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CIVIL ENGINEERING - SCIENCE AND PRACTICE

ŽABLJAK, 7-11 MARCH 2016

Zoran Krakutovski[1], Darko Moslavac[2], Zlatko Zafirovski[3]

APPLICATION OF SOFTWARE IN TRAIN RUNNING ANALYSIS FOR PROJECTS OF RAILWAY INFRASTRUCTURE

Summary

The application of software to design building structures is of great importance to the quality and efficiency of project documentation. The design for new railway lines needs to make train operating analyses that are essential in the process of evaluation and adoption of the most optimal alignment. Calculations of travel time and energy consumption can be done with specialized software. This paper presents the application of the software Railnet 2 for calculations of trains running time and energy consumption in pre-feasibility study for the project of a new railway line Pljevlja - Bijelo Polje, Berane border with Kosovo.

Key words

Railwy infrastructure, train running analysis, software

PRIMJENA SOFTVERA ZA ANALIZU KRETNJA VOZA U PROJEKTIMA ŽELJEZNIČKE INFRASTRUKTURE

Rezime

Primjena softvera u projektovanju građevinskih objekata je od velikog značaja za kvalitet i efikasnost projektne dokumentacije. U projektovanju novih željezničkih pruga neophodno je uraditi analize kretanja voza koje su od suštinskog značaja u procesu evaluacije i usvajanja najoptimalnije trase. Proračun vremena putovanja i potrošnje energije može biti urađen specijalizovanim softverima. U ovom radu je predstavljena primjena softvera Railnet 2 za proračun vremena kretanja vozova i potrošnje energije u pre-fizibiliti studiji za projekat nove željezničke pruge Pljevlja - Bijelo Polje, Berane granica sa Kosovom.

Ključne riječi

Željeznička infrastruktura, analiza kretanja voza, softver

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1. INTRODUCTION

Understanding of traffic intensity and track alignment elements are essential in the selection of type of locomotive and mass of train. The train running analysis make possible to determine the characteristics of train movement on the designed alignment. This analysis defines the weight of train, the speed of train running, the travel time, the energy consumption, and the capacity of railway network. The planned new railway line Pljevlja-Bljelo Polje-Berane-border with Kosovo should be electrified with single-phase alternating current system, voltage of 25kV and frequency of 50Hz. The usage of the software Railnet 2 concerns the train running analysis for above mentioned railway line in Montenegro.

2. THEORY BACKGROUND

The analysis of train running needs to determine the forces acting on train against their direction of travel. These forces are named resistance and they affect the acceleration or deceleration of train and train speed. For simplification of analysis, the train is treated as a material point set in the center of gravity of the train in which is concentrated all mass of the train. During the translational movement of the train could appear the following forces: Traction force (Z), Resistance force (W), Braking force (K).

The traction force is created in the locomotive and it causes the movement of the train. The different resistance forces appear when the train moves. The most of these forces are opposite to the direction of train running. The traction force should be greater than the resistance forces to be able the train accelerates and moves. The resistance forces are the result of constructive solutions of railway vehicles, conditions of track components and railway alignment. The resistance forces can be expressed in measure as a unit forces in SI system (N, daN, kN) or else in unit of masse (kg, t) in the case when the total force of resistance should be expressed, or as specific forces (specific resistances) which refer to one ton weight of train and then they are expressed in units of measurement N/kN, daN/t, kg/t, ‰ (ratio 1:1000).

The basic equation for the movement of train can be written in the following form:

$$Z(v) = M\frac{dV}{dt} + W_1(v) + W_2(s) \quad (1)$$

where:

Z(v) - traction force

$M\frac{dV}{dt}$ – resistance of inertia

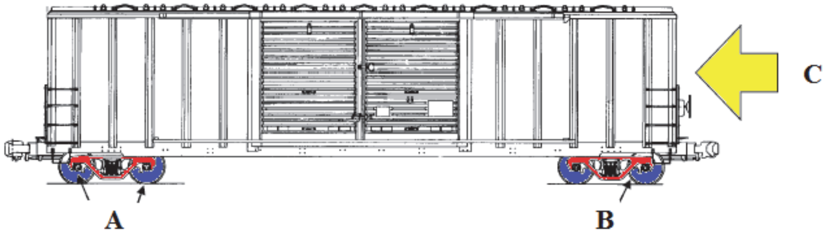
$W_1(v)$ – running resistance - mechanical and aerodynamic resistance when the train runs in horizontal and rectilinear section of railway alignment

$W_2(s)$ – local resistance caused by geometry of track alignment (curves, gravity of gradients and tunnels)

The formulas for determining running resistance are based on second degree polynomials introducing the speed V, and the general formula is written as:

$$W_1(v) = A + B \cdot V + C \cdot V^2 \tag{2}$$

According to the Davis [1], the first and second terms represent mechanical resistances, where the term A is independent of the speed and only depends on vehicle characteristics. The second term depends of train speed on first degree, and the third term depends of trains speed on second degree. The third term expresses the aerodynamic resistance (figure 1).



