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STUDY ON TIMETABLE KINEMATICS IN PLOTTING OF TRAIN TRAFFIC GRAPHICS

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Abstract: *The train diagram is the graphical representation of the train movement on the distance between the two sections. The total timetables valid for a certain period of time form the train running plan of that period. The train diagram represents the technological process of production of the railway network. The arrangements of shifts are drawn up on the basis of graphical representation by means of two orthogonal rectangular axes, in which the time is represented horizontally and the vertical axis represents the space for trains. Train diagrams are drawn up to the needs of the operation, separately for each traffic section, coordinating the transit of trains in the section head stations.*

Key words: *timetable, train diagram, railway traffic, speed, trains crossings.*

1. Introduction

Arrangement of shifts is a graph that establishes the train travel schedule for the trailer and the staff who drives or serves a train as well as the economic indicators calculated according to the optimal choice of matings of the hourly traffic intervals established by the timetable. The arrangement of shifts are drawn decadally, monthly and annually for locomotives, engine drivers and train staff (head of train and conductor). Depending on the fair use of the hourly train segments and the time allocated to the technological processes to guide / to shunt the trains and respectively placing into service / stabling the locomotives, as well as to ensure the necessary rest, the staff who runs and serves a train, after the drawing of the arrangement of shifts shall determine the working hours of the hauling locomotives and of its staff and train staff. At the same time, for the locomotives, the feed program (where applicable), as well as the maintenance programs for rolling stock (locomotives and waggons, electric rail car) are established to ensure scheduled interventions in the revisions and repairs.

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The linear route is the route made by the locomotives at the head of the trains (or the route locomotives provided in arrangement of shifts or in the hauling program), plus the route of locomotives used for double or multiple traction and isolated runs (for locomotives that run independently, without wagons) and the equivalent route is the result of the application of coefficients established by national norms.

The auxiliary service coefficient expresses the proportion of locomotive activities other than hauling trains as hauling locomotives, being calculated as a ratio between the trains of auxiliary services locomotives and the train routes of the locomotives. The coefficient of the auxiliary linear route is the ratio between the sum of the trajectories made by the multi-traction locomotives, plus the isolated routes and the total linear routes. The coefficient of the productive linear route is determined as a ratio between the linear route of the locomotives in the train composition (of the head locomotives, of the train head, and of the locomotives used in the multiple traction) and the total linear route.

By operating time, we only understand the time the locomotives are working according to the train diagrams, then the travel time coefficient can be calculated as follows:

$$k_{tm} = \frac{L_t}{V_t} \div \frac{L_t}{V_c} = \frac{L_t}{V_t} = k_{vc} \tag{1}$$

where: V_c represents the average commercial speed of locomotives and *kvc* is the commercial speed coefficient. The commercial speed of wagons is equal to the commercial speed of the trains in which they travel. The coefficient of the productive route (road use coefficient) expresses one of the qualitative sides of the wagon operation, calculated as a ratio between the productive (load) and the total route or the ratio between the load and the total stroke wagon.

The traffic capacity of a rail or traffic section is defined as the maximum number of trains that can transit through a unit of time (usually one day) on the railway or traffic section. The number of trains that can circulate daily on a railway section is even greater as the trains distances (or intervals) traveled along the same line are the same in the same direction as the crossing distances of the trains it runs in the opposite direction on the same line. the traffic capacity of a railway section varies directly in proportion to the number of crossing points located on it, because at a certain point the number of trains running on the section is always smaller with only one unit than the number of crossing points.

A train diagram is a sequence of distance charts that also encompasses the stopping times of the trains at the points of intersection during which various technical or commercial operations are carried out [5].

In this study, the basis for calculating the times, distances, velocities and accelerations that have been embedded is to determine the overall picture of the conditions to be fulfilled in the first place before drawing a arrangement of shifts and the train diagram in a traffic section or on multiple networks. Determinations on the mechanics of train movement between two or more stations of a traffic section are so essential, given that they are essential, before solving the problems associated with the determination of the operatingroutes.

