

ASPECTS ON THE CAPACITY FOR DOUBLE TRACK LINES WITH BLOCK SYSTEM; COMPRESSED TIMETABLE

Amedeo NECULCEA¹

Starting from the complexity of the term "capacity" and from the many approaches and definitions, of which a part is presented in this paper, the analysis focuses on two methods for evaluating the capacity of a double track equipped with fixed block system, proceeding to identify the convergence elements of those methods.

The aspects regarding how the train path compression can be realized, the factors which influence them and the effects to the size of available capacity are also analyzed.

This paper aims to demonstrate that when the graphic contains freight trains, whose timetables have a certain amount of strictness, the result is several forms of graphic compression with different results when it comes to the value of available capacity. Analysis of multiple forms of compression opens the way for research aimed at the determination of some rules (formulas) useful in the assessment of capacity utilization.

Keywords: freight corridors; capacity; mixed traffic; compressed timetable.

1. Introduction

One of the consequences of economic globalization and raising of our international economic integration is the increasing of the entire transport sector. Since the 1990s, many European countries began to suffer from congestion in major economic areas and main transport routes. Today there is no doubt about transport congestion situations in many countries of Europe. It is noted that rail freight is the first and hardest hit in situations of limiting of railway capacity. Now, this problem is beginning to threaten the economic competitiveness

The growing concern about the diminishing quality of service of rail freight in Europe has led to the elaboration of Regulation (EU) No 913/2010 - Regulation concerning an European rail network for competitive freight [13] - which took effect on the 9th of November 2010. This regulation requires Member States to develop rail freight corridors (Fig.1) based on a strong commitment to the market, in order to recover the attractiveness of the railway system for the transport of some wider categories of goods.

¹ PhD Student, University POLITEHNICA of Bucharest, Romania, email: amedeo.neculcea@yahoo.com

Optimizing the use of railway infrastructure is a complex and difficult task, especially in a mixed traffic situation. For this reason, it is necessary to analyze the situation of existing capacity in order to determine how much additional traffic can be absorbed by the current infrastructure and what investment will be needed for the development of new infrastructure.

The main purpose of a capacity analysis is to determine the maximum number of trains that would be able to operate on a certain railway infrastructure during an established time window, and on given operating conditions. Numerous tools have been developed to solve this problem; they are based on traffic models [15], analytical models [1], [2], [3], [16] or algebraic approach [14].

In Romania, the railway transport of goods and passengers has fallen continuously since 1989. If in 1990 the railway was carrying 218 828 000 tons of cargo and 407 931 000 passengers, in 2014 the rail market amounted to 50 739 000 tons transported and 64 760 000 passengers transported [source: INSE <http://www.insse.ro/>].

Although the decrease was substantial and apparently the capacity of the tracks was not diminished, unfortunately there are sections of railway network where the saturation phenomenon was registered. Even on the freight corridor Curtici- Simeria- Brasov- Bucuresti- Constanta, there are traffic jams for freight trains on adjacent sections of Curtici, Predeal, Constanta and other rail stations. This problem appears very often.

What causes this paradoxical situation? Is this only the result of a flawed and inefficient use of infrastructure? Are there objective factors that adversely affect the circulation capacity? This paper will try, among other things, to create the necessary conditions to obtain answers to these questions.

Starting from the idea of providing better conditions for the freight trains, the present paper analyzes two methods of assessing the railway capacity, one developed and applied mainly in Western European countries and the other, used in Eastern countries. Thus, after the synthetic description based on flow diagrams, the convergence points of these two methods are identified, mathematically demonstrating their complementarity zone.

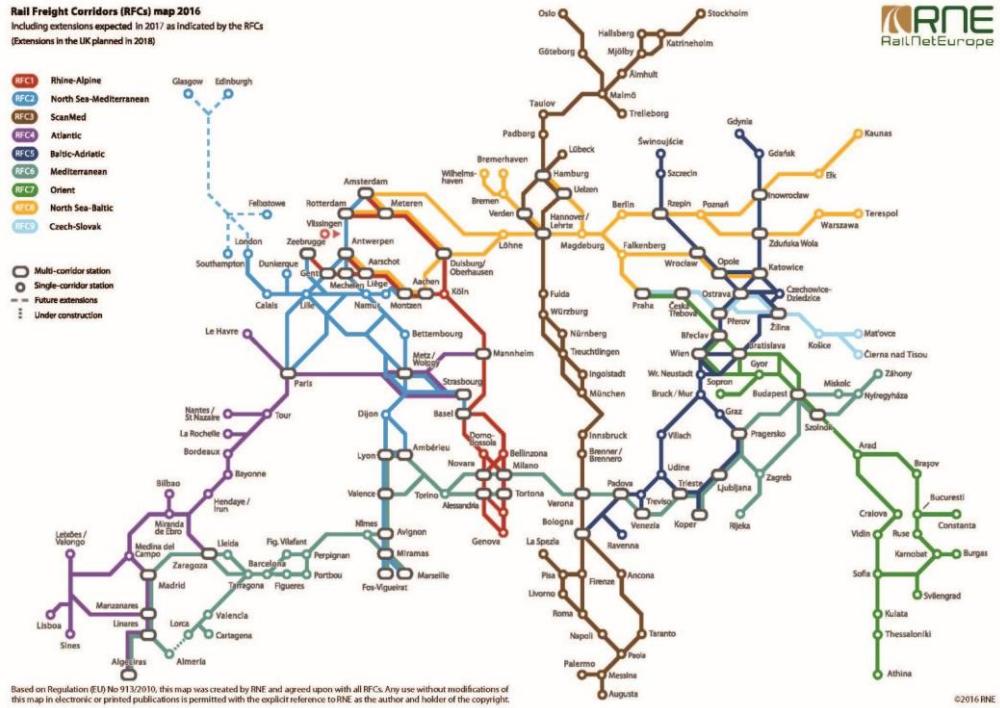


Fig. 1 - European corridors for rail freight - source: <http://www.rne.eu/rail-freight-corridors/>

The paper demonstrates that the way in which compression is achieved is not unique, at least when there are freight trains in the mix of trains, opening up a real perspectives for an in-depth analysis of the interaction in graphic between different category trains, different priority levels, and the determining of the effects of this interaction in terms of the capacity utilization.

