

## **TIMETABLE COMPRESSION CONSISTING OF TWO CATEGORIES OF TRAINS, WHEN THE FREIGHT TRAINS ARE PREPONDERANT, ON DOUBLE TRACK LINES, EQUIPPED WITH BLOCK SYSTEM**

Amedeo NECULCEA

*The European Union defined the rail freight corridors, intending to create favorable conditions for the movement of goods. In the common situation in which freight trains do not run on a dedicated infrastructure, they have to meet the rigors of a mixed traffic so it is necessary to judiciously manage the existing capacity.*

*If you insert one passenger train with higher speed and priority into a parallel graph formed of freight trains the resulted perturbation will not take a unique form. Depending of the relative position in the graph of these two types of paths, it will result in different levels of infrastructure occupation.*

*This paper presents a method of determining all forms of interaction between one high speed train and freight trains which run on a parallel graphic.*

*This results in a family of path configurations, different values of the indicators showing the degree of timetable compression corresponding to each of them.*

*Determination of all possible forms of graphic interaction between two categories of trains, with the related capacity phenomena, represents a first step towards a type of analysis that will be the base for the elaboration of certain new analytical tools, useful in optimal drawing and timetable evaluating.*

**Keywords:** capacity; mixed traffic; compressed timetable; family of configurations; family of reduction coefficients; maximum compression

### **1. Introduction**

The rising level of globalization and the economic specialization of countries or regions, inexorably lead to increased transportation needs and consequently, to the raising of fluxes of goods and passengers.

Each means of transport configures its offer depending on the concrete circumstances of the infrastructure and the capacity of the means of transport.

When it comes to railway transport, the dependence between infrastructure and vehicle (track, block system, electric system - wagon, locomotive, train) is higher than in other means of transport (road, water). Therefore joint development strategies of transport capacities should be considered, especially now, when the decisions for development of these two essential components of the railway system, are made in different places.

Regulation (EU) No 913/2010 concerning a European rail network for competitive freight [1] - aims to improve the conditions of the freight rail, providing adequate capacity for it, in accordance with market needs and adopting some

common targets for punctuality for freight trains to be achieved, at least on a part of the European rail network.

Although after 1990, the decrease of rail traffic in Romania and other eastern European countries was substantial and apparently, the capacity of the network was not diminished, unfortunately sections of the railway network where saturation phenomena are recorded still exist, at least at certain times of the year, freight transport being affected the worst.

An in-depth analysis of the capacity phenomena in the compressed graphs, in which two types of trains are put in "conflict", of which one is the object of the Regulation (EU) No 913/2010 [1], the freight train, could lead to interesting conclusions regarding the organization of traffic and the configuration of the network.

This paper is in the category of studies on the impact of the traffic heterogeneity on the railway capacity. One of the ways followed in such analysis was to determine a standard unit of capacity in which several types of trains are converted. Thus, the capacity used by the operating of a particular train type is adjusted, being expressed by means of a coefficient, in the standard capacity measurement unit [2-9].

In order to transform several types of trains into a standard unit, in [10] the concept of base train equivalents (BTE) is proposed, which is determined using the ratio between the impact on the capacity of a "base train" and the impact on the capacity of another train type. This ratio, known as a reduction coefficient, deduction coefficient or equivalence coefficient, used as the base train, in the older studies ([2-5]), the freight train.

In all cases, capacity analysis based on train equivalence in a standard unit are based on the determination of minimum headway between trains, this concept being studied in [2-5], [11-20].

Starting from the findings made in [21] that the timetable interaction between a higher speed and priority train and the base trains consisting of low priority and lower speed trains (the parallel graphic), may take several forms, the present paper proposes a method by which all forms of such interaction can be determined, with the related effects in terms of infrastructure occupation and the value of the reduction coefficient. On this way, the premises for an in depth analysis of the capacity "micro-phenomena" that occur in such situations, with specific mathematical tools, are created.

## 2. Problem formulation

In [21] it was shown that there is a link between the *infrastructure occupation*,  $A$  from [11] and the nature of the interaction between trains of different categories. If in a chosen time window,  $U$ , we have many freight trains and one

passenger train (Fig. 1), which circulate without stops on the section under discussion, depending on the way the graphic is compressed, may result a different level of the *infrastructure occupation*,  $A$ , (Fig. 2, Fig. 3, Fig 4). Between *infrastructure occupation* and *reduction time*,  $Tt$  from [5], there is the following mathematical relation [21]:

$$A = (n-2)I + Tt \quad (1)$$

where:

