ABOUT THE ENERGY CONSUMPTION IN RAIL TRANSPORT

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REZUMAT. Această lucrare tratează problemele legate de consumurile energetice din transportul feroviar și implicațiile numărului mare de restricții și limitări de viteză din punct de vedere energetic și al timpilor de parcurs. O mare parte din costurile serviciilor de transport feroviar, indiferent dacă este vorba de trenurile de călători sau de marfă, o constituie prețul energiei consumate. Lucrul mecanic necesar deplasării vehiculelor pe calea de rulare depinde de o serie întreagă de factori tehnici și nu numai. Conducerea trenului pe o linie pe care sunt prezente multiple limitări din punct de vedere a vitezei de deplasare, constituie o problemă de conducere optimală rezolvabilă cu ajutorul teoriilor de calcul variațional și de programare dinamică. Lucrarea de față își propune să studieze impactul pe care le au restricțiile și limitările de viteză asupra consumurilor energetice și a duratelor de parcurs asupra trenurilor.

Cuvinte cheie: energie, consumuri, restricție de viteză, conducere optimală.

ABSTRACT. Present paper deals with problems which are related to energy consumption and the involvement of the large number of restrictions and speed-limits in the matter of energy and travel time. A large part of the costs of rail transport services, be it passenger or goods trains is made up of the price of the consumed energy. Mechanic work necessary to move the vehicle on the roll-track depends on a whole series of technical facts and not only. Driving the train on a track where multiple limitations are present from the point of view of speed, constitutes a solvable problem of optimal drive with the help of variable calculation theories and dynamic programming. Present paper is intended to study the impact restrictions and speed limits have on energy consumption and route length on trains.

Keywords: energy, consumption, speed-limit, optimal drive.

1. INTRODUCTION

Problems related to energy consumption necessary to railway tractions make up some of the base engineering challenges related to rail exploitation.

In relation to direct and indirect costs that arise in the exploitation process of a rail transport system, a well established percentage is attributed to the price of electric power or the used fuel. In other words, we are talking about energy consumption in general.

Through the prism of environment issues, reduction of gas emission and pollution, the European Union is facing unprecedented energy challenges, from industrial and also macro-economic point of view. This is due to higher and higher dependence on raw material imports, such as natural gas and oil. The European Council, which met in Spring 2006, requested the endorsement of a medium term strategic plan to use energy more efficiently in order to achieve the objective of energy saving with more than 20% until 2020, without creating additional damage to the surrounding environment and without affecting the level of comfort or the quality of products and services [2].

Reduction of these consumptions and even more of the impact on the environment, must be a priority for the technical and political decision makers in relation to evolution strategies, investments and maintenance of the technical and industrial systems.

The reduction of energy consumptions in transports, especially in the field of rails acutally requires the design and creation of means of transport with best possible energy output, optimization of driving regimes (optimal drive), draw up of efficient traffic graphics, reduction of dead-time and waiting time. Among other necessary measures one can find the reduction of the number of speed limits. Elaborate and efficient technologies are also necessary through the distribution of market requests in relation to the offer of multi-modal transport, the most efficient under the aspect of registered consumptions (by priority, energy) and the effect on the surrounding environment [1].

2. TECHNICAL REASONS IN RELATION TO THE DRIVE OF TRAINS

In case of rail drive, notions linked to the necessary energy to win the advance resistance are treated in detail in the theory of the movement equation of the train. [10]. This studies problems related to the establishment of the weight of trains, speed determination and travel times, solving of breaking problems, choice of the type of railway engine necessary for the drive, depending on tow sections and weights, determination of energy consumptions through the study of mathematic expressions which establish the link between the movement of the train and the causes (factors) that produce it.

Mechanic work necessary for the movement of the train (to win the advance resistance) with a certain speed depends on a whole series of factors and limiting conditions. In case of passenger trains, the value of movement speed represents the most important factor as far as the weight of these factors is concerned. In case of goods trains, for which movement speed does not have the same relevance, the factors which determine the necessary mechanic work for the movement of the train are mostly dependant on weight.

Advance resistances are generated by four groups of factors which are:

- *Roll resistances* made up of the mechanic frictions in the bearing of the mounted axles, frictions due to the masses in rotation movement (traction engines' rotors in case of motor vehicles and some sub ensembles out of the breaking equipment);
- *Resistances due to the environment* (meteorological phenomena);
- *Resistances due to the track*. Here, such reasons are included which deal with the profile of the track, curve radius, value of the declivity and other geometric characteristics which have direct effects on the resistances of advance and implicitly on energy consumptions;
- *Aerodynamic resistances.*

Depending on the type and category of the train all these elements enumerated before, have different weight and implications.

