A Novel Approach to Strategic Planning of Rail Freight Transport

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1 Introduction

In especially complex networks, timetabling is a protracted process, which, despite computer aided methods, comes along with a high manual effort. The reason is based on the huge amount of technical, operative and economical requirements and its dependencies among each other. Hence, the underlying infrastructure, the train characteristics and its resulting driving dynamic properties as well as the conflict-free positions of the individual train paths exert decisive influence on the time table. Additionally, the operational requirements, for example connections, symmetry and locomotive crew changes, play a major role. Not negligible are economical factors, such as the demand of specific train paths and their qualities (running times, waiting times, transfer times). Consequently, timetabling must be regarded as the core decision for an economically reasonable business.

Due to the large amount of constraints and the operator's obligatory required knowledge about geographic circumstances as well as the infrastructure, the manual editing is only possible for small subnetworks.

Particularly planning rail freight train paths based on an existing operation program for personal transport trains poses an outstanding challenge. The resulting rail freight train paths are highly dependent on the already existing train paths. Additional restrictions, like minimum number of train paths and a given set of quality factors, increase effort of the time tabling process as well. Furthermore, the manual

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methods for determining rail freight train paths for different time table variants, in case of a predetermined time quota and budget, rapidly reaching their limits.

This presents the starting point for the software system TAKT [3–5]. In recent years, the group of the chair for traffic flow science at TU Dresden in close collaboration with the DB Netz AG have successfully developed a software system, which supports the decision maker in his tasks for the strategic planning phase. The software system TAKT automatically calculates and optimizes periodic train paths for complex railway networks by innovative approaches in strategic passenger and freight train timetabling.

In this work, the focus is set on the novel approach of strategic planning of rail freight transport by using the already implemented FLOWMASTER module of the software system TAKT. This results in different variants of strictly synchronized and conflict-free time tables with a maximum set of high quality rail freight train paths.

2 FlowMaster

The creation of the passenger's time table follows fixed standards like clearly defined paths and their runtimes and defined stops for each train. It exists a set of restrictions between the different trains, such as headway, symmetry and connections. Subsequently, the passenger operating program is fixed the degrees of freedom are only the departure times. The generation of rail freight trains has less restrictions. The path depends on an economic route between a defined start and end on a track which is open for rail freight trains. In addition, those trains only need to stop on specific stations for personnel changes or to allow passings of faster trains. For economic reasons, stops should have a minimum distance between each other.

The difficulty of the rail freight train generation is the determination of the taken tracks and all necessary stops between the start and the end based on the calculated passenger time table.

The novel approach of solving those problems lays in the creation of a set of sub paths, so called InfraAtoms, which can be combined to a conflict-free rail freight path. The creation and the reasonable combination of the InfraAtoms will be described in the following section.

2.1 InfraAtom Creation

In order to reach the goal of creating the InfraAtoms, we need to generate a set of sub paths which can be combined to almost all possible track variants.

Firstly, the generation of single rail freight trains with correct train characteristics as well as length, weight and traction units is done. The path will be bounded by the given start and end station for the train. By the built-in routing algorithm [6] of the software system TAKT, the best economic track will be found automatically.

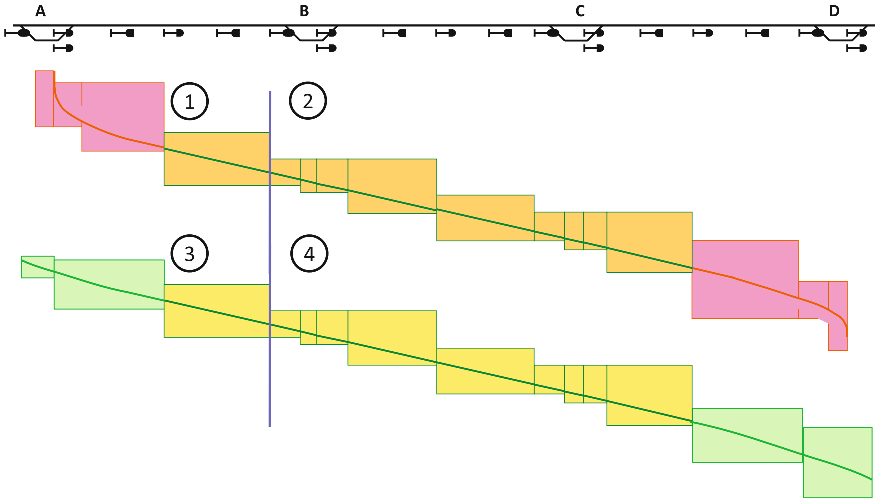

Fig. 1 The cutting of the train with and without stops at the intersection line results in four sub paths.

