Application of Expert Knowledge for Train Dispatching Decision Support
A. Fay, E. Schnieder & A. Janhsen
Institut für Regelungs- und Automatisierungstechnik, Technische Universität Braunschweig, D-38106 Braunschweig, Germany
E-mail: a.fay@tu-bs.de

Abstract

The challenge of increasing train velocities, highly interdependent schedules and higher traveller demands force train traffic providers to improve the punctuality and reliability of their train services. The dispatchers, which try to reduce the effects of unavoidable disturbances and to keep the trains close to the schedule, are overcharged by their tasks and need to be supported by advanced support systems, which should be able to develop dispatching actions and to propose them to the dispatcher, together with reasons, explanations and alternatives.

In this paper, a new decision support system, which is especially designed for future high speed maglev train networks, is described. The system visualises condensed traffic situation information, for which the traffic development of the next hour is estimated by simulation. The available data is analysed for existing or arising conflicts. Applying the stored dispatching expert knowledge, promising dispatching actions are developed. After having checked the consistency of these actions with various hard constraints, the probable effects of the selected dispatching measures are evaluated by simulation. The action which resulted in the greatest improvement in traffic quality is proposed to the dispatcher. Thus, the system contributes to an improvement in traffic performance, reliability and customer satisfaction.
1 Motivation

As train traffic providers do not belong to the government any longer, new aspects like profitability, customer satisfaction and quality assurance become more and more important for the holder. Hence, a high transport capacity should be obtained and maintained. Furthermore, the transport system has to be attractive to passengers. Train delays are a severe obstacle to these aims. To satisfy all these requirements, the traffic has to be supervised and controlled in a control center. The dispatcher uses a traditional human-computer-interface.

Considering state-of-the-art train control systems, today automation is only introduced into the operative layer (see Fig. 1) which communicates directly with the train system (Schielle [11]). Train Control is only persecuted in small time and space dimensions (30 seconds, 5 km). Train supervision and control, however, are located on the tactical layer (Fig. 1) which is not automated yet. Time ranges of 30 minutes and distances of 300 km are handled on that layer.

![Hierarchical layer structure](image)

**Figure 1: Hierarchical layer structure**

Train dispatching can be represented as a control loop as shown in Fig. 2. The time table demand is interpreted to generate the actual time table. This one is used to control the traffic process which in return results process data. A computer collects these data and presents them to the dispatcher. The dispatcher compares time table demand and actual process information and tries to minimize the difference by adjusting the actual time table.
As train traffic velocity increases (ICE, TGV, TRANSRAPID), dispatching of train traffic becomes more and more important. The dispatcher has to decide quickly and errorfreely. Using todays human-computer-interface and dispatching methods and facilities, the dispatcher reaches his limits because of the high velocity and system complexity. For right decisions in short time, he has to be supported by a sophisticated environment.

2 The DISPOS-System and its components

Due to its clear and homogenous structure, the german maglev train TRANSRAPID (Wiescholek [12]) was chosen for the exemplary development of a dispatcher support system in the frame of the BMBF research project DISPOS (see Chapter 5 for project sponsoring details).

The proposed dispatching support consists of a time-compressing simulation tool, a human-computer-interface for the visualisation of actual and future traffic situations (Müller [7]), and a decision support system for the development of dispatching proposals (Figure 3).
2.1 System architecture of DISPOS

The structure of DISPOS is shown in a channel agency net (Figure 4) which explains the interaction of the components. The real process is controlled by the dispatched time table. In addition it is influenced by external stochastical events. The results are process states displayed to the dispatcher by the human-computer-interface. The need for dispatching methods can be deduced directly from the state of process (e.g. in case of reservation conflicts) or from a comparison of time table demand and actual time table (e.g. delay time conflicts). The human-computer-interface displays the actual traffic situation by use of enhanced graphics which focus on already existing and arising conflicts. The former are detected by analysis of the actual process values and comparison with the schedule and other service guidelines, the latter by periodic simulation (Müller [8]) of the traffic development (about 30 minutes into future).

