Transactions on the Built Environment vol 34, © 1998 WIT Press, www.witpress.com, ISSN 1743-3509

# Information and knowledge – valuable assets used for train operation and control

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## Abstract

Train operation and control plays an important role in ensuring reliable and efficient railway traffic. This becomes especially important with competitive transport markets. Therefore, increasing attention has to be paid to improvements in train operation and control systems. An assistant system for train traffic control is presented, and the crucial role of both up-to-date information and profound knowledge for optimized train traffic control is emphasized.

## 1 Train operation and control

Public transport providers face increasing demands concerning

- competitive transport markets,
- need for effective and efficient use of resources,
- reduction of personnel for train operation and control,
- changing and increasing customer requirements,
- service reliability and availability.

High transport capacity should be obtained and maintained, and still the transport system has to be attractive for passengers. Irregular services - and especially train delays or cancellations - are severe obstacles to achieve these aims. The challenge of increasing train speeds, tight time schedules and higher traveler demands force train operators to improve the punctuality and reliability of their train services. Train operators can only meet with these requirements by quickly developing an efficient action in case of traffic disturbances (deviations from schedule, resource lacks or the like). The use of computer-aided systems in both planning and operations control of train traffic is becoming more and more important to augment effectiveness and efficiency. Possible areas of application range from strategic planning to operational monitoring and control.

Concerning train operation and control, it is the dispatchers' task to ensure optimal train traffic performance according to the schedule and to minimize the impacts of schedule deviations even in the presence of unforeseeable disturbances. The latter might be due to

- planning mistakes (like poorly calculated headways or service times),
- technical reasons (engine breakdowns, signaling failures, track closures, and the like),
- organizational problems (late or absent staff members, extra trains for urgent transportation demands).

These disturbances can cause traffic conflicts like:

- connection conflicts for passengers,
- resource conflicts for trains and personnel,
- availability conflicts for track sections, and
- delays (usually in combination with one of the above).

In general, traffic conflicts result in situations where not all of the technical and operational requirements can be met. A conflict can be resolved by relaxing some of the requirements. Only operational requirements, such as arrival times or predefined platforms, can be relaxed, whereas technical requirements, such as maximum speed restrictions, can not be changed. Possible dispatching actions might include

- prolonged or additional stops in stations,
- crossing and overtaking,
- shifts and detours,
- canceled or added trains.

Dispatching is a complex conflict solution and traffic optimization process. The dispatcher has to adapt various conflict resolution measures to the actual traffic situation and select one which resolves the conflict with a minimum of negative side effects, considering the different

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objectives of the traffic provider and the customers. These objectives, such as service cost minimization or connection possibilities, can be mutually exclusive and must be weighted against each other and combined in an optimal way.

To ensure an optimal dispatching process in an environment of crowded tracks and reduced personnel, the dispatcher has to be supported by improved tools which focus on the most important conflicts, present all the necessary information (see section 2), and offer effective solutions.

Regarding the development of train traffic control, two main trends can be observed:

- To optimize train traffic systems in the sense of an optimal use of resources, more and more sophisticated methods and algorithms are used in traffic planning. Railway planning and control have a similar problem structure, as explained in Fay/Schnieder[1], so there is desire to make use of them also for short-term problems such as traffic control. Unfortunately, most algorithms are too time-consuming for on-line control problems. Therefore, heuristics have to be found and employed to adapt the planning algorithms to reduce the solution space. These heuristics can be deduced explicitly from the human dispatchers' knowledge (see section 3).
- To further improve traffic safety, quality and profitability, most functions on the level of train, track and signaling control have already been automated. This development is to be repeated in the area of traffic operation and control for the same reasons. This is much more difficult because the technical and organizational processes are less formalized on this level. Computer-assisted traffic analysis and computer-aided development of conflict resolution proposals offer valuable support for this purpose.

# 2 The role of information in train operation and control

The manifold tasks related to train operation and control can only be coped with by the use of appropriate computer support. This is due to

- the increasing amount of measurable and measured data,
- the increasing amount of necessary information to be considered,
- the necessity to keep data and information up-to-date, consistent, and available in a distributed system.

It is important to strictly differ between data and information: information is what is needed by the operator for decision-making, whereas data is the basis to derive information from. Therefore, data bases and data base management systems (which make up-to-date data available), though necessary and important, can not replace the effort to select and interpret the data to obtain the desired information.

Lacking information usually is a major bottleneck of complex railway systems (e.g. Welty[2]). This especially complicates highly information-dependent tasks like train operation and control. As shown in section 1, the success of the dispatcher's decision depends on up-to-date information about the conflict situation in question. The most important information about existing or anticipated conflicts is: Where is the conflict? Which resources (tracks, trains, staff) are affected and for how long? And which resources remain?