2. Concepts and definitions

2.1. Definitions of capacity

Although they find a common denominator, the schools that were focused on the capacity phenomena have proposed definitions which reveal the relativity of each formulation, fact which confirms the particular or contextual character of the methods of calculation capacity resulting from them.

Russian classics in the field of traffic capacity, FP Kocinev et al [2] states: **Circulation capacity** of a railway line represents the maximum volume of traffic (in trains or wagons), which can be performed on this line during a certain specified period (operational day or hour) according to existing fixed installations (stationary), the type and power traction and the wagons type and the organization of traffic (graphic type).

Harald Krueger in [8] proposes another approach, its definition being as follows:

Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan.

Bergman Dietrich [9] defines capacity as follows:

Capacity is given by the minimum size of the window of time that can accommodate practically a number of trains on a particular section of the network.

From the perspective of UIC [6]:

A unique, true definition of capacity is impossible.

[...] there are different views of capacity. Because of these differences and given the various consequences of capacity-relevant constraints, a generally applicable definition is not appropriate.

Thus, the definition presented below [...] is supposed to work for as broad a spectrum as possible.

The capacity of any railway infrastructure is:

- the total number of possible paths in a defined time window, considering the actual path mix or known developments respectively and the IM's own assumptions;
- in nodes, individual lines or part of the network;
- with market-oriented quality.

This must also take account of the IM's own requirements.

Due to space constraints this list of definitions is far from exhaustive, but nevertheless gives an overview on the complexity of the subject.

2.2. *Types of capacity*

If we analyze just some of the capacity definitions, we would deduce that it is necessary to talk about a typology of railway capacity. In [7] there is a synthesis of perspectives offered by Western European specialized literature on capacity typology.

According to [4], [6], [7], it could be differentiated into:

Theoretical capacity: It is the number of trains that could run over a route, during a specific time interval, in a strictly perfect, mathematically generated environment, with the trains running permanently and ideally at minimum headway (i.e. temporal interval between two consecutive trains). Frequently, it assumes that traffic is homogeneous and that all trains are identical. It is an upper limit for line capacity. In the Eastern European literature [1], [2], [3], [5], it is called capacity in a parallel graphic.

Practical capacity: It is the practical limit of “representative” traffic volume that can be moved on a line at a reasonable level of reliability. The “representative” traffic reflects the actual train mix, priorities, traffic bunching,

etc. If the theoretical capacity represents the upper theoretical bound, the practical capacity represents a more realistic measure. Thus, practical capacity is calculated under more realistic assumptions, which are related to the level of expected operating quality and system reliability, as shown in Fig. 2. It is the capacity that can permanently be provided under normal operating conditions. It is usually around 60–75% of the theoretical capacity, which has already been concluded by Kraft in 1982 [12]. Practical Capacity is the most significant measure of track capacity since it relates the ability of a specific combination of infrastructure, traffic, and operations to move the most volume within an expected service level.

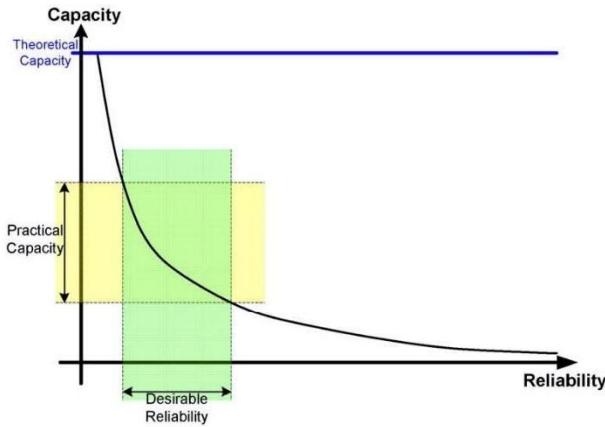


Fig. 2 – Practical capacity involves the desirable reliability level [7]

Used capacity: It is the actual traffic volume occurring over the network. It reflects actual traffic and operations that occur on the line. It is usually lower than the practical capacity.

Available capacity: It is the difference between the Used Capacity and the Practical Capacity. It is an indication of the additional traffic volume that could be handled in the route. If it allows new trains to be added, it is a useful capacity; otherwise, it is *lost capacity*.

Eastern Europe's perspective is synthesized, mainly in [1]. Thus, it could be differentiated:

The existing capacity is determined depending on the existing technical equipment of the section and the adopted method for the organization of train traffic.

The Possible capacity (or the projected capacity), is calculated based on the projected equipment of the section, and traffic organization.

The necessary capacity is calculated based on the estimated volume of transport and must satisfy the circulation of an expected number of trains, estimated for that section, taking into account a given tonnage of the trains and the necessary reserve.

The reserve of circulation capacity is not determined by regulations but is recommended to be on double lines around 15%-20% and on simple lines around 25%-35%.

The circulation capacity could be calculated for the entire line or section, or separately, for stations and circulation distances.

2.3. Additional definitions

Corridor All possible journey routes (main route or alternative routes), according to market needs, between a defined source and target [6].

Route: Consecutive lines and nodes as a whole, between a defined source and target [6].

Line: A link between two large nodes and usually the sum of more than one line section [6].

Nodes: Points of a network in which at least two lines converge. Nodes can be stations or junctions. They can be differently-sized, depending on the number of converging lines and their tasks [6].

. **Stations:** Points of a network where overtaking, crossing or direction reversals are possible, including marshalling yards [6].

Line sections: The part of a line, in which the traffic mix and/or the number of trains and the infrastructure and signaling conditions do not change fundamentally. It consists of one or more coherent sections, which are limited by two neighboring stations or nodes. [6].

Relevant block section: Block section within the chosen line section, which determines the minimum headway along the entire chosen line section [6].

Station interval: The section determined by two consecutive stations.

