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THE ARCHITECTURE OF DECISION-MAKING SUPPORT SYSTEMS USED FOR THE RATIONAL RAILWAY CAPACITY MANAGEMENT

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Abstract

Decision-making support systems in railway transport are systems that make it easier for traffic controllers and dispatchers involved in the regulation of train traffic to make individual decisions more easily and accurately. Without such systems, dispatchers usually make decisions based on previous experiences and feelings they have developed working in train traffic control. However, quality decision-making support systems are based on large amounts of data processed by one or several different artificial intelligence techniques. This paper will examine the architecture of such a system in railway transport, which helps the dispatcher to make decisions based on different criteria and values of individual criteria. The architecture of this decision-making support system has been developed to equal or, if necessary, use the maximum available double-track railway line capacity to resolve delays caused by lack of capacity for any given route. This system has been developed for the specific configuration of a double track, whereby each track is intended for one direction of train traffic. This paper will lay the foundation for understanding decision-making support systems and for the development of a specific model of decision-making support system in practice.

Keywords: railway capacity optimization, decision-making support system, dynamic traffic control

1 Introduction

The railway is a specific transport system because it comprises vehicles that can operate only on specific infrastructure. Furthermore, vehicles and tracks require particular signalling regulation and are limited to a specific direction of travel. Despite certain flaws (inability to change the direction of travel) ensures numerous benefits whilst ensuring a high level of safety. The railway can transport a great number of passengers or a large amount of cargo on a relatively small surface. For that reason, the railway has become the transport method of choice for mid-haul distances (150–600 km). From the expenses standpoint, the railway provides an additional advantage because it remains competitive for mid-haul journeys and is being used more and more. Many tracks that were built a long time ago require investments and modernization. Because of the excessive use due to numerous economic and ecological advantages and due to lack of investments, tracks have reached the limits of their transport capacities. This lack of available capacity on some tracks has led to operational traffic management whose aim is to minimize delays and maximize infrastructure utilization. This paper analyses the assistance systems used in making decisions in railway transport management. Also, the paper sets out to provide a comparative overview of systems to determine their benefits and drawbacks. Furthermore, the paper puts forward a new proposal for system architecture which would help make decisions in specific conditions that may arise on double tracks. Such systems are devised, planned, and implemented to help dispatchers to make decisions on train movement without or with minimum delays. At certain intervals of the day, month and year, there can appear disbalance in transport demand for some directions of transport. These situations lead to large capacity utilization and can generate substantial delays and traffic issues. However, since double tracks are constructed so that each track is intended for one direction of train travel, each track is limited in capacity, for both directions of travel.

2 Systems of decision-making in track capacity management

This part of the paper examines the systems that were developed for managing railway capacity. They can be used in managing various situations and assist in making decisions based on real-time processed and analysed data. These decision-making support systems follow the same principles based on which a dispatcher makes decisions. Dispatchers are in charge of operational railway transport management. They supervise the overall situation on a certain section of the track and based on knowledge, real-time data, and experience, they make professional decisions to normalize delays and reducing them to an absolute minimum.

According to [1] delays and disorders in transport impact the reliability and stability of the railway. They examine the simultaneous availability of larger disorders (temporary complete or partial blockage of tracks) as stochastic variation as the source of these disorders. The paper defines the time of the blockage and the time required to resolve the blocked track. A model was devised based on simulation and it includes dynamic priority rules for dispatching that aims to reduce the overall delay time. Also, a meta-heuristic scheme was devised that would search for available tracks within the limited capacity near the blockage. The model also calculates new arrival, departure, and journey times. It was tested on the Iranian railway network and, according to the authors, it yields very good and quick solutions equal to ones generated by commercial simulation and optimization software. The proposed solutions also include a lesser deviation compared to the solutions widely accepted today both by dispatches and standard software packages.

Author in [2] describes realistic solutions to transport coordination and coordination of transportation signalization in urban transport networks. The authors present a clock-face timetable that expands the network using a static and linear model. Such a transport flow model is based on the most modern statistic and dynamic models enabling at the same time the optimization of the timetable and coordination of the transport light signalling using precise techniques of mathematical programming. This paper also examines the inherent properties of journey times, demonstrating their capabilities in simulations made in high-quality simulation solutions.