2. Determining the Time Required to Run Certain Distances Given by the Arrangement of Shifts and the Traffic Speeds According to Certain Conditions Imposed at Distinct Time and Distance Intervals, Related to Different Inertial Reference

First, two trains with lengths l_1 and l_2, which were shipped at different time points and at distinct speeds v_1 and v_2 from a railway station *A*, will be considered to be on a double track to station *B*, it is necessary to determine the time elapsed until a traveler in one of the two trains notices the passage of the other train to him. For this, it will be considered that the speed of the first train is higher than that of the second train in the first case, the chosen inertial reference being defined by the railway bed.

At the moment $t = t_0 = 0$:

$$\begin{cases} x_{01} = \left|\overrightarrow{x_{01}}\right| \\ y_{01} = \left|\overrightarrow{y_{01}}\right| \end{cases} \Rightarrow \begin{cases} x_{02} = x_{01} + l_2 \\ y_{02} = \left|\overrightarrow{y_{02}}\right| \end{cases} \Rightarrow \text{ where: } v_{2x} = v_2;$$

At any moment *t*:

$$\begin{cases} x_1 = x_{01} \cdot t + v_1 \cdot t \\ y_1 = y_{01} \end{cases} \text{ and } \begin{cases} x_2 = x_{01} + v_1 \cdot t_1 \\ y_2 = y_{02} \end{cases}$$

At the moment $t = t_1$ (Figure 1) : $\begin{cases} x_1(t_1) = x_{01} + v_1 \cdot t_1 \\ x_2(t_1) = x_{01} + l_2 \cdot t_1 \end{cases}$

By imposing the condition that:

$$x_1(t_1) = x_2(t_2) \Rightarrow x_{01} + v_1 \cdot t_1 = x_{01} + l_2 + v_2 \cdot t_1 \Rightarrow v_2 = v_1 - \frac{l_2}{t_1}$$

At the moment $t = t_0 = 0$:

$$\begin{cases} x_{01} = \left|\overrightarrow{x_{01}}\right| \\ y_{01} = \left|\overrightarrow{y_{01}}\right| \end{cases} and \begin{cases} x_{02} = x_{01} \\ y_{02} = \left|\overrightarrow{y_{02}}\right| \end{cases}$$

The conditions are imposed: $\begin{cases} x_1 \cdot x = v_1 \\ x_2 \cdot x = v_2 \end{cases}$ (Figure 2).

$$\begin{cases} x_1 = x_{01} + v_1 \cdot t \\ y_1 = y_{01} \end{cases} \text{ and } \begin{cases} x_2 = x_{01} + v_2 \cdot t \\ y_2 = y_{02} \end{cases}$$

At the moment $t = t_2$:

$$\begin{cases} x_1(t_2) = x_{01} + v_1 \cdot t_2 \\ x_2(t_2) = x_{01} + v_2 \cdot t_2 \end{cases}$$

But: $x_1(t_2) - x_{01}(t_2) = l_1 \Rightarrow t_2 = \dfrac{l_1}{v_1 - v_1 + \dfrac{l_2}{t_1}} \Rightarrow t_2 = t_1 \dfrac{l_1}{l_2}$

One useful remark to note is that the timing $t = t_2$ does not depend on the magnitude of the travel speeds of the two trains. In the first train's own reference system, its speed is null:

$$\overrightarrow{v'_{1,1}} = \overrightarrow{v_1} + \left|\overrightarrow{-v_1}\right| = 0$$

$$\overrightarrow{v'_{2,1}} = \overrightarrow{v_2} + \left|\overrightarrow{-v_1}\right| \Rightarrow v'_{2,1} = v'_2 - v'_1 = -(v_1 - v_2) \Rightarrow v'_{2,1} = -(v_1 - v_2)$$