The dispatcher can receive the demanded support by the expert system, when it is initialised by the actual state of process and additional information. The expert system proposes dispatching actions to reduce the differences of time table demand and actual time table. The dispatcher can accept one of these proposals, modify them or try out his own solutions.

The expert system finds out dispatching methods and tests them using the simulation which simulates the real process in a time compressing simulation. Using a simulation time table and additional data for process control, the

![Diagram of DISPOS system architecture](image-url)

Figure 4: Channel-agency net of DISPOS
simulation system calculates the simulation states. The simulation consists of a model of the whole maglev train network, including the operating control system.

2.2 Human-computer-interface applying user-centered design methods

In the early beginning of train traffic, train velocity was low. So there was plenty of time for the dispatcher to optimize train service. Time and economical aspects were not critical. As a decision tool, time-travel-diagrams were used - hand drawn on a sheet of paper. When computers arose, time-travel-diagram and network overview simply were transferred to screens to automate the process of hand drawing. The capabilities and power of modern computers remained unconsidered up to now. Human mental capacity and its abilities (Anderson [1], Rock [10]) were never taken into account. To optimize the dispatching process, every partner of a man-machine-system - man and computer - should perform the tasks especially qualified for. Hence, a user centered design approach (Norman [9]) has been applied to train dispatching in DISPOS for the first time, i.e. a design, where the human being and his psychology are taken into account.

Based on cognitive psychology, it was examined how information should be presented in general and can be graphically transformed so that it can be easily perceived and understood by man. It was found out that the existing structure of the dispatcher's working area has to be reconstructed completely (Müller [7]). The whole room, the working and organisational psychological aspects of the work, and the use of dispatching tools, like screens, key boards and graphic tables have to be considered. Building models, a novel dispatching station and working area (scale 1:10), a novel working desk (scale 1:5), and novel I/O-Devices (scale 1:1) were built. The objective for the design of these models was to create a working area wherein the dispatcher feels comfortable as he himself is in the center (User centered design) and not the computer or conventionally developed orders. Regarding the dispatcher's working area, lots of improvements could be obtained, e.g. a big screen projection showing a projection of the whole network which can be perceived simultaneously by all members of the working group.

After having classified the process values of the maglev train and its control system into four layers, according to their relevance for train dispatching, different diagrams for their visualization were developed, following a multiple hierarchical information layer concept. In the highest layer, displayed on a large screen, only the general conflict state of the network is shown.

2.3 Simulation system

The simulation system of DISPOS allows a fast estimation of the future traffic situation. A simulation has always to be a compromise between simulation speed and result accuracy. An acceleration factor of at least 1000 is needed, as the decision of the dispatching system has to be available in a few seconds, taking into account that the expert system needs several iterations and therefore several
simulations to elaborate a suitable dispatching advice. Nevertheless, the simulation results have to be calculated precisely enough due to the fact that the traffic operation is essentially influenced by the length of train head times.

The use of Petri Nets for description language allows structured design of complicated and complex systems (David [5]). Thus, a mathematical based proof of safety is possible for the use in safety relevant applications (e.g. transport of people). The Petri Net model completely describes the static and dynamic behaviour of the train network and the control system. The system description designed within the period of system development is reused for consistency and effort reduction reasons and adapted for simulation purposes.

Petri Nets are a discrete event orientated description language. Every transition is checked whether its input and output arc inscriptions are fullfilled so that the transition is enabled to fire. In this case the transition fires, the tokens change from the input to the output places, and then the test for enabling starts again. Obviously, many transitions are checked without firing so that the computing effort is very high for large nets, reducing overall simulation speed.

The solution for this problem is the calculation of the reachability graph of all net components. The reachability graph is a complete calculation of the system states and implies the tests for enabling(Christensen [4]). It is very similar to the structure of state machines. Using this method, an efficient discrete event simulation model can be obtained (Chiola [3]). Regarding the input-/ output- signals of separated partial reachability graphs as input-/ output-arcs of the Petri Net submodels, a network of state machines (Mealy automata) is obtained.

The automata are transformed into object oriented C++-Code, so that after compilation a library of automata is available. Some examples for automata are:
- automata for track reservation (controlling the state of the guideway),
- automata for handing over the vehicle to the next block,
- automata for point control.