- A** *infrastructure occupation* [min] - is the result of the compression process and is measured at the beginning of the first block sector within a line section
- n** the number of freight trains from the chosen time window;
- I** *the minimum headway between two low priority trains* [min] – results from **the limiting block sector** [5] or, according [11] – **the relevant block section**. The limiting block sector is the sector where **the minimum interval between trains (I)**, has the highest value compared with other block sectors.
- Tt** *time of reduction*, [5] represents the time interval that cannot be occupied by predominant trains taking into account the presence of high speed trains. 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 the minority category. The formula of the reduction coefficient, is:

$$e = \frac{Tt - I}{I} \quad (2)$$

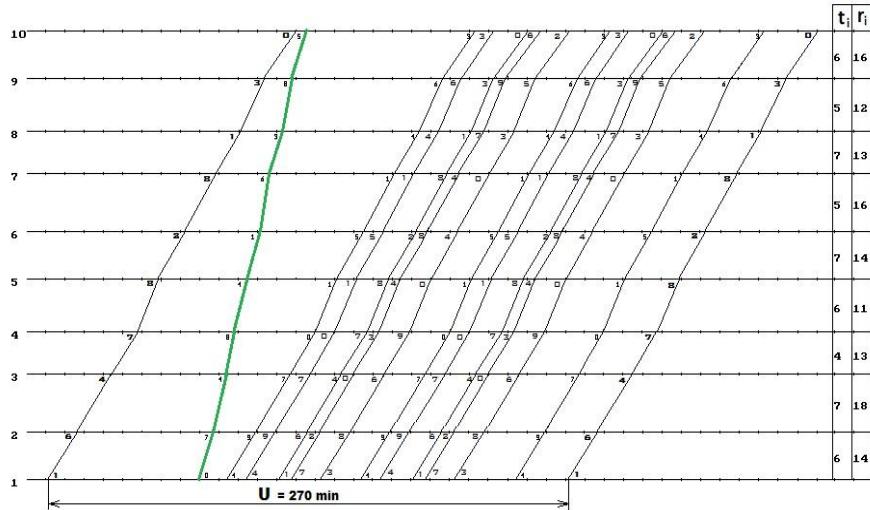


Fig. 1 – Uncompressed graphic, with two categories of trains

It has been noticed that  $Tt$  and implicitly  $A$  are changing according to the number of stations on the chosen section where the overtaking can be done [21]. It has also been observed that different values of  $Tt$  may occur if the interaction between different categories of trains differs, even if the stations in which the overtaking can be done are the same (see Fig. 3 and Fig. 4).

