Train passing optimization in a single-track line: a computer-based approach

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Abstract

This paper presents a computer-based approach to the problem of carrying capacity maximization of a single-track Light Rail Transit (LRT) line. Firstly, parameters on which carrying capacity depends are pointed out; then, the role of such parameters is analyzed by means of a special purpose simulation program realized by the authors.

1 Introduction

A growing interest is currently addressed to the problem of evaluating the carrying capacity of railway lines. Particularly, in Italy, an increasing importance is being attached to the analysis of carrying capacity of single-track lines, for two main reasons.

First, the track bed of some abandoned single-track railway lines is likely to be reused in order to realize new LRT systems, according to several plans of "regional metro system" development. Second, in some towns, the possibility of adopting a single-track layout rather than a double-track one in building new sections of LRT systems is now under examination, in order to achieve lesser cost and land use (the latter element is especially important for surface transportation systems, such as LRT lines).

In both cases, it must be verified that a single-track layout be consistent with the required carrying capacity; besides, it is convenient to tackle the problem of maximizing the carrying capacity of a single-track line.

Such a maximization problem may be approached on two levels: on a design level, and on an operational level. During the design of a LRT system, free variables that may be fixed in order to maximize the carrying capacity are the position of stations and signals, the length of passing tracks, the composition of trains. On the operational level, after the transportation system has been opened, the maximization problem can be formulated by assuming target speeds and departure times as free variables.
2 Carrying capacity of a single-track railway line

The carrying capacity of a railway line is defined as the number of trains that can run on the line in the unit time (generally one hour or one day). With reference to a section between two stations (see Fig.1), carrying capacity can be expressed as

\[ N = \frac{T}{t + t_d} \]  

where: 
- \( T \) = reference unit time;  
- \( t \) = time taken by a train to cover the section;  
- \( t_d \) = dead time related to train headway.

**Figure 1: A standard-type single-track section between two stations.**

In evaluating the carrying capacity of a line, equation (1) is usually applied to the most unfavourable block section, i.e., the one requiring the longest time (Bianchi\(^1\)). On single-track lines, block sections generally coincide with sections between two adjacent stations suitable for train passing. It is well known that, on single-track lines, the subdivision of sections between two stations into several blocks (as is often the case with double-track lines) does not increase carrying capacity in an appreciable way, unless the global traffic in the two opposite directions is unbalanced and it is necessary to operate a large number of consecutive trains in the same direction. Assuming that the traffic on a given line includes equal number of uproad and downroad trains, which alternate in covering a single-track section, the carrying capacity (in one running direction) on this section is given by

\[ N = \frac{T}{q + \left( \frac{1}{v_1} + \frac{1}{v_2} \right) L} \]  

where: 
- \( q \) = waste of time due to train passing;  
- \( v_1 \) = average speed of uproad trains;  
- \( v_2 \) = average speed of downroad trains;  
- \( L \) = length of the section considered.
The waste of time due to train passing, \( q \), can be considered as the sum of elementary time intervals. Assuming that a train \( T_1 \), which has entered the station \( S_2 \) first, must wait on a side track, and that the reception of a second train, \( T_2 \), takes place on the running track, the waste of time for the first train includes (see Fig. 1):

- shunting time, \( t_1 \), necessary to cover, at reduced speed (30 or 60 km/h, depending on the type of switches) the section between the entry signal, ES, and the stopping point,
- waiting time, \( t_2 \), which ends when the second train has entirely entered the station,
- departure dead time, \( t_3 \), necessary to obtain the permission to leave (the duration of \( t_3 \) depends on the type of block system and interlocking);
- time waste to get out, \( t_4 \), necessary to cover, at reduced speed, the getting-out switches in the station.

The train \( T_2 \) may be subject to no running irregularity (in this case, its waste of time is equal to zero) if it arrives at the warning signal, WS, when WS is set to "line clear". This occurs if, at that moment, the train \( T_1 \) has already entered the station, and the entire route for \( T_2 \) has already been fixed.

### 3 Maximization of carrying capacity

Train passing optimization takes an important role in maximizing the carrying capacity of a single-track line. According to different measures of carrying capacity, this maximization problem can be approached by assuming the number of trains per hour, as objective function, or the number of seats offered per hour. The capacity \( C \) of a LRT system, for each running direction, expressed in seats offered per hour, can be evaluated as

\[
C = n c_e N \tag{3}
\]

where:
- \( n \) = number of vehicles for each train;
- \( c_e \) = capacity of each vehicle, i.e. number of seats;
- \( N \) = carrying capacity of the line, as expressed by eq. (2).

