A Multi-Agent System Approach to Train Delay Handling

Johanna Törnquist and Paul Davidsson
Department of Software Engineering and Computer Science
Blekinge Institute of Technology, Ronneby, Sweden
{Johanna.Tornquist, Paul.Davidsson}@bth.se

Abstract

A disturbance in a transportation network, e.g., a train being delayed, causes deviations from the original timetable. Often, such a deviation causes timetable deviations also for other transports in the network, making the consequences of a single disturbance difficult to predict. The ability to compute an ETA (Estimated Time of Arrival) of high quality is essential for the transportation network managers in order to satisfy the customers, of both public and goods transportation. In particular, intermodal transports, where more than one type of transportation is involved, depend heavily on high quality ETAs. When a disturbance has occurred, the ATA (Actual Time of Arrival) often depends not only on the physical flows in the network but also on decisions taken by the managers of the network and by the transport operators. We are currently developing a system for calculating ETAs for the Swedish railway network that takes all these aspects into account. It consists mainly of two parts; a railway network simulator based on traditional simulations techniques, and a multi-agent-based simulator of the decision making actors (and the negotiation between these). In addition to provide ETAs of higher quality than are available today, we plan to use this system also for evaluating different decision and negotiation strategies. The goal would then be to find strategies that reduce the delays caused by a disturbance, and further on, increase punctuality.

1 Introduction

Intermodal is one of today’s buzzwords in the transport business. Intermodal, in this context, refers to “movement of goods in one and the same loading unit or vehicle that uses successively several modes of transport without handling of the goods themselves in changing modes” according to the definition of The European Conference of Ministers of Transport. However, it is natural to extend the definition to also cover personal travelling that includes two or more different modes of transportation.

Some transport chains are logically intermodal, by definition, due to the nature of the route, i.e. maritime and air transports have no real substitute whilst road and railway transports can be used on equal terms, generally speaking.

One major criterion for preferences of transport mode is punctuality. Independent of transport mode or type of transport, the customer expects to receive what was paid for. If there are deviations, however, it is also important to inform the customer about the deviations and potential consequences (e.g. change in ETA, Estimated Time of Arrival) in order to provide them with the opportunity to reduce any negative impacts. Information about deviations is also highly essential for intermodal transports. Picture a transport chain with goods transported on railway, by ship and on railway again. A delay in the first railway transport can cause propagating delays in the transport chain due to the departure time of the ship. Depending on the situation, the ship might be able to wait for some time in the port, or an alternative transport can be booked. Due to characteristics of the transport mode, the sensitivity to deviations is different. Road transports are much less sensitive to deviations than railway, depending on the limited capacity in the railway network. At the same time, a delay in a road transport are not likely to generate additional delays while a delay in a railway transport affects its environment to a greater extent. Hence, there is a need of information when railway transports suffer from deviations.

We will here describe a system for calculating ETAs for the Swedish railway network that is currently being developed. In addition to simulate the “physical activities” taking place in the network when a deviation has occurred, it will also simulate the decisions taken by the human actors involved, e.g., the managers of the network and by the transport operators. The system consists mainly of two parts; a railway network simulator based on traditional simulation techniques, and a multi-agent-based simulator of the decision making actors (and the negotiation between these).

In addition to provide ETAs of higher quality than are available today, we plan to use this system also for evaluating different decision and negotiation strategies. The goal would then be to find strategies that reduce the delays caused by a deviation.

We begin by providing a detailed problem description followed by a description of the simulation models used.

The paper is concluded by pointers to future work and comparisons to related work.

2 Problem description

The problem studied is a part of the larger problem of minimizing train delays. This first step is dealing with the need of an ETA of high quality, that is, the calculation of a new accurate ETA when deviations from the timetable occur. The solution of this problem will be used in a second step towards the solution of the larger problem, namely evaluation of measures, which aims to compare different strategies for deviation handling in real-time. In this paper, however, we will focus on the first step.
In order to be able to calculate the ETA of a train that suffers from deviations, the concerned traffic flow has to be modelled. The flow is determined by four main conditions:

- Network characteristics
- Trains characteristics
- Actions taken by train dispatchers
- Actions taken by the transport operators

2.1 Network characteristics

By network characteristics we refer to the physical characteristics of the network and the available capacity in every moment. (Below we will describe the Swedish railway network, but the networks in most other countries have similar characteristics.)

The railway network is divided into blocks, where each block normally can hold only one train at a time in order to maintain the required safety level. The lengths of the blocks vary from one to another. The monitoring of occupancy of blocks is handled by line blocking. Line blocking was developed during the 1930’s and senses if there is a train on the block, and gives information to the signalling system that no other train may enter that particular block. Each block has its own “track circuit” and the connections to the neighbouring ones are isolated. When a train is occupying a particular block, there will be a short circuit and electricity goes through the train. The short circuit is indicated and trackside cables lead the information to the signal box along the block, which then passes it on to the traffic signal.