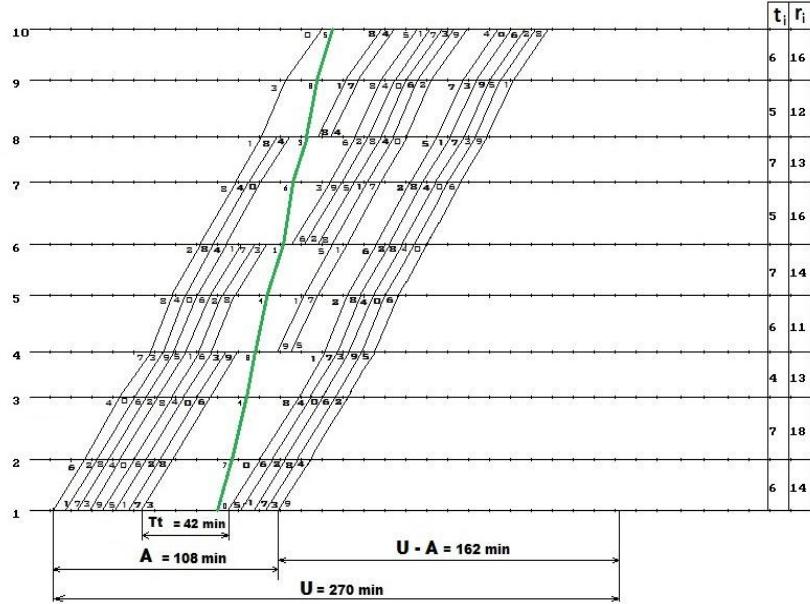


Fig. 2 – Compressed graphic, with overtaking in 3 railway stations

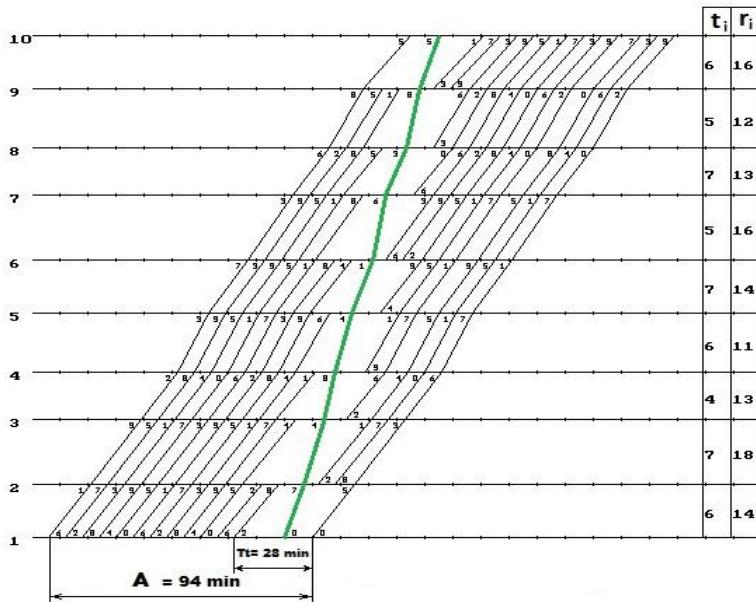


Fig. 3 – Compressed graphic, with overtaking in all railway stations

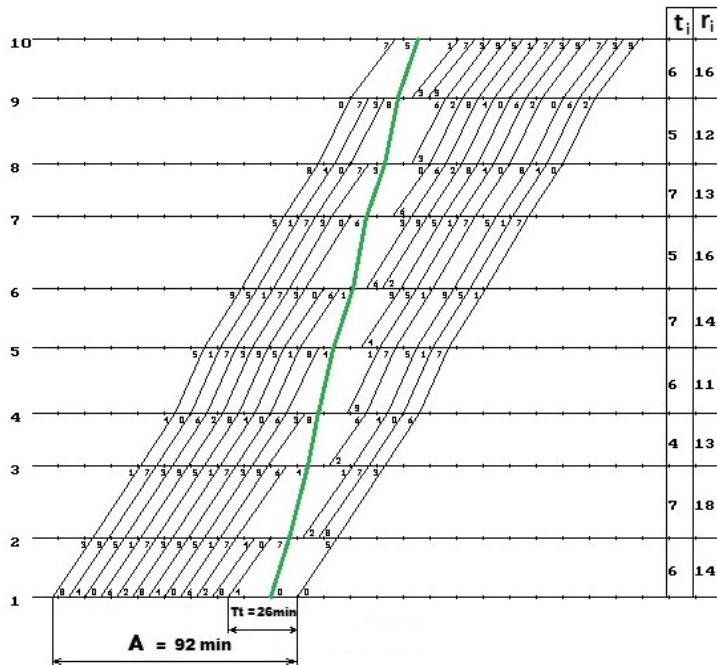


Fig. 4 – Compressed graphic, with overtaking in all railway stations, another form

Let's assume there is a parallel and compressed timetable consisting of freight trains - Fig. 5. If we want to introduce a high priority passenger train (Fig. 6), Infrastructure occupation,  $A$  will increase with a time interval  $Tt - I$ , as in Fig. 3 or Fig. 4. If this is not possible (there is not enough available capacity), then from the initial, parallel graph,  $e$ , freight trains will be suppressed to allow the circulation of the passenger train.

Analyzing Fig. 3 and Fig. 4 we deduct that  $Tt$  differs depending on the relative position of the passenger train path in relation to freight trains paths. In Fig. 3 the first freight train dispatch from the station no 1 precedes the dispatch of the passenger train from station nr 1 with 84 minutes, the rest of the freight trains are being sent from station no 1 at every minimum headway and stopped for overtaking in the most advanced stations possible. After the passenger train overtakes the stopped freight train, the freight train is dispatched as soon as possible. In Fig. 4 the dispatch of freight train 1 from station no 1 precedes the dispatch of the passenger train from station nr 1 with 81 minutes, the rest of the drawing rules being the same. The configuration resulted from Fig. 3 determines  $Tt = 28 \text{ min}$  and the configuration represented in Fig. 4 determines  $Tt = 26 \text{ min}$ , therefore the obtained compression is higher in the second situation.