A- resistances that vary with axle load

B - resistances that vary directly with speed (effects of sway and oscillation)

C – resistances that vary as the square of speed (aerodynamics of the train)

Figure1. Sources of rail vehicle resistance

The local resistance caused by geometry of track alignment can result from horizontal curves, from gradient of longitudinal profile, and from section of line in tunnel.

The resistance due to the curves can be calculated using the following general formula:

$$W_2(s_c) = \frac{C}{R} \cdot G_{train} \tag{3}$$

where:

- C is a constant
- R is a radius of horizontal curve in (m)
- G_{train} is a mass of train

The resistance caused by the gradient of longitudinal profile can be calculated by the following formula:

$$W_2(s_i) = i \cdot G_{train} \tag{4}$$

where:

- i is a gradient in (‰)
- G_{train} is a mass of train

$$G_{train}=L+Q \tag{5}$$

- L is a mass of locomotive
- Q is a total mass of wagons in the train

3. FORMULAS FOR CALCULATION OF TRAIN RUNNING RESISTANCE

It is recommended to use the following formulas for calculation of specific train running resistance (mechanical and aerodynamic) concerning the wagons and cars for railway network in the ZYZ[1], according to the Instruction 52 [4]:

- For railway vehicles with sliding axle bearings:

$$w_k = 2{,}0 + (k + 0{,}007) \cdot \left(\frac{V}{10}\right)^2 \quad \text{in (daN/t)} \tag{6}$$

- For railway vehicles with roller axle bearings (newest vehicles)

$$w_k = 2{,}2 - \frac{80}{V+38} + (k + 0{,}007) \cdot \left(\frac{V}{10}\right)^2 \quad \text{in (daN/t)} \tag{7}$$

where:

- k is coefficient that depends on type of wagon and their construction as well as the degree of loading of vehicle (table 1)
- V is a speed of train in (km/h)

Table 1. Values of coefficent k

k=0,107	Freight train composed of empty wagons
k=0,057	Freight train with mixed composition
k=0,032	Heavy freight trains
k=0,033	Passenger trains composed of 2-axle and 3-axle wagons
k=0,025	Fast trains composed of 4-axle wagons

Source: Instruction ZYZ 52/89

The most frequently used formula for calculation of specific running resistance (mechanical and aerodynamic) of locomotives is Davis formula in the following form:

$$w_L = 0{,}65 + \frac{13{,}15}{P} + 0{,}02 \cdot V + \frac{0{,}0046 \cdot F \cdot V^2}{L} \quad \text{in (daN/t)} \tag{8}$$

where:

- P is an axle load in (t)
- V is a speed of train in (km/h)
- F is a frontal area of locomotive in (m^2)
- L is a mass of locomotive in (t)

The specific resistance of the whole train can be calculated with the following formula:

$$w_o = \frac{w_L \cdot L + w_k \cdot Q}{L+Q} \quad \text{in (daN/t)} \tag{9}$$

[1] *ZYZ – Railway lines in the former Yugoslav railway network*

4. ESTIMATIONS OF TRAIN RUNNING RESISTANCE

The electrical locomotive E461 is used to carry out the train running analysis for different railway alignment. The characteristics of locomotive E461 are shown on the next diagram:

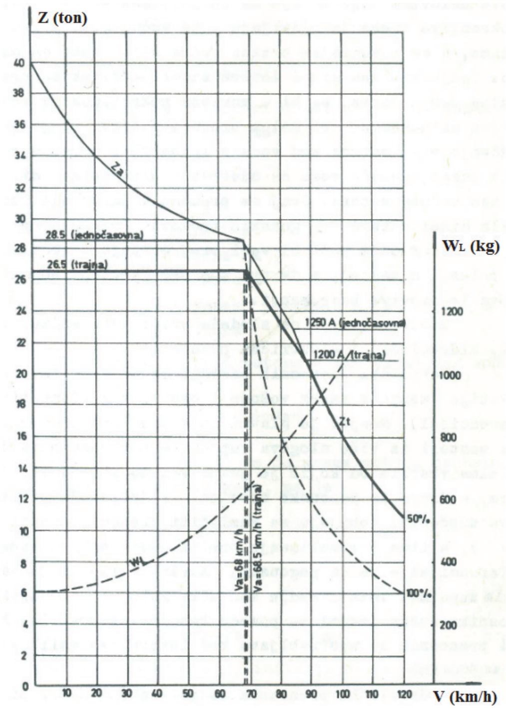


Figure2. Diagram traction force-speed for locomotive E461

The other characteristics of this locomotive are followings:

P = 20 t - axle load of locomotive E461

F = 11,5 m^2 - frontal area of locomotive E461

L = 120 t - mass of locomotive E461

The Davis formula for calculation of specific running resistance of locomotive E461 can be written as:

$$w_L = 1{,}3075 + 0{,}02 \cdot V + 0{,}00044 \cdot V^2 \quad \text{in (daN/t)} \qquad (10)$$

The derived Davis formula for calculation of specific running resistance of locomotive in the software Railnet 2 is following:

$$w_L = 3{,}5 + 0{,}006 \cdot V + 0{,}00059 \cdot V^2 \quad \text{in (daN/t)} \qquad (11)$$

The specific running resistance for wagons and cars in the train is calculated according to the formula (7), while the software Railnet 2 uses the following formula:

$$w_L = 1{,}5 + 0{,}003 \cdot V + 0{,}00054 \cdot V^2 \quad \text{in (daN/t)} \qquad (12)$$

The results for specific running resistance did not differ significantly when it is used ZYZ formula and formula in the software Railnet 2 (table 2). The calculations are made for freight train with mass of 800t.

Table 2. Results of calculation of specific running resistence of the whole train

Speed V (km/h)	w_o (daN/t) - ZYZ	w_o (daN/t) – Railnet 2	Differnece
0	0,86	1,76	0,90
20	1,30	1,85	0,55
40	2,97	2,77	-0,20
60	4,71	3,93	-0,77
80	6,84	5,53	-1,31
100	9,84	7,57	-2,28

Source: our calculations

The total forces of resistance are obtained adding the train running resistance, which depends on speed of train and mechanical conception of railway vehicles, and local resistance due to the geometry of railway line.

5. PRINCIP OF CALCULATION USING RAILNET 2

The software Railnet 2 is a product of EPFL[1] in Lausanne. The process of calculation begins by entering the input data. Each railway section between two stations is divided into geometrical homogeneous segments (figure 3).

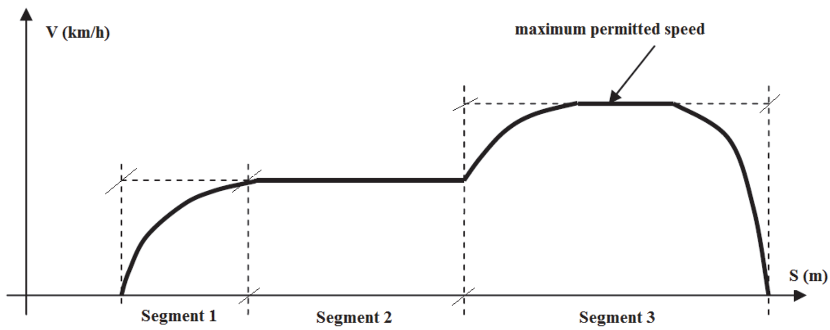


Figure3. Division of railway alignment on geometrical homogeneous segments

One basic homogeneous segment is defined by:

- Maximum permitted speed
- Constant gradient and curvature of the track
- Signs which allow determining if the section is in a tunnel or on open line.

[1] *EPFL- Ecole Polytechnique Fédérale de Lausanne (Swiss Federal Institute of Technology)*

The calculation of the running time and energy consumption is done on each segment of the railway alignment using the differential equations of train movement as following:

$$\frac{dV}{dt} = \frac{Z - W}{M \cdot (1 + \rho)} \tag{13}$$

where:
- Z is a traction force
- W is a total resistance of train running (running resistance and local resistance)
- M is a mass of train
- ρ is a mass inertia coefficient taking into account both the fixed and the rotating masses of rolling stock; ρ=1,2 for locomotives, ρ=1,1 for passenger cars, and ρ=1,02 for freight wagons,

The consumption of energy (electricity) for traction is obtained by the following formula:

$$E = \int N dt = \int \frac{1}{n_t} \cdot Z \cdot V \cdot dt \tag{14}$$

where:
- N is a power of the locomotive
- Z is a traction force
- V is a train speed movement
- n_t is a coefficient of efficiency of energy transmission
- t is a time interval