For goods trains, characterized first of all by heavy weight and relatively low movement speed, roll resistances of mechanical nature represent the biggest weight in relation to consumption of the energy necessary for movement.

In case of passenger trains, all elements that make up advancement resistances are factors with significant weight, being variables which are directly proportional with movement speed.

In case of high speed trains things are completely different. The main characteristic of these is the fact that they have a relatively reduced mass and the motor vehicles have installed very high energy necessary for movement at high speed. Most of the time high speed trains travel on special infrastructure made for tis purpose, characterized mainly by the curve with very high radius, declivities with low values and extremely precise geometric features.

Taking into account what was stated before, one can declare that energy used by high speed trains depends mostly on aerodynamic and environment resistances, both of them influencing simultaneously the movement of the train.

In other words, mechanic work necessary for the movement of the train depends in this case on the movement speed, more accurately on aerodynamic factors which vary proportionally with these [10].

In figure 1 one can note an eloquent presentation of the weight which the elements that make up the advance resistance of a train have on energy consumptions, depending on the type of the train.

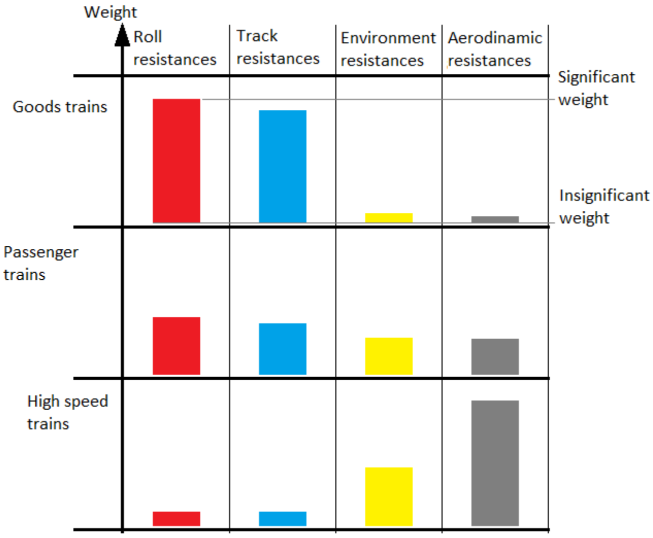

Fig. 1. The weight advance resistances have on energy consumptions, depending on type of the train.

From figure 1 one can note that for high speed trains aerodynamic phenomena and those related to the environment have the highest influence on advance resistances. Movement speed represents a criterion of maximum importance in relation to the exploit of trains and the problems related to energy consumption.

In chapter 4 the impact which speed limits have on the energy used will approached and studied and the study will be based on real exploit data for a certain electrified railway line (Bucharest - Ploiesti).

3. SPEED LIMITS AND THEIR IMPACT ON ENERGY CONSUMPTION

3.1 The rise in the number of speed limits on RRW network

In relation to the exploit of roll material on Romanian territory, specifically its circulation at maximum speed permitted by railway lines on the RRW network, an issue which must be taken into account is the high number of speed limits and restrictions present on the entire network.

Their existence is first of all due to the advanced state of degradation in which Romanian rail infrastructure is to be found [7]. Between 2001 – 2011, both the number of speed limits present on RRW network and their total length doubled in practice (table 1, fig. 2 and 3). In table 1 the variations of the number of speed limits on the RRW network and their total length between 2001 – 2011 is presented. The graphic representation of these is reproduced in figures 2 and 3.

Table 1

Number of speed limits and their total length between 2001 – 2011.

Nr. crt.	Year	Number of limits	Total length of the limits [km]
1	2001	**245**	**602**
2	2002	**186**	**624**
3	2003	**238**	**575**
4	2004	**224**	**644**
5	2005	**359**	**737**
6	2006	**506**	**964**
7	2007	**373**	**1019**
8	2008	**411**	**1103**
9	2009	**547**	**1408**
10	2010	**Approx. 610**	**Aprox.1510**
11	2011	**Approx. 650**	**Approx. 1600**

Source: MTI

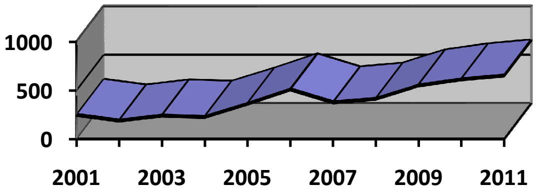

Figure 2. Variation of the number of speed limits between 2001 – 2011.