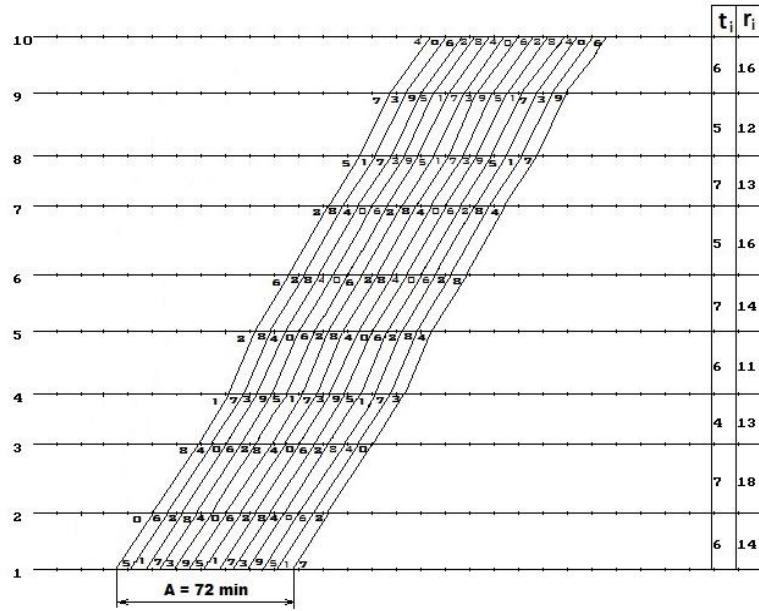


Fig. 5 – Parallel graphic with slow trains

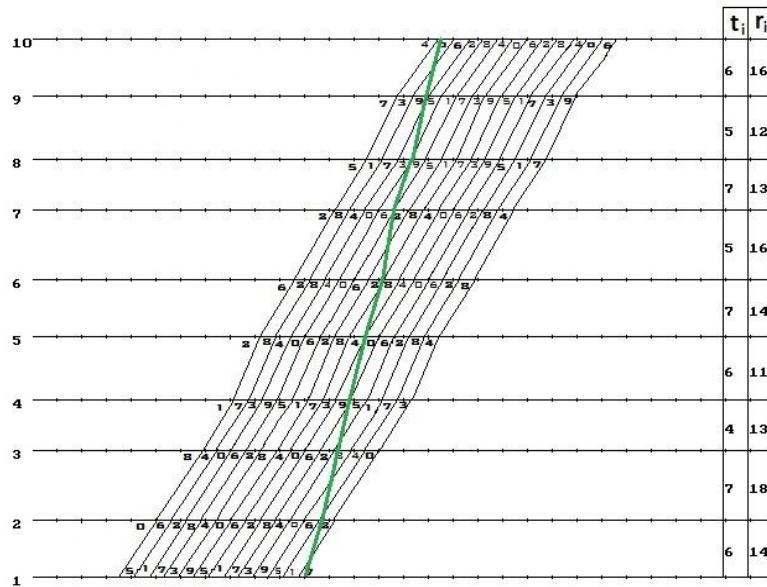


Fig. 6 – Parallel graphic in which will be introduced a train with higher speed and priority

### 3. Formalization

We plan to further formalize all the possibilities of interaction between these two categories of trains, the freight trains being the majority and the passenger train,

with higher speed, is going to circulate in relation to freight trains at different time intervals, so as to obtain all forms of interaction.

We will analyze a common situation in which the station intervals and running times are different. The hypothetical situation in which station intervals and, possibly, the related running times are identical, would probably offer multiple possibilities in terms of capacity optimization, but here we will focus on a case with no particularities, as often met in practice.

Let's consider a double-track line section with  $n$  stations ( $n-1$  station intervals) equipped with block system. The minimum headway for the preponderant trains is  $I$ , the arrival headways have the same value for each station,  $Is$ , and the departure headway have the value  $Ie$ , the same in all  $n$  stations.

The running times between two railway stations when both stations are transited without stops for freight trains, are  $r_j$ , and for passenger train are  $t_j$ , where  $j=1, \dots, n-1$ .

The passenger train has no stops in the stations that are inside of the section.

The starting additional time and the braking additional time for the passenger train are  $t_{dc}$  and respectively,  $t_{fc}$ , and for freight trains they are  $t_{dm}$  and  $t_{fm}$

We will note  $t_{dfm}$  and  $t_{dfc}$  the additional starting or braking times of the freight and passenger trains, which are considered only if they occur, even if they are mentioned in the calculations (for example, if the trains start at the first station or stop in the last station of the section).

The multitude of freight trains is  $M_{dm} = \{1, 2, \dots, i, \dots, q, q+1\}$ . Train  $I$  is the first train dispatched from station  $I$  (so that the circulation of this train is not disturbed by the passenger train path - which precedes it);  $q$  is the last freight train whose dispatch from station  $I$  precedes the dispatch of the passenger train;  $q+1$  is the train dispatched after the train of passengers from station  $I$ , whose path is undisturbed (Fig. 7).

The dispatch and arrival moments of trains  $1, 2, \dots, i, \dots, q$  in stations  $1, 2, \dots, j, \dots, n$  are  $X_{i,j}$  and after overtaking (we also consider train  $q+1$ ), they are noted  $Z_{i,j}$ .

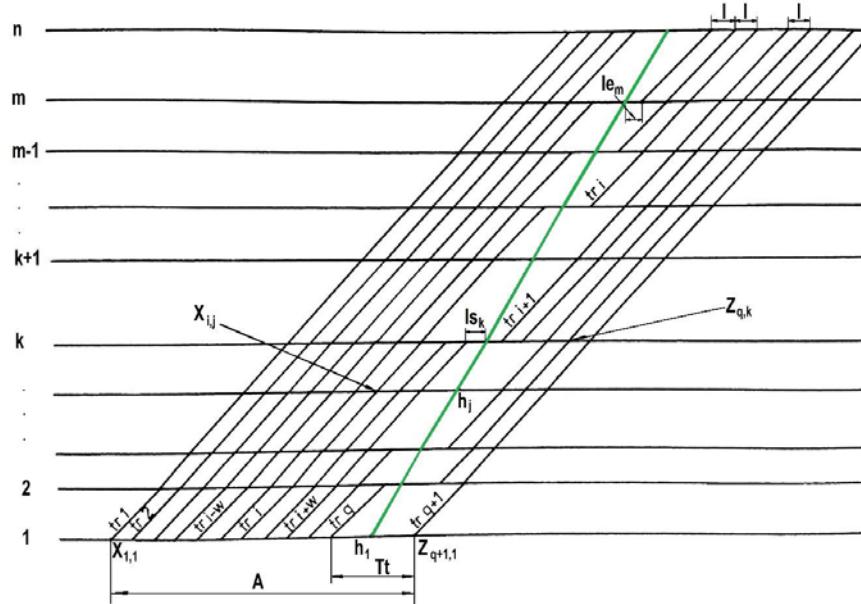


Fig. 7 – The parameters underlying the construction of the configurations

The moments at which the passenger train is in the  $j$  stations are noted them with  $h_j$

The distances between stations  $j$  and  $j + 1$  will be noted with  $d_j$ .