Generally, each block has one “main signal” and one “distant signal” for each direction. The main signal shows if the upcoming block is occupied or not, and the distant signal shows the status of the main signal in front of it. The distant signal serves the purpose to give the train drivers information about what the main signal shows, so they can operate their trains as effective and safe as possible (i.e. avoid stopping the train, but instead slowing down).

The physical characteristic can be speed limit, topology of the blocks, etc. The capacity in the network depends on two things; 1) if the blocks are available for train traffic or of it there is track maintenance planned during a certain time, and 2) the dynamic varying occupancy due to the train traffic.

2.2 Train characteristics

Train characteristics refer to static properties such as weight, transport operator, original timetable, etc., and dynamic properties such as ad hoc timetable (if deviations in the original has occurred), the current position and priority.

2.3 Transport operators

By transport operator we refer to a company that is allowed to use the railway network. Currently there are 24 transport operators in Sweden, including both public transportation and transportation of goods. Depending on the situation, the transport operators may have an influence on the selected measures for deviation handling. Primarily, the train dispatchers applies the principles that are established but in case of conflicts between trains operated by one and the same operator, the operator can have an internal established priority, which is given to the concerned train dispatcher.

2.4 Train dispatching

The train dispatching is in Sweden handled by Banverket. One responsibility of Banverket is train traffic control of the Swedish railways. The train traffic control is handled at eight traffic control centres, TLC, each responsible for a certain traffic area. The staff at a TLC is the operational decision maker when trains deviate from the timetable and new allocations of tracks and slots have to be made according to certain priorities. Since the train dispatchers at the TLCs and their responsibilities are divided into eight different territories, they have to deal with problems on a regional level with not enough time or a decision support system to consider the consequences for the whole system. Thus, the actions taken are often not globally optimal.

Today, in case of deviations, priority one is to be given to trains that follow the timetable, and to some extent they take into account the preferences of the transport operators, as mentioned. Beside those priorities, there are additional considerations and the train dispatchers take actions based on experience and their own judgement.

3 Model formulation

This chapter aims to formulate the model based on the characteristics of the parts described in the previous chapter. The model is based on different types of constraints.

3.1 Delimitations

The intention is to map the real problem situation taking into account all the factors that have an influence. However, the following simplifying assumptions has been made:

- Changes in timetables only concern new slot allocations for the original routes, i.e. changes in intermediate stations are not permitted.
- Likelihood of environmental impact are not considered since information on such things will be collected from existing information systems.
- Orally communicated information about the trains’ positions within a block is excluded.
- Margins for stopping are the same for all passenger trains and negligible for other trains.
- Economical aspects are not considered.

3.2 Constraints in model

The driving force of the simulation is the behaviour of the traffic flow, that is, the movements of trains according to their actual timetable.

The actual timetables are determined by several constraints, which are listed in table 1 below.

<table>
<thead>
<tr>
<th>Constraint type</th>
<th>Static data</th>
<th>Dynamic data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network characteristics</td>
<td>Planned maintenance, track characteristics, etc.</td>
<td>Line blocking, e.g. block occupation</td>
</tr>
<tr>
<td>Train dispatchers' decisions</td>
<td>Established priority rules</td>
<td>Circumstantial priority rules</td>
</tr>
<tr>
<td>Transport operators' preferences</td>
<td>Internal priorities</td>
<td>Internal priorities</td>
</tr>
<tr>
<td>Trains' characteristics</td>
<td>Original slots</td>
<td>Actual slots (traffic flow)</td>
</tr>
</tbody>
</table>

Table 1. Different types of constraints.
Since calculations of ETAs are only of interest for the part of the network that suffers from significant deviations, the first thing to do is to detect such a deviation. A deviation is the difference between the Actual Time of Arrival (ATA) at a certain point and the supposed arrival time. We will here assume that the detection of a deviation is performed by the user, that is, the user decides when to start the simulation.

3.3 Modelling the problem instance

The model of the problem consists of four parts: the network, traffic flow, train dispatchers and transport operators. These parts have a different representation, which is described below. The relationship between the different parts is illustrated in Figure 1.

1) Network representation

The network representation includes descriptions of the infrastructure and the line blocking function. The infrastructure is represented by a graph, where the blocks are represented by edges with different physical characteristics and the connections between blocks (i.e., stations and other block intersections) by nodes. Feasible combinations of occupied blocks represent the line blocking.

In order to represent the network and its constraints due to line blocking and other factors, the following has to be considered:

- Only one train is permitted to occupy a specific block at the same time
- A train can only occupy one block at a time
- If a train is occupying a certain block, no trains moving in the opposite direction are allowed to occupy the blocks that are in between the train and next intermediate node that permits meeting.

2) Traffic flow representation

The traffic flow consists of the moving trains according to continuously updated timetables. The individual trains have some static and some dynamic parameters that influence the flow. The static parameters that serve as input to the simulation are:

- the original timetable,
- train ID,
- type of transport (public/goods),
- maximum speed,
- weight, and
- transport operator,

whereas the dynamic parameters manipulated during the simulation are:

- the actual timetable, and
- position.