In [3] authors write about railway signals, which is the most significant component of the railway system as it is the only aspect that ensures safety during the realization of railway services. Therefore, when there is an interruption in railway transport, dispatchers aim to adjust the affected timetable and minimize the negative effects during and after the interruption. Dispatchers manage train traffic using railway signals to communicate with train operators at fixed blocks. In such systems, signals depend on the movement of previous trains on that particular section or in the entire network. Previous works written on this have not concerned the impact of a signal on train movement and regulation. This paper proposes a new set of signal restrictions to describe the impact of signalling terms. Signal restrictions are based on the if-then rule. The authors assert the policy of “green lights”, that is, trains operate whenever possible without limitation.

Paper [4] describe the model of managing urban-suburban transport while adopting dynamic timetable. This includes a support system used when adjusting the timetable to the real-time situation in railway transport by means of a genetic algorithm defined by rules of regulating railway transport and train movement. Such a model provides a response to increased demands for railway capacity, that is, better utilization of available track capacity. At the same time, the paper describes the use of an expert system to manage capacity utilization – to save electricity. Case studies in the paper prove the advancement of railway urban and suburban transport by saving power energy.
Based on an optimization method for solving issues in train timetables, in the [5] authors presented their own optimization method. The aim is to reduce the overall train journey time in the railway network. SIMARAIL is the software that is used to plan timetables, which takes into account capacity limitation and infrastructure features. The simulation model uses a detailed micro-model of tracks and stations and infrastructural information.
A deeper look into the papers and what they deal with reveals that all decision-making support systems work based on already existing criteria, values, and rules, based on which these decisions are made. An adequate definition of the criteria is, therefore, an important factor in making optimal decisions. Subsequent research should pay particular attention to defining the criteria so as to develop a quality decision-making support system. The substance and approach will be of great assistance in that process.
The criteria include entry parameters and optimal time and duration of opening a second track for the same direction which would quickly and efficiently resolve delays.

3 Decision-making support systems in operational transport management

This part of the paper examines the support systems used in decision making which can be of use in managing various situations or when making decisions based on processed data.
There are support systems for making decisions on train movement in real-time and real-world transport conditions. They aim to reduce pollution and energy use. Such systems help make decisions based on the same principles that dispatches follow. In a way, the systems enable the making valid business decisions or selecting the optimal variants. However, the most important in decision-making support systems are systems that help make an optimal decision on regulating train traffic, i.e. decisions that help dispatchers.
Decisions made by dispatchers mainly concern train transport on tracks with a large amount of traffic or the regulation of trains at peak times when the maximum track capacity utilization is likely. Dispatcher decisions are founded on experience, intelligence, and intuition, taking into account the situation in transport and the traffic structure itself. Commonly, this includes decisions on the number of passenger and cargo trains currently operating, and their type (speed). For the decisions to be more rational, dispatchers are advised to make decisions based on indicators and the change in indicators over time. Since dispatchers cannot monitor and process large amounts of data in real-time, specialized tools are used to make their jobs easier. This is the reason why decision-making support systems need to be developed, as they can handle huge amounts of data quickly. Numerous authors have developed similar systems [6], [7]. Therefore, as can be seen from previous efforts, decision making is an important issue, which many authors have struggled to resolve.
In [8], the authors dealt with the criteria that may affect decisions when track capacity must be increased in a single direction. It is vital to define the normative values of the criteria that are used in the decision-making process. To do so, decision-makers must be familiar with the criteria, how they impact the potential increase/decrease in value, as well as the train operation process. In addition, the entire process must include an automatic value monitoring so that the parameters could be used as entry data for the decision-making system.

In fact, the most important aspect of the criteria is their ranking and the cost of waiting for the capacity to increase. The importance of every criterion needs to be defined so that they can later be compared and used in the decision-making process.
The paper [8] also includes a solution simulation for additional capacity on the case study of the M104 line. Additional capacity would include another track to be used for train traffic for the direction opposite of the one planned. The simulation-obtained result which claims that the second track would use as much as half of the capacity for the direction that had been planned. The next chapter provides the architecture of such a system which would help dispatchers to make decisions based on monitoring certain parameters.