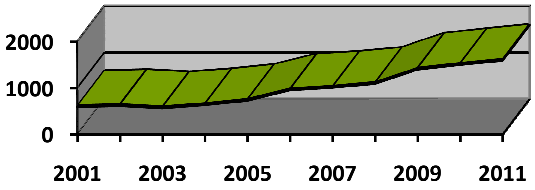

Figure 3. Variation of the total length of speed limits between 2001 – 2011.

The number of speed limits and their value also represents an extremely important factor with direct unfavourable influence on medium speed, on duration of the route and last but not least on energy consumption.

3.2 The influence of speed limits on energy consumption

Considering the electric energy or fuel consumption necessary for a train to move on a railway track with a high number of limits, an excess of energy consumption was observed, through analysis of the data registered by the measurement and registration equipment installed on board of the engine vehicles. The supplementary consumption registered in this case appears due to several causes. In figure 4 the way in which a speed limit generates excessive energy consumptions is resumed schematically.

On the closing of the train to the point where speed limit is (the weakened track part), the break necessity of the train appears and reduction of its speed to the value imposed by the restriction (*Sred*). Due to the way the breaking system works and to the elements that signal the restriction (placed at about. 1000 metres before it), speed reduction of the train takes places on a certain distance marked in the figure with *Bs* (break space). On this space route, through break equipment, part of the kinetic energy of the train is spread until reduction of real speed (*Sreal(t)*) to the value of movement speed imposed by the respective reduction or limitation marked with (*Sred*). Elimination of kinetic energy takes place through the emission of the heat generated by break systems, o matter what type they are (apart from the recuperative ones).

The value of kinetic energy emitted through breakage depends first of all on the difference between the established speed and restricted speed of every restriction or limitation and second of all on the length of the weakened track part. The higher the difference, the higher will be the energy consumption at breaking. Must be noted that in case of the endowment of the engine vehicle with recuperative break equipment this energy is partially recovered and returned in the supply network, due to the reversibility of energy processes in the respective equipment.