The circulation distance: The part of the railway where a single train is permitted to circulate [11]. The circulation distance is limited by two sectioning points. Thus it can be a station interval, a block sector (section) or an interval of motion post.

The sectioning point: A facility consisting of some lines, buildings and devices, or parts of installations (fixed block signals) that determine circulation capacity; two sectioning points define the distance on which there must not be more than one train. [10]

3. Calculation methods of capacity

We will mainly treat the case of circulation capacity on double track lines with block signals.

5.1. An Eastern European method

The first step is to determine the capacity on a **parallel graph** for the chosen section [1].

The parallel graph of the section is made up of train paths of the same category, which circulate in the same speed system, at minimum headway, and is characterized by the fact that it depends on the organization of the train traffic (type of graph) being obtained by multiplying of an identical sequence of trains paths, called **the period of the graph**.

When forming the parallel graph the category of train that is chosen is considered to be preponderant on the analyzed section. The type of the chosen train for the construction of the parallel graph will provide the measuring unit of the capacity. Another criterion when choosing the train type for the parallel graph is bound to the stated purpose of the line. For example, in the Romanian part of Corridor 4, Curtici-Brasov-Bucharest-Constanta, being part of the European network for competitive freight transport, even if freight trains are not prevalent now, there are important reasons to measure circulation capacity in such trains.

The circulation capacity of the section into parallel graph is the maximum number of trains which could run during a certain time in terms taking into account a specific type of adopted parallel graph. Capacity in parallel chart is corresponding to *theoretical capacity* described in Chapter 3 (the number of trains that could run over a route, during a specific time interval, in a strictly perfect, mathematically generated environment, with the trains running permanently and ideally at minimum headway (i.e. temporal interval between two consecutive trains) [7]).

To determine the capacity in parallel graph for a line with double track and block signals, first, we have to determine **the limiting block sector** (according [6] - **relevant block section**).

The limiting block sector is the block section of the selected line that determines the minimum interval between two trains along the entire section [6]. The limiting block sector is the sector where **the minimum interval between trains (I)**, compared with other block sectors, has the highest value.

The capacity in a parallel graph (maximum) for one direction, by double track, is calculated using the formula [1]:

$$N = \frac{1440}{I} \text{ [trenuri]} \quad (1)$$

In case of a non-parallel graph, trains have different movement speeds (Fig. 3b), unlike the parallel graph where all trains are considered having the same speed (Fig. 3a).

In case of a non-parallel graph, there are many categories of trains that circulate and they are differentiated by speed and priority level. Circulation capacity is expressed in trains from the preponderant category.

The time window which cannot be used for preponderant trains because of the circulation of other types of trains, is called **reduction time of the preponderant trains by the train from the minority category**.

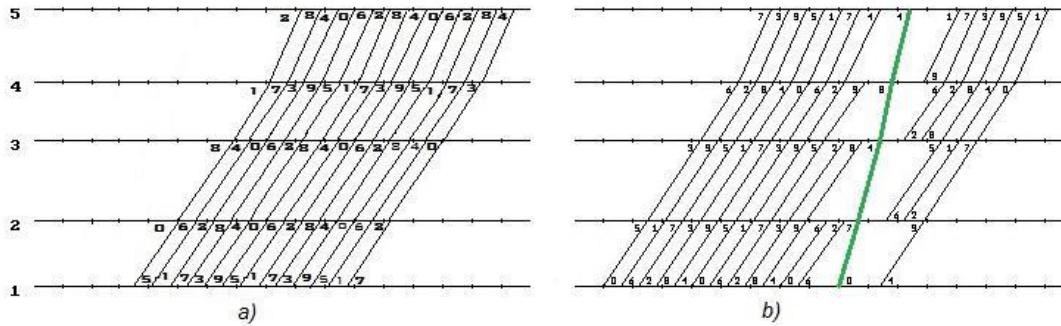


Fig. 3 – Graphic types: parallel and non-parallel - *source: Author*

The size of this time window depends on the ratio of speeds of the trains from different categories, by the place in graph where the minoritar train is drawn, dimensions of the circulation distances and the type of adopted graph.

The reduction time contain two parts:

- the infrastructure occupancy time by the minority train;
- unused time for preponderant train circulation due to the fact that the interval between minority trains is not a multiple of the graphic period, called additional time reduction.

The circulation capacity on double track, in case of a non-parallel timetable is determined by the relation:

$$N_p = N - \sum_{i=1}^n e_{np}^i N_{np}^i \quad (2)$$

where:

N_p capacity expressed in the number of trains from the preponderate category that can run in the chosen time period;

N capacity in a parallel graph;

e_{np}^i reduction coefficients corresponding to different categories of non-preponderant (np) trains; It is also called coefficient of equivalence of a train from minority category in trains from the preponderance category;

N_{np}^i number of non-preponderant trains from category i which are equated in preponderant category trains through the coefficient e_{np}^i .

The stages of the capacity calculation according to Eastern European perspective is shown schematically in Fig. 4.