At the moment $t_0 = 0$:

$$\begin{cases} x'_{0,2} = l_2 \\ y'_{0,2} = -\left|\overrightarrow{y'_{0,2}}\right| \end{cases} \Rightarrow v'_{2x} = -(v_1 - v_2).$$

At any moment t (Figure 3):

$$\begin{cases} x'_2 = l'_2 - (v_1 - v_2) \cdot t_1 \\ y'_2 = y'_{0,2} \end{cases}$$

At the moment $t = t_1$:

$$x'_2(t_1) = l'_2 - (v_1 - v_2) \cdot t_1$$

By imposing the condition that:
At the moment $t = t_0 = 0$

$$\begin{cases} x'_{0,2} = 0 \\ y'_{0,2} = -\left|\overrightarrow{y'_{0,2}}\right| \end{cases}; v'_{2x} = -(v_1 - v_2)\ .$$

To simplify the construction and presentation of train diagrams, the trains are considered to be running at constant speed, with no braking and starting times, throughout the distance *d* (*d* = *AB*, *A* and *B* being two consecutive stops from the same traffic section of trains) [1]. The movement diagram of a train (or the right-hand *AC* in Figure 5) is known as the trace.

The tangent of the drawn angle and the axis of the abscissae, or the angular coefficient of the trajectory, is the speed of the train and the inclination of the path to the axis of the abscissae and, implicitly, the travel time will be more large or smaller depending on the speed of the trains, the time being in a reverse proportion to the speed. In the case of two consecutive trains running between two stations *A* and *B* in the sense from *A* to *B*, the tracking interval is τ [4], [6]. The crossing interval is the time elapsing from the time of arrival at the crossing point of a train running in a sense and the time of shipment (or non-stop) from the same station of a second train running in the opposite direction (Figure 6). In a similar situation in which two other trains are shifted from the same railway stations *A* and *B* in opposite ways (Figure 7), the distance between the two CF stations being *d*, the train speeds $v1$ and $v2$ being given, the elapsed time will be determined until the two trains with the same lengths *l*1 and *l*2 encounter, *Galilei* equations of the two trains and then the time required to reach each train in the other station CF [3]. Considering $y_1 = y_{01}$ = trajectory of the first train and respectively $y_2 = y_{02}$ = the trajectory of the second train then, the equations of the two trains will be:

$$\begin{cases} v_{1x} = v_1 \\ v_{2x} = -v_2 \end{cases}$$

$$\sim\ = t_{01} = 0 \begin{cases} x_{01} = |x_{01}| \\ y_{01} = |y_{01}| \end{cases}$$

$$\begin{cases} x_{02} = x_{01} + d \\ y_{2x} = |y_{01}| \end{cases}$$

$x = x_0 + v_x \cdot t$

$x_1 = x_{01} + v_1 \cdot t$

$x_2 = (x_{01} + d) - v_2 \cdot t$

If *t* is the time when the two trains meet then:

$$\Rightarrow \begin{cases} x_1(t) = x_{01} + v_{x1} \cdot t \\ x_2(t) = x_{01} + d - v_2 \end{cases} \Rightarrow x_1(t) = x_2(t) \quad \Rightarrow x_{01} + v_{1t} = x_{01} + d - v_2 \cdot t \Rightarrow$$

$$\Rightarrow t \cdot (v1 + v2) = d \Rightarrow$$

$$\left.\begin{array}{l}\Rightarrow t=\dfrac{d}{v_1+v_2}\\ \begin{cases}\Delta x_1(t)=x_1-x_{02}\\ \Delta x_2(t)=v_1\cdot t\end{cases}\end{array}\right\}\Rightarrow$$

