

ALGORITHMS AND CONTROL SYSTEMS FOR COMPUTER-AIDED TRAIN DISPATCHING

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Summary

All railway companies try to attain more regular and reliable train services, in order to be able to offer their customers a higher reliability and flexibility. The present, expensive, strategy is increasing "physical" capacity. A more cost effective alternative is to first, as far as possible, improve quality in the train control process itself. The most important factor in this process is the train dispatcher, who from a control centre supervise (monitor and control) the movements of trains. The dispatchers chances to, in an active way, plan and control the train traffic is often crucial for how different disturbances effect train delays. Within this research area, one focus has been on development of algorithms and systems, which support optimal computer-aided train dispatching in real-time (CATD-RT).

We present a brief overview of existing knowledge and research and some important findings from a survey based on a set of interviews with dispatchers and train traffic experts. Also indicated are further studies necessary in order to, at the end, be able to successfully implement a system of this kind.

Key words

Train traffic control, decision support, optimisation algorithms, systems analysis,

Computer-Aided Train Dispatching (CATD) and Train traffic control.

All railway companies try to attain more regular and reliable train services, in order to be able to offer their customers a higher reliability and flexibility. The present, expensive, strategy is increasing "physical" capacity. A more cost effective alternative is to first, as far as possible, improve quality in the train control process itself [EC, 1990]. The costs for deficient punctuality are in Sweden very high, which has been stated both by Banverket (the National Rail Administration) and SJ (Swedish State Railways), as well as other sources. The same problem is also reported from other countries [Jovanovic et al., 1992].

Securing an, according to the published timetable, optimal control of the train traffic has therefore been focused on in the last few years. Faster trains, increasing traffic density, customer raised standards, and larger and larger areas controlled by one dispatcher, has made the time and ability of the dispatcher to one of the bottle-necks within the train traffic system. Dutch Railways have, for example, found that the control of train traffic was not optimal at the major railroad junctions, due to that tasks of the dispatchers had become too complex and too demanding [Lenior, 1993].

A distinctive feature of the train control process is that it is fairly easy to handle when trains are running according to their timetables and no disturbances occur, but is extremely hard to handle in an optimal way in case of disruptions. In order to improve decision-making in the process of train traffic control and thereby manage the above mentioned problems, several techniques and methods from System Sciences and Operational Research has been suggested and tried. In his survey [Oliveira, 1993] presented the contributions of such techniques in the area of railway system operation. Oliveira divides the decision support contributions into three categories: analytical models, simulation models, and interactive systems, discussing their fields of application and their potentials and limitations. Following the division made by Oliveira systems for computer-aided train dispatching in real-time (CATD-RT) fall into the category of interactive decision support systems in that they are constructed on the basis of co-operation between the dispatcher and a computer-based system, even though their kernel can be based on analytical models, simulation models, or other techniques .

Existing literature describes several models and algorithms handling this problem, although most of them were never implemented as a real-time tool for train dispatchers. Hereinafter we just mention a few of the more important, with no claim to be exhaustive. For a brief overview, see [Mills et al., 1991] or [Jovanovic, 1989].

[Komaya et al., 1989] have developed an expert system supporting high density train traffic control (double track) in disturbed situations, Estrac-III. It can automatically generate a rescheduling plan comprising many different types of schedule adjustments. It is based on a combination of basic simulations and a

knowledge base containing "if-then"-rules. This system is reported to support human dispatchers efficiently. They have also confirmed that generated plans are functionally equivalent to those of human experts working manually. Another interesting finding is that an unpractised dispatcher with the aid of this system can control the traffic as well as an experienced dispatcher (without aid).

Also [Schaefer et al., 1994] have reported on a complex CATD-RT system where the kernel is based on simulations intermingled with expert system techniques.

Another focus has been on development of systems, based on algorithms optimising the meet/pass plan of a railway line. The objective of the algorithms are normally to minimise total weighted train delay. A typical *optimal* CATD-system has the following features:

- It serves a line between two major stations or terminals. There are normally several meetpoints on that line.
- Every train has a schedule for that line. That schedule represents the initial optimum.
- There is a cost function of tardiness associated to every train.
- It is continuously served with new train positions from the signal systems.
- If there has been a disturbance, it calculates a new optimal meet/pass plan (schedule) that is presented to the dispatcher, who make the final decision.

A CATD-system that in real-time calculates a new optimal schedule has to be based on relatively advanced optimisation algorithms. In fact, these algorithms are one of the stumbling blocks when designing and constructing such a system. Research is still on finding heuristic solutions with good properties.

[Sauder et al., 1983] have reported on an actual implementation of an optimal train dispatching model. They have developed a method for single track performing a global optimisation. It is based on a partial enumeration of all possible meet/pass plans using a branch and bound method, minimising the total weighted train delays. The described method does not permit overtakings and demands long computation times. Despite these deficiencies it has been successfully implemented, probably because the computational burden and the human interaction problems are reduced by a low traffic density and long distances between meetpoints. They report that they have reduced delays with 25%! Unfortunately the details of the algorithm seem to be unavailable.

The main published work within this area is done by [Jovanovic, 1989], who has developed two new heuristic algorithms that generates good meet/pass plans for large problems. Although the algorithms does not allow overtaking, the result as a whole show that this technique is very promising.

