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Improving railway punctuality by automatic piloting

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Abstract—

Railway performance in Europe is hampered by frequent delays at stations. The usual method of punctuality estimation is neglecting the big share of smaller delays than 3 minutes in scheduled services. The hinder of approaching trains at railway junctions and in stations due to delayed trains still occupying the route can be minimized by the use of on-board processors that automatically determine the speed and travel time needed until the next main signal that protects the route of a conflicting train. The actual location, speed and distance of the trains to the conflict point are continuously recorded by on-board processors and communicated via GSM-R to other trains in the same area. A decision support system for traffic control identifies in time route conflicts between approaching trains automatically, estimates the remaining travel times and indicates the suitable speed to follow by each of the trains in order to assure seamless merging or crossing. The individual acceleration, braking and speed instructions would be transmitted to each train and automatically applied by the on-board processor. The automatic piloting of trains enables maximal use of available track capacity, while guaranteeing minimal train delays.

Index Terms—Train Operations, Traffic Control, Punctuality, Delay

I. INTRODUCTION

Punctuality of transport services has become a major issue during the last decade due to increased mobility of people, globalization of trade, competition with other transport modes, saturation of infrastructure capacities, and deregulation of the transport sector. Road congestion, and air and railway traffic delays are daily phenomena and seem to increase continuously. The franchising of railway services in Great Britain in 1996/97 led to contractual agreements concerning the aimed level of punctuality and reliability and financial incentives in the performance regime [1, 2]. The growth in patronage and service, however, was accompanied by a considerable decrease of punctuality [3].

The German Railways launched in 1997 a broad campaign for the reduction of train delays within one year by 50%, consisting of computerized dynamic train operations monitoring, monthly punctuality reports at every major station, and incentives for the railway staff. Three years later, the campaign was cancelled because of growing frustration of the public about decreasing punctuality of train services and unsatisfied managerial staff. European railway experts have studied the level of service of the Japanese Railways and were very impressed by its extraordinary high degree of punctuality with less than one minute average delay per train [4]. However, they did not succeed in applying the same methods and achieve similar performance due to institutional, organizational and cultural differences.

Recently, the Dutch Minister of Transport and the Dutch Railways agreed upon the determination of punctuality levels including a yearly improvement by 1% to be assured, as well as the introduction of fines and payback regulations to railway customers in case of insufficient performance [5].

The aim of the paper is to discuss the following research issues:

- How can train delays be measured in a scientifically consistent manner?
- Which statistical distributions and parameters characterize delays in train operation?
- How conflicts between different train routes can be avoided?
- Which impact on punctuality would have automatic piloting of trains?

The paper is organized as follows: First the principal modes of measuring train delays are described. Then, results of a detailed statistical analysis of delays at the Dutch railway station Eindhoven are briefly presented. Then, a concept of automatic piloting of trains at railway junctions is presented. Finally, its impact on punctuality is assessed.

II. MEASUREMENT OF TRAIN DELAYS

Punctuality of train services, in general, is expressed as the percentage of trains passing, arriving or departing at given locations of the railway network no later than a

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certain time in minutes. Delays smaller than 5 minutes are usually not considered as delays by the European railway companies because of limited precision of the applied modes of measurement, tolerances of the timetable and insufficient means of control of operations in practice. As there are no standard definitions and the mode of measurement of delays is varying, the punctuality rates of the railways differ a lot [6, 7].

As the time difference with regard to the scheduled time can be determined only on the basis of a timetable the latter's degree of precision determines the precision of the punctuality estimation. A computerized timetable design enables, however, to determine the planned arrivals and departures by fractions of a minute, e.g. in steps of 5 or 10 sec. A high timetable precision of seconds is applied in Japanese Railways and even some European railway companies use this for internal purposes. But, so far, the punctuality levels published by most of the railway companies do not include a lot of trains with small delays and therefore create a much too positive image compared to reality.

