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A comparison of algorithms for minimising delay costs in disturbed railway traffic scenarios

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ABSTRACT

The advent of modern railway signalling and train control technology allows the implementation of advanced real-time railway management. Optimisation algorithms can be used to: minimise the cost of delays; find solutions to recover disturbed scenarios back to the operating timetable; improve railway traffic fluidity on high capacity lines; and improve headway regulation. A number of researchers have previously considered the problem of minimising the costs of train delays and have used various optimisation algorithms for differing scenarios. However, little work has been carried out to evaluate and compare the different approaches. This paper compares and contrasts a number of optimisation approaches that have been previously used and applies them to a series of common scenarios. The approaches considered are: brute force, first-come-first-served, Tabu search, simulated annealing, genetic algorithms, ant colony optimisation, dynamic programming and decision tree based elimination. It is found that simple disturbances (i.e. one train delayed) can be managed efficiently using straightforward approaches, such as first-come-first-served. For more complex scenarios, advanced methods are found to be more appropriate. For the scenarios considered in this paper, ant colony optimisation and genetic algorithms performed well, the delay cost is decreased by 30% and 28%, respectively, compared with first-come-first-served.

1. Introduction

1.1. Background

Trains on a railway network are scheduled and controlled according to a timetable. Timetables are designed to be conflict free, that is, they should not contain any situations where a train is restricted in its scheduled movement by another train. However, in practice not all trains run according to the timetable, due to delays such as: excessive dwell times at stations, infrastructure and/or train faults, and the late arrival of crew. When trains do not operate according to the timetable, even by only a few seconds, there is an increased likelihood that they will cause conflicts with other trains, resulting in those trains also being delayed. Railway operators therefore attempt to run trains to timetable, or failing this, they try to minimise the cost of delays.

Generally, in today's operating railway, most train control is carried out by human operators – signallers. They are able to control the operation of signals to regulate and prioritise traffic flow. In simple scenarios signallers are able to manage the flow of traffic effectively; however, it has been shown that as situations become more complex there is an increased likelihood of signallers making sub-optimal decisions. This is particularly likely in disturbed situations (Balfe et al., 2007).

In recent years, railway operators have sought technology-based solutions that help signallers make improved decisions. Such systems have been deployed on many networks. These simple algorithms are able to provide useful solutions in certain cases, but as situations become more complex they do not perform well, even providing infeasible solution when the network is not deadlock free (D'Ariano et al., 2007). Therefore many researchers throughout the world have considered the use of real-time optimisation approaches for railway traffic management.

1.2. Optimisation

The primary objective of any optimisation approach is to find the 'best' solution to a problem given a cost function (sometime known as the objective function). Optimisation approaches have been used in many applications in the transport domain, including traffic management for highways (Papageorgiou et al., 2003) and aerospace (D'Ariano et al., 2010). In the railway domain, applications have included: improving railway traffic fluidity on high capacity lines (Chen et al., 2010), improving headway regulation (Ho and Yeung, 2000), timetable generation (Cacchiani et al.,

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2008), finding solutions to recover disturbed scenarios back to the operating timetable (D'Ariano, 2008) and energy utilisation (Bocharnikov et al., 2007). As well as including train rescheduling studies but different purpose (Corman et al., 2010; D'Ariano et al., 2008).

There are many different algorithms that can be used for optimisation of railway rescheduling, each with its own strengths and weaknesses. For real-time train control, there is a trade-off between computation time and the identification of an optimal solution (i.e. the best possible solution). This paper therefore aims to compare eight algorithms suitable for real-time railway control.

This paper compares eight methods for finding solutions of the train rescheduling problem. The rail infrastructure considered is an area bounded by two simple junctions. Four scenarios of disturbances on this area are used to evaluate the algorithms.

1.3. Problem formulation

The scenario considered in this paper can be visualised as in Fig. 1. Destinations A–D can be considered to be stations at which the trains should stop. If the trains pass through the flat junction according to the timetable (see Table 1), no conflict occurs. However, if Train 2, for example, is delayed by a few minutes, it is likely to conflict with Train 3. Given this scenario a signaller must decide which train should pass first.