The basic technique of calculation of travel time and energy consumption with the software Railnet 2 is shown on the next figure (figure 4):

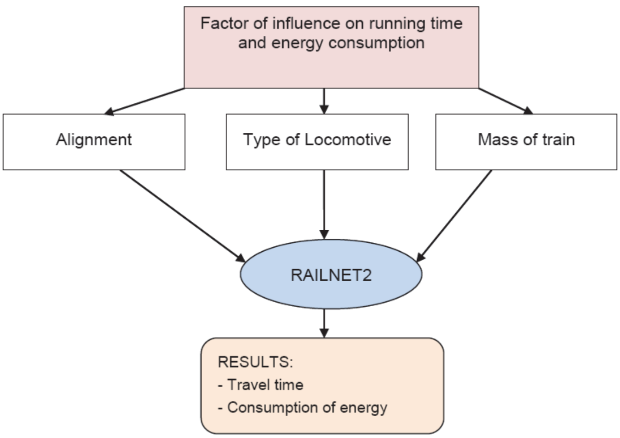


Figure4. Principal of calculation with Railnet 2

The calculation of train running time and consumption of energy is done with the software for seven alignment variants from Pljevlja to Bijelo Polje and for five alignment variants from Bijelo Polje – Berane to Kosovo border. The outputs of these calculations are used in the multi-criteria analysis for alignments assessment. For each variant of alignment the software can plot the schema of longitudinal profile, and the geographic position of stations.

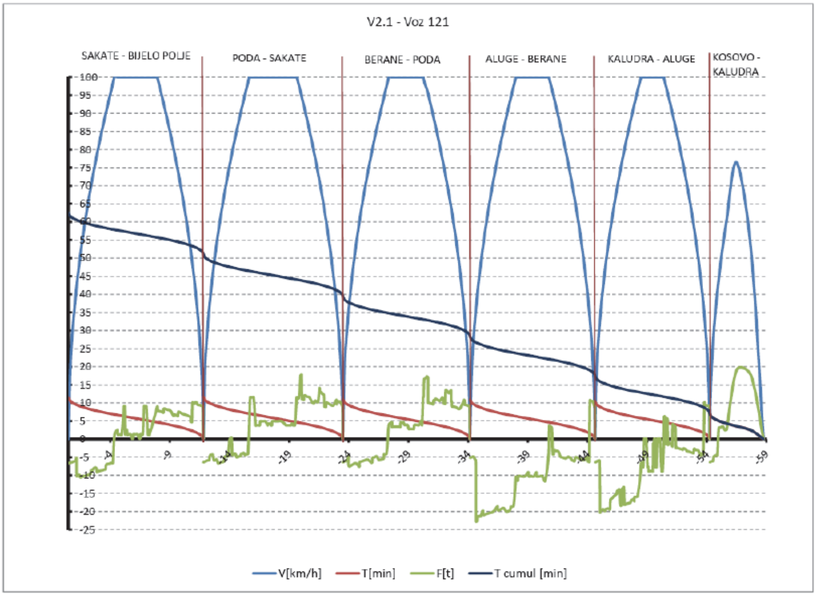


Figure5. Example of calculation with Railnet 2 – train running time

6. CONCLUSIONS

The usage of software for train running analysis is a useful approach to improve the quality of analysis and to obtain faster results. Nevertheless, the usage of software should be affected prudently because there are diverse rolling stocks in each country. This means that the standards and lifetime of railway vehicles (locomotives, coach, wagons, and cars) should be considered, verified and adapted in the software data base, before the process of calculation.

REFERENCES

[1] W. J. Davis: "The tractive resistance of electric locomotives and cars", General Electric Rewiew, vol.29, October 1926

[2] Dušan Bajić, "Osnovi projektiranja železničkih pruga", Gradjevisnki fakultet u Beogradu, Beograd, 1978, p. 334

[3] V.A. Profillidis, "Railway Management and engineering", Third edition, Ashgate Publishing Company, Burlington, USA, 2006, p.469

[4] Zajednica Jugoslovenskih Železnica – ZJŽ, "Uputstvo o tehničkim normativima i podacima za izradu i izvršenje reda voznje, br.16-3/257, Beograd, 1989, p.411

[5] R. Rivier, "Le vehiclule ferroviare et sa dynamique – System de transport I", Document n.401/2, Institut des Transports et de Planification, Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Swizerland, 1997, p.69