Additionally, it is possible to find a set of possible paths within a given detour factor which will generally cause a higher number of InfraAtoms. The driving dynamics of this train will be calculated without any stop of the train. This intends hat the train will start with a given speed and leaves the scope with the current speed.

Based on a calculated passing train an associated train will be generated, which stops on each possible station on the track that matches the requirements like minimum length. At this point, it is very important to choose the correct stop for the train in a station. Usually, it exists different possible stop nodes in a station. The passing train uses the through track. For this reason, the passing stop node should be excluded to prevent stops on the through track. The stop nodes on the opposing direction should be excluded as well, in order to avoid capacity degradation. Finally, choosing the stop node on the siding track is the best solution. If there is no suitable siding track, no stop will be automatically generated.

In the following step the trains with and without stops are split into sub paths. The intersection is a point on the track between two stops, where the blocking time of both trains is similar. As shown in Fig. 1, the intersection line is before station B at the end of a similar block. This cut results in a set of four sub paths. The halt train is cut into part 1 and 2 and the passing train into part 3 and 4. By the combination of sub path 1 and 4 and sub path 3 and 2 it is possible to create two additional InfraAtoms.

The routing algorithm and the driving dynamic calculation generate trains, which are traveling by using the maximum possible train speed which is limited by the maximal velocity of the traction unit and the maximal track velocity. For capacity reasons it could be a better solution to choose more than one slower train instead of one fast train. For these cases, it is useful to create additional InfraAtoms which are adjusted to the velocity of the trains associated to the current track. In order to calculate the new maximum velocity, a graph-theoretical approach will be used.

Based on the determined path of the passing train, a two dimensional network will be created with a set of nodes and edges. The x-axis defines the distance from 0 Km to track length and the y-axis defines the time interval from 0 min to the train period. For each dynamic distance step and static time step a node will be created. The connection between two nodes has the necessary speed as a property which is determined by the distance and time delta of the start and end node. In this way, it is also possible to model additional stops by creating connections between nodes at the same distance.

The resulting network can be reduced by eliminating all nodes whose time values are intersecting the blocking time of an existing train. Edges will not be generated, if the corresponding speed values do not match the current train characteristics.

Finally, a shortest path algorithm can determine the best path with the highest possible train velocity and necessary additional stops. The resulting train with the adjusted velocity will be used as a base train for the InfraAtom creation.

2.2 InfraAtom Combining

The InfraAtom creation results in a directed acyclic graph (DAG) like illustrated in Fig. 2 with a set of InfraAtoms $K = \{1, \ldots, 15\}$ which can be used to construct a path from a source InfraAtom in $Q = \{1, 2, 3, 4\}$ to a sink InfraAtom in $S = \{13, 15\}$. For modeling the InfraAtom connections, the function

$$\begin{aligned} I : K &\to 2^K \\ s &\mapsto I(s) \end{aligned}$$

maps each InfraAtom $s \in K$ to the set of its incoming InfraAtoms and the function

$$\begin{aligned} O : K &\to 2^K \\ s &\mapsto O(s) \end{aligned}$$

maps each InfraAtom $s \in K$ to the set of its outgoing InfraAtoms, respectively. Based on the graph shown in Fig. 2 $I(13) = \{8, 9\}$, $I(3) = \emptyset$ and for outgoing related InfraAtoms $O(1) = \{5, 6\}$, $O(3) = \{8\}$.

The remaining task is the determination of a train path defined as a set of InfraAtoms $T \subseteq K$ such that

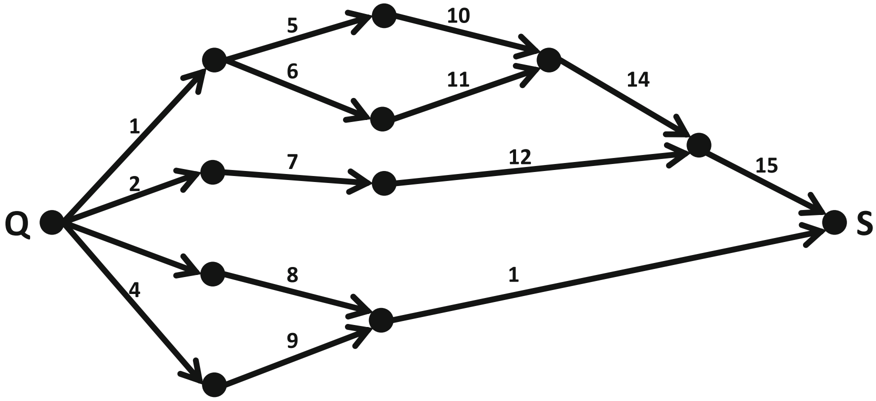

Fig. 2 Illustration of an example graph with a set of 15 InfraAtoms $K = \{1, \ldots, 15\}$ including 4 source InfraAtoms $Q = \{1, 2, 3, 4\}$ and 2 sink InfraAtoms $S = \{13, 15\}$.

