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## The effect of temporary speed restrictions, analyzed by using real train traffic data

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### Abstract

This paper studies the effect of temporary speed restrictions (TSR) in railways. We present a method for analyzing the effect of TSR. TSR, or slow orders, are imposed on the railway to ensure safe use of the infrastructure. We have documented that TSRs give variations in the running times for trains. The impact of the TSR is basically depending on several factors, including the difference in speed between normal and reduced speed, the length of the TSR and the length and weight of the train. We found that speed restrictions typically caused delays up to 60 seconds. A best fit analysis indicates that a TSR adds about 25 seconds plus added time depending on the length of the TSR. This corresponds relative well with theoretically expected values. The effect of TSRs is on average relatively well aligned with theoretical calculations. However, the variations are large. Our study has shown that TSRs can have negative effects on the precision of the railway system. As a part of the research, we developed a tool that identifies and evaluates the effect of TSRs on traffic.

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## 1. Introduction

The purpose of this paper is to study the effect of temporary speed restrictions (TSR) in railways. We present a method for analyzing the effect of TSRs. TSR, or slow orders, are usually imposed by railway dispatchers for sections of track that are deficient, or when there is a requirement to perform maintenance, see for example Bruzek et al. (2015); Macciotta et al. (2016). The railway groups' standard GK/RT0038 and GK/RT0075 (Railway Group Standard, 2000, 2015) defines speed restriction as “a set out principles governing the signing and advice of permissible speeds, temporary speed restrictions and emergency speed restrictions on running lines to ensure that train drivers have sufficient information to control their trains safely”. Speed restrictions influence the running times of the trains. TSRs tend to disrupt timetables and can affect time-sensitive shipments, so railroads should have incentives to get them cleared as soon as safely possible. TSRs can be issued for several occasions, such as poor welding of rails, issues with settling ballast, or rail geometry defects. Violation of TSRs can cause serious accidents (McNaughton, 1977).

A reduction in speed would cause longer running time on the affected part of the line. Delays can be a consequence of a TSR, especially on single line tracks. Speed reductions should therefore be imposed carefully. On single line tracks can delays cause propagated delays on other trains. Therefore it is important that the minimum restriction should be imposed, lasting the minimum time span possible, and allowing the maximum allowable speed, while taking the need for safety and operating conditions into account (Samuel, 1961). The number of slow orders can be used to benchmark the asset management performance of a railway infrastructure manager. Which is the case in Norway, in addition to TSRs, infrastructure management is evaluated based on registrations of delay cases, related to the infrastructure, and selected other parameters.

There are a number of factors which can influence punctuality in railway traffic (Olsson & Haugland, 2004; Vuchic, 2005). Common influencing factors include capacity utilization, passenger number and behavior, weather, timetable characteristics, quality of rolling stock and infrastructure, as well as other factors internal and external to the railway system. TSRs can be included in this list. Lv et al. (2015) highlight that availability of traffic data have been exploding recently, they propose to rethink the traffic flow prediction problem based on deep architecture models with big traffic data. Chen et al. (2015) shows that traffic data refer to datasets are becoming available and provide an overview of approaches for data visualization, to support analysis of distributions and structures of datasets in order to reveal hidden patterns in the data. This paper joins this research tradition. There has been some previous research on TSRs, including Gorman (2009) and Lovett et al. (2013). Olsson and Haugland (2004) made related investigation on factors affecting punctuality, which was a point of inspiration for this articles research questions. In their research, they have used the Norwegian railway network near Oslo and on the Nordland line to analyse the effect and correlation of certain variables to punctuality. The correlation between TSR and delays was found to be weak and sometimes opposite to what is expected. Liu et al. (2009) discuss optimal driving patters on line with speed restrictions. Junfeng and Dong (2010) analysed management of temporary speed restrictions in CTCS-systems. Zhao and Wang (2012) and Yuan et al. (2013) present a model for representing temporary speed restrictions in the Chinese Train Control System-3(CTCS-3). Zhou and Mi (2013) analyse of the effect of speed restriction based on simulations. Bruzek et al. (2015) developed a model to automatically issue slow orders based on a model for rail heat prediction, they compared theoretical heat slow orders generated by the model and found good accuracy in predicting slow orders. Lovett et al. (2013) discussed descriptive degradation models, which can consider the costs of slow orders and compare the delay from slow orders to the risk of an accident.

