Automatic conflict detection and advanced decision support for optimal usage of railway infrastructure

Purpose and concepts
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Abstract
This paper describes conflict detection and advanced decision support in the control of route setting operations, leading to optimal usage of railway infrastructure. Such a system is currently in development at the Netherlands Railways. By accurately forecasting train movements, conflicts can be detected in advance. A decision support module gives a what-if scenario, presenting alternative options to solve the selected conflict. Available measures are weighed by the system, using a cost function, and presented to the operator sorted on overall quality. Using Operations Research Techniques a generic system is obtained, giving reliable evaluations of the problem in short response times.

1 Introduction

Today's operation of railway systems shows a highly intensified usage of the railway infrastructure, in order to accommodate the required transport capacities. National governments pursue an active policy of discouragement for car usage and promotion of public transport. The scheduled capacities reach the theoretical limits of the railway system. As a consequence margins for readjustments, in case of process distortions, are significantly reduced. Small deviations can have major implications if they are not handled appropriately. As a result the product quality is vulnerable.

Market forces, on the other hand, require transporters to deliver a better punctuality and a higher reliability of their services, in addition to
the increased capacities. Large scale expansions of the railway infrastructure, or innovative train protection systems that make better use of existing infrastructure (ETCS), are promising, but can only provide solutions to these problems in a long term. For the medium term, therefore, these opposing forces have to be met by a better traffic management.

This paper describes the requirements for improving the control of route setting operations. Two essential elements in this improvement are (1) a shift from manual dispatching of routes to automatic route setting and (2) providing support in the process of planning and supervising route setting by the addition of an on-line system for early conflict detection and advanced decision support (CD/DS). Chapter two further details on the objectives for these improvements in the control of route setting operations. The components of a CD/DS system are described in chapter 3. The concepts for advanced decision support are discussed in chapter 4.

The description is based on the experience gathered at the Netherlands Railways, over the years '94 - '97, in defining a CD/DS system. This system is currently in development. The system implementation and early test results on the technical feasibility are presented in a separate paper at the Comprail '98 conference (Makkinga, Metselaar [1]).

2 Improved control of route setting

2.1 Automatic route setting

Traditionally routes are set manually by the train dispatchers by means of pressing buttons for the starting track, ending track and intermediate route selection on large switchboards. The actual state shown on the switchboard is compared with the predefined time-table and on the basis of this information routes are set when needed. The focus for the train dispatchers is primarily on operating the buttons and on monitoring the current state. This working method unfortunately leads to ad-hoc interventions and hence to sub-optimal readjustments. Better results could have been possible if measures were taken earlier. Another disadvantage is the labour-intensive character of this working method. As a consequence (a) the train dispatchers must be supported by a supervisor, who is responsible for anticipating train movements and resolving conflicts, and (b) the area controlled by a train dispatcher is
quite small. The separation of work between dispatcher and supervisor is a limiting factor in handling severe distortions, where all co-ordination, communication and route setting actions become dependable on the supervisor. Furthermore, the controlled area’s are too small to effectively eliminate the consequences of a process distortion.

In view of these disadvantages an effort must be made to combine the functions of dispatching and supervising in a single person, the train process supervisor, and to increase the area controlled by this supervisor. The necessary increase in productivity is achieved by releasing the train process supervisors of the routinely performed aspects of route setting, using automatic route setting, allowing him to concentrate on the actual problem: finding the most optimal readjustments to resolve conflicts and eliminate the consequences of distortions. The timely setting of routes requires disproportional high attention from train dispatchers. Now this timing can be performed by computer software, based on an electronic route setting scheme. The train process supervisor maintains this scheme.

The use of an electronic route setting scheme also significantly lowers the required level of verbal communication between train process supervisors and third parties (drivers, conductors, track supervisors). These third parties can now automatically obtain the adjustments made to the scheme, through EDI, from the moment they are entered (by the train process supervisor).

The Netherlands Railways introduced the Trace PSS computer-based system to accommodate the use of an electronic route setting scheme and automatic route setting (Renkema, Vas Visser [2]).

2.2 Conflict detection and decision support

With the use of an electronic route setting scheme routes can be set automatically. However, the effectiveness of this procedure is completely dependant on the correctness of the route setting scheme, i.e. it must be free of conflicts. Especially in severely distorted situations the train process supervisor must still be able to keep the route setting scheme up-to-date, to prevent falling back to manual route setting. Such a fallback would completely collapse the process of route setting operations in these distorted situations. The supervisor must be able to make modifications to the scheme with a minimum of effort. This is only feasible with the application of an on-line system for automatic conflict detection and advanced decision support. The requested solution is specified by the supervisor along the main lines. The CD/DS system subsequently fills in the details. Also, solutions that require complex
calculations, for example trains overpassing between stations, now become feasible.