All trains will start from the first station of the section and will stop in the last station of the section.

We will note with  $\tau$  a quantum of time (a small interval of time) that if it is multiplied by a natural number we can obtain any of the values needed to construct the graphic representations ( $I, Ie, Is, r_j, t_j, h_1, t_{dm}, t_{fm}, t_{dc}, t_{fc}, X_{1,1}$ ) where

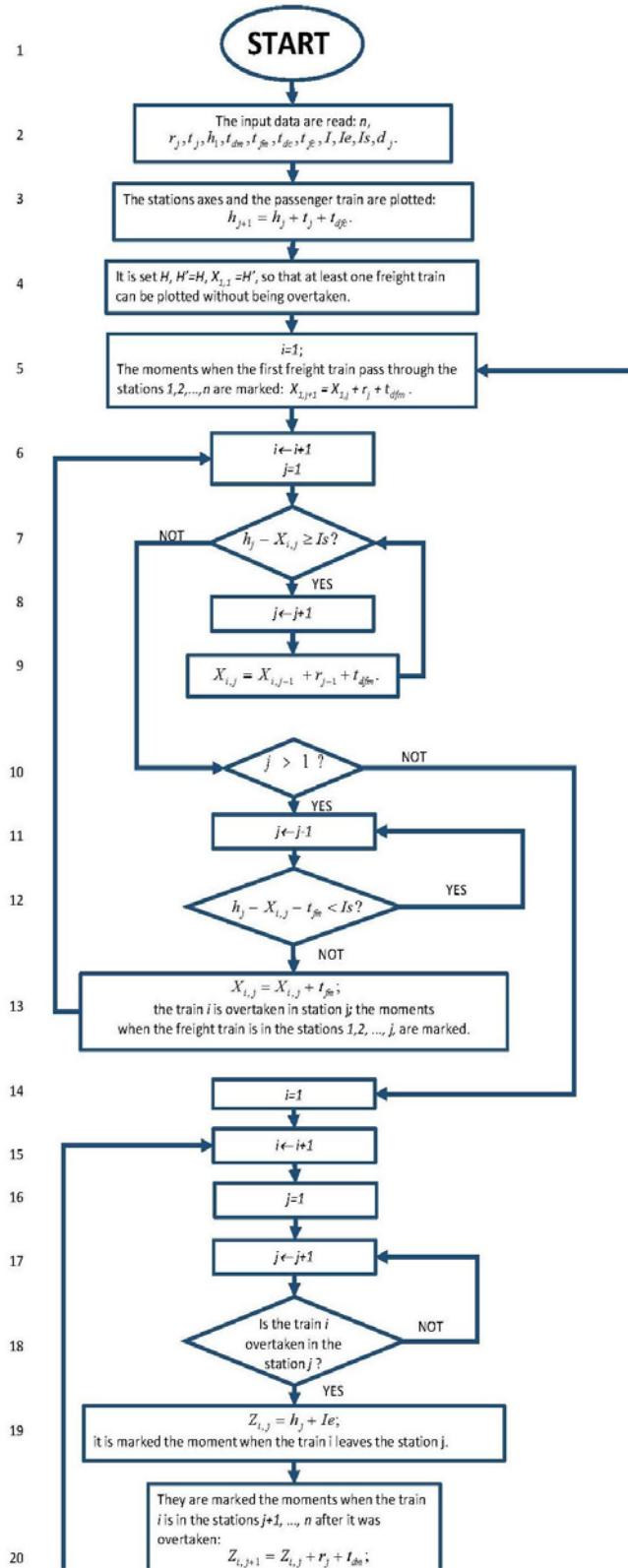
$$0 < \tau \leq \min \{ I, Ie, Is, r_j, t_j, h_1, t_{dm}, t_{fm}, t_{dc}, t_{fc}, X_{1,1} \}. \quad (3)$$

For example,  $\tau$  can be **1 min** or **0,5 min**.

We will call  $\tau$ , *deviation value*; this name will be justified in the following.

$I, Ie, Is, r_j, t_j, h_1, t_{dm}, t_{fm}, t_{dc}, t_{fc}, X_{1,1}, \tau$  are measured in minutes.

The stages of constructing the graphical representations, are described in Fig. 8.