$$\exists! s \in Q : s \in T$$
$$\exists! s \in S : s \in T$$
$$\forall s \in T \backslash Q : |I(s) \cap T| = 1$$
$$\forall s \in T \backslash S : |O(s) \cap T| = 1$$

Finding T can be done by a polynomial time algorithm. However, each InfraAtom is bound to constraints of a Periodic Event Scheduling Problem (PESP), which is NP-complete [7]. Hence, finding such T is NP-complete as well. Subsequently, the resulting PESP regarding the InfraAtom graph will be encoded to the Boolean Satisfiability Problem (SAT) [1, 2] and be solved by a state-of-the-art SAT solver. This encoding is not covered in this work.

3 Results

In a real-world example the FLOWMASTER was tested to determine and maximize the freight train paths on a highly frequented corridor. On this track, with a total distance of about 230 km, an operation program for passenger transportation was given. In a base period of 120 min, 88 trains with different periods from 30 min up to 120 min are traveling on the track. In addition, 10 connection restrictions between trains were given as well. In the first step, the FLOWMASTER module generated a set of 96 InfraAtoms. The quality of a rail freight train can be measured by the parameter $BFQ = t_{\text{run}}/t_{\text{fastestrun}}$, which is the quotient between the runtime and the fastest runtime. A train whose BFQ is higher than 1.4 is not acceptable. The FLOWMASTER was set up to determine 10–16 rail freight train paths. By the combination of the InfraAtoms, the algorithm could automatically find 10–15 rail freight train paths with a ranging BFQ from ≈ 1.23 to ≈ 1.8. A higher number of paths results in more stops on the track with longer halt times, which actually cause a higher BFQ. Finally, the best time table was calculated for 12 rail freight train paths with a total BFQ of about 1.3. The experiment has successfully shown that the algorithm could find five different time tables, each for every train path count, in half an hour. Creating such a set of time table variants manually would take at least half a year, but only by a worker with a deep knowledge of the infrastructure. By comparison, the automated generated rail freight train path with the manual created ones, the correctness and usability as well as the high performance of the novel approach could be proved.

4 Conclusion

In this work it is shown how to create rail freight train paths based on an existing passenger operation program. Firstly, a useful set of sub paths (InfraAtoms) based on the current time table is created. In terms of capacity reasons, it is useful as well to create InfraAtoms with different velocity, fitting the track requirements and the trains traveling on the track. By combining the InfraAtoms, it is possible to create new train paths which will be accepted if the Periodic Event Scheduling Problem is feasible for the restriction system with the additional restrictions for the new train path. Although the number of InfraAtoms is still quite limited, experimental results have shown that this technique can be successfully applied to real-world scenarios.

References

1. Biere, A., Heule, M., van Maaren, H., Walsh, T. (eds.): Handbook of Satisfiability. IOS Press (2009)
2. Großmann, P., Hölldobler, S., Manthey, N., Nachtigall, K., Opitz, J., Steinke, P.: Solving periodic event scheduling problems with SAT. In: IEA/AIE. LNAI, vol. 7345, pp. 166–175. Springer (2012)
3. Großmann, P., Weiß, R., Opitz, J., Nachtigall, K.: Automated generation and optimization of public railway and rail freight transport time tables. MTM **5**, 23–26 (2012)
4. Nachtigall, K.: Periodic Network Optimization and Fixed Interval Timetable. Habilitation thesis, University Hildesheim (1998)
5. Opitz, J.: Automatische Erzeugung und Optimierung von Taktfahrplänen in Schienenverkehrsnetzen. Logistik,Mobilität und Verkehr, Gabler Verlag(2009)
6. Pöhle, D., Weiß, R., Opitz, J., Großmann, P., Nachtigall, K.: Innovative automatische Laufwegsuche mittels neuartigem Routing-Algorithmus zum Nutzen der Fahrplanoptimierung. VWT, Dresden (2012)
7. Serafini, P., Ukovich, W.: A mathematical model for periodic scheduling problems. SIAM J. Discrete Math. **2**(4), 550–581 (1989)