$$\Rightarrow \Delta x_2=-v_2\cdot\frac{d}{v_1+v_2}$$

$$\Delta x_2(t)=x_2(t)-x_{01}-d=-v_2\cdot t$$

If $v_1 > v_2 \Rightarrow |\Delta x_1| > |\Delta x_2|$

then, the meeting point between the two trains is closer to the CF *B* station. If $|\Delta x_1| < |\Delta x_2| \Rightarrow$ the meeting point is closer to CF *A* station. If the two trains of lenghts *l*1 and *l*2 move in the same direction and in the same direction to an Oxy fixed inertial reference (Figure 8), one of the trains having the same relative speed in the mode with the other train relative to it is v = , the time spent by an observer on one of the trains will be determined to see the other train pass by him. $v=[m/s]$, If the two trains of lenghts *l*1 and *l*2 move in the same direction and in the same direction to an *Oxy* fixed inertial reference (Figure 8), one of the trains having the same relative speed in the mode with the other train relative to it is *v*, the time spent by an observer on one of the trains will be determined to see the other train pass by him.

Case (Figure 8): $v_{1x}^{'}<0$ < 0 și $x_{10}^{'}=0$.

$$\begin{cases}x_{02}=x_{01}+d\\ y_{2x}=|y_{01}|\end{cases}$$

At the moment t_1:

$$\left.\begin{array}{l}x_1^{'}=-v_1^{'}\cdot t_1\\ x_1^{'}(t)=-l_2\end{array}\right\}\Rightarrow t_1=\frac{l_0}{v_1}$$

$$\begin{cases}x_1^{'}=l_1-v_1^{'}\cdot t\\ y_1^{'}=|y_{10}^{'}|\end{cases}$$

Case 2 (Figure 9): $v_{1x}^{'}>0$

$$\begin{cases}x_1^{'}=-l_2-v_1^{'}\cdot t\\ y_1^{'}=|y_{10}^{'}|\end{cases}$$

At the moment $t_2 : v_2^{'} = v^{'}$ (Figure 8):

$$x_1^{''}(t) = 0 \Rightarrow (l_2 + v_2^{'} \cdot t_2) = 0 \Rightarrow l_2 + v'^{'}_2 \cdot t_2 = 0 \Rightarrow t_2 = \frac{l_0}{v^{'}}$$

At the moment $t = t_1$:

$$\begin{cases} x_1^{'} = v_1^{'} \cdot t \\ y_1^{'} = \left|y_{10}^{'}\right| \end{cases} \Rightarrow \begin{cases} v_1^{'}(t_1) = v_1^{'} \\ x_1^{'}(t_1) = l_1 \end{cases} \Rightarrow t_1 = \frac{l_0}{v_1}$$

Given that the relative speed of the first train to the second train is the opposite of the relative speed of the second train to the first train, then it is obvious that if:

$v_1^{'}(t_1) < v_1^{'} \quad \Rightarrow v_2^{'} > 0$ provided that: $\left|\overrightarrow{v_{1,2}^{'}}\right| = \left|\overrightarrow{v_{2,1}^{'}}\right| = v^{'}$

Case 3: $v_{1,2}^{'} < 0$ in the reference system of the first train (Figure 10).

$$\begin{cases} x_2^{'} = v^{'} \cdot t \\ y_2^{'} = -\left|y_2^{'}\right| \end{cases}$$

At the moment $t = t_1$ (Figure 11):

$$\begin{cases} x_2^{'}(t_1) = v^{'} \cdot t_1 \\ x_2^{'}(t_1) = l_2 \end{cases} \Rightarrow t_1 = \frac{l_0}{v^2}$$

$$\begin{cases} v_2^{'} = -l_1 \cdot v^{'} \cdot t \\ y^{'} = -\left|y_{0,2}^{'}\right| \end{cases}$$

At the moment $t = t_2$ (Figure 12):

$$\begin{cases} x_2^{'}(t) = -l_1 + v^{'} \cdot t_2 \\ x_2^{'}(t) = 0 \end{cases} \Rightarrow t_2 = \frac{l_1}{v_2}$$

The minimum distance to which two moving means of movement can move apart is defined by the distance between two points of sectioning [2]. This distance is called running distance and is at least equal to the train's braking distance. The quality of the trains' diagram after the set turnus is expressed by the percentage of trains deviated from the chart, essentially representing the ratio between the number of trains shipped per day over the course of the day and the total number of trains shipped during the day.