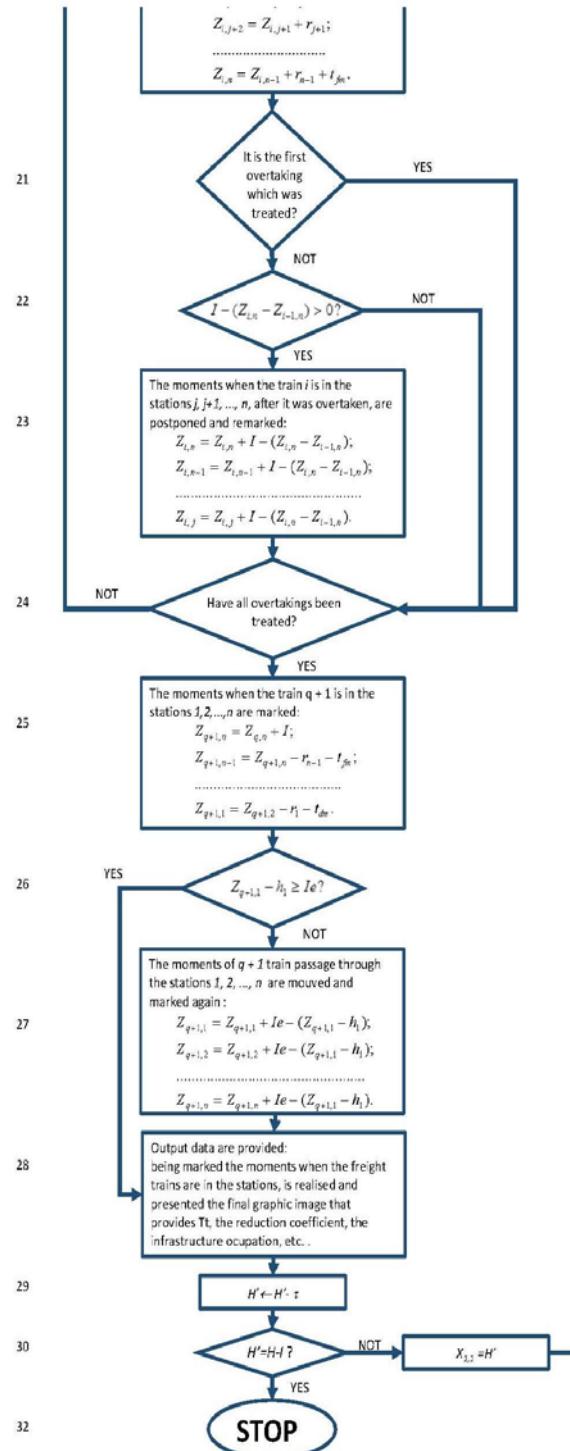


Fig. 8 – The stages of constructing the configuration family

Transposed in a few words, the described *deviation method of the dispatch moments* of the trains from the parallel graphic, is:

- a) the railway stations axis and the passenger train that departs from station  $\mathbf{I}$  at the moment  $\mathbf{h}_1$  are plotted;
- b)  $\mathbf{H}$  is the dispatch moment of the first freight train from station  $\mathbf{I}$ ; in the first iteration  $\mathbf{H}'=\mathbf{H}$ ;
- c) the first freight train that is dispatched from station  $\mathbf{I}$  at the time  $\mathbf{H}'$ , before  $\mathbf{h}_1$  and which is not overtaken, is drawn;
- d) at the moment  $\mathbf{H}'+\mathbf{I}$ , the second freight train is dispatched from station  $\mathbf{I}$ , at  $\mathbf{H}+2\mathbf{I}$  the third is sent, at  $\mathbf{H}+3\mathbf{I}$ , the fourth, etc., their paths being drawn up to the station where they are overtaken; all the trains which cover at least the first station interval are plotted, respecting the minimum arrival headway,  $\mathbf{I}s$ , in the stations where the overtakes occur;
- e) the interrupted freight train paths are drawn respecting the minimum departure headway,  $\mathbf{I}e$ ; in the stations where the overtakes occur and the minimum headway between the freight trains the train  $\mathbf{q}+1$  is also drawn;
- f) time of reduction,  $\mathbf{Tt}$ , reduction coefficient,  $e$ , infrastructure occupation,  $A$ , are calculated;
- g)  $\mathbf{H}'$  is decreased with  $\tau$  and the cycle is resumed again at point c) until  $\mathbf{H}$  should be decreased by  $\mathbf{I}$ .

It is easy to see that if  $\mathbf{H}$  was reduced with  $\mathbf{I}$ , we would get exactly the same configuration as in the first iteration, with the insignificant difference that an additional undisturbed path would exist.

Thus,  $\mathbf{I}/\tau$  distinct configurations are obtained, corresponding to  $\mathbf{I}/\tau$  reduction coefficients. For example, **Fig. 9, 10, ..., 14** are presented, for which we considered  $\tau=1min$ .

