Base vehicle equivalents standardization for rail and road capacity analysis

OANA DINU, MIRCEA AUGUSTIN ROŞCA, CRISTINA ŞTEFĂNICĂ
Department Transport, Traffic and Logistics
University Politehnica of Bucharest
Spl. Independentei, No.313, Bucharest, 060042
ROMANIA
oana.dinu@upb.ro, augustin.rosca@gmail.com, cristina_stefanica@yahoo.co.uk
http://www.ingtrans.pub.ro

Abstract: Heterogeneity structure of traffic flow for both road and rail system makes capacity evaluation quite difficult, therefore imposes simplifications: it appeals to equivalents in case of road infrastructure and a traffic predominant component in case of rail infrastructure. The interaction of different train types is a key factor affecting rail line capacity. In a conventional railway system, trains with different characteristics commonly operate on the same track and line capacity is defined as trains per day that does not reflect the specific train type.

Key-Words: traffic heterogeneity, passenger car unit, base train unit

1 Introduction

Traffic flows are composed of heterogeneous traffic entities. The occupied space, travel speed or occupation time of the same infrastructure element represent characteristic values of traffic flow structure. These are directly connected with traffic type entity (car, train, ship, etc.), with its destination (for transport of persons or goods), with mechanical and gauge characteristics which, in turn, must be gradated by relationship "leader - crew - roadway - environment" from which, additional factors that in particular increase lack of homogeneity of traffic flow. We consider physiological factors (e.g., visual acuity, strength, reaction speed) and psychological (motivation, attention, temperament), related to crew leaders but also factors that depend on technical and loading condition of particular type traffic entity or infrastructure characteristics (variables during operation) or environmental conditions (rain, wind, slime, fog, ice) [7].

2 Base vehicle equivalents

Heterogeneity structure of traffic flow requires simplifications: it appeals to equivalents in case of road infrastructure and a traffic predominant component in case of rail infrastructure.

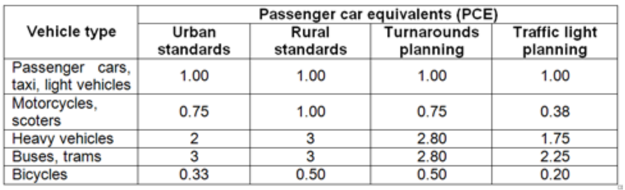
For road transportation, different car types can be converted into a specific unit by using “passenger car equivalents (PCE)” and capacity is defined as “passenger car units (PCU)” per day. However, there is no standardized procedure to determine rail line capacity. Can we standardize the rail unit?

2.1 Base vehicle equivalents standardization for road

In terms of structure, traffic flow has, at least in case of road infrastructure, such spatial and temporal specificity that makes it almost impossible to reproduce faithfully by means of mathematical modelling and computer simulation.

In order to express the maximum flow of arterial road usually is used passenger car equivalent obtained by using evaluation coefficients. The nature of these coefficients of equivalence is relative. Limited validity of this equivalence is demonstrated by the differentiated values in relation to infrastructure location (urban or rural) and with the element of design (arterial road, signalized or not junction). Table 1 presents passenger car equivalents for different situations [3].

Table 1. Road passenger car equivalents



Vehicle type	Passenger car equivalents (PCE)			
	Urban standards	Rural standards	Turnarounds planning	Traffic light planning
Passenger cars, taxi, light vehicles	1.00	1.00	1.00	1.00
Motorcycles, scoters	0.75	1.00	0.75	0.38
Heavy vehicles	2	3	2.80	1.75
Buses, trams	3	3	2.80	2.25
Bicycles	0.33	0.50	0.50	0.20

Source: Hobbs, F. D. Traffic Planning and Engineering, Pergamon Press, Oxford, p.54

