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Track maintenance between trains simulation

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ABSTRACT

Infrastructure managers (IMs) need to plan their maintenance work about 1½-2 years before a new train time table (TTT) comes into force to minimise the effect on traffic. Maintenance work that is planned in less than one year ahead of the TTT has to compete with, or need to be fitted into, operators' applications for capacity. However, maintenance work is at times planned only a few weeks before execution, and depending on the railway line in question, a few hours during night can be available for maintenance. In addition, sudden failures in track normally require repair immediately or within a day. If rail transportation increases, it also becomes harder to find time in track for maintenance. Therefore, it is of interest to simulate maintenance tasks between trains to minimise track maintenance possession time. Such simulation can be used to: study maintenance work in TTTs with random and regular train departures; study the effect of exceeding allocated maintenance windows; and to study the effect of increase in train frequency. In this paper, Monte Carlo method is applied to simulate track maintenance between trains as a function of train frequency.

Keywords

Maintenance, operation, rail infrastructure, maintainability, maintenance supportability, planning, scheduling, maintenance window, service window, Monte Carlo method.

1. INTRODUCTION

The aim of rail infrastructure maintenance planning is to minimise the effect on traffic. Therefore, infrastructure managers (IMs) start planning their maintenance work far ahead of time to fit with the planning of train time tables. In the European Union (EU), each IM is obligated to publish a Network Statement (NS) with all the information needed for train operators interested in capacity [3]. The NS must be published about a year before a new train time table comes into force. Consequently, the planning of major maintenance work starts about 1½-2 years before a new train time table. Maintenance work that is planned after submission of the NS has to compete with, or be fitted into, operators' applications for capacity. However, some work is planned only a few weeks before execution, and depending on the railway line in question, a few hours during night can be available for maintenance. Besides late planned maintenance work, failures in track normally require repair immediately or within one day. In addition, with increasing rail transportation it becomes harder to find time in track for

maintenance [2]. Therefore, it is of interest to simulate maintenance tasks between trains. Such simulation can be used to:

- Study maintenance work in train time tables with random train passages to find suitable time windows, e.g. freight trains
- Study maintenance work in train time tables with regular train passages/departures, i.e. urban areas. As an example, a certain maintenance work can take a very long time to complete at a train frequency of 10 minutes, while cancelling a group of trains or running one train out of three may be impacting the train service unnecessary negatively; i.e. cancelling each second train may then be the most optimal choice.
- Study the effect of exceeding allocated maintenance windows. As an example, the available maintenance window may be four hours, but it is known from experience and historical data that the work in question takes five to six hours. Possible solutions are: carry out the work in one shift, exceeding the four hours, and do the last work between the trains; do the work in two shifts, i.e. eight hours over two days; or increase the number of personnel in the maintenance team if possible.
- Study the effect on maintenance of future increases in the frequency of trains. This is especially important in maintenance contracting, as contracts are often performance based and stretch over several years [4]. If a possible increase in the numbers of trains running is not properly taken care of within the maintenance contracts, the infrastructure manager and contractor may end up in a disagreement.

The study of maintenance between trains was initiated in the AUTOMAIN project [5, 6]. In AUTOMAIN, the effect of exceeding an allocated maintenance window was studied by comparing an alternative maintenance approach. Specifically, the simulation concerned the decision to use one or two welding teams for frog (common crossing) replacement of switches & crossings (S&Cs). Maintenance work between regular train departures, i.e. urban areas, was also studied in an attempt to balance maintenance cost and train services. As a continuation of the study in AUTOMAIN, Monte Carlo method is applied to

simulate track maintenance between trains as a function of train frequency.

2. METHODOLOGY

Maintenance time in terms of travel, preparation, repair and clearance can be estimated through experience and use of historical work order data. However, the actual time to complete a particular maintenance task depends on the train time table and safety regulations governing entrance to and closure of the railway section in question. With these inputs, the actual time to maintenance can be estimated. Matlab software is used for model construction and Monte Carlo simulation. Monte Carlo method is used to predict increases in maintenance time by sampling random train time tables (TTTs). The model has a number of input and output parameters. The input parameters are as follows:

- Train time table (TTT)
- Non-value adding (NVA) time (t_{NVA}): Consist of preparation, confirmation, communication, waiting and lost time, for entrance to and closure of track
- Active repair time (t_{Active})
- Minimum time for maintenance (t_{Min})
- Arrival point in the time table

Minimum time for maintenance (t_{Min}) can be set as a fixed value or based on t_{Active} . As an example, if the required time for a maintenance activity is 150 minutes and t_{Min} is set to 10 % of that time, i.e. 15 minutes, then no maintenance will be carried out if the time left for maintenance between two trains is less than 15 minutes.