Some findings from the survey

A survey, based on a set of interviews of train dispatchers and other experts on train traffic control has been performed. The objective of the survey was to get

a better understanding of the working conditions of the train dispatchers and at the same time make a compilation of the dispatcher's views and opinions on different phenomena related to their control tasks. The focus has been on decision-making under "normally disrupted" conditions. Some important findings are e.g.:

Generally

- All interviewed persons agree in that there is a substantial potential for improved decision-making in the process of traffic control. The result would be a better on-time performance, primarily due to a reduction in the so-called secondary delays. Quantifying this potential is difficult, but according to SJ the secondary delays amounts to 35 % of the total amount of delays (may-97).
- From a dispatching point of view there are main differences between various parts of the railway network. The possibilities to in an active way monitor and control the traffic varies due to a large number of factors, e.g. traffic density, type of traffic, number of tracks etc. We have therefore grouped the various parts of the network into the following categories.

category 1: The commuter area, representing a few percent of railway trackage in Sweden. It's characterised by a very high traffic density (especially during peak hours), mainly passenger trains. Traffic control is marked by almost no planning in advance, extremely time-critical decision-making, and very small possibilities to take corrective measures. A small disturbance in the traffic propagates fast influencing many trains, but it does not necessarily cause any large delays.

category 2: The double track area (less than 15%). The features are: high traffic density, mixed freight and passenger traffic. Some planning in advance, less time-critical decision-making, and some possibilities to take corrective measures characterises traffic control in this area. A small disturbance in the traffic does not need to propagate and effect many trains, nor does it necessarily cause any large delays.

category 3: The single track area (over 80%). Its primary characteristics are a rather evenly distributed mixed freight and passenger traffic and a *relatively* low traffic density. Traffic control is marked by long planning in advance, even less time-critical decisions, relatively good possibilities to take corrective measures, i.e. changing meetings and overtakings, and these corrective measures has to be done with a high precision. A small disturbance in the traffic run the risk of causing large propagation effects on many trains and result in great delays for some of them.

From a CATD-RT perspective the conclusion is that the most promising area for an introduction of a decision support system is the single track area.

Control

- The dispatchers are in case of disturbances, not able to fully consider the effects of all possible alternative actions. They have to be selective and try to choose a few of the best alternatives, which they then more thoroughly compare with each other.
- The dispatchers have problems predicting the consequences of their various decisions. One cause is probably that they have no other decision support tools than a pencil, a rubber, and a sheet containing the "graphical timetable".
- The smallest *time unit* used by dispatchers is "some minutes". This condition has to be changed if future demands are to be met.
- The dispatchers have not full information regarding the planned running times between any two meetpoints along a trains route, they know the exact position of a train only at certain (discrete) points of time, and they are only able to roughly estimate train arrivals to stations and meetpoints.
- Disturbances are often detected to late. The reasons are technical (the control system) as well as organisational.
- The dispatchers controlling one territory from a control centre does not communicate with the dispatchers in adjacent centres to any larger extent.

Organisation

- The regulations concerning traffic control within SJ are today based on train priorities. These regulations do not give full support in the decision-making process. For example, they lack rules for handling disturbances where several trains are involved. The dispatchers have further more a number of rules of thumb that they follow. Some of the most important are: "never let a delayed train, delay other trains." ; "it is better to further delay one train than to let several trains be delayed."; "keep the trains rolling as far as possible."; "use common sense.". They also state that they in the first place tries to find a good overall solution, sometimes disregarding regulations and rules of thumb.
- There are very large differences in attitude and competence within the group of dispatchers. This fact raises some important questions regarding recruitment, basic education, training, effects on design of systems etc.
- Last, but not least, most of the dispatchers find their work both interesting, creative, and developing. It is important to keep it that way.

CATD-RT - some key problem areas.

There are many design challenges to be overcome in developing and actually implementing a CATD-RT system. Most of the published work done so far has been on the static properties of models and algorithms, leaving the dynamic aspects disregarded. Some of the more important issues that existing literature seldom deals with are *how to*: functionally adapt existing algorithms and models to a dynamic environment; handle the, by all facts, existing national differences which has effect on how to choose cost function and what to optimise; deal with

the man-machine communication problems that definitely arise; design the system and the operator interfaces; decide which part of a company's railway net that gives the highest return if it is equipped with a CATD-system; treat the role of education and training in this process; handle the stochastic properties of the surrounding world etc. In order to at least fill some of this gap we have therefore presented the role of human-computer research for design of user interfaces in another publication [Sandblad et al., 1997]. We have also found that in order to fully analyse the actual work situations, the analysis must be based on a model describing the components of the studied system and how they are related to each other. A preliminary version of such a model is presented in yet another publication [Andersson et al., 1997].

Discussion

This project focuses on the properties of the algorithms and models of a CATD-RT system in a dynamic environment and from a national point of view, but also other aspects, as for example man-machine communication aspects, are taken into consideration. The main objective of our research is to reach a level of knowledge that makes it possible to evaluate the benefits of a future introduction of a CATD-RT system in Sweden.

In our next study we will examine the properties of some of the more important existing algorithms in a laboratory environment, in order to show their possibilities and limitations, angled towards the conditions and the "control culture" that prevail within the Swedish railway society. These algorithms will be implemented and tested with data from a single track main line in the middle of Sweden, with mixed operation of freight and passenger trains with different speeds. The main issues that will be studied are: implications on algorithms and cost functions from the decision criteria actually used in Sweden; evaluation of system proposed schedules, through dispatchers opinions; demands from an dynamic environment on algorithms and models.

The work done so far can be improved and extended in numerous ways. We believe that, due to the complexities involved in the decision making of a dispatcher, further studies of the dispatching process have to be done in a laboratory environment. An interesting continuation is to develop a relatively simple "Real-Time Control Simulator", RTCS, thereby making it possible to implement and test different types of algorithms, and at the same time study the design of the operator interfaces and other aspects of human-computer interaction. In a further extension a RTCS could also be used to investigate and evaluate the potential profits of an implementation of a CATD-RT system.

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