2.2 Base vehicle equivalents standardization for rail

2.2.1 Slow trains reduction factor

For the case of railway infrastructure with mixed, heterogeneous traffic (different categories of passenger and freight trains), expressing maximum and actual flow through prevalent traffic entities involves also equivalence calculations in certain steps of solving. Due to railway infrastructure management authority, which states clear rules for achieving running schedules in which the security prevails, equivalences take into consideration the occupation interval of each infrastructure element by different train category in circulation which moves in a certain sequence, imposed by timetable.
In this case the capacity is measured in freight direct trains, as follows [6], [9], [10]:

$$N_{mf}^{directe} = N_{mf}^{\max} - e_{cal} \cdot N_{cal} - e_{mf}^{l} \cdot N_{mf}^{l} \qquad (1)$$

where,

$N_{mf}^{directe}$ is the number of direct freight trains that results from the timetable;

$N_{mf}^{\max}$ - the maximum number of direct freight trains that may enroll in a parallel timetable;

N_{cal} - number of passenger trains which must be introduced on timetable;

N_{mf}^{l} - number of freight trains which must be introduced on timetable;

e_{cal}, e_{mf}^{l} - reduction coefficients obtained for passenger and local freight trains;

The time interval used for scheduling a passenger train respectively a local freight train determines a deduction due to actual train movement and a further reduction due to the occurrence of intervals that are too small in order to be used.
In this case, the reduction factor, *e*, equals to:

$$e = \frac{t_{red}}{t_{mf}} \qquad (2)$$

where:

t_{red} represents the timetable deduction time due to passenger and local freight train circulation;

t_{mf} - the freight train circulation ocupation time on timetable.

We also have the relation:

$$t_{red} = t_{cal} + t_{red}^{\sup l} \qquad (3)$$

where,

t_{cal} represets the passenger train circulation ocupation time on timetable;

$t_{red}^{\sup l}$ - the additional reduction time constituted by difference between the journey time of a whole number of freight trains and the journey time of a passenger or local freight train
In this case:

$$e = \frac{t_{red}}{t_{mf}} = \frac{t_{cal}}{t_{mf}} + \frac{t_{red}^{\sup l}}{t_{mf}} = e_1 + e_2 \qquad (4)$$

where:

$$e_1 = \frac{t_{cal}}{t_{mf}} \qquad (5)$$

e_1 is the reduction factor due to the actual circulation of the passenger train;

$$e_2 = \frac{t_{red}^{\sup l}}{t_{mf}} \qquad (6)$$

e_2 is the reduction factor due to the additional time interval in which no train can be inserted.
Coefficient e_1 can be calculated precisely, if known the journey time of such trains on critical distance on the line.
Coefficient e_2 may vary from 0 (where the timetable is drawn from the critical distance, first drawn speed trains and then further freight trains) and 1 (where the timetable is drawn defective, that is, the additional reduction time tends to limit to the journey time of the freight train), as outlined in figure 1.

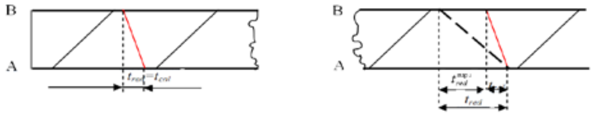


Fig. 1 Running trains plotting for critical distance

Thus, knowing the reduction coefficient, *e*, we can determine the capacity (in freight trains) of any railway line, according to (1) from the maximum capacity calculated in freight trains based on the parallel timetable period, from which decreases the number of passenger trains that will join the timetable multiplied by the reduction factor allowed.
This method for calculating the maximum capacity - the number of standard trains that can circulate on a railway line over a defined period (standard type is the type of predominantly trains that circulate on the line) is extremely useful because of its simplicity.

2.2.2 “Train type proportion” concept

In practice, different types of trains circulate on a railway line, varying in number in each direction. Capacity, as calculated above, is simplified on the assumption that there is a predominant type of train, and any other type of train can be equated with it without affecting the level of capacity.

In fact, the capacity does not have a unique value. It may differ depending on the proportions of different categories of trains that circulate on a railway line [11].