The scientific contribution of this paper is to evaluate the effect of TSRs based on empirical data. To a certain extent, it would seem self-evident that a temporary speed restriction would cause a delay. Given that the timetable is based on a certain maximum speed on a line section, not being able to drive that fast would cause a delay. Train drivers frequently make this argument, and they obviously have a point. However, running time margins are generally added to the timetable, as described by Goverde (2005). Nominal running times are based on a maximal speed profile in normal conditions. To make a timetable realistic, planners add margins to allow for variations in rolling stock performance, individual driving patterns for drivers, variations in weather conditions and, for example temporary speed restrictions. Depending on the train operator's geographical location or country of origin, there are different magnitudes of the margins that are added in the timetable. Running time margins are typically expressed as a percentage of the nominal running time. Norwegian railways use 4% running time margins as a basis, but extra

margins are added at critical stations and during major construction works. This can include speed restrictions that are known during the timetabling, and are expected to last for major part of the timetable period. A similar practice is common in other countries, as pointed out by Pachl (2002), who suggest that running time margins in Europe are in the range of three to 7 percent.

The physics for calculating train running times is well known, and described by for example Profillidis (2006) and Hansen and Pachl (2008). Running time of a train is a predefined scheduled time set that defines the total duration of a travel between departure and destination stations. Running time is composed of different time sets including pure running time between scheduled stops, dwell time at scheduled stops, recovery time and scheduled waiting times. Running time of a train can be calculated from infrastructure model along with a description of rolling stock characteristics. Such calculations are implemented in time tabling support tools. The movements of the train between these two stop points are composed of acceleration, running at constant speed, run out and braking. There are associate calculations of force, inertia, acceleration and other parameters that determine the speed characteristics of a particular type of rolling stock on a particular part of the railway line (Pachl, 2002).

A TSR can be regarded as an exception to the speed curve that a timetable is based on. Fig. 1 shows the development of speed over time during a TSR. The timetable is based on what is labeled “normal speed” in Fig. 1. When the train approaches the speed restriction zone, the train operator needs to decelerate from normal speed to reduced speed. The reduced speed is then kept constant throughout the zone. After exiting from the speed restriction zone the train accelerate to regain the permissible speed set. In Fig. 1, the normal speed before and after the TSR is set as the same, but is not a necessity.

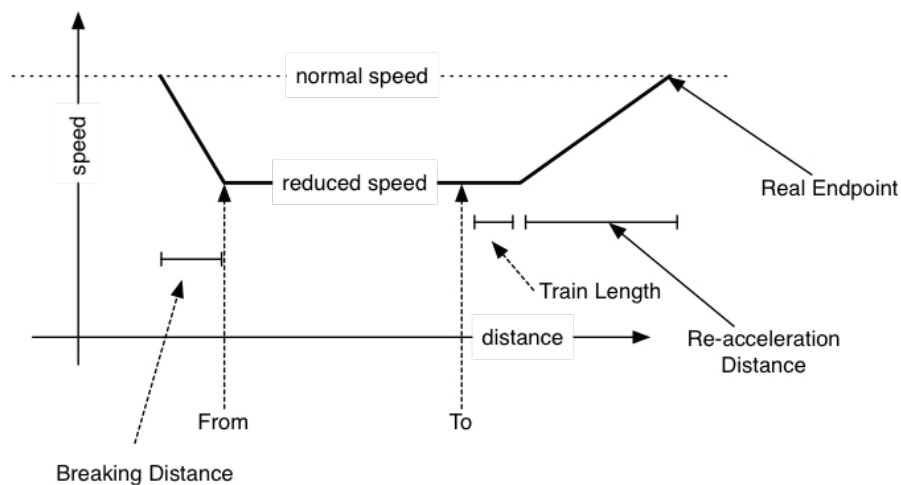


Fig. 1. Principles for the effects of a TSR

The impact of the TSR depends on several factors, including the difference in speed between normal and reduced speed, the length of the TSR and the length and weight of the train. In addition, the gradient and other characteristics of the track can influence the effect of a TSR, and especially retardation and acceleration.