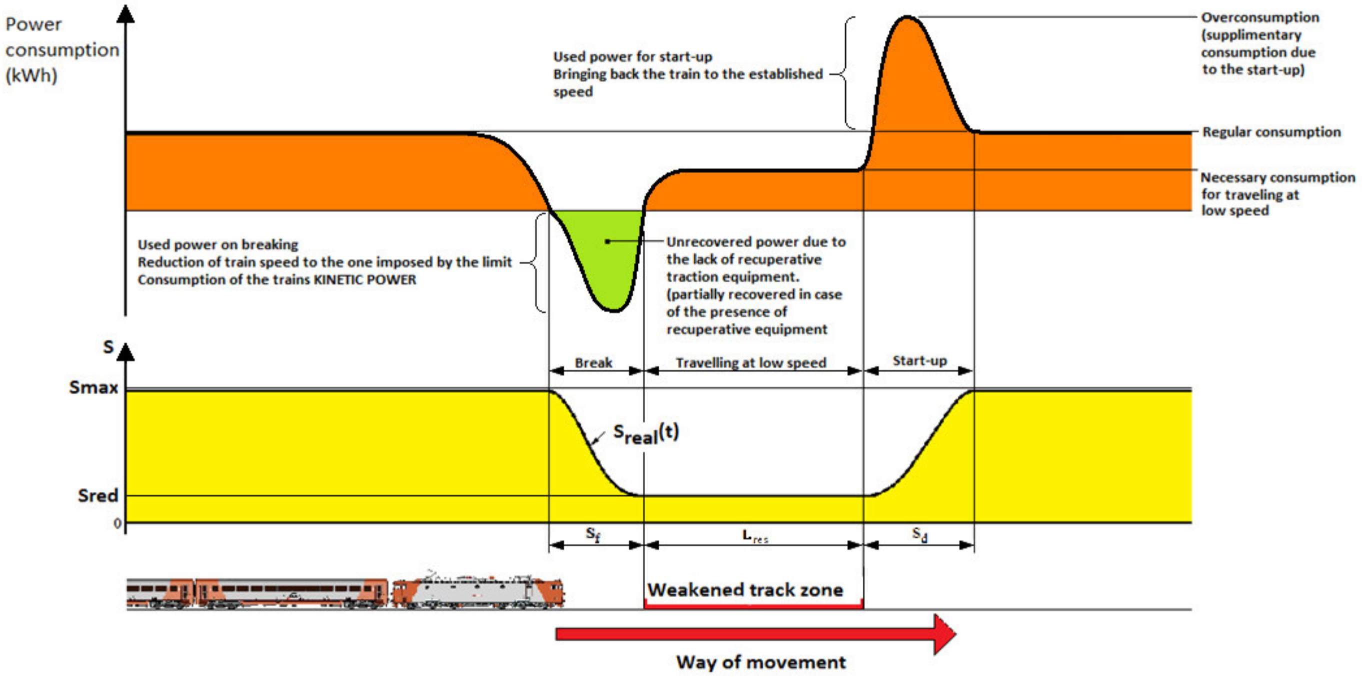

Figure 4. Influence of a speed limit on the energy consumption of a train.

In the following, after outpassing the area with speed limit, marked in the figure with , acceleration of the train being necessary until reaching maximum speed, a supplementary energy consumption is registered which is represented in the figure. Acceleration happens similar with breaking along a space marked with *Sd*. The size of this space depends on the value of the reduced speed, length of the train, its weight, the value of the declivity, the installed power of the engine vehicle, the adherence coefficient, the mechanic's ability, etc. The spread of kinetic energy in the moment of speed reduction, but also the overconsumption due to the acceleration, both represent values which are strictly due to the presence of the respective restriction. The weight which these values have towards the regular consumption necessary for movement with maximum constant speed depends directly or indirectly on a whole series of factors, most of them enumerated before.

OBSERVATION: out of travel safety considerate, the real speed of the train (*Sreal(t)*) represents a variable value which regularly must be at most equal with the maximum speed or the reduced speed. Out of those presented before comes the fact that the presence of a speed limit on a railway track implicitly generates supplementary energy consumptions. The frequenter that track area is circulated and the number of restrictions is higher, the higher will be the value of overconsumption.

4. STUDY OF THE IMPACT OF SPEED LIMITS ON ENERGY CONSUMPTION FOR THE BUCHAREST – PLOIESTI RAILWAY TRACK PART

With a view to the estimation of the values of energy overconsumption due to the presence of a high number of speed limits, the energetic behaviour of some passenger trains which belong to the SNTFC "RRW Passengers" SA national company will be analysed on Bucharest – Ploiesti distance with an approximate length of 60km.

For the rehabilitation and modernisation of the first railway track Bucharest – Campina, a segment which is part of the IVth Pan European Passage, about 225 million euros were spend in the first part of the 2000s. These investments were initially made with the purpose of creating a roll track on which, according to the projects, to travel with a maximum speed of 160km/h [7]. Unfortunately, at present time on this rehabilitated sector trains travel with a speed of 120km/h and only a few of them with 140km/h and on the whole distance permanent speed limits are present of 70 or 50km/h (table 2).

This situation was generated first of all by the lack of funds necessary for maintenance and reparation works. It is well known that after finishing the remake or modernisation of a railway track, a series of periodical maintenance works must be ensured, the cost of these being directly proportional with he maximum travel speed of the specific track.

In table 2 the nine speed limits which were present on the Bucharest – Ploiesti railway track in the decade 21-28 of February 2010 are presented. To be able to determine the real overconsumption generated by these restrictions, data registered by the counter installations on some of the electric railway engines belonging to SNTFC "RRW Passengers" SA were analysed. For every studied engine a pair of fast trains were taken into account (at present time Inter Regio), which were towed by these on the respective track part between 21-28 of February 2010.

The consumptions of electric energy which resulted for these trains are compared with the ones registered on the same track line and by the same pairs of trains through a period when no speed limit was available (table 3).

Table 2

Speed limits present on the two travel lines for the Bucharest – Ploiesti track part, values of the restricted speed, kilometric position for each of them.

Nr. crt.	Travel line I		Travel line II	
	Value of speed	Kilometric position	Value of speed	Kilometric position
1	50	7+020 – 7+675	50	7+020 – 7+675
2	70	13+550 – 13+600	70	9+900 – 9+950
3	70	16+450 – 16+500	50	30+950 – 31+200
4	70	52+000 – 52+300	80	47+050 – 47+100
5	-	-	70	52+050 – 52+100

Source: CNCF „CFR" SA – Track division, B.A.R. Bucharest, approving bulletin of speed limits, decade 21-28 of February 2010

Table 3

Speed limits present on the two travel lines for the Bucharest – Ploiesti track part, values of the restricted speed, kilometric position for each of them.