With the application of the electronic route setting scheme the focus of the train process supervisors shifts from the moment ‘now’ to the moment ‘next’. Of course this is a necessary condition to obtain a higher quality and better reliability of the services delivered to transporters. It is also in this area where the CD/DS system provides essential support. As conflicts are reported automatically, before they actually occur, they stimulate a pro-active attitude towards adjusting the route setting scheme. The advanced decision support module gives the best way to solve these conflicts, reducing delays and the number of broken connections, thus leading to an optimal usage of the railway infrastructure and a neutral arbitration between transporter’s priorities.

A third objective for the CD/DS system is to obtain better uniformity in the execution of the route setting scheme (best practices). The adjustments made by the train process supervisor, to handle a particular situation, become more independent of the person on duty.

3 System description

3.1 System architecture

The architecture of the CD/DS system is shown in figure 1. Using current train movements and the route setting scheme a prediction of future train movements is calculated. Based on these predictions conflicts are detected and reported to the train process supervisor through the Man Machine Interface (MMI). At the MMI the supervisor can select a conflict and request a solution. The result is a so called ‘DS-Session’. Within a what-if scenario the supervisor can select from the available options to resolve the initial conflict and any resulting subsequent conflicts. When satisfied with the overall solution, the corresponding adjustments are applied to the route setting scheme. The predictions are recalculated and reporting of the concerning conflict is withdrawn. The next paragraphs describe the different modules in more detail.

3.2 Prediction module

Future train movements are predicted based on the route setting scheme, which also incorporates the time-table, and detailed running time calculations. These running time calculations constitute the Achilles heel
The static variables to be accounted for in the running time calculations include infra structure layout (position of switches, hills, curves, speed signs) and train characteristics (such as accelerating and braking curves). The dynamic variables include the time-table, train compositions and possible temporary speed limitations. As the system must also be reliable in severely distorted situations, it is essential that signal aspects are predicted accurately in order to simulate the effects of one train on the next train. The actual train movements are continuously monitored and compared with the predictions. When significant deviations are found the predictions are recalculated.
3.3 Conflict detection

The aim of the conflict detection module is to support the train process supervisor in planning activities by highlighting inconsistencies and conflicts in the route setting scheme. The main conflicts detected by the system are:

- Route conflict; two planned routes, which cross, must be set at the same time.
- Occupied platform track; a track can not be scheduled for use by two trains simultaneously, unless the trains are to be coupled.
- Broken connections; a passenger connection that will be broken due to delay of the arriving train.
- Broken rolling stock connection; if two trains are to be coupled to form a third train, the third train may not leave until the first two trains have arrived and are coupled.
- Route not available; if part of the infrastructure has been taken out of service, or is in defect, the routes using that infrastructure can not be set.
- Train sequence; the sequence of departing trains does not confirm to the time-table.

3.4 Decision support

The purpose of the decision support module is to support train process supervisors in resolving the conflicts, reported by the conflict detection module, in such a way that the result meets the requirements of the transporters as effectively as possible. Solutions are constructed from a number of sets of measures, each set designed to resolve a particular type of conflict. The available measures include alternative route selection, alternative track selection, setting priorities between movements (train A will proceed before train B at point X), scheduling overtaking manoeuvres between trains, etc.

There are two operational modes for the decision support module, a simple mode and an advanced mode. In the simple mode the available measures are presented to the train process supervisor in a fixed order, predefined for that particular set of measures. In the advanced mode the available measures are weighed by the system and shown sorted on the overall quality of the solutions for that particular problem. The concepts of the advanced mode are discussed in more detail in the next chapter.
4 Advanced decision support

4.1 Approaches

There are basically three approaches to advanced decision support:

**Operations Research**
Using the high computational power of current computer systems the problem is analysed numerically. The method most commonly used for issues related to optimising schemes is Constraints Satisfaction Programming (CSP). Solutions of the conflict, obeying to the constraints, are determined and weighed with the use of a cost function.

**Expert systems**
Decision rules are drawn-up for each type of problem, based on expert opinions, and explicitly programmed into a computer system. The solution for a particular conflict is then found by referencing the decision rules.