The presence of trains is detected automatically by means of axle counters, track circuits or induction loops. In general, the start and the end of the occupation of a signal block or a track section by a passing train is recorded and the data is saved a certain time for safety reasons. The location of the devices, however, varies and depends on the track layout and the design of the signaling system. In most cases the last measurement point before a station is situated some hundred meters or even more than a kilometer upstream of the platforms, whereas the first one after a station is located typically close to the departure signal. Moreover, the stop position of trains at a platform may vary if the length of trains is changing over time-of-day or day-of-week and the passenger access to the platform is not located at only one end. Therefore, the distances between the last (first) train detection devices before (after) the station and the stop position of the different trains at the platform are to be determined in order to estimate the remaining deceleration (acceleration) time of the trains until (from) the stop.

Accurate data of Dutch railway operations has been obtained from information of interlocking and signaling systems by so-called TNV-systems. A TNV-system is continuously recording in real-time the actual state of all relevant signal controls and monitoring information in a traffic control area, including the attached track, signals, points, and route relays, in so-called TNV-logfiles. Each TNV-logfile of a single day consists of about 25 MB ASCII-format.

We have recently developed the tool TNV-Prepare [8] that converts TNV-logfiles into tables per train series (line) and route suitable for data analysis. Within TNV-Prepare, the rail infrastructure and signals are implemented as a set of coupled and connected objects. TNV-Prepare filters the files on the relevant objects, automatically tracks the (standard and non-standard) train routes from the data, recovers the signaling and interlocking events corresponding to individual train movements along the route, and checks the consistency of the results.

TNV-Prepare runs on MS Windows 95 and NT operating systems. TNV-logfiles of several periods and traffic control areas of the Dutch Railways have been obtained, which have been converted off-line using TNV-Prepare into separate files corresponding to individual train series and (sub) routes. This gives reliable and compact tables of successive events along a train route, including for instance successive section entrances and clearances, proceed and stop signals, and point switches

The accuracy and reliability of the (logged) event times has been tested by means of a check whether synchronous events show equal occurrence times, e.g. start of occupation of a track section, the attached TNV-step and the stop sign of the previous signal. The computation time has been found negligible and the transmission of messages from the signaling system noise-free. Another logical test is related to the chronological sequence of events, e.g. the consecutive occupation of track sections along the routes of a train in one direction. It results in discarding inconsistent data.

The actual train length and speed of each train at the last block signal upstream of the station can be estimated simply on the basis of the difference of the check-in and check-out times and the scheduled train characteristics. Estimation errors due to train speed and deceleration variations during the approach are filtered by means of a least squares method and comparison of the calculated speed with the design speed, e.g. at the signals and turnouts [9].

The train detection at the platform track section itself lasts until the clearance time of the train at the departure signal. The precise moment of the train stop and the start of acceleration at departure, in general, is not recorded automatically, except when the train is equipped by an on-board processor and the data is transmitted to the track-side control system. The remaining deceleration and acceleration time of the train from and to the signals, however, can be estimated on the basis of the known standard deceleration and acceleration rates per type of train. The arrival and departure times of each train at the platform tracks are determined with a precision of about one second, which is sufficient for the empirical analysis of train delays.

III. STATISTICAL DISTRIBUTIONS OF DELAYS

The train detection data of one week in September 1997 at the Dutch railway station Eindhoven has been used for testing the tool TNV-Prepare and analyzing the train delays [10]. The statistical analysis has been done by means of the software tool S-Plus. For each line serving this railway station several event and process times have been analyzed, including the arrival delay, departure delay, dwell time, and occupation times of sections on the inbound and outbound routes. In total, 1846 trains have been recorded, 30% IC-trains, 30% IR-trains and 40%

local trains (AR). Freight trains have been discarded in this analysis.

For each train line the mean and standard deviation of each event or process time distinguished by time period (morning peak, daytime, evening peak, and evening) has been determined. Analogously, the mean and standard deviation distinguished by type-of-day (Sunday, weekday, Friday, and Saturday) has been analyzed. Moreover, appropriate theoretical distributions of the event and process times have been assessed and tested on goodness-of-fit, including data separations in time period and type-of-day. The data of the various train series has also been compared mutually for correlation of train type (local, interregional, and express trains) and originating route.