Nr. crt.	Travel line I		Travel line II	
	Value of speed	Kilometric position	Value of speed	Kilometric position
1	No speed limits were present			

Source: CNCF „CFR" SA – Track Division, B.A.R. Bucharest, approving bulletin of speed limits, decade 11-20 of December 2011

The values which resulted for the two analysed periods (21-28th of February and 11-20th of December 2011) are presented in tables 4 and 5. After calculating the differences between the values obtained in case of the two periods (the one in which nine restrictions are present on the track part and the one without restrictions) supplementary consumptions for the respective engines are reproduced in table 6.

Table 4

The value of consumptions registered between 21-28 of February 2010

Decade 21 – 28 of February 2010						
Nr. crt.	Date	Locomotive No.	Registered energy consumption			
			Bucharest North – Ploiesti South distance (Line I)		Ploiesti South – Bucharest North distance (Line II)	
			Active energy consumption [kWh]	Reactive energy consumption [kVARh]	Active energy consumption [kWh]	Reactive energy consumption [kVARh]
1	21/02 -2010	EA 324	1150	485	984	433
2	22/02 -2010	EA 397	1176	501	1007	471
3	23/02 -2010	EA 363	974	405	958	414
4	24/02 -2010	EA 891	1093	460	1055	446
5	25/02 -2010	EA 379	1501	566	680	259
6	26/02 -2010	EA 872	1075	467	1112	482
7	27/02 -2010	EA 692	1291	729	1104	617
8	28/02 -2010	EA 784	1301	756	1158	708
Total			**9561**	**4369**	**8058**	**3830**
Medium values			**1195**	**546**	**1007**	**479**

Registered data:

Locomotive: series 060EA, company CFR Călători SA
Train: Rapid 651/651, 10 carts, Maximum speed 140 Km/h
Registration date: 21 – 28 of February 2010
Magister: Bucharest – Ploieşti (rehabilitated area of the IVth Paneuropean passage)
Distance: 60 km

Table 5

Value of consumptions registered between 11 – 20 of December 2010

Decade 11 – 20 of December 2010						
Nr. crt.	Date	Locomotive No.	Registered energy consumption			
			Bucharest North – Ploiesti South distance (Line I)		Ploiesti South – Bucharest North distance (Line II)	
			Active energy consumption [kWh]	Reactive energy consumption [kVARh]	Active energy consumption [kWh]	Reactive energy consumption [kVARh]
1	11/12 -2010	EA 692	1218	753	884	543
2	12/12 -2010	EA 328	881	256	839	324
3	13/12 -2010	EA 131	845	311	838	390
4	14/12 -2010	EA 2004	798	504	729	533
5	15/12 -2010	EA 802	923	559	898	584

6	16/12 -2010	EA 335	957	392	902	467
7	17/12 -2010	EA 871	982	579	915	560
8	18/12 -2010	EA 613	875	322	802	353
Total			**7479**	**3676**	**6807**	**3754**
Medium value			**935**	**459**	**851**	**469**

Registered data:
Locomotive: series 060EA, company CFR Călători SA
Train: Rapid 651/651, 10 carts, Maximum speed 140 Km/h
Registration date: 11 – 20 of December 2010
Magister: Bucharest – Ploieşti (rehabilitated area of the IVth Paneuropean passage)
Distance: 60 km

Table 6

Value of the resulted supplementary consumptions

Resulted supplementary consumptions			
Bucharest North – Ploiesti South distance (Line I)		**Ploiesti South – Bucharest North distance (Line II)**	
Active energy [kWh]	Reactive Energy [kVARh]	Active energy [kWh]	Reactive energy [kVARh]
2082	**693**	**1251**	**76**

It comes out that only in a period of eight days those engines had on the Bucharest – Ploiesti distance a supplementary consumption of electric energy of **2082 kWh** (active energy) and **693 kVARh** (reactive energy) only for the Bucharest – Pliesti travel way (line I). For the Ploiesti – Bucharest travel way (line II) an overconsumption of **1251 kWh** (active energy) ad **76 KVARh** (reactive energy) resulted.

Although it is about the same analysed distance on both ways and trains with the same maximum speed (140 km/h), the differences between the calculated values are due to the altitude disparity between the two towns, Bucharest being higher (at about 85m) than the sea level, and Ploiesti at about 150m.