Traditionally, the time loss from temporary speed restrictions in Norway is calculated based on the following parameters: deceleration:  $-0.7 \text{ m/s}^2$ ; acceleration:  $0.5 \text{ m/s}^2$ ; train length: 200 meters. As a comparison, Profillidis (2006) states that common acceleration values for freight trains are  $0.2$  to  $0.4 \text{ m/s}^2$ , and  $0.4$  to  $0.6 \text{ m/s}^2$  for intercity trains. Profillidis (2006) also lists common deceleration values. For freight trains are  $-0.25 \text{ m/s}^2$ , and  $-0.4$  to  $-0.5 \text{ m/s}^2$  for intercity trains. Hansen and Pachl (2008) mentions common deceleration values for freight trains to be  $-0.225$  to  $-0.3 \text{ m/s}^2$ , and for passenger trains  $-0.375$  to  $-0.7 \text{ m/s}^2$ . We note that the values used in Norway are more representative for passenger trains than for freight trains. The data in our study only includes passenger trains.

Time loss from a TSR has three components: (1) deceleration from normal speed to the temporary lower speed, (2) running at the temporary lower speed, (3) and acceleration up to normal speed. Note that acceleration can start after the full train has exited from the TSR part of the line. This means that the distance that is applicable for

component two of the three components is equivalent to the length of the TSR plus the train length. The description and, the situation on Fig. 1 assumes that the train can reach normal speed after the TSR. As Hansen and Pachl (2008) point out, this does not have to be the case. They show two other possible cases, both in which the train does not reach normal speed after exiting the TSR. In one case, the train may not have acceleration capabilities to reach the normal speed. In another case, the train needs to start braking before reaching normal speed because of lower permitted speed on following sections on the line. According to Patel and Callen (2012) a classic ATC system does not take TSR into consideration.

Growing data volume and data availability enabled researches to study delays and delay causes on a relatively detailed level. This research utilizes the access to high-resolution punctuality data, as well as a database (established by ourselves to facilitate the research) of temporary speed restrictions. Wallander and Mäkitalo (2012) present that data-mining can be used for analyzing rail transport delays, their aim was to develop more robust timetable structures, and provide tools for rail network planning. This paper has a similar objective, and shows an example of how it can be applied on studying one influencing factor on punctuality: speed restrictions.

The research questions addressed in this paper are:

- what is the effect of TSR, when comparing train running times with and without TSR?
- how is the distribution of added time due to TSR?
- how has the development been the last years regarding the volume of TSR in Norway?

To be able to address these research questions, we present a method for analyzing the effect of TSR.

## 2. Design, methodology and approach

TSR are communicated to the different parts of the Norwegian railway sector based on written documents, in MS word format. These documents were scanned, machine read and structured to create the data set for TSRs. A database was created which consists of all of the TSR in Norway between 2010 and 2014, along with all punctuality registrations in the same period. These include a total number of about 4000 TSRs, affecting several millions train journeys. To obtain a uniform data set, we have only included passenger trains in our analysis. TSR and punctuality data are stored in databases. A tool was developed for joint analysis of the two data sets. Based on existing documentation on TSR, we established a database for TSRs. A TSR is compared to a reference time period with normal speed limit. The reference period has the same length as the length in days of the TSR, assuming the two periods have a comparable number of trains, for the punctuality data. In the chosen approach, the normal operation is compared with the reduced speed operation. The TSRs that are between stations are analyzed piece by piece. Each TSR was analyzed by pulling traffic data from the time period that the TSR was enforced. This traffic data is then compared with historic traffic data. Before pulling historic data from the established time period, we check that there was not a TSR in the reference time period. If there was a TSR in the reference period, then the reference period is moved another 14 days back in time, and then the same check is performed, as shown in Fig. 2. The process is repeated up to a year back in order to find a time period without TSR. The punctuality measurements are taken from the departure of the first station to the arrival of the other station. Punctuality data is readily available, and has been widely used for analyses of railway traffic. The use of TSR information has been less common in Norway. Industry has asked for analyses of TSR, because they are a frequent topic in discussions between train operators and infrastructure managers about railway traffic quality.