In most systems of organization of railway traffic, space intervals between trains that follow do not depend on traffic speeds. This leads to the difference between the calculation of the flow (capacity) on railway and road infrastructure. If in the case of road infrastructure the maximum flow rate depends on the density and speed, which are characteristic values in a certain correlation, and dependent on the structure of the traffic, but in the case of rail infrastructure, one dependency of the capacity for a given technical endowment and some way of organizing the circulation, is the duration of infrastructure element occupancy to each category of train. Duration of occupancy depends upon both average speed of each category of trains on specific infrastructure element and the sequence of the various categories of trains in timetable [2], [8].

Unlike road traffic, in the case of rail traffic, the infrastructure manager is responsible for organizing traffic and thus may promote the structure of traffic succession entities which corresponds the best infrastructure use.

$$\alpha = \frac{N_m}{N_m + N_c} \tag{7}$$

where:

N represents total trains number;

N_M - slow trains number;

N_C - fast trains number;

V_M - slow trains speed;

V_c - fast trains speed.

Rail capacity analysis is therefore an iterative process, the base step being the variation of train type proportion taken into consideration. As presented before, using “preponderant train type” can lead to imprecise capacity value so, for a more accurate capacity calculation we can use the concept “train type proportion”.

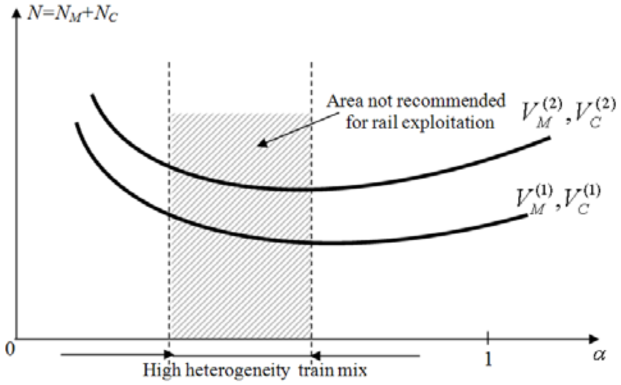


Fig. 2 Railway exploitation from traffic entity point of view

Rail capacity analysis is therefore an iterative process, the base step being the variation of train type proportion taken into consideration. As presented before, using “preponderant train type” can lead to imprecise capacity value so, for a more accurate capacity calculation we can use the concept “train type proportion”.

In correlation to this concept, total traffic percentage that each type of train determines is named “proportional distribution” and total traffic percentage that each circulation direction determines is named “directional distribution”.

For each pair “proportional distribution- directional distribution” (for every particular traffic mix) potential line capacity is different as seen in fig.2.

3 “Base Train Equivalent” approach

The interaction of different train types is a key factor affecting rail line capacity. In a conventional railway system, trains with different characteristics commonly operate on the same track and line capacity is commonly defined as trains per day that does not reflect the train type this unit refers to.

A new concept, Base Train Equivalent, is proposed along with a standardization process to convert different types of trains to a particular train type – “Base Train Unit”[4], [5].

Each railway system has various train types and may have different classifications on the “base train”.

Instead of assigning a particular type as BTU, this new method aims to develop the general concept and standardize process.

Estimate delay-based BTE for Simulation and Parametric Capacity Analysis - Rail capacity models can be categorized into analytical, simulation (estimate delay based on given infrastructure configurations and decision rules of train dispatchers) and parametric (developed from simulation and focus on the key elements of line capacity) analyses.

Both parametric and simulation models are delay-based capacity analysis models so we can develop a delay-based BTE standardization process for both capacity methods.

Delay-Based “Base Train Equivalent” Model - The delay-based approach considers the delay in the road traffic stream caused by heavy vehicles [1].

The same concept can be adopted for developing the delay-based “Base Train Equivalent” model for rail capacity analysis - BTE can be expressed as the ratio of the impact (delay) caused by one subjected train (non-base train) to one base train.

$$BTE = 1 + \frac{\Delta d_i}{d_b} = \frac{d_b + \Delta d_i}{d_b} = \frac{\frac{d_b^T}{N} + \frac{(d_m^T - d_b^T)}{(N \times P)}}{\frac{d_b^T}{N}} \qquad (8)$$

where:

Δd_i represents the additional delay caused by one non-base train in the mixed flow;

d_b - delay of one base train in the base flow;

${d_b}^T$ - delay of total trains in the base flow;

${d_m}^T$ - delay of total trains in the mixed flow;

N - total number of trains and

P - percentage of non-base trains.