Summing up the two values the total supplementary consumption is obtained for both travel lines due to the speed limits which are present on this distance. A total of **3333 kWh** (active energy) and **769 kVARh** (reactive energy).

During one year, for the pair of analysed trains engines register an overconsumption of approx. **150 MWh** and **34,5 MVARh**. In reality though, the energy used in surplus has a much higher value, because in this study only a single pair of trains was analysed (passenger train with a maximum sped of 140 km/h). If all trains that travel during one year, passenger and goods trains, some with different types of drive (electric, diesel – electric, diesel – hydraulic etc.) are to be taken into account, real resulting values would be much higher.

5. REDUCTION OF ENERGY CONSUMPTIONS IN RAILWAY TRANSPORT THROUGH THE OPTIMIZATION OF THE DRIVING OF THE TRAIN

5.1. Introductive notions of optimal drive

In conformity with those mentioned in the first chapter, reduction of energy consumption in transports, especially in the railway field, aims at the projection and creation of means of transport with better energy efficiency, optimization of the drive regimes (optimal drive), at the draw up of efficient travel graphics, reduction of dead and waiting times, reduction of the number of speed limits, elaboration of efficient transport technologies through distribution of travel and transport requests of goods and passengers in relation to the multi-modal transport offer, the most efficient under the aspect of registered consumptions (with priority energetic ones) and the effects on the surrounding environment. All these precede the specialists' concern of a larger space – time coverage which the society, as a whole must acknowledge, which are those oriented towards the reduction of the social mobility need [1].

Optimal drive constitutes one of the basic technical problems in the exploit of transport systems.

In case of driving the train on a certain travel section which presents multiple limitations from the point of view of travel speeds but also in relation to the maximum towed weight, choosing a drive regime with corresponding minimum energy consumptions is a complex problem theoretically and practically as well.

According to those mentioned before, the optimal drive regime represents the combination of ways through which train speed can be varied while covering a distance between two points on the network, in such a way that a minimum energy consumption is obtained. Otherwise, minimum energy consumption, necessary for the drive of the train through such a regime can generate larger route duration (additional travel times).

Most of the time, in engineering matters related to optimal drive and exploit of trains, the choice of the most advantageous alternative from all points of view is made after the calculation of travel times, energy consumptions, depending on the case.

For example, in case of goods trains with large weight, where problems related to travel times do not have the same commercial involvement as in the case of passenger trains, minimum energy consumptions represent the main criterion in adopting different drive regimes.

What concerns passenger trains, not only energy consumption represents the main problem related to the exploit process. The size of the duration of the routes in the sense of their reduction occupies an important place in the field of passenger trains' exploit. That is why; an optimal drive regime in this case must generate minimum energy consumption, but also as short as possible route durations. The percentage these two criteria have in the travel of trains depends on their category, maximum speeds, number of carts (capacity), profile of the line, etc.

In theory, finding an optimal driving regime of the train leads to the approach of engineering calculation models for the solving of which mathematical methods of variation calculations and/or dynamic programing is used [8].

5.2. Example of determination of a driving regime through the dynamic programing method

To exemplify the solving of such a problem, which refers to the choice of the combinations of optimal regimes of driving a train on different profile elements of the roll track in such a way that for the entire route the energy consumption must be minimal, a section made up of 4 profile element (Fig. 5) will be considered. In this way it is a wish that between **O** and **F** energy consumption must be minimum. In order to simplify the calculation, it was assumed that for every profile element, depending on the speed of the train at the beginning of the profile element, three possible driving regimes can be adopted.

In table 7 energy consumptions for every drive type is presented in part.

The multitude of possible choices to be adopted, different sequences and activity of the criterion, places the problem in the category of solutions which are related to dynamic programing. Through this calculation method optimal strategy is obtained through the concatenation of potentially optimal strategies from every profile element in part.

Dynamic programing allows through the keeping of the rigour of the solution the substantial reduction of the number of possible alternatives. The calculation process takes places in the opposite direction of the evolution (from the end to the beginning) and takes place in stages. In every stage potentially optimal strategies are being calculated. This solution is based on Bellman's Optimality Principle [8], according to which in every moment the optimal strategy does not depend on the preceding solution (on the evolution of the system), but only on the state of the system at the given time and the choice related to the next evolution

In figure 5 the considered section with the 4 profile elements is presented, in case of which the optimal drive calculation will be made according to Bellman's optimality principle.