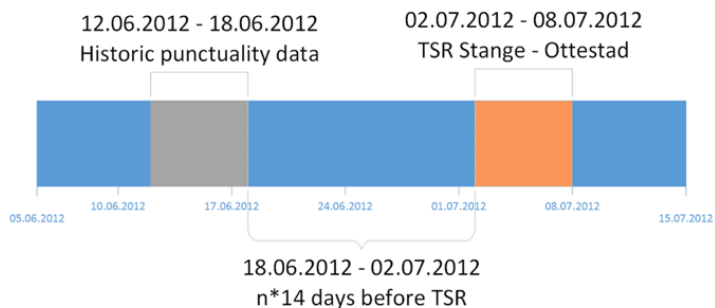


Fig. 2. Punctuality data versus historic punctuality data, illustrated with an example between stations Stange and Ottestad

The punctuality measurements are taken from the departure of the first station to the arrival of the other station. The two sets of punctuality data are compared with each other, in a two-sided t-test. For significance, all results with a p-value >0.2 are discarded. We have focused on variations in running times. We have not addressed punctuality as such, but analyzed travel time variability. The approach has similarities to the one used by Noland and Polak (2002) who used distribution of arrival times as a measure of punctuality.

### 3. Results

We find that speed restrictions typically caused delays up to 60 seconds. Fig. 3 shows the distribution of deviations between running time with a TSR compared to running times 14 days earlier. 60% of all TSRs caused between 0 and 60 seconds added running time. 22% of the TSRs caused even longer added running time, while trains had shorter running times with a TSR than without one for 18% of the studied TSR.

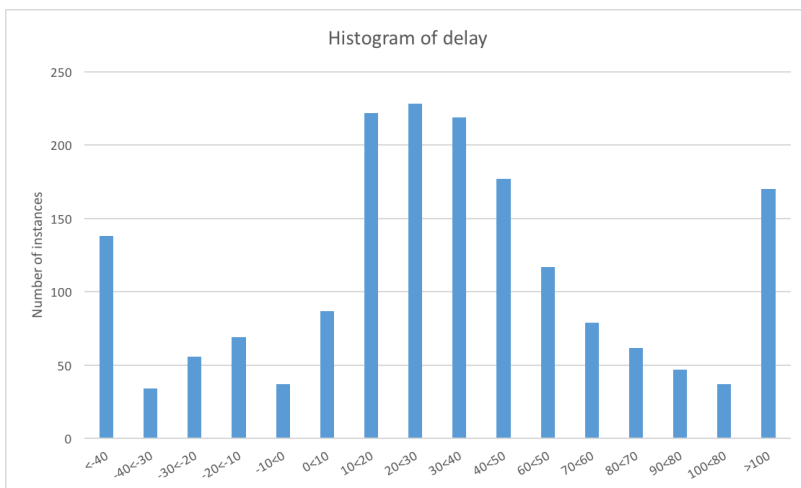


Fig. 3: Distribution of difference between a situation with a TSR, and 14 days before. Measured in seconds.

We analyzed the relation between length of TSR and the increased running time. As shown in Fig. 4 the best fit line is  $y=9.5 x + 25.5$ , indicating that a TSR takes minimum 25 seconds, and 9.5 seconds for each additional kilometer ( $R^2$  is 0.0995). This corresponds relatively well with theoretically expected values. An average TSR had a speed limit of 47 km/h. A common normal speed is 70 km/h. Based on a reduction from 70 to 47 km/h and established calculations, a 1-meter TSR would give 9 seconds of added running time, and 1 km of TSR would give 34 seconds added time. Fig. 4 shows the calculated added running times. For TSRs longer than a few kilometers, observed times are typically less than calculated, indicating that for longer TSRs, the train drivers utilize slack of the

timetables to reduce time loss. We have also studied alternative functions to fit the series of observations, and none of them had better fit than the linear regressions shown here.