4 The architecture of decision-making support systems in railway track capacity management

The previous chapter described the support system used in decision making. However, for the system to function properly and assist dispatchers to make decisions, it needs to be adequately described and devised. To do so, we first need to have a good understanding of how dispatchers make decisions. Since the system cannot think on its own, it needs to be made "smart" by providing it with quality input parameters. These parameters must be properly defined. The logic of the system has to rely on it providing a satisfactory solution.
For the system to be operational, it needs to be simulated using quality tools because this system is designed to in some way optimize the adequate use of the railway traffic network, or part of the double-track railway in this case. As this system has been conceived to optimize the adequate utilization of transport networks, the simulation should adopt a Petri net, given that it is a mathematical tool that can represent discrete systems such as train traffic on Fig. 1. [9]

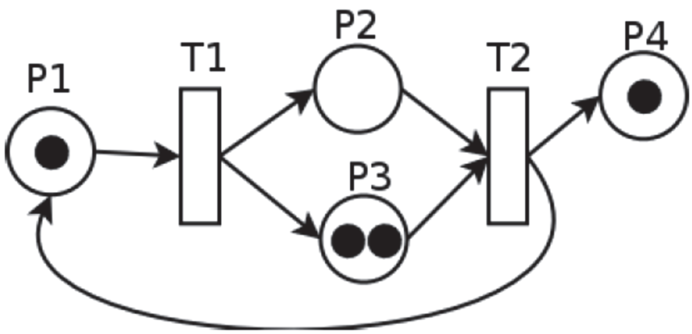

Figure 1 A Petri net model chart

Fig. 1 illustrates the Petri net places (P), transitions (T), markings, and input and output places. Places are marked with circles and transitions with rectangles or short straight lines. Markings represent tokens at places. The number of tokens equals the value of the marking. Input and output places are marked with one-way arcs.
Apart from the discrete events of time flow, the model needs to define the requirements and restrictions imposed by the system. Petri nets are first and foremost focused on conditioning the transition from one state to another after a condition or an event has been met, whereby the event can be the moment a certain time has passed in a state.
As Petri nets do not have features required to simulate such complex dynamic processes, they have to be upgraded to:

- High-level Petri nets: New generation of Petri nets with the same features
- Hierarchical Petri nets: have the option of creating hierarchical nets where the movement of tokens is monitored at several levels. Furthermore, Petri nets here can become a token of the Petri net
- Timed Petri nets: an important feature because it allows tracking of trains moving through railway junctions
- Stochastic Petri nets: train delays can be added to the model. Delays are modeled based on some of the established distributions or laws
- Colored Petri nets: have a practical way of using different colors to mark every train or type of train. This ensures train movement management in the model as well as a detailed tracking and analysis of train movement.

Therefore, the combination of all these upgrades together with external tools used in decision-making makes it possible to develop a system which can help dispatchers to make decisions on utilizing additional track capacity, based on tracking the criteria and parameters that affect those decisions.
In that conceptualized overview of the railway system modeled using Petri nets, places (p) are tracks or blocks of tracks. Transitions (t) indicate block signals and other elements that impact or can impact the normal train operation. Tokens indicate trains that operate on the network or parts thereof. Using colored Petri nets, additional train parameters can be marked. Such concepts of train simulation and mathematical modeling the Petri net can be used to devise and simulate a specific system that can be used in the decision-making process that regulates capacity management. This is particularly useful for when transport demand exceeds capacity supply. [9]

5 Conclusion

The railway is a complex dynamic system which regularly faces new demands and increase in traffic, that is, more and more transport services combined with fresh organizational and technological challenges. The challenges are mainly the inability to respond to ever greater demands for unutilized capacity put forward by railway undertakings. For this reason, experts are continuously trying to answer the challenges and utilize the capacity to the fullest by optimizing train operation. Dispatchers are in charge of operational train transport. With their skill and experience, they make decisions on how trains should operate. However, sometimes these decisions are not optimal, which is why some infrastructure managers are looking into specialized decision-making support systems. The proposals for potential solutions are based more amounts of data which are often more precise than the ones at dispatcher's disposal at any given moment. It is essential that these systems can in a very short time process large amounts of data with great precision, based on which they then can make a decision.
For exactly that reason, this paper has outlined the architecture of the decision-making support system for operational train transport management which would help improve dispatcher decisions concerning maximum capacity utilization. The system is largely based on input criteria which are constantly tracked. Based on these values and the impact these criteria have on each other, optimal solutions are provided.
The concept of such a system has already been tested in various case studies and by using simulation tools for model railway systems. This paper has put forth a proposal for upgrading the system and simulate it by using Petri nets as foundations for further system development.

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