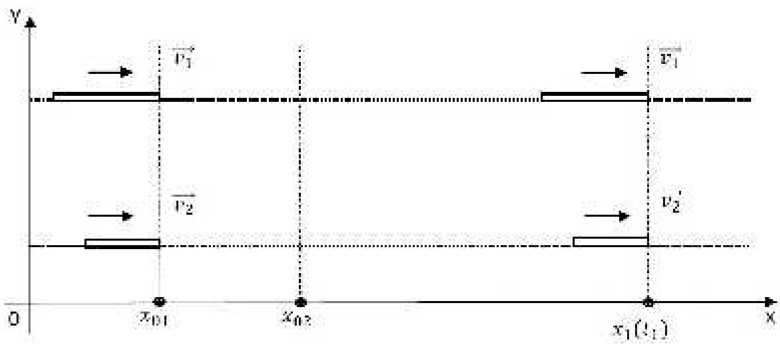

Fig. 1. *Scheme of the two trains at the time* $t = t_1$

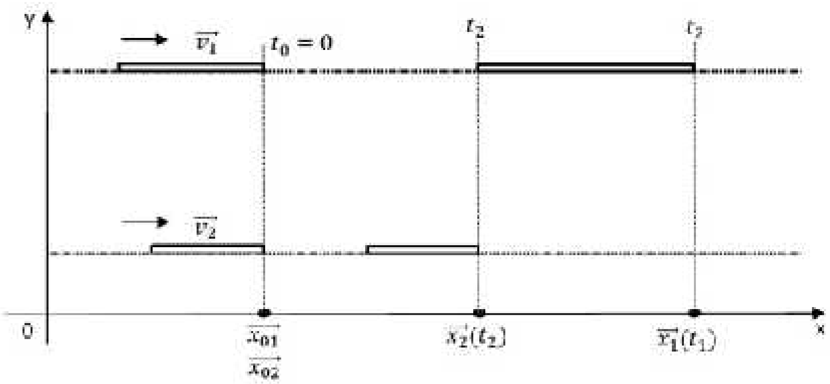

Fig. 2. *Scheme of the two trains at the time* $t = t_2$

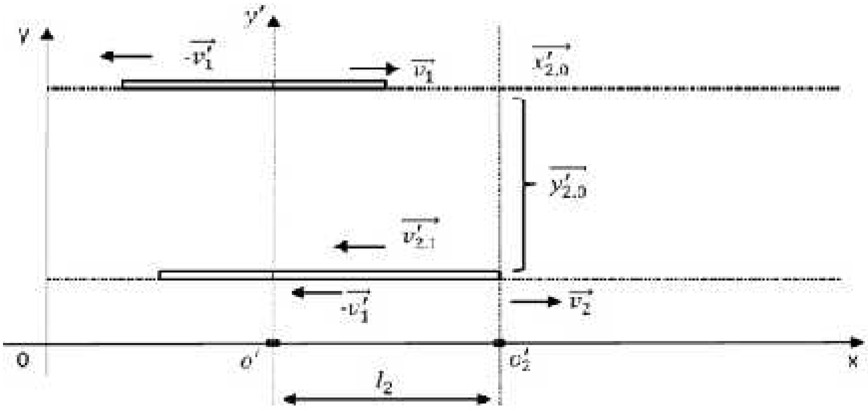

Fig. 3. *Scheme of the two trains at any time t*

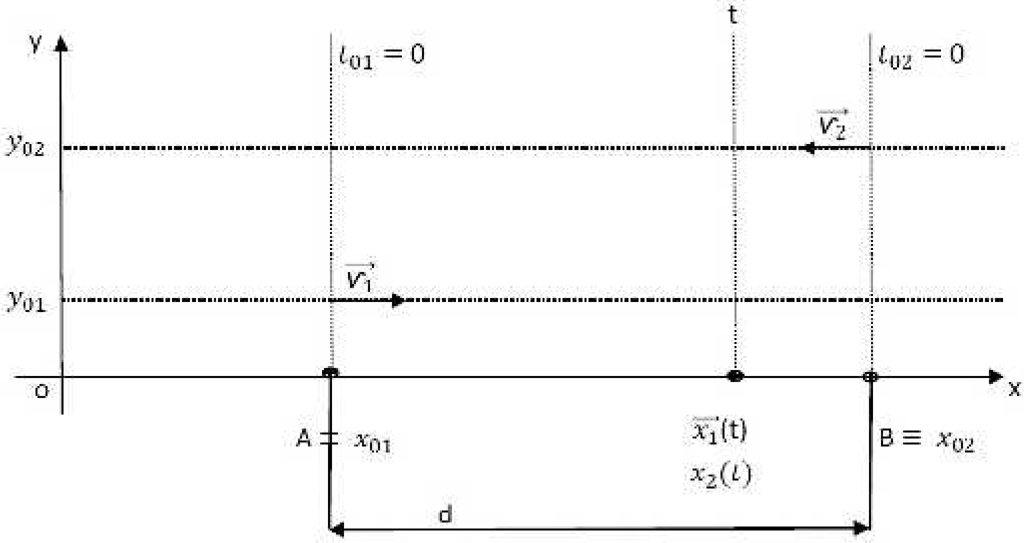