In other words, the disturbance that a passenger train produces in a parallel graph formed of freight trains can take for a certain value of  $\tau$ ,  $\mathbf{I}/\tau$  possible forms or configurations.

**3.1. Definition.** The multitude of all the possible configurations (forms) that the disturbance produced by a single train,  $\mathbf{TR}$ , in the parallel (base) graphic, for a certain value of  $\mathbf{I}$  and for a certain value of  $\tau$ , will be called *the configurations family* of the train  $\mathbf{TR}$ , at headway  $\mathbf{I}$  and deviation value  $\tau$ , and we will note it:

$$F_{c_{I,\tau}}^{TR} = \{C_1, C_2, \dots, C_u, \dots, C_{I/\tau}\}, \quad (4)$$

where:

$\mathbf{TR}$  is the category of train that produces the disturbance in the parallel graphic;

$C_1$  is the initial configuration.

$C_u$  is the configuration resulting after  $u-1$  successive deviations of the preponderant trains dispatch moments with  $\tau$  minutes from the first station;

**3.2. Definition.** The multitude of all reduction coefficients values that a train  $TR$  can cause in the parallel graphic, will also be called a *family of reduction coefficients* of the train  $TR$  at headway  $I$  and deviation value  $\tau$ , and we will note it:

$$F_{I,\tau}^{TR} = \{e_1, e_2, \dots, e_3, \dots, e_v\}. \quad (5)$$

It should be said that  $v \delta I/\tau$  because situations can arise where for different configurations correspond the same value of the reduction coefficients (**Fig. 9** and **Fig. 10**). Therefore we can speak about a non-injective function

$$f_c : F_{C_{I,\tau}}^{TR} \rightarrow F_{I,\tau}^{TR} \quad (6)$$

Applying the deviation method in the concrete case, described in section 1 of this paper, results the configurations family given by **Fig. 9-14**.