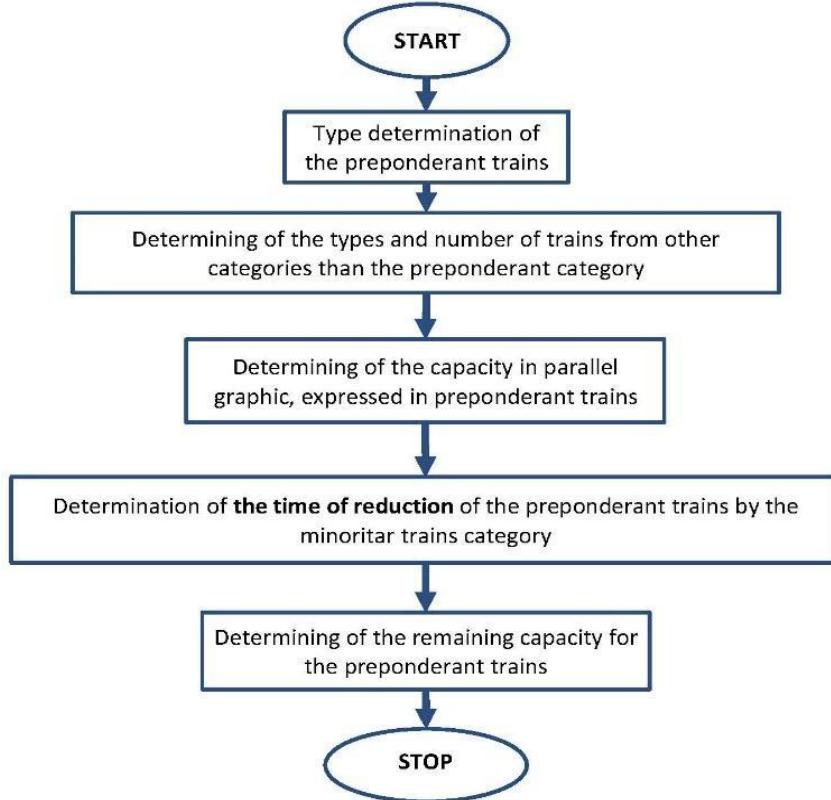


Fig. 4 – The steps of the capacity calculation - Eastern European model - *source: Author*

5.2. A Western European method

The calculation method, described in [6], starts from the acceptance of the following fact: railway infrastructure capacity depends on how it is used, the capacity consumption is the only value that can be measured objectively, the capacity itself being immeasurable.

Therefore, the methodology is based on an examination of the existing timetable, which reflects market needs in terms of the trains operating using a specific infrastructure. This timetable, which expresses market needs, considers only scheduled trains and trains with high probability to circulate. The analysis is done on a *section of line* by compressing of the train paths in a predefined time window. During this compression, we take into account not only the paths, but any other time of occupancy, even if they have no connection with the paths.

The effects of compression on the adjacent line sections are not taken into account. This is acceptable, because the analysis must be performed for the limiting section line and any conclusions on the feasibility timetable for neighboring sections of line will not be drawn from this analysis.

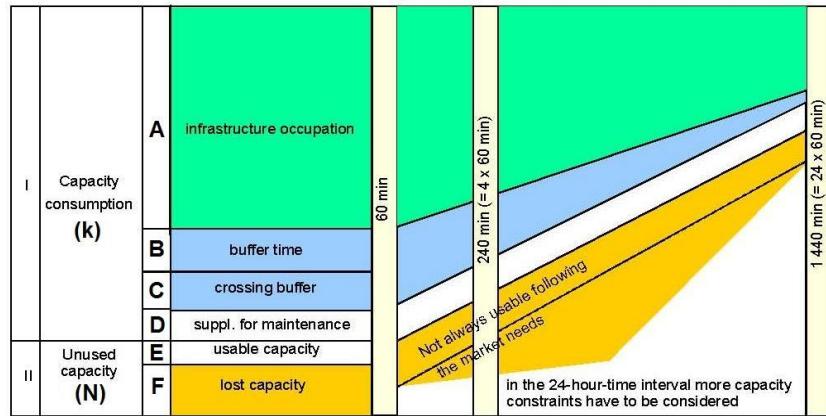


Fig. 5 – Determination of capacity consumption - source:[6]

The result of the compression process is the so-called **infrastructure occupation**. Capacity consumption will be measured depending on the infrastructure occupation, with the addition of **buffer times** for stability of timetable and, if necessary, the addition of the required afferent maintenance times.

If the infrastructure occupation level is greater than a established specific value, the infrastructure will be declared congested. If this specific value is not reached, a rest of capacity will become available. How the **unused capacity** can be used for additional paths will be established in each case, depending on market needs.

The methodology for determining the **capacity consumption** is based on the formula (3) that describes mathematically Fig. 5.

$$k = A + B + C + D \quad (3)$$

where:

- k: *Capacity consumption* [min] – shall be measured by infrastructure occupation, resulted from the compression of paths in the defined time window, to which is added time supplements for timetable stabilization and, where necessary, maintenance requirements; represents total time consumed.
- A: *Infrastructure occupation* [min] - shall be the result of the compression process and shall be measured at the beginning of the first block section within the line section
- B: *Buffer time* [min] – with role in ensuring of the timetable stability
- C: *Supplement for single-track lines* [min]- buffer time for crossing
- D: *Supplements for maintenance* [min] - may either be part of infrastructure occupation (A) or may be shown as an additional supplement. It shall be part of capacity consumption.

K: *Capacity consumption [%]* ; $K = k \cdot 100 / U$. It is another way for the expression of capacity consumption.

U: *Chosen time window [min]* – the chosen time interval to do the capacity analysis.

N *Unused capacity [min]* - The difference between capacity consumption and chosen time-window; $N = U - k$. The amount of unused capacity is determined by the possibly "usable capacity" and "lost capacity".

E *Usable capacity [min]* shall exist if unused capacity can possibly be used for additional train paths, providing they meet the customer requirements (typical characteristics of the paths) for the area considered. The additional train paths shall be incorporated into the original timetable before compression.

Afterwards, a new analysis of capacity consumption is necessary.

F *Lost capacity [min]* - Ultimately, there will come a time when no further train paths can be added. This time shall be called "lost capacity".