Fig. 4. *The diagram of the other two trains shipped in the opposite direction from the two stations*

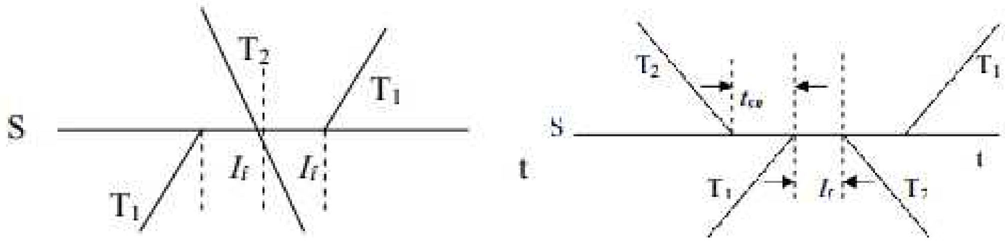

Fig. 5. *Crossing interval diagram of two trains and non-simulated arrival times of trains in stations*

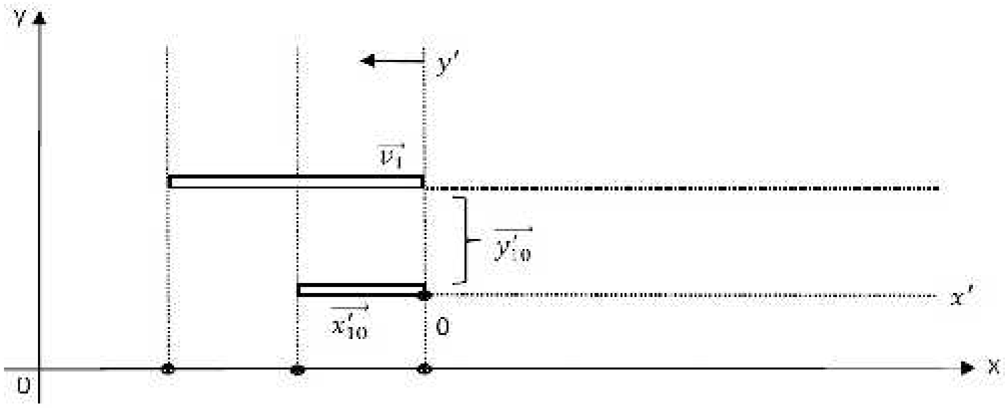

Fig. 6. *The diagram of the other two trains shipped in the opposite direction from the two stations (A and B) at equal speeds in the module*