At the next step, building blocks can be generated by integrating the automata and defining the parameters depending on the modeled traffic system and its project data. Using a graphical editor a complete simulation model consisting of automata based building blocks (instead of Petri Nets) can now be constructed (Zeigler [15]).

The execution of simulation experiments is controlled by the initialization and a set of control commands. The initialization can be either an actual state of the real process operation or an interstage or final stage of a former simulation experiment. With this concept, the expert system is enabled to reject decisions while looking iteratively for an optimal dispatching. It can be restarted from a good interstage to try out other dispatching methods.
2.4 Expert System

The task of the expert system is to generate appropriate, evaluated dispatching proposals which have to be explained to the dispatcher (Grabs [6], Yang [14]).

In case of difficult conflicts which can neither be solved by the underlying automation (Araya [2]) nor by the dispatcher alone, the dispatcher can ask the decision support system for advice. Furthermore, the decision support system simultaneously analyses the actual traffic situation as well as the one predicted by the simulation tool in order to detect conflicts as soon as possible. Ascertained conflicts are then classified by a diagnostic tool.

The knowledge of the expert system consists of the application specific knowledge and the ability to combine this knowledge and to apply it to the problem to be solved. Because dispatching experience for maglev train systems does not exist yet, the needed expert knowledge was received from dispatchers working in conventional train traffic (Wunderlich [13]) and then adapted to the specific needs of the high speed maglev train.

The knowledge base is scanned for rules which are suitable for tackling or solving the actual conflict with regard to overall traffic objectives and strategies. By application of the appropriate rules to the conflict situation, a set of promising dispatching measures is derived (Figure 5).

These measures are checked for fulfilling the hard constraints (e. g. for overtaking, the parallel track has to be long enough). Only the measures that fulfill all hard constraints are further considered.

Figure 5: From conflict to solution proposal
To predict the probable effects of each measure, they are applied to the actual traffic situation in parallel simulations, making use of the simulation component described in chapter 2.3. The emerging scenarios are evaluated automatically with regard to different quality criteria, taking into account the various desires of all persons and organisations involved in the traffic process. If the measures seem to be inadequate to solve the conflict, or if additional conflicts (usually minor ones) arise during simulation, the selection and assessment of dispatching measures is repeated iteratively for further improvement. A complete search in the set of all possible solutions of dispatching problems results in a combinatorial explosion and can therefore not be realised. Therefore, heuristic strategies for result oriented searching are applied.

The dispatching measures which result in the best conflict solutions are proposed to the dispatcher, together with explanations how they were achieved, to which grade they contribute to the solution of the problem and the general traffic optimization, and which other solutions may exist. The dispatcher can either follow the advice and accept the proposal, modify it or try out his own solutions. In any case, the dispatcher has still the final control over the executed dispatching measures.

DISPOS is capable of simulating sections (in time and space) of the real process with arbitrary initializations, e.g. with inter states or final states of preliminary simulations. In an iterative search for an optimal dispatching possibility, dispatching methods found out to be inconvenient can be withdrawn, and the simulation can continue from a previous state, trying out other disposition measures. Figure 6 explains this by a search tree where the nodes arranged above each other (e.g. process states 1.1.2, 1.2.1) follow sequentially in the simulation process, whereas nodes arranged beneath each other (e.g. process states 1.2.1, 1.2.2) represent decision alternatives.

3 Conclusion

The intelligent assistant system DISPOS for dispatching support presented in this article can be integrated in a control office, where its realisation will be completed. The actual phase of development and implementation will be followed by a period of realisation, in which practical tests with dispatchers are planned.
Due to its flexible and modular structure, DISPOS can be used as a basis for the development of dispatching support systems of other high speed train systems. DISPOS assists the dispatcher by the proposal of sound, validated and traceable dispatching measures. Thus, it contributes to an improvement in traffic performance, reliability and customer satisfaction.

4 Acknowledgements

This research project was sponsored by the German Ministry of Education and Science, Research and Technology BMBF (the former German Ministry of Research and Technology) under the label BMFT No. 514-7291 TV 9405.

5 References