Nowadays, operating centers (called "Betriebszentralen" in Germany) largely replace the local control stations in Germany and elsewhere (e.g. Oser/Wegel[3], Sundblad[4]). In these centers, train supervision and operation functions are concentrated and carried out for large network areas (Oser/Wegel[3]). Furthermore, the supervision and management of maintenance works is integrated in these centers to optimize coordination with train operation. Modern signaling and control technologies allow the automation of large-scale systems and processes.

The increased requirements imposed on train traffic control can only be met by automation of tedious routine jobs and complicated calculations. Thus, the human dispatcher can concentrate on those tasks which require human creativity, such as developing new solutions for new problems.

Information about the current position and state of all vehicles, tracks and other system components is always available at the operating center. Therefore, many of the tedious dispatching tasks usually performed manually in conventional train systems (such as information gathering) can be automated. This provides additional time for the more important and difficult dispatching problems.

State-of-the-art dispatching relies on historically-developed diagrams which show the available data about the traffic situation. The time-travel-diagram displays the time-space-relationship of the trains in the past, which is linearly extrapolated into the near future in case it differs from the trains' schedule. The network overview displays the current position of the trains and the track sections reserved for them. Delays are coded in different colors. Compared to the important dispatching questions about conflict location and affected resources, these diagrams give no explicit answers. They contain only data which has to be interpreted arduously by the dispatcher. By the use of modern dispatching support systems (Fay/Jansen/Schnieder[5]), the important information is derived from these diagrams (and additional information sources) and displayed on an innovative human-computer interface (Müller/Schnieder[6]). Thus, the dispatcher has the necessary information at hand an can concentrate on the problem solution process.

# 3 The role of knowledge in train operation and control

It is widely acknowledged that knowledge is one of the most important assets of organizations. They depend on highly educated and skilled employees as well as on short innovation cycles, high flexibility and creativity. One of the prerequisites to achieving this is a systematic management of the key success factor "knowledge". Knowledge management is primarily an issue of enterprise organization and enterprise management but there are many central and important issues which can be supported or even enabled by state-of-the-art information systems.

The ever increasing complexity of large-scale technical systems (such as manufacturing sites, power plants or traffic systems) makes new approaches for their effective and efficient operation and control inevitable. Control - in a wide sense - denotes an appropriate reaction in the case of a malfunction or failure to regain a regular process flow. For this kind of "conflict management", the usage of available expert knowledge about the process and its problems is of utmost importance. The key to a successful conflict management is to support the human decision-maker with modern information systems which do not only provide information but also utilize previously gained knowledge. Decision Support Systems (DSS) yield an enormous potential as they develop - on the basis of appropriately stored problem solution knowledge - solutions specially adapted for the current conflict situation. These solutions form a proposal for the human operator, who - in contrast to fully automated systems - is still in charge of deciding whether to follow this advice or not.

For most technical systems, much problem solution knowledge exists. Usually, this knowledge is not explicitly available, but exists as the experience of experts who have dealt with these problems for a long time. By the use of sophisticated knowledge acquisition and knowledge representation techniques, this valuable know-how can be gathered and utilized.

The core of the DSS is the rule base. It contains the relevant dispatching expert knowledge. Preliminary investigations on the basis of related existing research (e.g. Komaya[7]) and on dispatching field studies resulted in the insight that the dispatching knowledge is mainly coded in rules, with a few special situations added as case-based knowledge. A rule-based implementation in a computer system can consequently represent most of the knowledge in a manner very close to the original (Puppe[8]). This is a crucial prerequisite for the later system to produce results which are traceable and understandable by the dispatchers, and this is essential for the acceptance of the system.

Both the description of a conflict situation and the formulation of expert knowledge regarding appropriate actions for this conflict are frequently vague. Hence, the success of knowledge-based systems is mainly dependent on how this knowledge could be modeled with explicitly taking into consideration these types of vagueness. Fuzzy concepts have emerged as a suitable means to be applied here (Zimmermann[9]). The fuzziness is due to two sources:

- The conditions which have to be fulfilled for the application of a certain rule can only be specified imprecisely by the experts. Typical examples are "When the train is much delayed, ..." or "When the connection is important for many passengers, ...". These formulations elude of an exact fixation. Precise limits or intervals cannot be given, nor are they necessary for the dispatchers' everyday work.
- The conditions which have to be fulfilled for the application of a certain rule are not available precisely. Instead, rough numbers are given. So - to stay with the example used above - the number of passengers which want to catch a certain train is not recorded exactly but estimated by the conductor.

Both kinds of fuzziness have to be taken into account during knowledge modeling. Artificial boundaries or exactness must not be introduced, but the fuzziness has to be modeled explicitly to make the best possible use of the expert knowledge.

# 4 The train traffic control assistant

## 4.1 System structure and functioning

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In this section, a dispatching support system is described which has been developed at the authors' institute (Fay/Schnieder[5]). The system is con-sidered for use in railway operation control centers and comprises of a knowledge-based decision support system, a simulation tool and a gra-phical user interface. The assistance provided by the system consists of

- simulation of the traffic development in the near future (approximately 1 hour),
- detection of conflicts,
- display of relevant information,
- prediction of certain dispatching measures' impacts,
- proposal of adequate dispatching actions based on accumulated expert knowledge.

