

PERFORMANCE OF METRO CONTROL SYSTEMS

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Abstract: This contribution deals with train operations on urban rail transportation systems (e.g. metros) as well as with vital control parameters. The analysis of train control functions show that the lengths of block sections ensuring train protection are very important for the technical expenditure. On the other hand, they determine the system behaviour during regular and disturbed operations. In a first step, the design of the block lengths considers the minimum temporal headway between two station-inbound trains. The operations caused by train delays are treated by computer simulations where the blocking-time step function plays an important role. Furthermore, the tasks of speed regulation and proposition of target speeds are investigated.

Keywords: Urban rail traffic, train control, system design, block sections, train headway, regular and disturbed operations, speed regulation, simulation.
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1 INTRODUCTION

The application of advanced components for train traffic control can be evaluated by the achieved operational efficiency and quality. With view on track-guided urban transportation systems, the travel times, the attainable train headways, the propagation and limitation of train delays are particularly important. Therefore, the train control system has to be enabled to deal with traffic peak hours and has also to be highly reliable. Analysing different system versions with on-board and trackside equipment, specially those parameters have to be taken into account which have direct influence on regular and disturbed operations.

In this respect the lengths of the block sections for automatic train protection should be discussed particularly. They determine the minimum train headway times, the amount of trackside control and transmission elements as well as the train trajectories during disturbed operations. Therefore the system performance is basically affected.

2 SYSTEM ARCHITECTURE

The following components or functions have to be considered with respect to their effects on train operations:

- train location system,
- odometric devices (for determination of train position and speed),
- supervision of braking distances and speed restrictions,
- data transmission between track and train.

Figure 1 demonstrates the co-operation of the named components solving the task of headway protection. The realized solution determines the maximum number of trains per time unit with regard to station occupancy and clearance.

A well-known system solution is given by a combination of audio frequency track circuits for train location (in case for data transmission) and of quasi-continuously working trainborne processors for odometric and safeguarding functions.

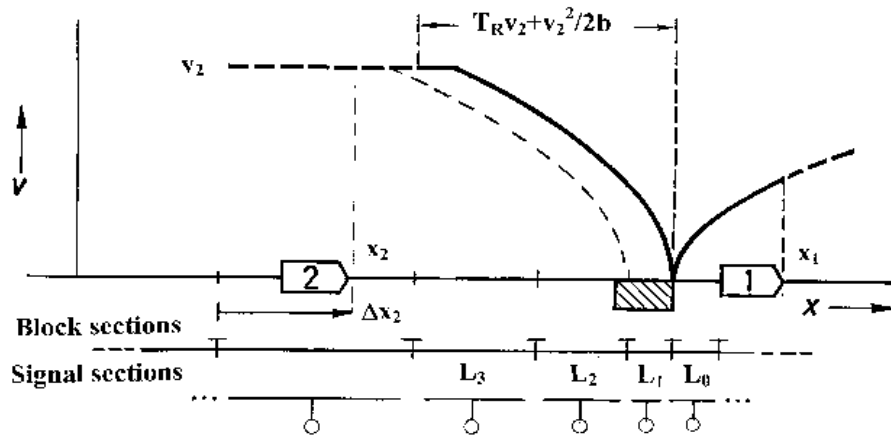


Figure 1: Components of an automatic train control system and vital process data with respect to minimum train headway.

