instrument display. A PC added sound to the simulator.

**Display without predictive aiding**

Figure 1 shows the instrument display. The diagram in the figure is used to monitor the state variables speed and position of the train. Speed is plotted on the y-axis (in km/h) and the position along the track is plotted on the x-axis. Along the speed axis the current speed is presented in digits. As speed changes this digit will move up and down over the axis accordingly.

**Display with predictive aiding**

Now the predictive aiding is added to the display. From the current position and speed in figure 1 three lines emerge, representing the three types of predictive aiding. The line above the speed trajectory is the speed prediction of the train for the next 20
seconds, given the current position of the combined throttle and braking lever. The line pointing down most is the emergency brake curve. It points out how the speed of the train will decrease and where the train will stop, when the emergency brakes are applied. The second line pointing down is equivalent to the latter, but is computed for full service braking. The curves were obtained by integrating a fast-time dynamic model of the controlled system (i.e. the train) with the current state of the train as initial condition. (Sheridan and Ferrell, 1974)

![Figure 1: Instrument display with predictive display](image)

**Controls**

The combined throttle and braking lever is a joystick-like lever located in the cab at the right of the train driver. This lever was used to control both thrust (forward) and braking (backwards) input of the train. The center position generated no input and was notched for reference.

**Tasks**

The test runs encompassed two different tasks: *speed control* and *station stopping*. The *speed control* consisted in keeping the current speed on the plotted speed trajectory by generating input using the throttle/braking lever. Two speed trajectories were used, one having a mostly constant speed trajectory, while the other having a more changing speed trajectory. (Figure 2)
When reaching a station subjects were allowed to drop the speed control task to focus on the station stopping task. This involved stopping the train as close as possible to a prescribed point at the station.

**Procedures**

The experiment was performed by 9 subjects. All subjects were students of the Massachusetts Institute of Technology (MIT). Financial rewards were based on a hour rate and a bonus for good performance in both tasks could be gained. The subjects were handed a training tutorial at least one day before performing the experiment. The entire experiment consisted of a training and testing session. A training session, lasting one and a half hour and was performed immediately before the testing. During this session the subjects practiced parts off the test runs, both with and without predictive aiding, guided by the experimenter. The testing session, lasting about two hours and a half, consisted of driving four test runs

1. constant speed trajectory without predictive aiding,
2. constant speed trajectory with predictive aiding,
3. more changing speed trajectory without predictive aiding,
4. more changing speed trajectory without predictive aiding.

After each test run a subjective question form concerning workload and strategies used was administered. At the end of the testing an additional overall question form was to be completed.

**Results**

**Speed control**

The performance of the speed control task was measured by logging the deviation of the current speed with the plotted speed curve, which had to be followed. The results for the different runs are compared in figure 3.
Comparing the performance for the constant speed trajectory the mean deviation is lowered slightly when using predictive aiding (P). ($\bar{x}$=1.30 meter compared to $\bar{x}$=1.25 with P.) The standard deviation is much higher with predictive aiding. (0.23 meter compared to 0.86 with P.)

Evaluating the test runs with more changing speed trajectory, the decrease speed deviation with predictive aiding is more considerable. ($\bar{x}$ =1.50 meter - $\bar{x}$=1.33 with P.) Again the standard deviation is higher with predictive aiding, although the difference in standard deviation is smaller the test runs with more changing speed trajectory. (0.25 - 0.60 with predictor)

**Station stopping**

During testing 4 stops with and 4 without predictive aiding were made by each subject. Boxplot is shown in figure 4. The mean deviation (in meters) is decreased with predictive aiding. ($\bar{x}$ = 2.42 compared to $\bar{x}$=1.37 with P.) The standard deviation is lowered too. (1.40 - 0.57 with predictor). More appealing is the reduction from 4 to 1 of 'big' errors. (deviation larger than 5 meter)
**Workload**

The workload was measured by administering a subjective question form right after each test run. Subjects were asked to quantify the perceived mental effort and stress on a scale from 1 to 7. For mental effort bottom of the scale (1) is: *very little concentration needed, activities are almost automatic*, top of the scale (7): *high concentration needed, highly complex activities*. For stress (1) is: *low stress, very little confusion or frustration* and top (7) *high stress, high determination and self control required*. To monitor the amount of control actions made by subjects during a test run, the position of the combined thrust and braking lever was continuously measured.

When driving the test runs with constant speed trajectory, the mean perceived mental effort per test run is lowered from \( \bar{x} = 4.67 \) to \( \bar{x} = 3.67 \) with P. Perceived stress decreases from \( \bar{x} = 3.33 \) to \( \bar{x} = 2.67 \). Reductions are more evident while driving the test runs with a more changing speed trajectory. Here mean mental effort decreased from \( \bar{x} = 5.17 \) to \( \bar{x} = 3.44 \) while mean stress was lowered from \( \bar{x} = 4.39 \) to \( \bar{x} = 2.33 \).

<table>
<thead>
<tr>
<th></th>
<th>constant speed trajectory</th>
<th>variable speed trajectory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mental effort</td>
<td>stress</td>
</tr>
<tr>
<td>no P</td>
<td>4.67</td>
<td>3.33</td>
</tr>
<tr>
<td>with P</td>
<td>3.67</td>
<td>2.67</td>
</tr>
<tr>
<td>mean per test run</td>
<td>4.67</td>
<td>3.33</td>
</tr>
</tbody>
</table>

In the final question form subjects were asked three question. 1) Do you like or dislike the aiding? 2) Does the aiding increase or decrease the workload? 3) Do you take more or less control actions when using the aiding? Giving the situation without aiding an index 10, what would the index be for the situation with predictive aiding. (answers in Figure 5) All subjects like the aiding, most feel a decrease of workload using it and most think they use less control actions.