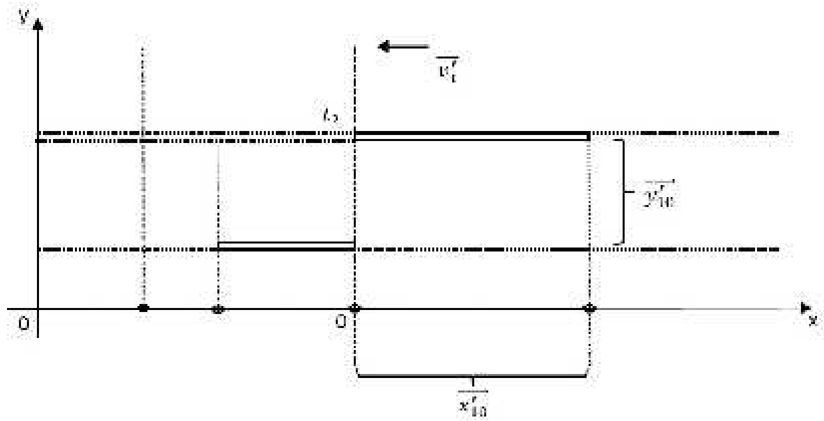

Fig. 7. *Diagram of the two trains shipped from stations A and B where* $3'_{1,x'} > 0$

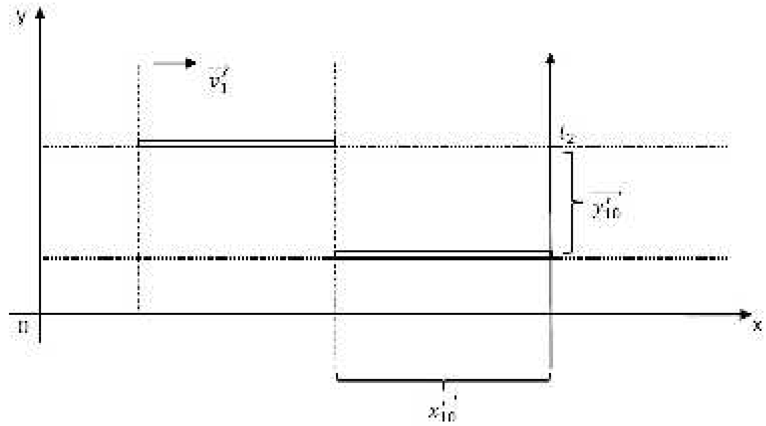

Fig. 8. *Diagram of the two trains shipped from stations A and B where* $3'_{2'} = 3'$