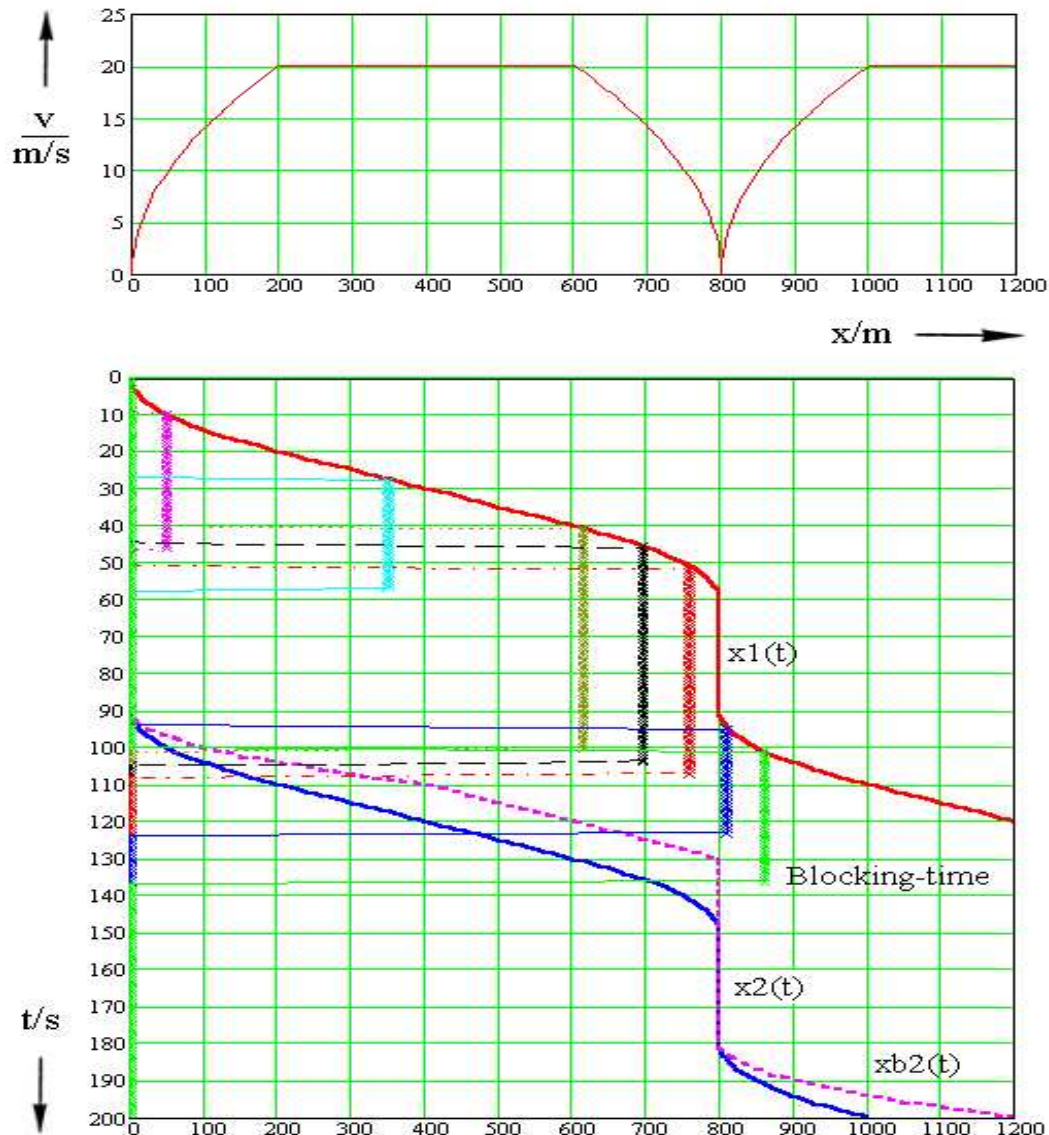


Figure 2: a) Speed-position-plot $v(x)$; b) position-time-plots $x_1(t)$ and $x_2(t)$ with braking distance $x_{b2}(t)$ and blocking-time step function for a typical urban railway track with two stations and scheduled temporal headway $\tau_0=90$ s.

Transponders or conductor loops can be used as an alternative for track-train data transmission. All these technical solutions can be taken into account for system modelling and simulation.

The technical advantages and problems of the various solutions to realize block sections are not discussed in this paper. It concentrates on the effect of block lengths on the train operations which are independent of the system version used, be it track circuits or transponders or conductor loops.