If only one train is delayed, and only a small area is considered, this can be a straightforward problem. However, as the geographic area under consideration and number of trains increase, the problem becomes more complex. Furthermore, each of the trains shown in Fig. 1 may be of differing types (high speed, commuter or freight). This means that each train will have different accelerating and braking profiles and different top speeds. The problem of deciding on an optimal solution then becomes even more complex, even for a simple scenario such as that shown in Fig. 1.

In order to decide on an optimal solution it is necessary to specify a cost function. The cost function can contain many parameters. In this paper a simple cost function will be considered:

$$J(\theta) = \sum_{i=1}^{n} DT_i(\theta) DP_i \quad (1)$$

where n is the number of trains to be considered, DT is the delay time for each train in minutes at its destination, DP is the delay penalty per minute for each train, θ defines the ordering of trains through the junction and $J(\theta)$ is the total delay cost of each ordering. The optimal ordering $\hat{\theta}$ is given by:

$$\hat{\theta} = \arg\min J(\theta) \quad (2)$$

i.e. it is the ordering that minimises the delay cost.

The complexity of the rescheduling problem depends on the number of trains to be considered. For example, a six train conflict could have up to 6! (= 120) different potential orderings. Due to the constraints of the railway system, only a proportion of these orderings are physically possible.

1.4. Example scenarios

Throughout this paper a layout based on the North Stafford and Stenson Junctions on the Derby to Birmingham line in the UK is considered. It should be noted that both junctions in this scenario are 'flat-junctions'. Fig. 2 shows the layout with 12 approaching trains, numbered 1–12. The letters shown in brackets are of the form (*origin*, *destination*). It is assumed that initially the 'junction area' is clear. In this simulator, the speed limited at junction area is 64 km/h, and moving block signalling system with automatic train protection is used.

The conflict-free timetable and train-specific delay penalties are shown in Table 2. The delay penalties, measured in £/minute (GBP/minute), are shown in Table 2. These depend on the type of train, with high speed trains having a greater penalty than commuter trains, which in turn have a greater penalty than freight trains. Table 2 also shows the 'Initial distance from junction area' when the algorithm is started, the destination of the trains (station A–D) and the scheduled arrival times at destination.

Four scenarios that have delay distributions in line with this those commonly found in the real-world, are considered:

Scenario 1: Train 1 is delayed by 3 min – for this scenario a single train, the first train to pass through the junction area, is delayed;

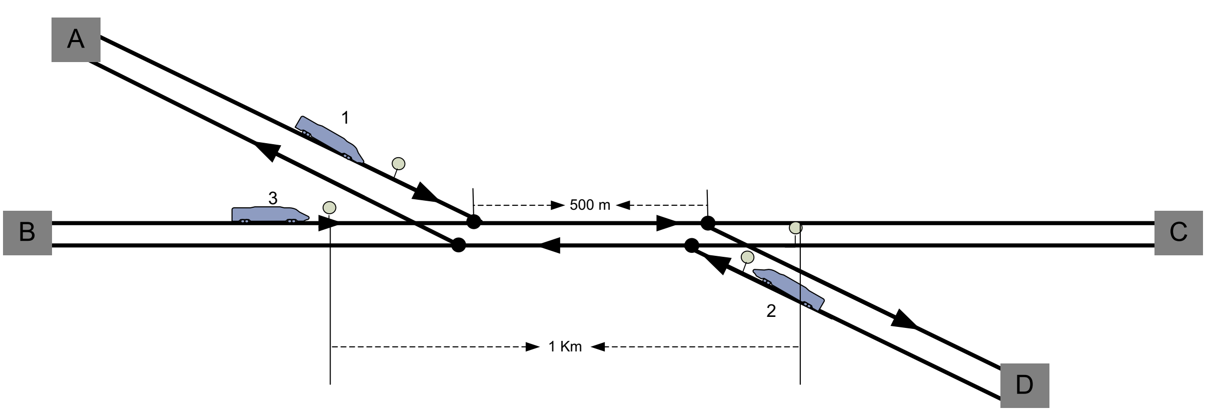

Fig. 1. Sample junction.

Table 1
Simple junction train details.

Train	Timetabled arrival at junction area (min)	Train type	Destination	Train speed through junction (km/h)
1	13	High speed	D	64
2	17	Commuter	A	64
3	19	Freight	C	64