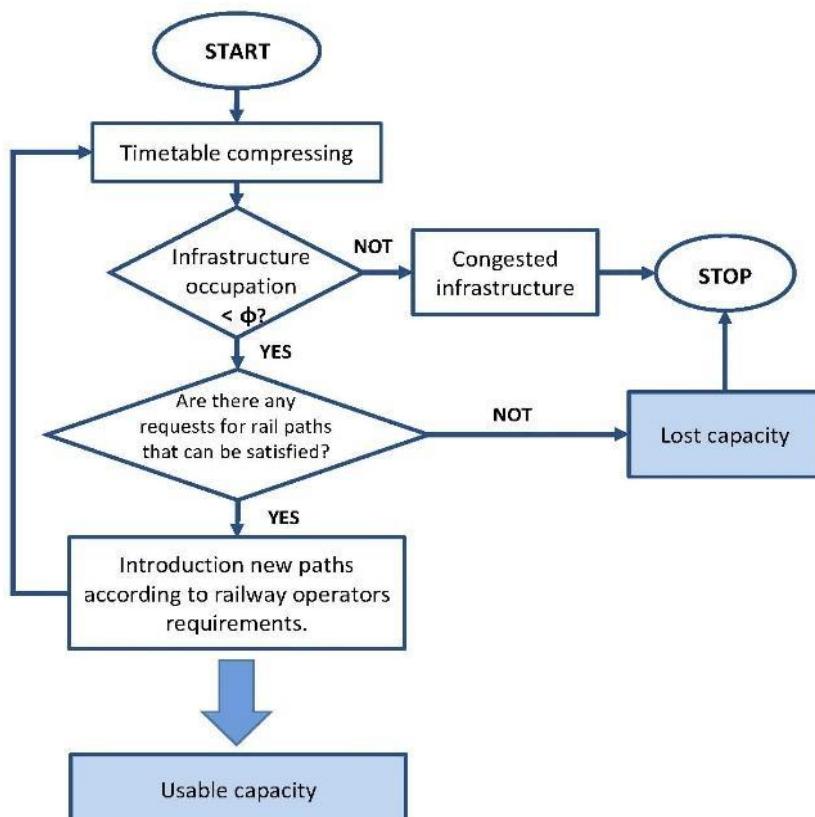


Fig. 6 – The steps of the capacity calculation – Western European method - source: Author

The capacity consumption analysis is done in the steps corresponding to the diagram presented in Fig. 6.

The major difference between these two methods consist of the measurement units which are allocated for capacity. If in the first described method, capacity is expressed in trains during a certain time interval, in the second, the measurement unit of capacity is a unit of time (the minute).

Let's analyze the aspects which approach these two calculation methods.

3.3. Compatibility elements between these two methods

Suppose we have a line section consisting of 10 stations and we set a time window, as is shown in **Fig. 7**, where the paths of 14 trains are drawn. One of them is higher rank (for example, a passenger train) running with high speed and 13 trains with lower priority (freight trains) running with equal but smaller speed. We analyze the situation of double track lines and automatic block system, so unidirectional traffic.

The elements which are used for drawing the traffic diagram are:

$I = 6 \text{ min}$ the minimum headway between two low priority trains;

$I_s = 5 \text{ min}$ the minimum arrival headway between two different and successive trains

$I_e = 5 \text{ min}$ the minimum departure headway between two different and successive trains

$t_{dc} = 1 \text{ min}$ starting additional time for passenger trains

$t_{fc} = 1 \text{ min}$ braking additional time for passenger trains

$t_{dm} = 1 \text{ min}$ starting additional time for freight trains

$t_{fm} = 1 \text{ min}$ braking additional time for freight trains

Running times between two railway stations when both stations are transited without stops for freight trains, r_j are:

$$r_1 = 14 \text{ min} \quad r_4 = 11 \text{ min} \quad r_6 = 16 \text{ min} \quad r_8 = 12 \text{ min}$$

$$r_2 = 18 \text{ min} \quad r_5 = 14 \text{ min} \quad r_7 = 13 \text{ min} \quad r_9 = 16 \text{ min}$$

$$r_3 = 13 \text{ min}$$

Running times between two railway stations when both stations are transited without stops for passenger trains, t_j are:

$$t_1 = 6 \text{ min} \quad t_4 = 5 \text{ min} \quad t_6 = 6 \text{ min} \quad t_8 = 7 \text{ min}$$

$$t_2 = 5 \text{ min} \quad t_5 = 7 \text{ min} \quad t_7 = 4 \text{ min} \quad t_9 = 6 \text{ min}$$

$$t_3 = 7 \text{ min}$$

The question is to compress the graph shown in Fig. 7. The chosen time window is $U = 270 \text{ minutes}$, measured from the moment of the departure of freight train No 1 from station No 1 and the moment of the departure of freight train No 13 from station No 1 (Fig. 7).

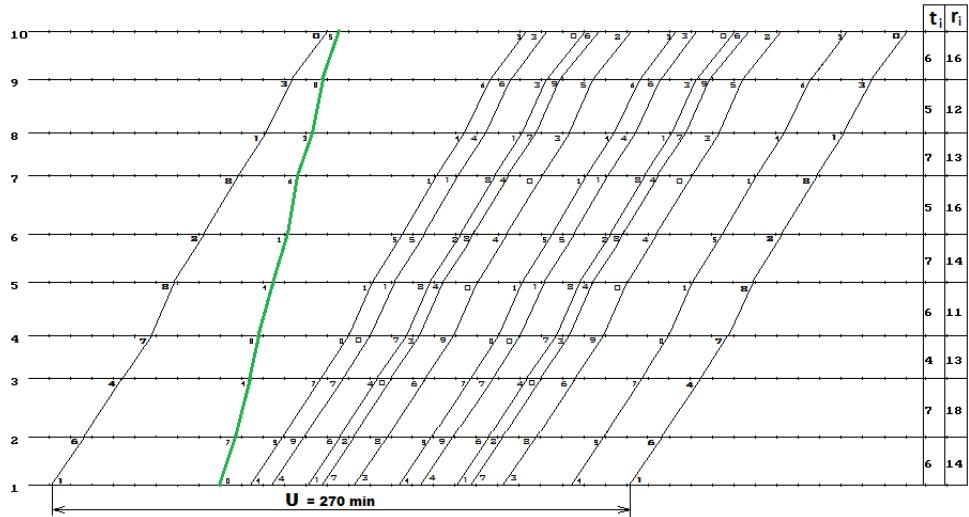


Fig. 7 – Uncompressed graphic, with two categories of trains - source: Author

Compression rules stipulated in [6] provide that:

- ✓ all single train paths are pushed together up to the minimum theoretical headway according to their timetable order, without recommending any buffer time;
- ✓ during the compression process, neither the timetable running times, nor the given overtaking, crossings or stopping times (which are requested by railway undertakings), may be changed;
- ✓ this compression can be done: by constructing graphical analysis or suitable tools for this case or by analytical calculation.