Both types of timetables consist of departing, intermediate and final stations and time of arrivals (TA). The original timetable stores the planned route and times for comparisons with the actual timetable that belongs to each train. The actual timetable is based on the original timetable and is updated according to new slot allocations or other changes. Position refers to last known position of a train, i.e., which block it occupies.

The train ID is used for identification of a particular train in order to be able to use criteria based on train characteristics. The other parameters define the train and its ability to adapt to new situations and preferences given by the transport operator.

3) Train dispatcher representation

There are eight TLCs with responsibility of one specific territory of the railway network each. Each TLC has several people working there, but their efforts will be modelled as a single unit, i.e., an intelligent agent. Thus, there will be a total of eight agents representing the train dispatchers, each having a dedicated part of the network and interacting with the neighbouring agents. A TLC agent has the following abilities:

- If necessary, the agent will negotiate with adjacent TLC agents that are affected.
- If possible, the agent will negotiate with the concerned transport operator agents.
- The TLC agent is able to take appropriate measures based on the current traffic situation, the network characteristics, the train characteristics, the priority rules and the negotiation with the parties mentioned above. These measures consist of changes in the trains' actual timetables, which will result in allocation of slots.

A set of priority rules is used to model the decision making of the TLCs. The priority rules concern the parameters of the trains and since the expertise within the TLCs varies, the rule base of priorities and their interrelations has been built in a way such that modifications easily can be made. At this stage, following rules are applied:

- Trains that follow their timetable have higher priority than deviating trains.
- Trains operating at a low speed (often transportation of goods) should not be in front of high speed trains in order to avoid additional delays.

The aim is, of course, to define the set of rules that corresponds as closely as possible to the actual behavior of the TLCs. However, in addition to the explicit rules mentioned above, also tacit knowledge influence the decisions of the TLCs. These aspects will be studied further.

![Figure 1. The architecture of the simulator.](image-url)
4) Transport operator representation
Each transport operator is represented by an agent. The transport operators affect the situation only if there is a situation where the agent is permitted to prioritise between two trains operated by one and the same transport operator. Such a conflict can be detected through the train IDs. The transport operators may have internal established priorities such as express transports have a higher priority than coal transports, and these are stored in a database of priorities between trains based on the train IDs. Since the market changes continuously, it is of great importance that this framework is modelled in a way that allows for modifications when necessary.

3.4 Simulation output
The outcome of the simulations is, as pointed out earlier, to provide ETAs of higher quality than are available today. This will provide an opportunity for all using the network to better deal with the consequences of potential deviations. A result in the long run, may be a higher flexibility and reliability in railway transportation than today. In order to evaluate the simulations and the accuracy of the estimations, the ETAs are compared with the ATAs.

Furthermore, this system can be used as a strategic tool for evaluation of different sets of priority rules and for training purposes.

4 Related work
The background to this paper have been studied in the R&D project Förbättrat informationsutbyte mellan Banverket och dess kunder (Eng. Improved information exchange between Banverket and its customers) [6], which have been financially supported by Banverket. Knowledge about the problem area in this paper is one part of the results of the R&D project.

Several research areas deal with closely related issues. The area of operational aircraft scheduling [1] also deals with real-time rescheduling of vehicles in a network with a limited capacity, and also the computational effort is highly crucial for the practical viability of the system. The air traffic has various similarities with train traffic, and the use of agents in air traffic management can contribute in this area [3] and vice versa. Auction-based railway scheduling [4] is another area where certain elements are similar and parallels can be drawn.

Furthermore, there have been studies within the area of using simulation of train traffic as a part of a real-time control system. Kraay and Harker [5] have written about CAD (Computer-Aided Dispatching) models and their use in this area. The authors have also suggested additional approaches, but not with the same perspective as our research proposes. The use of agents in this particular area is rare, but some similar approaches can be found, cf. [3].

Finally, it is also highly important to study areas not concerning the problem per se, but influenced by it and vice versa. The area of train dispatchers’ working environment is one example. In Sweden, research within this field, has been carried out during some years by researchers in co-operation with Banverket [1].

5 Conclusions and further research
As stated in the very beginning of this paper, the problem and approach just described is merely the first step towards a final goal where the model and the simulations are implemented as a decisions-support tool for train dispatchers in operations. After this first step is finished and the evaluation of the model has shown valid results and reliability, the next step is to simulate possible actions and their impact in parallel with the simulations of the real traffic flow. The additional simulations will be complemented by an optimisation approach with several goal functions that, in short, serve the purpose to partly consider the interest of the whole system, partly consider the gain for the individual trains. One global goal, for example, is to minimise the difference between the original ETA, (i.e. the timetable) and the updated ETA for all trains, but only applying such a goal function may be in conflict with other criteria. The second part aims to increase the punctuality of the train traffic.