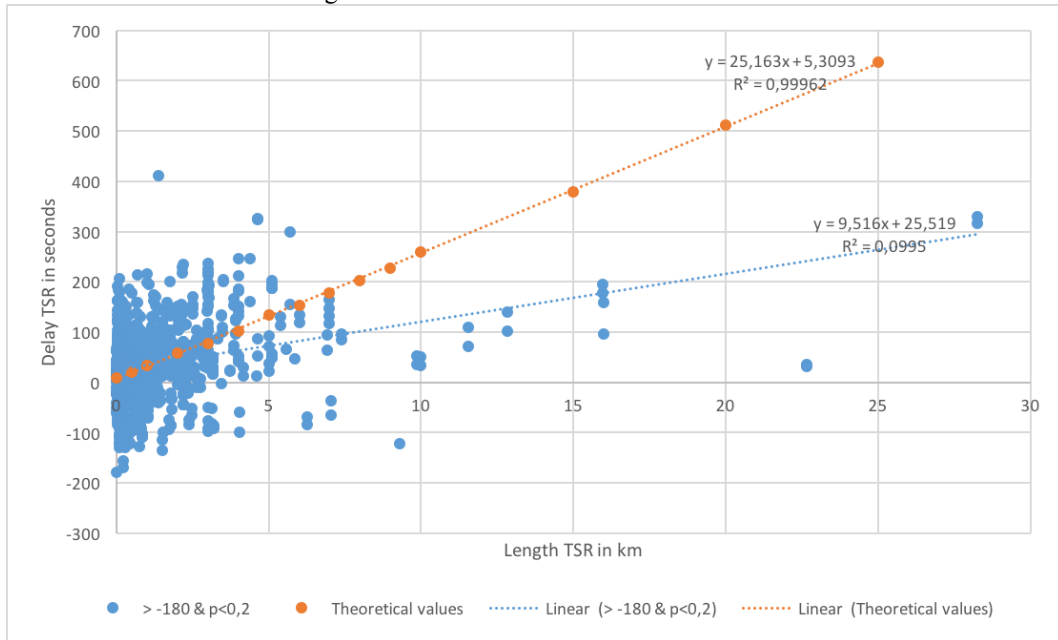


Fig. 4. Relation between length of TSR in km and the increase in train running time

Fig. 5 shows effect in relation to relative size of the TSR. As expected, if the TSR covers a longer part of a line section it creates a larger increase in added running time. A best fit line is  $y=110x + 24.2$ , almost indicating the same, namely that a TSR typically takes a minimum of 24 seconds (R2 is 0.077).

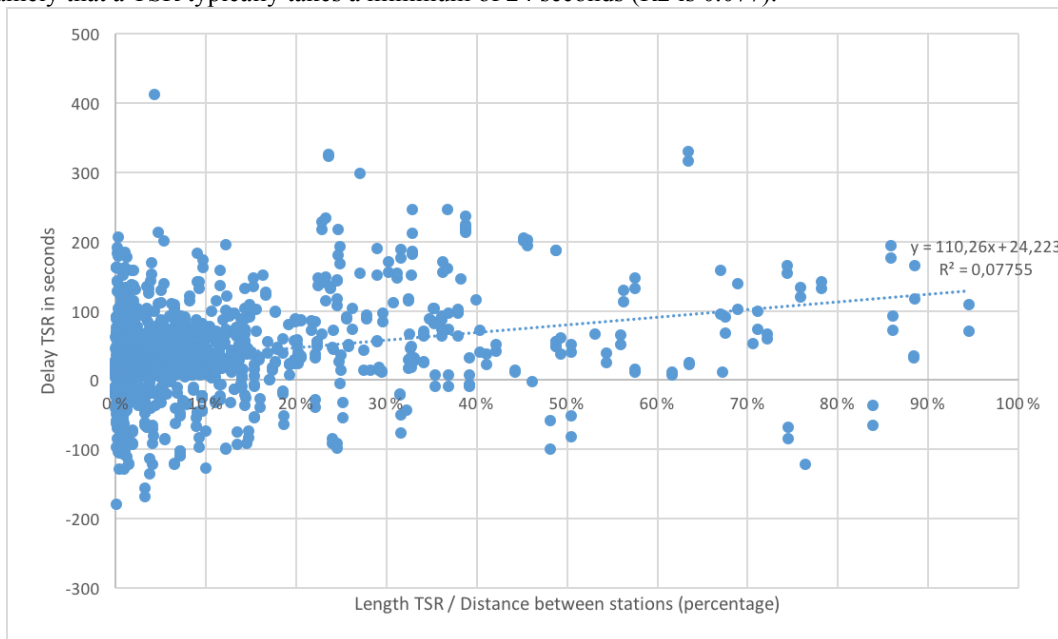


Fig. 5. Development of size and impact of TSRs during the studied years.