One form of compression is shown in **Fig. 8**. The following changes were made:

- ✓ passenger train kept the same path;
- ✓ the path of the freight train no 1 remained unchanged because it arrived in station no 10 with 5 minutes (the minimum value of the arrival headway, I_s) before the arrival of the passengers train;
- ✓ freight train no. 2 was dispatched from station no. 1 earlier at an interval $I_e = 5 \text{ min}$ after the passenger train. Other freight trains (3-13) are circulating together, at minimum headway after freight train no. 2.

According to UIC notations, specified in [6], *Infrastructure occupation* A_1 is 150 minutes while *the unoccupied remained time* (W_1) after compression is $U - A_1 = 120 \text{ minutes}$.

The unoccupied remained time, W_1 , from time window U , contain the following components:

- B *buffer time for existing trains;*
- D *supplements for maintenance;*
- N₁ *unused time which remains for additional train path.*

The total buffer times, B, for existing trains and supplements for maintenance, related to time window U are constant values, while N may be different depending on how the compression is done.

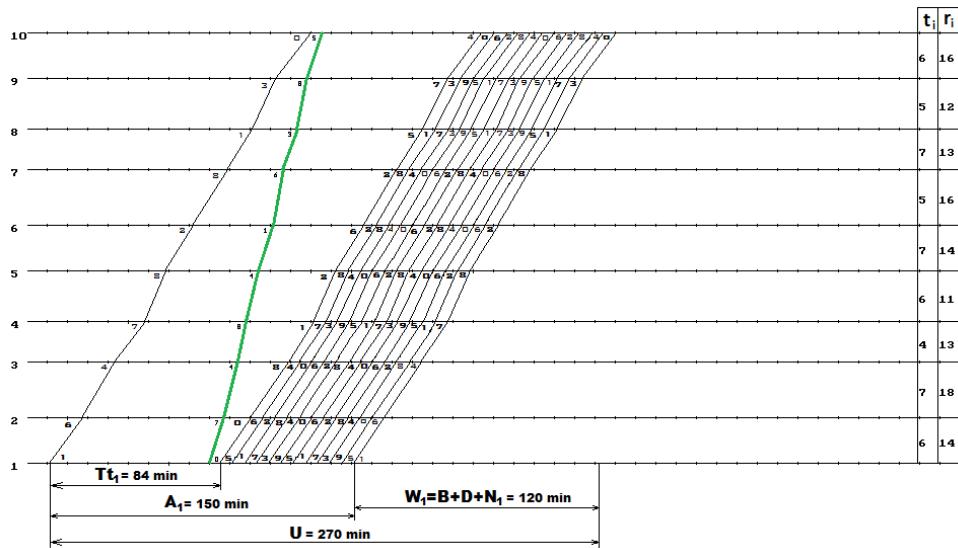


Fig. 8 – Compressed graphic, without overtaking - source: Author

In Fig. 8 the time interval is also specified *Tt*, *time of reduction*, taken from Eastern European literature [1] that represents the time interval that cannot be occupied by predominant trains taking into account the presence of the high speed train. This interval, *Tt* is the basis for the calculation of the *reduction coefficient* of the minority train, *e*, representing practically the number of trains from the parallel graph that are removed by one train from minority category. The formula of the reduction coefficient, is:

$$e = \frac{Tt - I}{I} \quad (4)$$

In Fig. 8, $e_1 = (84 - 6)/6 = 13$. Thus, if instead of high speed train we would introduce freight trains, it could run other 13 trains.

It is justified to wonder if in Fig. 8 there is a maximum compression. If the intermediate stations allow overtaking, then that is not maximal compression.

If we assume that in station 6 overtaking can be done, compressing would lead to the configuration of Fig. 9.

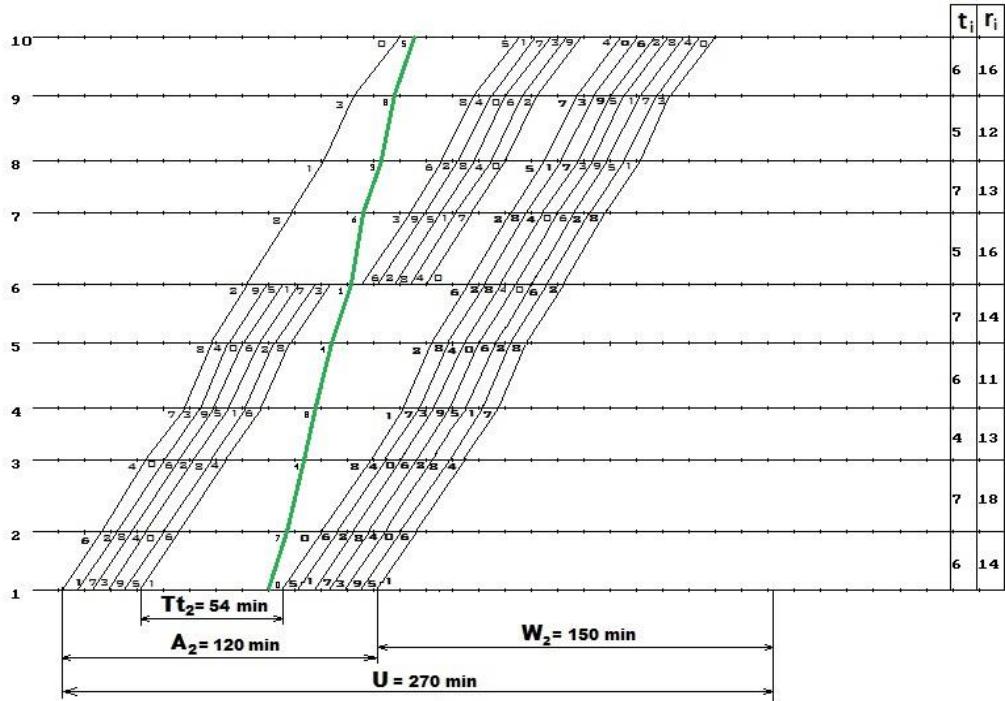


Fig. 9 – Compressed graphic, with overtaking in a single railway station - source: Author

In this situation (Fig. 9) we have:

Infrastructure occupation	$A_2 = 120 \text{ min}$
Unoccupied remained time	$W_2 = 150 \text{ min}$
Time of reduction	$Tt_2 = 54 \text{ min}$
Reduction coefficient	$e_2 = 8$

What will be the situation when overtaking can be done in all of the intermediate stations? After the compression process it results the configuration of **Fig. 10**.