3 DESIGN OF BLOCK LENGTHS

The optimisation of the lengths of the block sections which may always be occupied by only one train at a time is a very important task because the minimum temporal train headway is affected as well as the number of devices and the control system reliability. In addition to the results of (Kraft, 1988) and the investigations of (Hill and Yates, 1992; Rosenkranz, 1997) based thereon, it will be shown how the length of each individual block between two stations can be determined. Furthermore, the time margin of the regular schedule can be demonstrated by position-time-plots modelling the functions of the automatic train protection system (ATP). This task requires a mathematical model including the steady-state parameters of the trains and of the ATP as well as the blocking-time step function. Figure 2 refers to regular operation on an urban railway track with scheduled headway $\tau_0=90s$ and with minimum headway $\tau_{min}\approx 70s$. The sections L_0 , L_1 and L_2 are given by the formulae of figure 3, whereas the remaining sections follow from considerations concerning disturbed operations.

4 SIMULATION

With view to disturbed operations causing train delays the system behaviour can be illustrated by computer simulations. Once again the design of block lengths has to be discussed corresponding with optimal use of the free state-space of trains, see e.g.(Schnieder and Gückel, 1986; Schnieder and Kraft, 1983). An example where the station dwell time of train 1 is extended beyond the scheduled value can be seen in figure 4. It shows a trajectory of train 2 processing only the ATP-signals and an „optimal“ trajectory which can be achieved by suitable processing carried out by the trackside computer and by transmission of target speeds. The aim of this strategy is the realization of an energy-saving train speed regulation with sufficient passenger comfort even during disturbed operations.

Additionally, the blocking-time step function for this case is plotted in figure 5 demonstrating the effect of an extension of the station dwell time. This function establishes the time-depending permitted values $v_2(t)$ and $x_2(t)$ of train 2.

A similar case is shown in figure 6 where the trajectories of the delayed train 1 and the succeeding train 2 have been plotted. Here, the lengths of all block sections are arbitrarily small („moving block system“). This simple case has been chosen in order to demonstrate the theoretical limitation of the propagation of train delays, (see figure 3). The example uses the following time parameters: nominal travel time $T_t=60s$, minimum headway time $\tau_{min}=60s$ with $T_s=30s$, scheduled headway time $\tau_0=75s$, delay of train 1 $T_{d1}=30s$. Therefore, the delay of train 2 is given by the difference $T_{d2}=T_{d1}-(\tau_0 - \tau_{min})=15s$, the travel time $T_{t2}=75s$. These results are confirmed by figure 6.

Parameters: train length L_T , acceleration rate a , braking rate b , station dwell time T_S ,
system reaction time $T_R\approx 0$, operative speed v_o ,
minimum temporal headway τ_{min} , operative (scheduled) train headway τ_0 ,
train delay time T_d , $T_{d2}=T_{d1}-(\tau_0-\tau_{min})$
block lengths L_i , $i=0,1,2,\dots$

$$\tau_{min} = \frac{L_1}{v_o} + \frac{v_o}{b} + T_S + \sqrt{2 \cdot \frac{L_0 + L_T}{a}}$$

$$L_1 = L_0 = \frac{v_o^2}{a} - v_o \cdot \left[\sqrt{\left(\frac{v_o}{a}\right)^2 + \frac{2}{a} \left[L_T + v_o \cdot \left(\tau_{min} - T_S - \frac{v_o}{b} \right) \right]} - \left(\tau_{min} - T_S - \frac{v_o}{b} \right) \right]$$

$$L_T > L_1, \quad L_2 < v_o \cdot \left(\sqrt{2 \cdot \frac{L_0 + L_T}{a}} - \sqrt{2 \cdot \frac{L_T}{a}} \right), \quad L_2 + L_3 < v_o \cdot \left(\sqrt{2 \cdot \frac{L_0 + L_T}{a}} - \sqrt{2 \cdot \frac{L_T - L_1}{a}} \right)$$

Figure 3: Selection of important formulae.