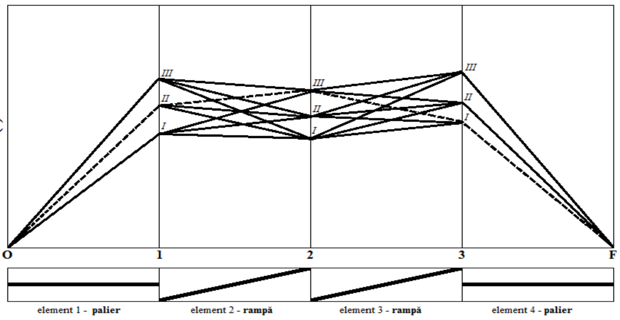

Figure 5. Towing section with 4 profile elements considered for calculation and possible drive regimes of the trains on this section.

Table 7

Values of energy consumptions for every possible drive alternative of the train with the four considered profiles.

Vertical from *i* ***Trajectory***	**Energy consumptions**			
	0	**1**	**2**	**3**
0 - I	90	-	-	-
0 - II	100	-	-	-
0 - III	110	-	-	-
I-I	-	60	70	-
I-II	-	70	75	-
I-III	-	80	80	
II-I	-	65	65	-
II-II	-	75	70	-
II-III	-	85	80	-
III-I	-	45	55	-
III-II	-	50	60	-
III-III	-	55	70	-
*I-**F***	-	-	-	30
*II-**F***	-	-	-	40
*III-**F***	-	-	-	50

In the following, for the establishment of the optimal drive regime of the train on the section considered in figure 5, the solving of the problem starts, from the final stage (profile element 4). On the last element (the vertical in point 3) the train can enter with three values of speed, to which following energy consumptions correspond until the stop of the train (point F):

On the earlier element (vertical in point 2) the train can also enter with three speed values. From every point on vertical 2 using the three different drive regimes one can get to any point in vertical 3. In the following the potentially optimal strategy will be found on this element, comparing all variants of the movement of the train after the minimum of total energy consumptions on the last two elements of the profile:

$$F_2 = min(Q_2 + Q_3):$$

$$F_2^I = min(30 + Q_3^I; 40 + Q_3^{II}; 50 + Q_3^{III}) = min\,(30 + 70; 40 + 75; 50 + 80)$$

$$= min(100; 115; 130)$$

$$F_2^I = 100 \ \rightarrow Q_2^I = 70(35?)$$

$$F_2^{II} = min(65 + Q_3^I; 70 + Q_3^{II}; 80 + Q_3^{III}) = min(65 + 70; 70 + 75; 80 + 80)$$

$$= min(135; 135; 160)$$

$$F_2^{II} = 135 \ \rightarrow Q_2^{II} = 65$$

$$F_2^{III} = min(55 + Q_3^I; 60 + Q_3^{II}; 70 + Q_3^{III}) = min(55 + 70; 60 + 75; 70 + 80)$$

$$= min(125; 135; 150)$$

$$F_2^{III} = 125 \ \rightarrow Q_2^{III} = 55$$

The potentially optimal strategy Q_2^I, Q_2^{II} □i Q_2^{III} (70; 65; 55) were marked on figure X with dotted line. Similarly, the conventionally optimal strategy is determined for the next profile:

$$F_1 = min(Q_1 + F_2)$$

$$F_1^I = min(60 + F_2^I; 70 + F_2^{II}; 80 + F_2^{III}) = min(60 + 100; 70 + 135; 80 + 125)$$

$$= min(160; 205; 205)$$

$$F_1^I = 160 \ \rightarrow Q_1^I = 60$$

$$F_1^{II} = min(65 + F_2^I; 75 + F_2^{II}; 85 + F_2^{III}) = min(65 + 100; 75 + 135; 85 + 125)$$

$$= min(165; 210; 210)$$

$$F_1^{II} = 165 \ \rightarrow Q_1^{II} = 65$$

$$F_1^{III} = min(45 + F_2^I; 50 + F_2^{II}; 55 + F_2^{III}) = min(45 + 100; 50 + 135; 55 + 125)$$

$$= min(145; 185; 175)$$

$$F_1^{III} = 145 \ \rightarrow Q_1^{III} = 45$$

Due to fact that the initial state of the system is uniquely determined (initial speed of the train V_0 = 0), in the last stage we only find one single optimal value (minimum) corresponding to the transfer function:

$$F = min \sum_{i=0}^{n-1\,(3)} Q_i = min(Q_0 + F_1) = min(90 + F_1^I;\ 100 + F_1^{II}; 110 + F_1^{III})$$

= min(90+160; 100+165; 110+145) = min(250; 265; 255)

$$F = 250 \ \rightarrow Q_0 = 90$$

This resulted optimal value is marked on the diagram with dotted line in the first profile element.