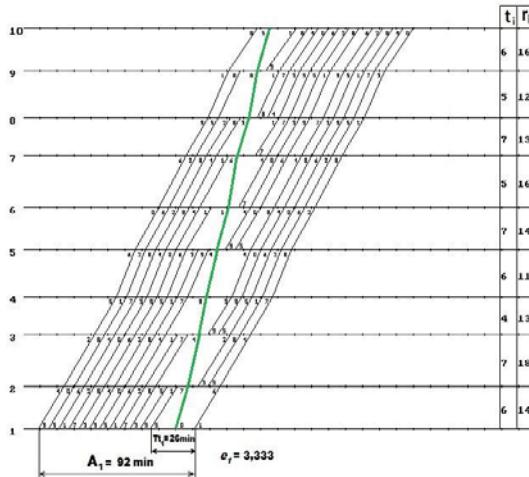


Fig. 9 – Configuration C<sub>1</sub>

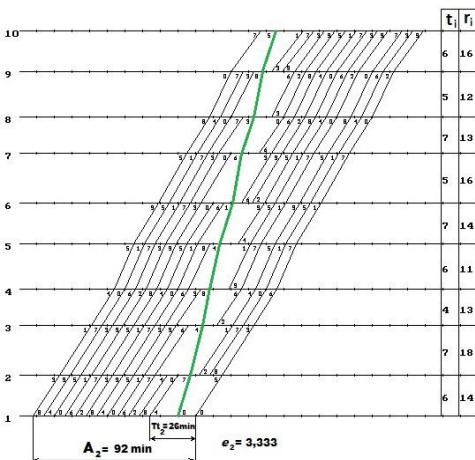


Fig. 10 – Configuration C<sub>2</sub>

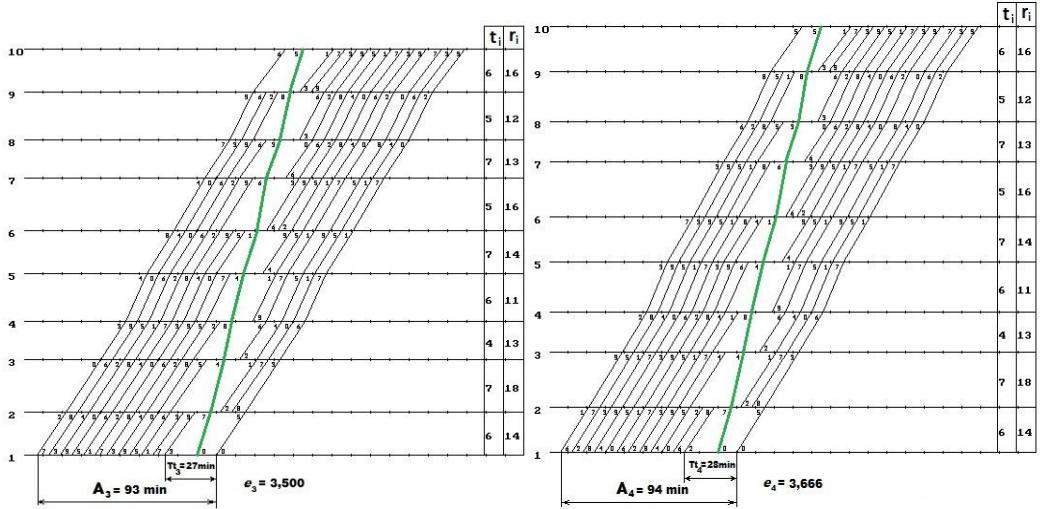

 Fig. 11 – Configuration C<sub>3</sub>

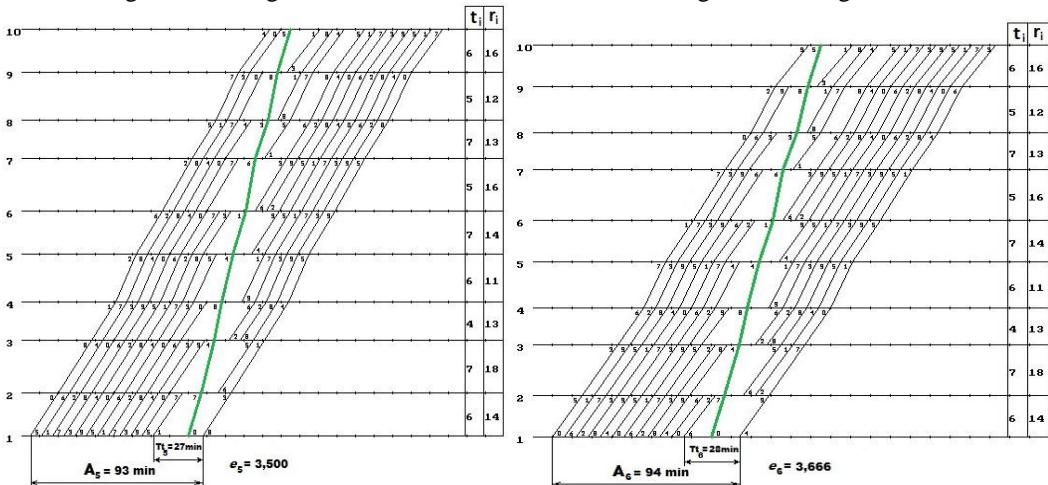
 Fig. 12 – Configuration C<sub>4</sub>

 Fig. 13 – Configuration C<sub>5</sub>

 Fig. 14 – Configuration C<sub>6</sub>

Analyzing Fig. 9-14 we see that the minimum size of the window of time in which those 13 freight trains and the passenger train can circulate, in the spirit of the capacity definition given in [22] (*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*), respectively maximum compression, is shown in Fig. 9 and Fig. 10 in which the infrastructure occupation,  $A$  is minimum, 92 minutes. Also, the time of reduction,  $Tt$  is minimum, 26 minutes, resulting in a minimum reduction coefficient  $e = 3.333$ .

It can be observed that there are two forms of compression which lead to the maximum values of  $A$ ,  $Tt$  and  $e$ , corresponding to a minimum compression, namely those shown in Fig. 12 and Fig. 14.

If we address the case of two passenger trains, with the same speed, which are placed into a freight trains parallel graphic, a number of configurations,  $N$ , should be analyzed, where:

$$N = I/\tau \cdot (P-I)/\gamma \quad (7)$$

The first family of  $I/\tau$  configurations would be when the passenger trains would run in bunch, and the last family of configurations would result when there was an interval  $P$  between the passenger trains when the "perturbations" produced by these two train paths would no longer interfere.  $\gamma$  is the *time deviation* value for shifting of the second passenger train path in relation to the first.

We deduce that the possibilities of train interaction are many (theoretically, with  $\tau$  and  $\gamma$  tending to 0, the number of configurations will tend to infinite) and the value of the tracked indicators depends on the position of the passenger train(s) in relation to the base trains.

#### 4. Conclusions

In order to determine with maximum accuracy all possibilities of interaction of two types of trains the paper proposes a *deviation method* of the dispatch moments from the first station of the base trains in relation to a high-speed train. The term *configurations family* is imposed, and its analysis gives us the specific cases where the infrastructure occupation is minimum, maximum, or takes intermediate values.

The paper demonstrates that the "simple interaction" of a single high-speed train with the trains which are in a parallel graphic (base trains), has in fact many forms, and their number depends inversely proportional of deviation value,  $\tau$ .

Even if we consider the interaction of a single high speed train with the parallel graphic, the graphical analysis of all the possibilities of conflict and of the effects in terms of capacity consumption, is a relatively cumbersome one, even more so when the deviation value,  $\tau$  is lower, resulting the necessity of constructing  $I/\tau$  configurations.

It is an obvious question whether it is possible to determine direct mathematical methods to provide the necessary numerical data for graphic construction of the paths of these two categories of trains and the specific values of the  $Tt$ ,  $e$  and  $A$  compression indicators, without using the graphic construction of all the possibilities of conflict.

The solution to this issue will be the subject of a future paper.

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