**Learning systems**
The system starts with zero knowledge on how to solve a conflict and completely relies on it’s ability to learn from the measures taken by the train process supervisors. It is then capable to emulate this behaviour at later times and to extrapolate from these data in order to solve other types of situations. The two most common examples of this technique are neural networks and the use of fuzzy logic.

The Netherlands Railways were looking for a generic system that could be applied to all traffic control centres, with a minimum of local configuration data. The cost of defining and maintaining this data would be too large. Hence the use of expert systems was rejected. Refer to Fay and Schnieder [3] for an example of the application of an expert system in resolving conflicts. Due to it’s flexibility and deterministic behaviour the choice was made for Operations Research as the basis for the advanced decision module. Early tests with a system prototype confirmed the technical feasibility of this approach in solving realistic problems.

Although encouraging results have been obtained elsewhere with neural networks and fuzzy logic, these methods were still rated too immature and the results too indeterministic to justify it’s application in
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this critical TRACE PSS component. However, the ability of fuzzy logic systems to effectively handle uncertainties in the input data, i.e. train movement predictions, still holds promising perspectives for the future.

4.2 Decision tree

The aim of the advanced decision module is to find the best path in the decision tree originating from the selected conflict C1 (refer to figure 2). Conflicts are denoted by circles and measures to resolve these conflicts are denoted by arrows. The available measures at the starting point resolve conflict C1, but in this example each will result in a new subsequent conflict (the conflicts C2, C3 and C4). The conflicts C2 and C4 can be resolved without introducing new conflicts. The measures to resolve conflict C3, however, each result in another subsequent conflict (the conflicts C5 and C6), that in turn can be resolved without introducing any new conflicts. What now is the best overall solution? This is determined by weighing the solutions with a cost function.

The size of the decision tree grows exponentially with the level of subsequent conflicts. In realistic situations the decision tree is much too large to completely calculate and weigh all options within the limited response time. Typical numbers are 10-50 options per level and 3 levels per problem, giving around $10^5$ options in total.

Figure 2. Decision tree
With good search strategies (heuristics) the relevant part of the decision tree must be isolated quickly.

4.3 Cost function

The cost function is used to determine the quality of a solution. How does it work? The first important observation to be made is that it should not weigh the measure as such, but rather the route setting scheme obtained from this measure. This is comparable to the field of chess computers. The movement of, for example a knight from C1 to D3, can not be given an absolute value. It is the evaluation of the resulting positions on the board that determines the value of this movement. Also for the CD/DS system the resulting scheme determines the value of a measure.

The next question that comes to mind is how should a route setting scheme be ranked? The occurrence of residual conflicts is an obvious one. Therefore the system always calculates to the point where all subsequent conflicts for the concerned trains are solved, within the region controlled from that traffic control centre. The path to the best obtainable residual scheme is presented on top, the path to the second best residual scheme below that, etc.

The primary objective to evaluate a route setting scheme is the amount in which this scheme is able to meet the requirements set by transporters. Corresponding parameters include the amount of delay given to trains, any broken connections and any changes made in the use of platform tracks. The second objective is a rating of the feasibility of the modifications for the train process supervisor. The advised adjustments must be in balance with the nature of the problem. There must be enough time available to effectuate for example a change in the use of platform tracks. The basic patterns of the scheme should not be broken to easily. This is achieved by giving penalties to the various types of adjustments.

4.4 System prototype

The functionality of the CD/DS system was tested with a system prototype, that was able to give realistic simulations of the Eindhoven station and near surroundings. Preliminary versions of the CSP module and cost function were incorporated in this prototype. The results are promising. The train process supervisors were able to effectively handle situations ranging from mild distortions to severe disruptions.
5 Conclusion

Today's operation of railway systems shows a highly intensified usage of the railway infrastructure, in order to accommodate the required transport capacities. Market forces, on the other hand, require transporters to deliver a better punctuality and a higher reliability of their services, in addition to the increased capacities. The improved control of route setting operations provides a solution to these opposing forces. Two essential elements in this improvement are (1) a shift from manual dispatching of routes to automatic route setting and (2) providing support in the process of planning and supervising route setting by the addition of an on-line system for early conflict detection and advanced decision support (CD/DS).

The application of Operations Research Techniques provides a good basis for the implementation of a generic CD/DS system, with an advanced decision support module that is able to give reliable evaluations of a problem in short response times. The feasibility of such a system was tested at Netherlands Railways with a system prototype. The results are promising. The train process supervisors were able to effectively handle situations ranging from mild distortions to severe disruptions.

References