Starting with the first point O and successively going through the dotted lines marked on the diagram (corresponding to the potentially optimal strategies) until the final point F, we determine the optimal strategy of the whole process (the dotted bold lone). This will be:

$$F = Q_0 + Q_1^{III} + Q_2^{III} + Q_3^I = 250$$

Similarly, with the help of this method of dynamic programming problems of optimal consumption can be solved for any section of railway, including the introduction in the calculation of speed limits which can be considered as restrictive conditions to the limit of the respective profile elements on which these are present.

6. ECONOMIC EFFECTS DUE TO THE SPEED LIMITS FROM THE POINT OF VIEW OF ENERGY CONSUMPTION

Additional costs registered by the railway operators due to the overconsumption in the restricted areas must be compared to the value of necessary investments for the mending of the defects which are present at the elements of infrastructure. With a view to the technical-economic analysis of the restrictions and from the point of view of decision-making a choice must be made between earmarking funds necessary for remediation works of the dangerous points and areas in the network or assuming higher costs due to the resulted supplementary energy consumption. Taking into account that in Romania the administrator of the infrastructure RRW SA, the main railway passenger operator SNTFC “RRW Passengers” SA and the goods operator SNTFM “RRW Goods” SA are national companies in state property, it results that an economy in the investment budgets aimed for the reparation and maintenance of the infrastructure give to RRW SA causes indirectly through the effects of speed limits economic losses for the operators and implicitly for state budget [7]. It must be said that RRW Passengers SA operator is subventioned by the Romanian state only for insurance of transport activities, no for eventual additional costs due to railway infrastructure.

7. CONCLUSIONS

Fuel and electric energy consumption necessary for the process of towing trains represents an important element of the cost for the economy of a railway company or a private railway operator.

Another element that must be taken into account is the fact that Romanian regulations and legislation in the field do not offer railway companies deductions for the taxes on fuel consumption, although in European countries a special reduction is being applied in relation to these companies (for example in Italy the level of deduction for fuel taxes is of 70% and this way the price is approximately 35% lower than regular market level) [8].

Electricity consumption is lower than the fuel one, considering the same useful mechanic work made by the drive vehicle (the same useful weight transported on the same distance).Unfortunately, at present time on the whole RRW network over 500 dangerous points with speed limits are present, some of them having a huge difference between maximum and restricted speed (5, 15 or 30 km/h on areas of 100 or 120 km/h maximum speed).

The general consequence of all these mentioned before is first of all is the affection of state budget for railway transport and also sustaining the infrastructure at an optimal safety level imposed by legislation and regulations and second of all a reduction of he quality of the railway transport service, perceived by the traveling population and customers in case of goods transportation.

Necessary solutions to be adopted in order to solve or at least reduce the problems outlined before are the following:

✓ Initiation by the administrator of the infrastructure of a deepened and detailed study which concerns all dangerous points on the network and grouping them on several categories depending on the importance of the track on which each of them is present, the value of the traffic and maximum speed on that track part (this because in case of a secondary track which is scarcely travelled upon and has a low travel speed, the presence of a restriction generates an infamous economic end energetic effect and the start of ample investments in order to solve the problems which would not be repaired through the reduction of energetic consumption would not be justified);

✓ Making of economic calculations through which supplementary energy (electric energy and fuel) costs, due to the speed restrictions and limits from the intensely travelled main tracks could be quantified and centralise of these obtained data;

✓ Exact calculation of sums necessary for the remediation of every week or dangerous point on the network, which has as an effect a speed restriction or limit and comparing these with the value of supplementary consumption du e to these;

✓ Determination of the period in which supplementary costs generated by every restriction (mainly by those on the main intensely travelled tracks) reach the value necessary for remediation through repair works of the respective defect;

✓ Directing and allotting funds for repair and remediation works in case of restrictions on the network, in case periods calculated at the point before are small;

✓ Prioritization of these respective works, in case of magister intensely travelled tracks;

Through the implementation and materialization of all actions listed before, railway and The Ministry of Transport as well would obtain substantial economies at the budget for medium and long term through reduction of necessary energy costs. These sums could be channelled towards other investments and acquisitions of equipment which is necessary for the growth of the quality of railway transport services offered to the public, a trend in which most civilized countries already are.

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