The rest of this paper focuses on the last point: the development of dispatching actions. The other features have been described in detail in Fay/Schnieder[5], for example.

The complexity of the problems to be dealt with in real-time traffic control makes the employment of sophisticated expert knowledge indispensable to guide the search for appropriate dispatching actions. Therefore, dispatching experts' knowledge has been acquired, and a rule base has been derived from this knowledge which can be used for the automatic development of dispatching possibilities.

On this basis, the expert system tries to develop a solution for the actual traffic conflict. 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 actions is derived. They 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.

To predict the probable effects of each measure, they are applied to the actual traffic situation in parallel simulation runs. The emerging scenarios are evaluated automatically with regard to different quality criteria, taking into account the various desires of all persons and organizations involved in the traffic process. These criteria might be operational ones like punktuality or smoothness of traffic flow, economical criterial like minimization of costs and optimal use of resources or maximal customer satisfaction.

If the measures seem to be inadequate to solve the conflict, or if additional conflicts arise during simulation, the selection and assessment of dispatching measures is repeated iteratively for further improvement.

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.

## 4.2 System implementation

The crucial steps in the development of the knowledge-based component (as of any expert system (see Puppe[8])) are:

- the knowledge acquisition process,
- the appropriate modeling of the (fuzzy) knowledge,
- the structuring of the rule base for evaluation purposes.

Therefore, these steps have been carried out to prove the feasibility of our approach.

The knowledge has been acquired at the dispatchers' control centers during several sessions. Thus, the elicited knowledge could be worked off and structured afterwards, and gaps could be closed and ambiguities and contradictions could be solved in the following session. Altogether, about 100 rules have been accumulated this way, some of them have been further refined later.

The knowledge has been modeled in fuzzy rules to respect the vagueness of the knowledge and the uncertainty of the fulfilment of the conditions of the rules. This concept is described in more detail in Fay/Schnieder[10]. An example is given below.

The rules have been sorted according to several conflict classes. Each rule is based on two to eight conditions, which partly overlap in each conflict class. Some rules are structured hierarchically. During this procedure, even a small set of rules (three to ten rules) in one conflict class can become difficult to handle.

To enhance the clarity of the rule base, the rules are represented in a graphical manner by the use of Fuzzy Petri Nets (see Fay/Schnieder[10] for details). An example is given in the following subsection.

## 4.3 Example

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The following example is based on a simplified selection from the real problem domain. It deals with the following situation: In a certain station, train B waits for train A to arrive to allow passengers to change from train A to train B. Train A is late. In this situation, the following alternatives may be taken into account:

- Train B waits for train A to arrive. In this case, train B will depart with delay.
- Train B departs in time. In this case, passengers disembarking train A have to wait for a later train.
- Train B departs in time, and an additional train is employed for the passengers who wanted to change from train A to train B.

To make a decision, several side conditions have to be taken into account: the length of the delay, the number of changing passengers etc. An optimum has to be found regarding the divergent aims mentioned above. Concerning this traffic conflict, the following four rules have been collected from domain experts:

Rule 1: IF *many* passengers would like to change for train B
AND the delay of train A is *small*
THEN let train B wait for train A.

Rule 2: IF the delay of train A is *large*
THEN let train B depart according to schedule.

Rule 3: IF there is an *urgent* need for the track of train B
THEN let train B depart according to schedule.

Rule 4: IF *many* passengers would like to change for train B
AND train B departs according to schedule
AND train B was the last train in this direction on this day
THEN employ an additional train (in direction of train B).

The preconditions printed in italics are fuzzy and are, therefore, represented by fuzzy numbers. These fuzzy numbers state

- to which degree the delay is small or large,
- in which way the estimated number of changing passengers equals the expert's idea of "many",
- how urgent the track is needed for other purposes.

By means of evaluation of the preconditions, the rules which can fire are determined. Firing of these rules allows the computation of the support for the alternatives in question. Thus, possible alternatives are ordered with respect to the preference they achieve from the knowledge base.

# 5 Conclusion and Outlook

It has been shown that information on the one hand and knowledge on the other are indispensable requirements to solve train traffic conflicts. Both, information and knowledge, are available at the railway operators or can be made available with moderate effort. Instead of improving traffic quality by expensive infrastructure extensions, it is advisable to make use of these assets for enhanced dispatching capabilities and, thus, improved traffic quality and reduced operation costs.

The proposed assistant system for dispatching support presented in this paper can be integrated in an operating center. Due to its flexible and modular structure, the system is the core for the development of dispatching support systems for various public transport systems and can contribute to an improvement in traffic performance, reliability, and customer satisfaction.

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