In general, about 40% to 80% of the trains of a line arrived more or less late (Table 1). In case the common definition of delays (> 3 minutes) is used the percentage of "punctual" local trains varies from 94% to 100%, and for the other trains this ranges from 66% to 96%.

There is some evidence that the arrival delay during the entire week is normally distributed for two of the IC-lines and all of the IR-lines (Figure 1 and 2). The hypothesis of normal arrival delays is rejected for the other three IC-lines and the local (AR) lines. The standard hypothesis of a negative-exponential distribution of train delays, introduced first by Schwanhäusser [11] is not confirmed in the case of the train arrivals in Eindhoven, where delays of less than one minute and early arrivals have been included.

Table 1 Arrival delays of the trains at station Eindhoven (September 1997)

Line	From	To	Av. [s]	St. dev. [s]	Share of late trains	Share delays > 1min	Share delays < 3min	Av. late trains [s]
IC 800	Haarlem	Maastr.	83	100	0,76	0,57	0,83	122
IC 800	Maastr.	Haarlem	39	130	0,46	0,33	0,86	148
IC 900	Haarlem	Eindh.	138	144	0,84	0,67	0,66	171
IC 1500	Den Haag	Heerlen	69	166	0,61	0,35	0,85	149
IC 1500	Heerlen	Den Haag	49	85	0,71	0,45	0,93	88
IN 1800	Keulen	Eindh.	63	97	0,66	0,48	0,86	112
IR 1900	Rotterd.	Venlo	24	118	0,49	0,28	0,88	117
IR 1900	Venlo	Rotterd.	- 46	82	0,25	0,17	0,92	77
IR 2700	Venlo	Eindh.	7	49	0,50	0,23	0,96	48
IR 3500	Utrecht	Eindh.	85	124	0,80	0,60	0,69	132
AR5200	Deurne	Tilb.West	20	85	0,55	0,27	0,94	77
AR6400	Weert	Eindh.	4	63	0,40	0,23	1,00	81
AR9600	Utrecht	Eindh.	- 1	62	0,41	0,19	0,96	62

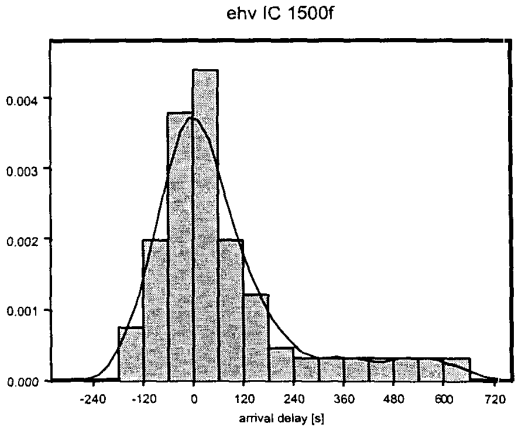

Figure 1 Histogram and kernel estimate of the arrival delay of IC 1500 Heerlen-Den Haag at station Eindhoven (September 1997)

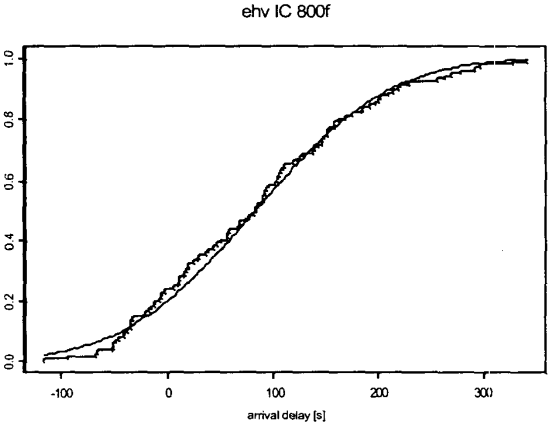

Figure 2 Cumulative distribution and exponential fit of the arrival delay of IC 800 Haarlem-Maastricht at station Eindhoven (September 1997)

A considerable number of trains coming from line terminals that are situated about 50-100 km towards the east and south of Eindhoven, e.g. Venlo, Heerlen and Maastricht, arrive too early. If the early and punctually arrived trains were excluded from further analysis, the late arrivals can be fit in most of the cases by the exponential distribution, also for weekdays, evenings, and the entire week (Figure 3). Thus, the findings of Schwanhäusser [11] are confirmed for the trains arriving late.