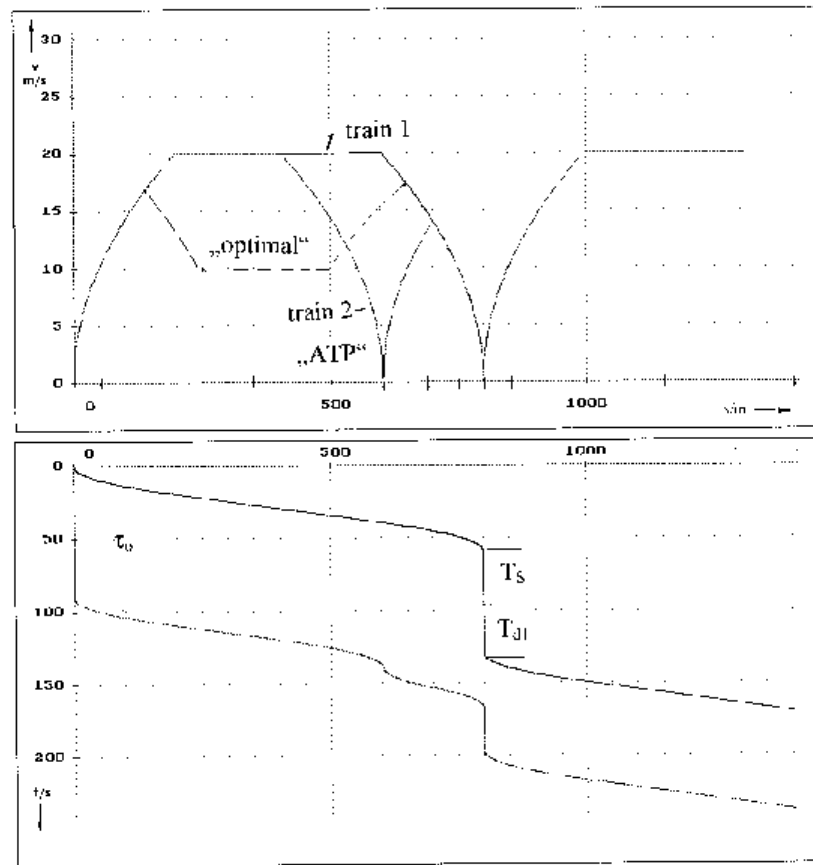


Figure 4: Simulation result with regard to disturbed operations (lengths of block sections as in fig. 2).