Fig. 6 shows that the number of TSRs has varied during the studied years. In addition, we see that the effect of the TSRs are not directly related to the numbers of TSRs. The number of TSRs are reduced in the studied period, but the relative effect of them appears to have not been reduced.

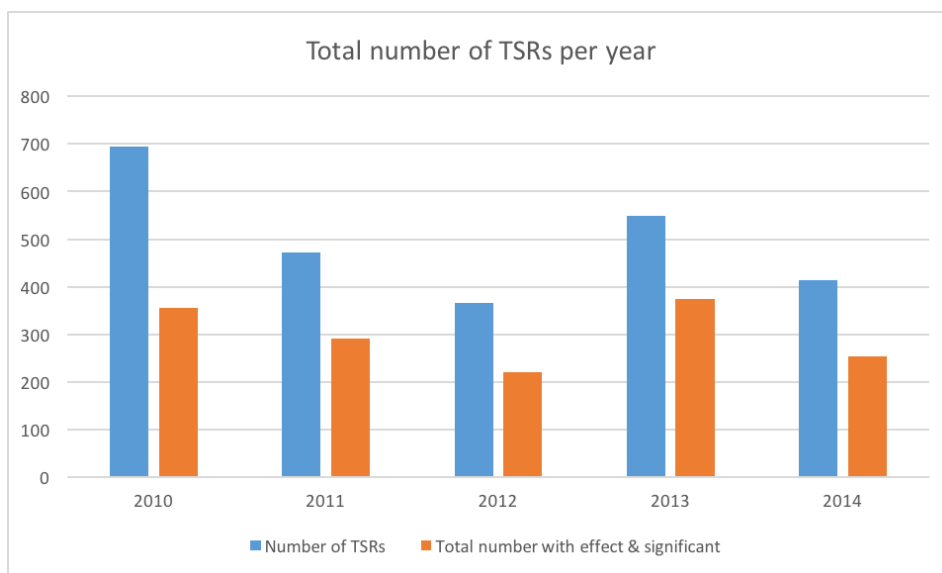


Fig. 6. Development of size and impact of TSRs during the studied years.

#### 4. Conclusion

This paper has studied the effect of temporary speed restrictions (TSR) in railways. We developed a method for analyzing the effect of TSRs. We have briefly described the nature of TSR, or slow orders in the railway sector. The empirical material is based on analyzing 4000 TSR in Norway, and their effect on running time for passenger trains. We studied the effect of TSR, by comparing train running times with and without TSR. To be able to address these research questions, we presented a method for analyzing the effect of TSR. We have documented that TSRs give variations in the running times for trains. The effect of TSRs is on average relatively well aligned with theoretical calculations. However, the variations are large. We have shown that TSRs can have negative effects on the precision of the railway system. The used tool can identify and evaluate the effect of speed restrictions on traffic. The tool can show the general picture of TSRs, but also enables a user to zoom in on the TSRs that are particularly unfortunate for the railway traffic, based on evaluations of their actual effect on train running times. A best-fit analysis indicates that a TSR adds about 25 seconds plus added time depending on the length of the TSR. We studied the distribution of added time due to a TSR, and found that the majority (60%) of the TSRs caused added running time of up to 60 seconds. However, some TSRs did not cause added running time. Impact of TSRs on delays measured at the end station was not possible due to an incomprehensive infrastructure model, and could be addressed as further research. The study also addressed the development has been the last years regarding the volume of TSRs in Norway. In the period from 2010 to 2014, there are fewer TSRs in the end of the period compared to the beginning. Somewhat worryingly, the effect of TSRs appears not to have been reduced during the studied period.

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