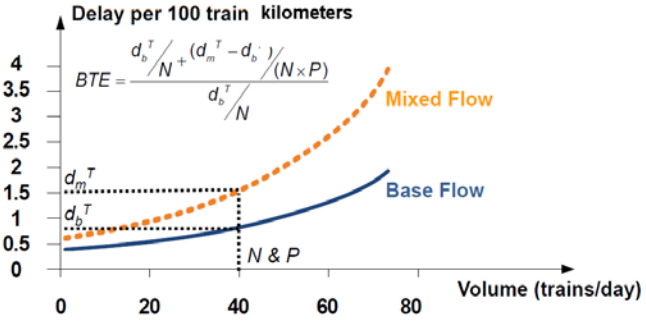


Fig. 3 Estimate delay-based BTE for simulation and parametric capacity analysis

As seen in fig. 3, even if, on a certain rail infrastructure element, the train number increases considerably if traffic structure is homogenous than total registered delay is significantly smaller than the delay registered for the same train number in a heterogeneous structure (mix of different train types). The proportion considered above is 50% slow trains and 50% fast trains.

4 Conclusion

A delay-based “Base Train Equivalent” method has been proposed for capacity analyses and if railroads can form a consensus on the standard unit along with possible route and train characteristics, a comprehensive database for both parametric and simulation models can be developed.

It is also a necessary element for a future “Railroad Capacity Manual”.

With the proposed “Base Train Equivalent” concept and method the unit of rail capacity can be standardized, the impact of an additional train can be easily assessed and the capacity measurements from different lines or systems can be compared and evaluated, resulting in meaningful and useful attributes.

In the future this “Base Train Equivalent” method can be developed for analytical rail capacity models and also can be developed techniques to deal with multiple train types (more than three types).

References:

[1] Benekohal, R. and Zhao, W., Delay-based passenger car equivalents for trucks at signalized intersections, *Transportation Research Part A: Policy and Practice*, Volume 34, Issue 6, August 2000 , Pages 437-457

[2] Burdett, R. L. and Kozan, E., Techniques for absolute capacity determination in railway, *Transportation Research Part B: Methodological* 40(8), Elsevier, 2006, Pages 616-632

[3] Hobbs, F.D., *Traffic Planning and Engineering*, Pergamon Press, Oxford, 1979, ISBN 10: 0080226973

[4] Lai, Y.C., Liu, Y.H., and Lin, T.Y., Development of Base Train Equivalents to Standardize Trains for Capacity Analysis, *Transportation Research Record - Journal of the Transportation Research Board*, 2012, No. 2289, Pages119–125

[5] Lai, Y.C. and Barkan C.P.L., Comprehensive Decision Support Framework for Strategic Railway Capacity Planning, *ASCE Journal of Transportation Engineering*, 2011, Vol. 137, No. 10, 738–749

[6] Kocinev, F. P., Maximovici, B.M., Tihonov, K., *Organizarea circulației la căile ferate*, Bucureşti, Centrul de documentare şi publicații tehnice, 1969, Pages 394-410

[7] Raicu, Ş., *Sisteme de transport*, Editura AGIR, 2007

[8] Raicu, Ş., Maşală. Gh., *Transport feroviar. Funcționare – Dezvoltare – Eficiență*, Editura Stințifică şi Enciclopedică, Bucureşti, Pages 200-204

[9] Tănăsuică, I., *Modele grafice şi matematice ale circulației trenurilor*, Bucureşti, Centrul de documentare şi publicații tehnice,1973

[10] Tomescu, C., *Exploatarea tehnică a rețelei feroviare*, Editura didactică şi pedagogică Bucureşti, 1966

[11] UIC. 2004. Capacity (UIC code 406). *International Union of Railways (UIC)*: Paris, France.