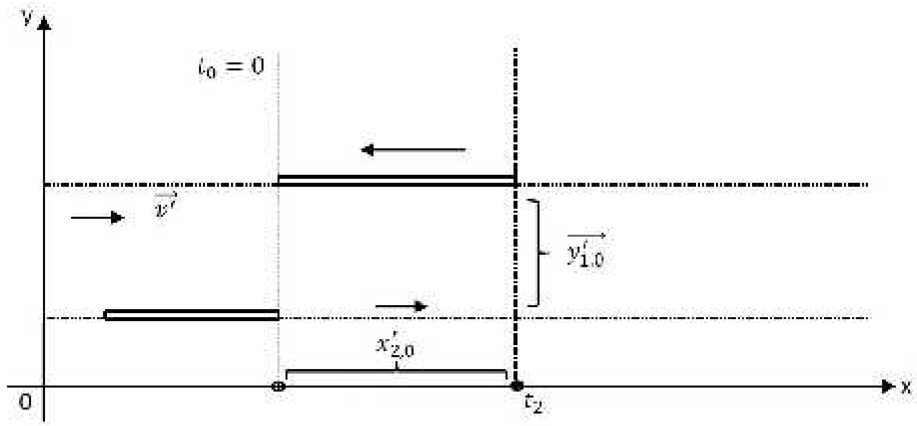

Fig. 9. *Diagram of the two trains at the time* $t = t_1$

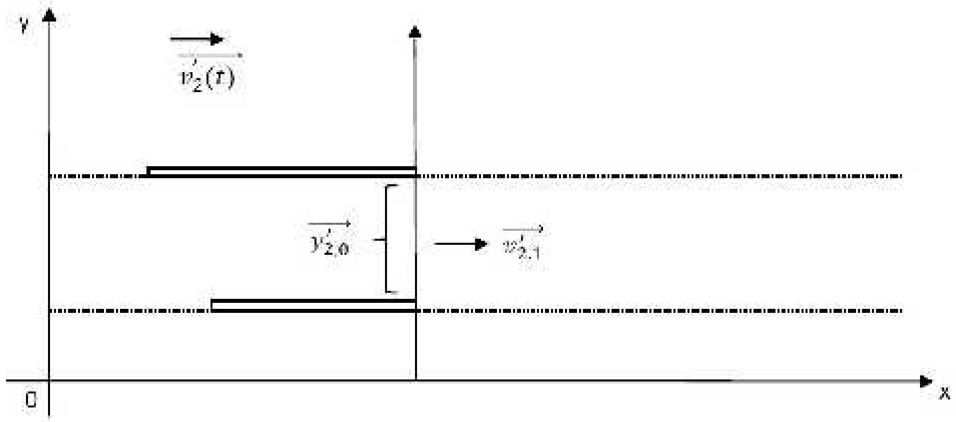

Fig. 10 *Scheme of the first train reference system when* $t = t_1$

3. Conclusions

It is imperative to know that the managerial staff in the transport units, in addition to the duties provided in the job description, has also major obligatory duties, such as the availability of the employees according to the specific labor conditions and the conditions envisaged for the establishment of labor standards, means of transport, installations, equipments, apparatus and tools, in order to fully exploit the transport and production capacity, as well as the full and efficient use of working time.

A well-drawn arrangement shifts diagram allows the best use and the most economical exploitation from the point of view of increasing the cost of production costs in the trains. In order to draw up the arrangement shifts diagram it is necessary to know in advance the relevant data such as the nominal traffic program, the train depot towers, the types of rolling stock to be used at each arrangement of shifts, the type of trains, the time needed for equipping and preparing the locomotives and rake of coaches, the duration of the technological processes for equipping and preparing the rolling stock, the length of stay at the head of the train at departure and arrival at both the station, home depot (of the train and hauling personnel) and the terminal station, according to the legislation in force, the duration of the maximum continuous service for train crew and train crew that is not regulated until now.

In the drawing of the timetable and the arrangement of shifts, one must also take into account the type of the hauling section or the electrified section or not, double or no line, traffic sections closed accidentally totally or only one of the circulating wires for rehabilitation works, restoration or modernization, but also by the traffic capacity of a traffic section, being capped by the economic indicator which is equal to the circulating capacity corresponding to the limiting distance. The traffic capacity of a main traffic section is equal to the traffic capacity of the limiting section on its contents.

The time taken by a train or a pair of trains to limit the distance is to be determined for each traffic section on the basis of several assumptions, such as those related to the train running regime through the stops limiting the stopping distance : stops at both stations, stops only at the first (or second) station, or stops without stopping at both stations. Another hypothesis is that of the speed of the trains running through the limiting distance, speed which is dependent on the traffic regime, the excess or the cant deficiency of the path in the curves, the tonnage of the trains, the traction system used, etc.

At the same time, for trains of passengers, two types (series or classes) of motorized rolling stock with differently installed power may be included (on the arrangements of shifts) by imposing the condition that the driving times be calculated with locomotives having the lowest traction power. If the reverse is done, locomotives with the lowest traction power will prolong the driving times.

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