From Fig. 10 results:

Infrastructure occupation	$A_3 = 93 \text{ min}$
Unoccupied remained time	$W_3 = 177 \text{ min}$
Time of reduction	$Tt_3 = 27 \text{ min}$
Reduction coefficient	$e_3 = 3,5$

By analyzing Fig. 8-10 we can easily see that we can get a maximum available time for the introduction of new trains (W) when it is possible to have overtaking in all intermediate stations (Fig. 10). Also the time of reduction (Tt) is

minimum when W is maximum. The relationship between W and Tt is

$$W = U - (n-2)I - Tt, \quad (5)$$

where n is the number of low speed trains, with lower priority (here, freight trains)

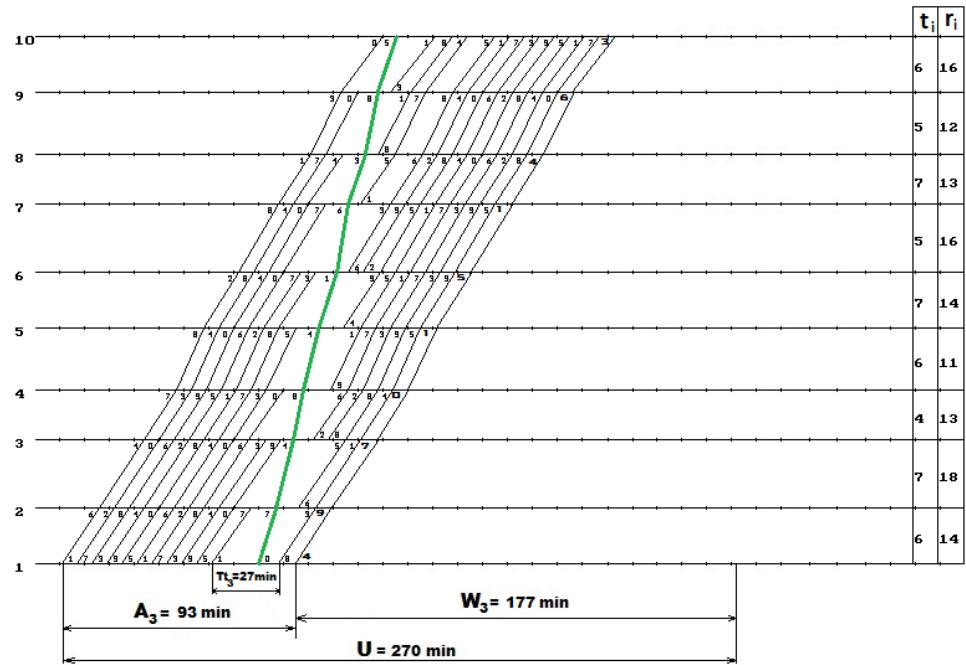


Fig. 10 – Compressed graphic, with overtaking in all railway stations - source: Author

In the already described context, we know that $U - (n-2)I = 270 - (13-2) \cdot 6 = 204 \text{ minutes}$ and it is a constant. So, the *unoccupied remained time* (W) depends directly on the *time of reduction* (Tt). W is maximum when Tt is minimal.

4. Conclusions

It may be objected that the compression did not fulfill one of the rules specified in [6] that the train paths were not approached, respecting the same initial order.

Indeed some of the freight trains paths, are dispatched from station 1 before the passenger train (Fig. 9, Fig. 10) but they reach the destination after it, being overtaken on the way. The model is realistic because for freight trains the moments of entering on the section in question and the fact that some stops are necessary for overtaking are less important, compared with the advantages resulted from the obtaining of additional capacity available.

Infrastructure occupation, A, decreases from 150 min in Fig. 8 to 93 min in Fig. 10 (38% reduction), because the *time of reduction, Tt*, decreased with the same number of minutes (57).

In this place, the Eastern European perspective which studies the *reduction of time, Tt*, and the *reduction coefficient, e*, as an expression of the equivalence between predominant trains and other category trains, meets the Western European perspective materialized in UIC 406/2004 because:

- ✓ *Time of reduction, Tt* is determined following analysis of the conflict" between a predominant category of trains that run according to a parallel graphic, with the trains circulating at the minimum headway (so, a compressed graph), and one train from another category, for whose introduction in timetable is necessary the elimination of some trains from the preponderate category.
- ✓ *Infrastructure occupation, A*, determined on the base of the timetable compression can be determined depending on *Tt*:
- ✓

$$A = (n-2)I + Tt \quad (6)$$

However, it is true that determining the time reduction *Tt* is done on the base of a particular case of compression, that is when in the compressed graph window exist only two categories of trains.

Analyzing this type of conflict, when two categories of trains are the passengers trains with superior speed and the freight trains with lower speed, it is entirely legitimate on the established corridors as dedicated to the competitive freight traffic where, in fact, have to be solved the thorny issue of mixed traffic where the passenger trains have high priority.

In line with the definition given by Dietrich Bergman [9] (**Capacity is the minimum cycle length that can feasibly accommodate a given number of trains over a given section of track in each cycle**) we have the following questions:

- Does Fig. 10 offer the configuration in which compression is the highest?
- What is the minimum time interval that could accommodate the trains represented in Fig. 7?
- What would be the maximum value of traffic that can be reached on a given infrastructure, in the conditions of a particular mix of traffic?
- To what extent this maximum can be achieved and which is the optimum level that can be achieved in operational conditions?

In this chapter we can answer the first question, the remaining 3 questions will receive answers in future studies.

In the analyzed example in Fig. 8-10, the maximum traffic value is reached when those trains would require a minimum occupancy of the line, $A = \text{minimum}$, respectively $Tt = \text{minimum}$.