The output parameter is the (actual) maintenance time: the time from the arrival of the maintenance team until the work is finished and the track is cleared.

Figure 1 demonstrates the model. Given that t_{NVA} equals 10 minutes, t_{Active} equals 50 minutes and $t_{Min} = 0.1t_{Active} = 5$ minutes, the maintenance time becomes 109 minutes, i.e. 118 % more than the 50 active minutes required.

Figure 1. Demonstration of the model.

Random TTTs are generated using a uniform distribution, with the exception that adjacent trains must have a minimum distance in time of x minutes. An example of a 120 minutes maintenance task in randomly drawn TTTs is shown in Figure 2.

Figure 2. Example of random drawn TTTs with a 120 minutes maintenance work.

3. RESULTS

The number of trains occupying the Iron Ore Line between Kiruna, Sweden, and Narvik, Norway, is predicted to increase from 42 trains per day in 2014 to 50 trains per day in 2020[1]; see Figure 3.

Figure 3. Predicted increase in train frequency of the Iron Ore Line [1].

For the simulation: operating time is set to 18 hours per day; the number of trains per day is set to range from 10 to 60; a random uniform distribution is used to set out trains passages; an exception is added whereby adjacent trains must have a minimum distance in time of five minutes; t_{NVA} is set to 5 and 10 minutes, giving two different cases; t_{Active} equals 120 minutes; t_{Min} equals 10 minutes; and the number of random TTTs is set to 1000 for each train frequency and t_{NVA} . The result is shown in Figure 4: the data points are the mean values; their whiskers are the standard deviations; and the density function and box plot, with whiskers of 1.5 IQR (interquartile range), are for the highest data point. As indicated in the figure, the maintenance time has an exponential or polynomial growth as the train frequency increases.

By comparing the results with the predicted increase in trains, it is found that the average maintenance time increases with 29 % ($t_{NVA} = 10$ minutes) when the number of trains per day increases from 42 to 50; see Figure 5. With t_{NVA} of 5 minutes, the maintenance time increases with 18 %.

Figure 4. Predicted increase in maintenance time with increase in train frequency.

Figure 5: Predicted train frequency and maintenance time.

In the results above, t_{Active} equals 120 minutes. If t_{Active} is set to vary, while keeping the other constants as given above, with $t_{NVA} = 10$ min, it is seen in Figure 6 that the maintenance time increases linearly with t_{Active} . Each data point in Figure 6 is the mean value of 1000 simulations.

4. DISCUSSION

The method for predicting increase in maintenance time, as a function of increase in train frequency, is based on random drawn TTTs with uniform distributions. However, depending on the railway line in question, the configuration of a future TTT, with more trains, can be known. It is still not known, however, when a failure will take place, i.e. randomness. Thus, the presented method can alternatively be used with a fixed TTT and some distribution for failures. Sampling TTTs or sampling failures will, to a certain extent, yield similar results. As an example, randomly setting out a failure in a TTT is analogous to randomly setting a TTT to a failure.

The simulation considered a maintenance work that can be temporarily stopped to let trains pass. Other maintenance work can include work steps that have to be finished before trains can pass. As an example, frog replacement requires two out of four welds to be completed before trains can pass. This type of maintenance must be put into allocated maintenance windows, e.g. at night, or in sufficiently large windows within the TTT. This kind of works can be simulated by sampling random TTTs with a fixed maintenance window. Thus, by including the various types

of maintenance work, a final predicted increase in maintenance time can be achieved. Historical maintenance data can be used for this purpose, together with expert judgement. It should also be noted that adding the logistic time (travel time) will reduce the increase in maintenance time as the logistic time is unaffected by the train frequency.

Figure 6. Maintenance time as a function of trains and active repair time (t_{Active}).

5. CONCLUSIONS

Monte Carlo method can be used to predict maintenance time as a function of train frequency. It has been shown that the maintenance time increases exponentially with train frequency (Figure 4). This effect is due to safety regulations governing entrance to and closure of railways.

Specific to the case study, with the model input values used, the average maintenance time on the Iron Ore Line in Sweden, will increase by ~30 % ($t_{NVA} = 10$ minutes) from year 2015 to 2020. Nevertheless, expert opinion and parameter study can improve the prediction, and is required if the method is applied in practice.

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