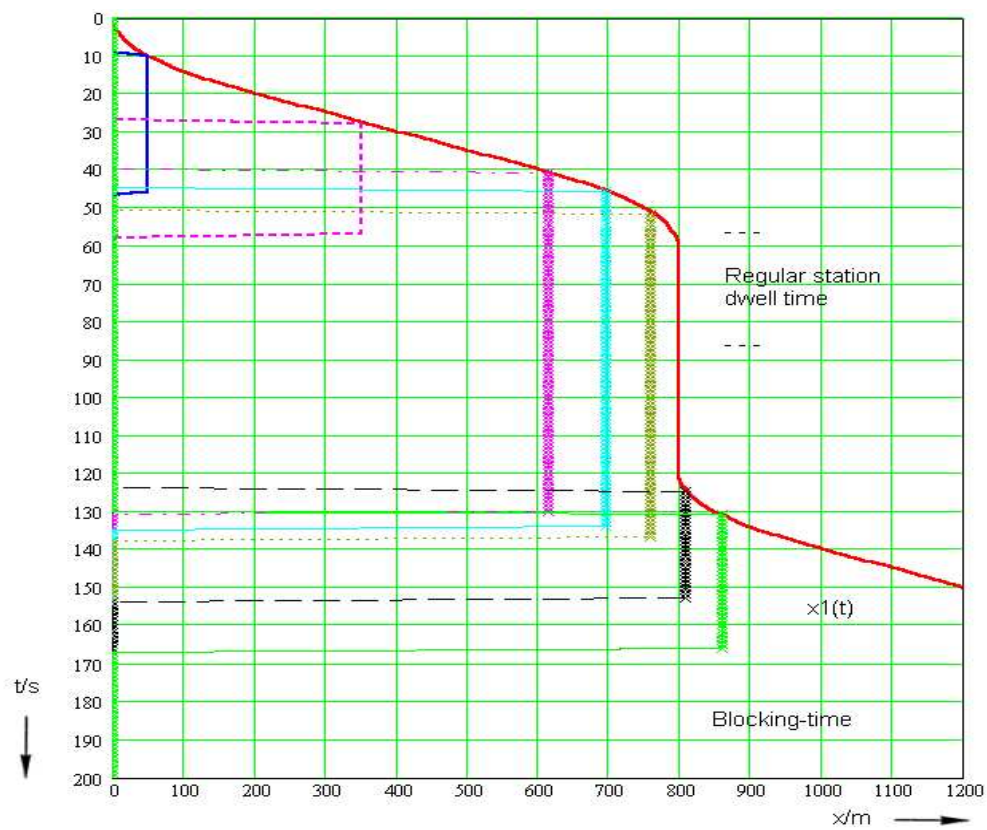


Figure 5: Time-position-plot $x_1(t)$ and blocking-time step function for the case of an extended station dwell time.

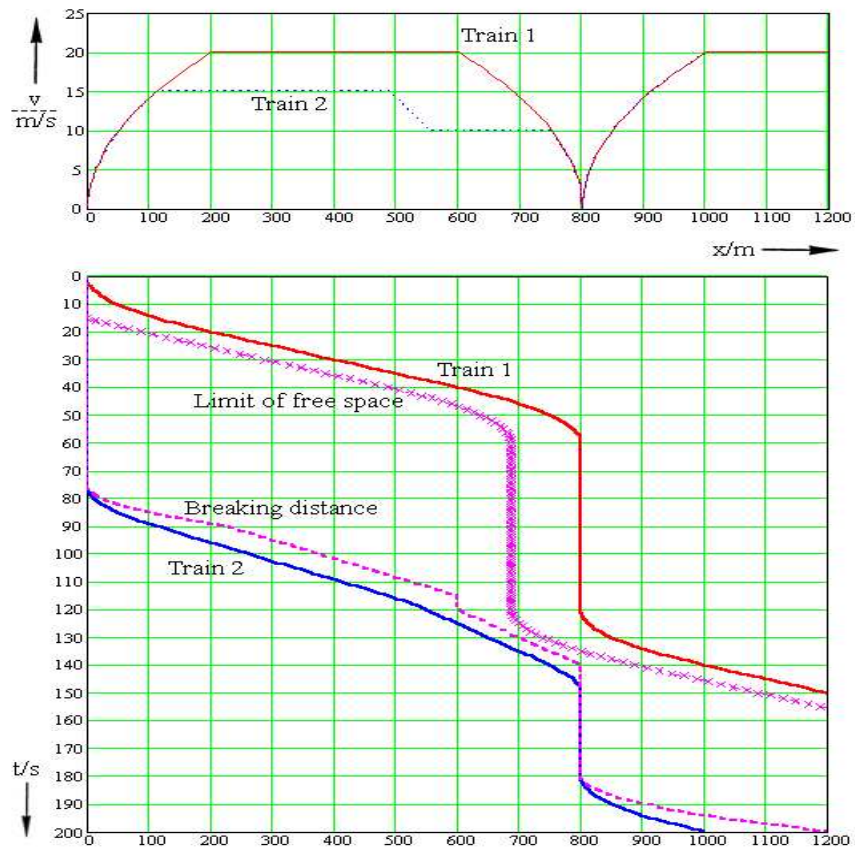


Figure 6: Simulation of a „moving block system“ for the case of an extended station dwell time.

The target speeds for train 2 starting at the scheduled departure time $t=75s$ are the following: (75s,20m/s), (90s,15m/s), (115s,0), (120s,10m/s), (140s, 0). The time-depending target speed values can be calculated by a trackside computer considering the free state-space caused by the preceding train as shown in figures 4-6. Furthermore, these determinations can be improved by processing of the predicted time of station clearance. This procedure provides an optimum train running with respect to the operational situation.

5 CONCLUSIONS

The block sections are very important parts of an automatic train control system and have significant influence on regular and disturbed train operations. A design of blocks between two stations of an urban railway track should be checked by the blocking-time step function drawn into a train position-time-plot. The sections in the neighbourhood of a station can be determined by the developed formulas with respect to a given minimum train headway, the other sections follow from simulations of disturbed operations where particular functions of the control system and the trajectories of the trains have to be considered. An improvement of traffic flow and passenger

comfort can be achieved by suitable processing of additional process information.

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