Train traffic control by re-planning in real-time

J. Wikström, A. Kauppi, P. Hellström, A. W. Andersson & B. Sandblad
Human-Computer Interaction, Dept. of Information Technology, Uppsala University, Sweden

Abstract

Today’s train traffic control systems are most often designed with a focus on controlling the technology rather than on supporting the train traffic controller in achieving optimal traffic solutions.

Train dispatchers often have to interact with many separate information systems in order to understand the traffic situation, to make decisions and to perform control tasks. An integrated and complete picture, showing the status of the entire traffic situation, is most often not at hand.

We have found that train dispatchers create their own picture, in the form of a dynamic mental model, based on long experience and available fragmented information. This is a very demanding cognitive process that forces the dispatcher to focus on understanding and gathering information about the situation instead of solving the problems. In the future these mental models will also be very difficult to maintain since new demands, more trains and higher speeds increase the complexity of the traffic process. Conflicts and disturbances also complicate the situation, forcing the train dispatcher to settle for a working rather than an optimal solution.

However, by presenting all decision relevant information in a single graphical user interface and providing well designed tools for re-planning, we shift the focus from controlling the infrastructure to planning the traffic flow. By performing re-planning tasks in a computer based interactive time-distance graph, the train dispatcher’s job will be to find a new optimal plan for the traffic. As long as this plan is free from conflicts, and the automatic train protection system is intact, it can be automatically executed by rather simple train route automates. This makes it possible for the train dispatcher to focus on the entire traffic situation and on solving conflicts as early as possible.

To test our ideas we have developed an experimental work place, where prototypes of the new control system can be evaluated in a simulated traffic control environment.
1 Introduction

In order for train dispatchers to better control the train traffic of tomorrow new control systems must be developed. The future brings higher speeds, more frequent traffic, and many independent traffic operators all making the control task more difficult and complicated. Our research is focused on the problems of how to control future train traffic and the user interfaces between the train dispatcher and the information- and control systems. Our intention is to develop a new interface that provides better overview, better control of the traffic flow, easy and straightforward manual interaction, access to decision relevant information and an integrated decision support system.

We have developed a new strategy for controlling train traffic where operators are able to follow the dynamic development of the traffic system over time and hopefully be able to prevent disturbances before they occur. Also, under normal circumstances train dispatchers can be relieved from the tedious and time consuming task of manually controlling train routes and instead focus on the traffic plan. We call this new control strategy control by re-planning.

2 Train traffic control today

Today train dispatchers tend to focus more on controlling the underlying technical structure than on the actual traffic flow. A simplified outline on how this is done can be seen in figure 1. This model is the result of an extensive series of interviews with train dispatchers conducted at control centers. A group of experienced train dispatchers have had an active role in the research work during the entire project. We will not go into details about the model but rather identify some of the problems with this strategy.

A lot of information needed in order to correctly understand the current traffic situation is normally not easily obtained. Instead the train dispatchers have to
create their own understanding, based on the mental models they have formed of the processes. This is a cognitive demanding task that reduces the ability to concentrate on the actual task.

Train dispatcher control the system by giving commands that directly affects the technology. Because of low resolution, or even absence of, information it is necessary to have deep knowledge about all technical details involved in the process in order to use the resources available in an effective manner.

Since the technology only allows control measures at certain moments in time one has to know about this and adapt the work so that control commands are issued at the right time. One consequence of this is that it makes planning in advance more difficult.

3 A new control strategy

To achieve efficient control of systems in general there are a number of things that need to be considered. The operator controlling the system should have a clear goal and an accurate mental model of how the entire system works under various conditions. The system should provide the operator with good observeability as to the systems past, current and predicted future status. Adequate possibilities to interact with and control the system are also crucial according to [1].

As mentioned control today is much focused on the infrastructure, and through the control of the infrastructure the traffic is managed. We suggest that the goal should not be to control the infrastructure but rather to plan and control for the train traffic operating on it. The key to the proposed control strategy is re-planning. Due to the nature of traffic, the original traffic plan easily becomes obsolete. To solve this, the train dispatcher should be provided with the re-planning means to continuously re-formulate the current traffic plan into a new functional plan. The aim of re-formulation of the plan is to turn a plan with conflicts or inefficient traffic into a better more optimized plan for how the traffic should be carried out. From this plan the order of which trains are allowed to use the shared track resources can be derived. Provided that the system has access to a valid functional traffic plan, it is possible to implement an automatic function that executes the plan. The main control task will then be to perform continuous real-time re-planning resulting in a valid traffic plan that can be executed. However, unfortunately there are situations where mere planning will not be sufficient. In case of signaling or some mechanical failure in the infrastructure manual control will still be required. Manual control can then be applied completely or partially over a control area. To be able to perform partial manual control and re-planning tasks at the same time it is necessary that the user interface clearly indicate to the operator what the status of the automatic execution function is.