Under the same conditions, the waste of time due to train passing is proportional to the length of trains, that is, to \( n \); this proportionality can be expressed by

\[
q = k_1 + k_2 n \tag{4}
\]

The dependence of capacity \( C \) on the number \( n \) is therefore explicated by the expression

\[
C = \frac{n c_e T}{k_3 + k_2 n} \tag{5}
\]
where \( k_1, k_2, \) and \( k_3 \) are suitable coefficients, dependent on parameters which determine the carrying capacity of the considered line. Formula (5) shows that a single-track line is to be operated by scheduling fleets of trains on the same running direction, alternately, if the highest carrying capacity must be obtained; this result is also achieved in Canciani\(^2\) by different argument than the above mentioned one.

However, this approach leads to unacceptably low train frequency, which is detrimental to the quality of service. Therefore, it is convenient to face the problem by maximizing the number of trains per hour; the discussion upon the number \( n \) should be treated as a post-optimality analysis.

Free variables that can be fixed by the designer in order to maximize carrying capacity are:

- position of stations suitable to train passing,
- position of warning signals and entry signals,
- type of switches (especially, length and operative speed on siding track).

Stations suitable to train passing should be equally spaced. Carrying capacity is also increased by drawing warning and entry signals near respective stations, within the bounds imposed by braking distance. The reduction of distance between signals and stations is made possible owing to higher train deceleration. For instance, on a standard-type LRT system, assuming maximum line speed equal to 70 km/h, speed on siding tracks equal to 30 km/h, increasing train deceleration from 0.6 to 0.7 m/s\(^2\) causes a reduction of 7 s in the waste of time due to train passing (9 s if the train \( T_2 \) must transitorily stop at the entry signal because of route interference with \( T_1 \)). The total effect of such a reduction on carrying capacity must be weighed by considering the number of stations where a train passing occurs.

Also the installation of switches suitable to higher speed than 30 km/h on siding track causes an increase of carrying capacity, in spite of the longer section which must be covered at reduced speed. For 30 km/h and 60 km/h switches, it can be proved that the aforesaid assertion is true if \( L_2' - 2L_2 < L_1 + L_3 \) (see Fig.2). This condition is satisfied with switches currently used on Italian railways (30 km/h switches are approximately 30 m long, 60 km/h switches are 40 m long) (Mayer\(^3\)).

Lastly, the length of trains affects the minimum length of siding tracks and the waste of time for trains that are platformed on a siding track. If uproad trains and downroad trains alternate, the increase of the length of trains causes a reduction in carrying capacity as much as the speed on siding tracks is lower than line speed.

On the operational level, free variables that can be fixed in order to maximize carrying capacity are target speeds and departure times of trains. The train passing between two trains, \( T_1 \) and \( T_2 \) (see Fig.1) can be optimized by minimizing the sum \( J \) of their running times, \( J_1 \) and \( J_2 \), on the section between the stations \( S_1 \) and \( S_3 \), as follows:

\[
\min \sum J \{ J_1 + J_2 \} \tag{6}
\]
where $x$ is the vector of free variables. For the present study, the following free variables are proposed:

$$x_1 = DT_1 - DT_2$$
$$x_2 = v_2$$

where $DT_1$ and $DT_2$ are the departure times of trains $T_1$ and $T_2$ from their respective stations, $S_1$ and $S_3$.

**4 Software tools for train passing optimization**

The importance of train passing optimization in determining the carrying capacity of a single-track LRT line can be evaluated by means of computer simulation. A special purpose program for computer simulation of train running has been developed with the software tool MATLAB, and it has been applied to a case study, that is the LRT line 11.8 km long (currently being designed) that will connect Savona (an Italian sea town with 70,000 inhabitants) to Vado Ligure and Albisola, which are small towns along the Ligurian coast. By this program, the expressions of carrying capacity proposed in the previous section and the reported data about capacity maximization have been validated. Train passing optimization has also been investigated by means of the software tool FERSIM, written in Object Pascal language (Galaverna & Sciutto\(^4\)).

This is a general purpose rail traffic simulator developed in the Electric Engineering Department of the University of Genova. By this program, a succession of situations have been simulated, characterized by an increasing number of running trains that saturation of line carrying capacity is reached. Therefore, carrying capacity has been determined as the maximum number of trains that turned out to be likely to be scheduled, before the occurrence of
traffic irregularity. Computer-based approach allows one to overcome the limitations specific to analytical methods, because the effects of many concurrent parameters can be taken into account. Particularly, in single-track line analysis, train passing can be reproduced in a very accurate manner.

5 Conclusions

In Italy, the planned realization of new LRT systems and the likely reuse of single-track railway lines closed to traffic are currently arousing interest in evaluating the carrying capacity of single-track lines. The weight of train passing optimization in determining the carrying capacity of a single-track line has been investigated both analytically and by means of computer-based techniques. To this end, computer simulation of train running represents the most suitable tool.

References