It can be observed that in Fig. 10 the time of reduction is less than in previous situations and corresponds to the case when the overtakings were all done in intermediate stations. However, can we state that Tt is minimal?

Let's analyze Fig. 11. It can be observed that the reduction of time Tt_4 is smaller than Tt_3 . From this it follows that in the analyzed situation, the compressed graph can take many forms leading to different values of the *infrastructure occupation*, A , *time of reduction*, Tt , respectively *the reduction coefficient*, e .

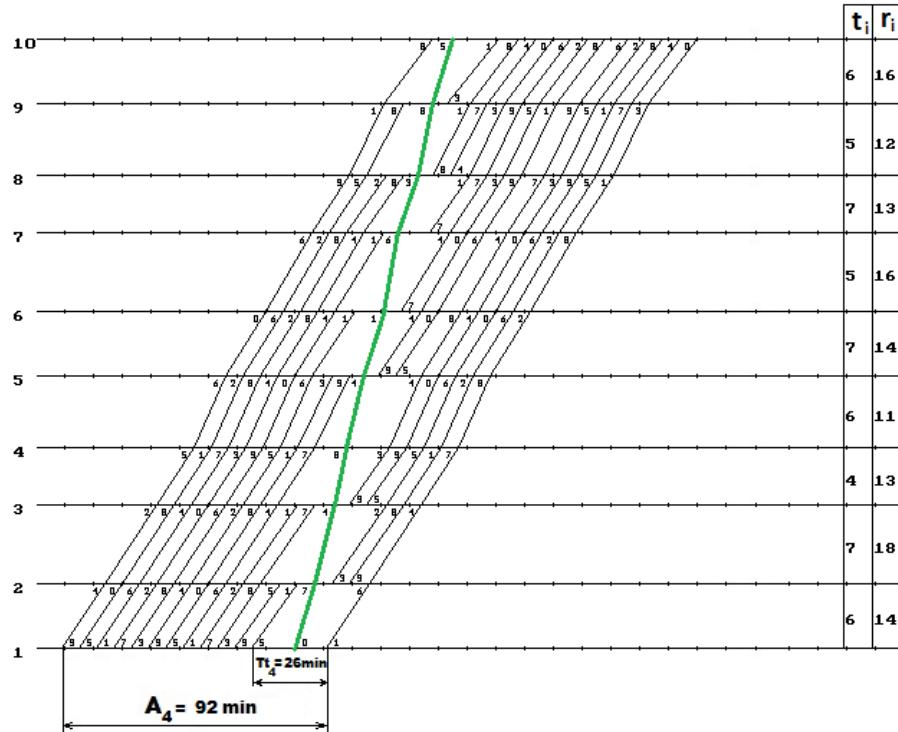


Fig. 11 – Compressed graphic, with overtaking in all railway stations, another form

The undertaken analysis leads us to the idea that the concept of compression of paths is not benefiting from sufficient clarity, so it is necessary to continue and deepen the analysis of this concept and its implications which the complex interaction between different typologies of trains generates related to use of traffic capacity.

R E F E R E N C E S

- [1]. *Paul Francu, Serban Raicu*, Capacitatea de circulatie a caii ferate (statii, sectii si alte compartimente) (Circulation capacity of the railway (stations, sections and other compartments)), Institutul Politehnic Bucuresti, Facultatea Transporturi, 1986.
- [2]. *FP Kocinev s.a.*, Organizarea circulatiei la caile ferate (Organisation of the circulation on the railways), Ministerul Cailor Ferate, Centrul de Documentare si Publicatii Tehnice, 1969.
- [3]. *FP Kocinev s.a.*, Probleme de organizare a circulatiei trenurilor (Problems of train traffic organizing), Editura Transporturilor si Telecomunicatiilor, 1963.
- [4]. *Thomas Albrecht s.a.*, Railway timetable & Traffic, Eurailpress, 2008.
- [5]. *Instructiunea Nr. 115*, Instrucțiuni pentru calculul capacitații stațiilor și secțiilor de circulație (Instructions for calculation of capacity of stations and circulation sections), Ministerul Transporturilor, Autoritatea Feroviara Romana, Anexa la OMT 1002/2000.
- [6]. Leaflet UIC code 406, Capacity, International Union of Railways (UIC), Volume IV – Operating, 2004.
- [7]. *M. Abril, F. Barber, L. Ingolotti, M.A. Salido, P. Tormos, A. Lova*, An assessment of railway capacity, 2008.
- [8]. *Krueger, H.*, Parametric modelling in rail capacity planning. In: Proceedings of the 1999 Winter Simulation Conference, pp. 1194, 2000.
- [9]. *Bergmann, D. R.*, Integer programming formulation for deriving minimum dispatch intervals on a guideway accommodating through and local public transportation services, Transportation Planning and Technology, 3, 27–30, 1975.
- [10]. Regulament pentru circulatia trenurilor si manevra vehiculelor feroviare Nr. 005 (Regulation for trains circulation and shunting of railway vehicles, Nr. 005), aprobat prin OM nr 1816 din 26.10.2005.
- [11]. *Constantin Tomescu*, Exploatarea tehnica a retelei feroviare (Technical exploitation of the railway network), Editura Didactica si Pedagogica, 1966.
- [12]. *E.R. Kraft*, Jam capacity of single track rail lines. Proceedings of the Transportation Research Forum, 23 (1), 461–471 - 1982.
- [13]. Regulation (EU) No 913/2010 of the European Parliament and of the Council of 22 September 2010 concerning a European rail network for competitive freight, Official Journal of the European Union, 2010.

- [14]. *Egmond, R.J. van.*, Railway Capacity Assessment, an Algebraic Approach, TRAIL Studies in Transportation Science, S99/2, Delf University Press, 1999.
- [15]. *Forsgren, M.*, Computation of Capacity on Railway Networks, Technical Report T2003-12, Swedish Institute of Computer Science - 2003.
- [16]. *Petersen, E.*, Over-the-road transit time for a single track railway, Transportation Science 8, 65–74 - 1974.