**Control Actions**

To monitor whether the use of the predictive aiding had influence on the amount of control actions the subjects made, the combined lever position was logged. Viewing those measurements plotted, it is clear that in the situation with predictive aiding the subjects took less control actions. (appendix A)
As those plotted files are large and the curves representing the lever position aren’t very smooth, it’s difficult to extract the exact amount of control actions taken. Instead taking the nominal value of the difference between two sample points, the number of differences bigger than a certain value were counted. Taking the mean of all subjects, this lead to the following results.

Table 2: Amount of occurrences of the control lever position difference > X of successive sample points.

<table>
<thead>
<tr>
<th></th>
<th>Test Run</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No P.</td>
<td>P.</td>
<td>No P.</td>
<td>P.</td>
<td></td>
</tr>
<tr>
<td>Difference &gt; 0.05</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td># of occurrences</td>
<td>1298</td>
<td>683</td>
<td>4289</td>
<td>1715</td>
<td></td>
</tr>
<tr>
<td>Ratio (No P.)/P.</td>
<td>1.90</td>
<td>2.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference &gt; 0.1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td># of occurrences</td>
<td>306</td>
<td>175</td>
<td>1253</td>
<td>458</td>
<td></td>
</tr>
<tr>
<td>Ratio (No P.)/P.</td>
<td>1.75</td>
<td>2.74</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference &gt; 0.2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td># of occurrences</td>
<td>17</td>
<td>18</td>
<td>142</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Ratio (No P.)/P.</td>
<td>0.95</td>
<td></td>
<td>2.54</td>
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</tr>
</tbody>
</table>

From the table it can be concluded that more control actions are made in test runs 1 & 3 (no P.) than in test runs 2 & 4 (P.).

**Discussion**

Within the discussion of the results the performance is weighted with the workload. Keeping in mind that a train driver will have to drive for hours, it is important to
consider the workload a task imposes. So better performance doesn’t automatically lead to better results.

Looking at the speed control task when driving the constant speed trajectory, the average deviation is not lowered highly with the predictive aiding. However the median is lowered a lot with predictive aiding. In other words, a much larger standard deviation.

When subjects were asked for the strategies used to perform their tasks, it appeared some found the display to be a little confusing, as too many curves gather around the current position and speed point. This could be the reason for the large standard deviation. An other reason might be the amount of help the predictor gives to perform this rather easy task. The task might have become too boring with predictive aiding.

This is made clear when considering low subjective ratings on mental load and small amount of the control actions. Overall, it is possible to perform better using the predictor, however the display of the aiding should be improved. Besides the task may be too boring.

When evaluating the test runs with a more changing speed trajectory, performance is improved due to the predictor. Once again the standard deviation in the speed deviation increased when using the predictor, however the difference is smaller compared to driving the constant speeds. The amount of control actions was lowered substantially. Looking at the subjective question forms, both mental effort and stress are reduced more than when driving the constant speeds. The predictive aiding gives the subjects an insight in the dynamics of the train while it changes speed. It relieves the subjects from mentally computing the train speed response to control input.

Concluding the evaluation of the speed control task, the predictor seems to improve performance, more considerable with changing speeds. Extracted from strategies used, it's advantage is mostly effective when accelerating or decelerating.

The train stopping task is performed with more accuracy with the predictor.

When evaluating the mean (3.35 -1.98 with Predictor) stopping deviation, it is clear the predictor is an efficient aiding. More interesting however are the big errors (deviation more than 5 meters) made by the subjects. Without the aiding 4 big errors occurred, whereas with predictor only 1 big error was made.

Concluding the station stopping task, beside the better performance, the predictive aiding takes over all lot of the mental load, induced by the station stopping. Subjects stress the good help they experience and it seems to give them confidence in fulfilling their task. As it is a reasonable hard task the influence of the predictor is big, as subjects ‘need’ the help.

In the final question form it is made clear that all subjects like the predictive aiding. Three subjects sense an increase of workload, whereas most don’t. Two subjects think the amount of control actions taken with predictive aiding increase, while in fact all subjects use less control actions.
To finalise this discussion I would like to make the similarity of the predictive aiding with a calculator. A calculator reduces mental effort, specially when calculations to be made are complex. When a calculator is used to add two simple numbers it's effect on mental load is small, as the simple calculation can be done by the human himself. He/ she is faster in computing the answer than in entering the numbers in a calculator. The difference in performance, with or without the help of a calculator, is also more considerable when the computations are complex.

As the tasks of a train driver in real life do not stick to only speed control, there will be less time to perform this task and therefor making it more difficult. In my opinion this will only stress the benefits of the predictive aiding.

References


Appendix A

These plots illustrate the throttle position during a test run. Plotted are the four winners per test run. It can clearly been noticed that the amount of control actions is less in the case with predictive aiding.

Throttle position of winner in **test run 1** (constant speed trajectory, no pred.)

Throttle position of winner in **test run 2** (constant speed trajectory, pred.)

Throttle position of winner in **test run 3** (changing speed trajectory, no pred.)

Throttle position of winner in **test run 4** (changing speed trajectory, pred.)