Other goals with this proposal are to predict how the situation will look like. By presenting clear and detailed information we help in the understanding of what is going to happen in the future and reduce the risk of surprises. Since the
future work certainly will be more complex than today it is also important to provide tools that help the train dispatcher in making decisions. These tools should, at least in the beginning, be easy and straightforward and provide a solid base for planning and control.

An outline of the new proposed control strategy is shown in figure 2. A real-time database keeps track of the status of the entire traffic process as well as on the current plan that we constantly re-plan.

For a more detailed description on the new control strategy we refer to [2].

4 A way to achieve control by re-planning

To verify and evaluate the control by re-planning strategy a tool that allows the operator to interact with the traffic plan has been implemented. This tool consists of two different modules, a simulator and a graphical user interface. The simulator system is based on the kernel of the previously developed simulation system SIMON/TTS, see [3], which has been used by Banverket (the Swedish National Rail Administration) for off-line simulations in the planning processes. The simulator has a modular architecture making it possible to connect external control and presentation systems. The graphical user interface is written in Java and developed in a highly iterative process where train dispatchers have taken an active and very important role. It is designed to integrate all decision relevant information into one unified interface and to support continuous awareness of the dynamic development of the traffic process. Today it is possible to control simulated train traffic, reformulate the plan and dynamically follow the traffic process. The system can also be adapted as to fit different kind of evaluation purposes and it is also possible to run the interface without the simulator or over the Internet.

The most important component of the graphical user interface is the interactive time-distance graph. It maps the traditional paper graph into a
computer based graph with interaction possibilities and different types of decision supportive tools.

```
<table>
<thead>
<tr>
<th>Time (Future)</th>
<th>Interactive Time-Distance diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Re-planning tool)</td>
</tr>
<tr>
<td></td>
<td>Traffic Plan: Time Table, Track Usage</td>
</tr>
<tr>
<td></td>
<td>Planned and current train deviations; train position; train order; train id; duration of stop; type of stop; deviation; conflict detection; time; plan verification; construction work; tested, reserved and used track; Planned speed; Speed restrictions; Train type; automatic function indication; Minimum train running time; special transport;</td>
</tr>
<tr>
<td></td>
<td>Linear distance scale; Correlated graphics</td>
</tr>
</tbody>
</table>
```

Figure 3: An overview of the computer based time-distance graph.

Figure 4: A screenshot of when a train dispatcher worked on solving the second problem scenario.
Below the computer based time-distance graph is a simplified track diagram showing stations and tracks as well as other information such as curve- and height profiles. At the bottom of the graphical user interface are information boxes presenting train types, speed, length etc. Figure 4 shows the interface used in the experiment described later.

5 Performed experiment

In order to begin verifying and evaluating the new strategy an experiment was conducted at the traffic centre in Ånge, Sweden. A modified version of the prototype was used in this experiment in which interaction was simplified and the automatic execution function simulated.

5.1 Aim

The aim of this experiment was three folded. First, to evaluate how well the computer based graph worked when solving problems. Second, to test and evaluate a method for measuring situation awareness of train dispatchers working with the computer based graph. Third, to get valuable feedback from the intended end-users.

5.2 Realization of experiment

Each experiment, which took approximately one hour to complete, started with an introduction to the system. This was done in the same way for all participants following a list of instructions that were mediated by the experiment leader. After that each participant had to solve a first problem scenario. If the participant was not able to complete this problem for some reason they had to do it again until they managed. This way we somewhat guaranteed that all participants had the same skill when starting on the following two problem scenarios. The first problem scenario consisted of an engine breakdown on a station with only two tracks. The participants were informed that the problem scenario should be solved within ten minutes and that their job was to re-plan so that surrounding traffic suffered as little delay as possible.

The first real problem scenario consisted of a track resource being unavailable for use due to repair. Since the automatic function follows the plan, re-planning is necessary in order for the traffic to continue. Again the task was also to reduce the overall delay as much as possible. During this experiment we also tested a method for measuring the train dispatchers’ situation awareness. We will explain and discuss this method further in the results section.