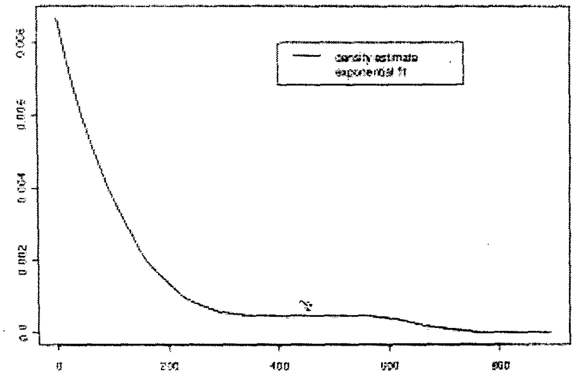

Figure 3 Density estimate and exponential fit of the late arrival delay of IC 1500 Den Haag-Heerlen at station Eindhoven (September 1997)

The average departure delay of the trains of all lines, except IR 3500 Eindhoven-Utrecht, is estimated between 51 sec and 154 sec. The mean delays per line, in general, are growing during the stop. The percentage trains with less than 3 minutes departure delay, is situated between 69% and 98%. Departure delays can be fit well by an exponential distribution (Figure 4). Note that, in general, early departures of railway trains are not allowed. Therefore, this finding is completely in line with the normal distributions of the arrival delay.

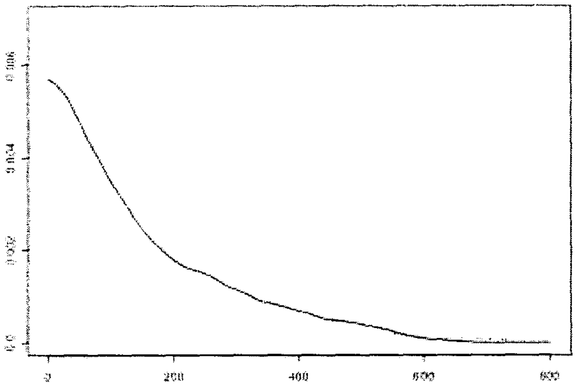

Figure 4 Density estimate and exponential fit of the departure delay of late arrivals of IC 1500 Den Haag-Heerlen at station Eindhoven (September 1997)

IV. AUTOMATIC PILOTING OF TRAINS AT JUNCTIONS

The drivers of trains approaching to a railway junction or station, in general, don't have any information concerning the actual location, speed and braking or acceleration of other trains that are still occupying or intend to use (a section of) the same route. In case one or both trains that approach a point or crossing at the same time are delayed differently by more than the available buffer time, one of them would encounter a yellow or even a red signal implying a braking. In practice, a braking of a passenger train to stop on open track causes a minimal delay of about 2 to 5 minutes, depending on the actual speed because of the time loss during braking and accelerating. If the first train entering the route is travelling at less than the design speed the occupation time of the block lasts much longer than usual and would hold back the second train even more. Train delays propagate in densely frequented station areas and networks and can fade out only in time, if there exist sufficient buffer times in the timetable.

The automatic piloting of trains and the decision support system for dynamic traffic control would work in the following steps:

1. Registration of the actual arrival time of the trains at the last upstream stations
2. Determination of the actual departure delay of each train at the last upstream stations
3. Calculation of the remaining travel time of the trains until the protecting block signals of the following conflict point
4. Forecast of the arrival delay of each train at the protecting block signal of the conflict point on the basis of historical data and the delay distribution for this type of trains or line
5. Estimation of the projected overlap of the block times of the approaching trains at the block signals and calculation of the minimal headway between the trains
6. Determination of the sequence and projected headway including buffer time between the trains
7. Calculation of the actual speed of the trains until the block signals and further to the conflict point taking the actual position of the trains into consideration
8. Verification of the matching between the actual and the forecasted train positions and passing moments via radio communication (GSM-R) and, if necessary, revision of the calculation
9. Transmission of the actual speed limit and braking curve information to the trains
10. Supervision of the matching of actual and forecasted headway at the block signals.