The second problem scenario involved re-planning as to fit an extra train into the plan. Again the train dispatchers were instructed to re-plan so that surrounding traffic suffered as little delay as possible. After completing these problem scenarios all participants filled out a questionnaire with questions about the computer based graph, its interaction and usability.
A total number of eight dispatchers participated in the experiment. Simulating the automatic execution function was done by letting the trains follow the plan so that it appeared as if the train drivers always followed the timetable perfectly. Conflicts were introduced by loading different scenarios into the system. A problem scenario finished in one of two ways. Either the dispatcher had solved all conflicts or failed to solve a conflict that reached the current time.
Re-planning was done by altering the departure and arrival times on stations and by changing the track usage. Conflicts in track usage were indicated as red circles while other conflicts were left to the dispatcher to identify.

5.3 Results

When first introduced to this new tool for controlling train traffic almost all the dispatchers were a bit skeptical. But after completing the first problem scenario they were all interested and motivated to continue. The paper graph, which they use in their everyday work, have stations on the vertical axes and time on the horizontal while in our computer based graph it is the other way around. We anticipated this to be one of the major adjustments that they had to do in order to successfully work with the tool. It turned out that this was not such a big problem after all. When working on the first scenario many of the dispatchers turned their head so that they could look at the graph as they normally see it. However, when they worked on the last scenario this almost did not occur at all. So if it only takes thirty minutes to adapt, even a little, to this new tool having the axis switched then we probably do not have to worry about that aspect.

The train dispatchers were instructed to strive to minimize the overall delay caused by the introduced disturbance (engine failure, track repair and an extra train). All dispatchers managed to find a solution without a conflict ever reaching the current time and after completion they were asked if their solution was a solution that they would have settled for in real-life. They all agreed on this, but some of them added that they probably would have made some more fine-tuning. Below in figure 7 we present the total delays for each participant and problem scenario.

Figure 7: The total delay times for all eight participants and all three scenarios.
We mentioned earlier that situation awareness was measured during one of the problem scenarios. According to [4] situation awareness can be defined as “the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.” Achieving situation awareness is central to maintaining good decision making and human performance. The method used for this was an interruptive technique that from time to time halted the simulation by blanking the screen. Then the experiment leader asked four questions, noted the answers and started the simulation again so that they could continue solving the problem scenario. This was done four times and each time the same questions were asked. We programmed the system to automatically handle the process of blanking the screen. We saw that the dispatchers found this interruptive method a bit frustrating because they really wanted to work on the problem at hand. In each of the four rounds we asked the following questions:

**Will the change that you’re about to do lead to more, fewer or the same number of conflicts?**
- MORE □
- FEWER □
- SAME □

**How sure are you on your answer?**
- 50% □
- 60% □
- 70% □
- 80% □
- 90% □
- 100% □

**Are there more trains at the same time on the station where you marked the node?**
- YES □
- NO □

**How sure are you on your answer?**
- 50% □
- 60% □
- 70% □
- 80% □
- 90% □
- 100% □

When analyzing the answers and comparing them to the right ones we find that the dispatchers answers were 56% correct on the first question and 47% correct on the second question. These are very low scores, especially considering that just chancing would give 50% on the second question. There are many possible reasons to why they achieved such a low score. Perhaps they did not understand the questions correctly, did not quite care and just wanted to continue with the problem solving, etc. But one could also argue the importance of designing the tool so that it is absolutely clear what effects a change to the plan really have.

The questionnaire asked how information shown in the computer based graph was perceived, how it felt working with the graph and how they experienced doing re-planning in the graph. Each question had a number of sub-questions which later could be translated into a grade ranging from one to five, where five is the highest grade. We received very high grades on all of the questions showing us that we are indeed on the right track.

### 6 Discussion

This experiment showed us that it is possible for train dispatchers to handle disturbances using the control by re-planning strategy. Much work remains before we can verify that the strategy really holds, especially when switching between manual control and an active automatic execution function. Decision support tools need to be further developed and tested and train dispatchers will
have to participate in more advanced and complicated experiments. However, so far we have not received any indication to why this concept should not work.

Acknowledgements

This project has been financially supported by the Swedish National Rail Administration and Vinnova, Swedish Agency for Innovation Systems.

References