Automatic piloting of trains does not necessarily mean driver-less operations, as the train driver might retain the responsibility for the supervision of safety during boarding and alighting of passengers by confirming the ready-to-depart signal. This mode corresponds to the first level of automatic train operation (ATO) that is already applied in modern metro and high-speed railway lines.

The standard automatic train protection (ATP) system consisting of route setting and authority to run for individual trains remains in function, while the automatic piloting will be limited to dynamic supervision of speed, acceleration and braking of interacting trains. In case of automatic protection of platform tracks and supervision of boarding/alighting by means of platform doors and CCTV, as applied by VAL in Lille and Toulouse or METEOR in Paris, or track-side sensors, as used by the SkyTrain in Vancouver and Detroit, even driver-less train operations are feasible.

The dynamic control of speed and distance of virtually coupled model train units has already been successfully proven in a laboratory test facility [12]. The principles of knowledge representation and reasoning of the decision support system would be similar to Fuzzy Petri Nets [13]. The installation of intelligent on-board computers for automatic piloting, continuous position detection and GSM-R communications on trains and in railway traffic control centers will allow to test seamless train operation in practice.

V. IMPACT ON PUNCTUALITY

The majority of small delays occurring daily would be reduced to nearly zero, provided there are sufficient station track capacity and reasonable buffer times between scheduled train paths available. Instead of about 40 to 80 % of the trains being more than one minute late it is expected that this percentage could be reduced to about 10 to 20 % by means of automatic piloting if the level of technical failures causing longer delays were kept at least constant.

The automatic piloting system would enable the trains to realize a predefined level of punctuality during scheduled line services at a high level of significance by innovative timetable design. The scheduled travel times between and dwell times at stations would be based on appropriate empirically measured distributions. The corresponding distributions of the block times of the routes and the remaining buffer times between the train paths would be determined in such a way that a seamless occupation of routes is achieved.

Deeper knowledge about the existing slack of network timetables and insight in the specific causes of train delays will permit a higher level of use of the railway infrastructure while improving the punctuality. The positive elasticity between the number of trains operated in railway networks and the amount of train delays, experienced in practical operations, might be rejected in future due to automatic piloting.

VI. CONCLUS IONS

The importance of high punctuality of train operations is given by the travellers' requirements on the quality of service and the competition with other transport modes. The empirical analysis of train delays, so far, was mostly limited to larger delays than 3 minutes for practical reasons. However, modern train detection systems and computing facilities enable a much more precise data collection and analysis than in the past. Thus, train delays should be measured and analysed in seconds. This would enables a much more effective search of the reasons of delays and finally would lead to an increased punctuality of the scheduled services.

The statistical analysis of arrival times at the Dutch Railways station Eindhoven shows that about 20% to nearly 70% of the trains of the different lines were delayed by more than one minute. The percentage of the IC- and IR-trains with an arrival delay of 3 minutes or less in most cases was significantly lower than the officially aimed 90%. These facts indicate that the large number of smaller train delays has an important impact on the quality of service and regular more detailed investigation is worthwhile in order to increase the level of punctuality of the Dutch Railways. The proven fit of most of the delay times to normal and negative-exponential distributions respectively will allow an improved design of the timetable and more reliable forecasts of train delays during operations based on historic empirical data.

The punctuality of line services would be improved considerably by installing on-board computers in each train that continuously monitor the actual delay with regard to the timetable and transmit the actual train position by GSM-R to the area traffic control center. The development and introduction of a decision support system for automatic piloting would enhance the performance of the railway operations. It would estimate the expected delay of each train at the protecting signals of the downstream conflict point and determine the appropriate speed, acceleration or braking in order to arrive at the right time at the block signal and to enable a seamless occupation of the downstream route. This would reduce the probability of train delays during the approach to conflict points and stations significantly and thus increase the level of punctuality of operations.

Current research focuses on suitable models of train delay propagation in stations and networks.

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LIST OF FIGURES

TABLES