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COMPARATIVE ANALYSIS OF TRAIN TRAFFIC USING SIMULATION MODELS

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Abstract *– Trains move in a specific way, along a pre-determined path, i.e. rails. The wheels of railway locomotives and rails are steel, and because of this, it is possible to achieve very high speeds, with relatively low resistance to movement. Analysis and research related to the movement of trains are very important from many aspects, especially for traffic safety. In this paper, a simulation of train movement under realistic conditions was performed. The simulation was created using the Python programming language. Infrastructure data, locomotive data, and resistances were used as input data, which Python later converts for simulation. The results of the simulation are presented both graphically and numerically. All data used in the Python simulation model was also input into the verified railway simulation software OpenTrack. The results from both tests were compared and analyzed, and a report was generated on the feasibility of using the created program in real-world scenarios.*

Keywords – traction, braking, simulation, open track.

1. INTRODUCTION

Railway systems involve significant expenses during both construction and operation. From this perspective, it is essential to build a system without deviations or to minimize them to an acceptable level. Creating realistic conditions under which the railway system can be tested is challenging and usually unprofitable. Therefore, simulation models are necessary to predict and analyze various operational scenarios before the actual construction and implementation of the railway system.

Simulation models allow engineers and planners to evaluate the system's performance under different conditions, identify potential bottlenecks, and optimize design choices without incurring the high costs associated with physical testing. These models can simulate various factors, such as train speed, track resistance, signal systems, and interactions between trains and infrastructure. By utilizing simulation models, engineers can assess how the railway will perform in real-world conditions, ensuring that all critical parameters are met. This approach enables more efficient planning, helps avoid costly adjustments during or after construction, and ensures that the final system operates smoothly within predefined safety and performance limits.

The theory of traction studies the basics and methods for calculating traction to determine the optimal conditions for train movement. The basic elements of traction theory in railway track design provide a foundation for defining the movement characteristics and regimes of a train on the projected route. To perform a traction calculation in simulation models, it is necessary to identify the forces acting on the train during movement and define the conditions of train movement. To simplify the calculation while maintaining a certain degree of accuracy, the train's mass is assumed to be concentrated at its center of gravity, with a mass corresponding to the total mass of the train. During train movement, the following external forces act on the train [1]:

- Traction force
- Resistance to movement
- Braking force

The values implemented in the simulation should be derived from the list above. Additionally, the formulas used to calculate train movement should be recognized and scientifically validated. These formulas may vary across different countries due to differences in

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equipment and technology used.

Simulations can be developed using various programming languages, but the core results remain consistent across platforms, with differences arising mainly in efficiency, scalability, and user interface designs.

2. MODELLING IN PYTHON

Modelling of train movement consists out of four parts:

1. Forming basic formulas for train traction,
2. Integrating these equations with topology and resistance data,
3. Calculating train braking,
4. Representing the results graphically.

The specific active traction force is the force that remains after subtracting the resistances from the tractive effort, and it is used for train acceleration:

$$F_{va} = F_v - W \text{ [daN/t]} \quad (1)$$

Where:
F_v – traction effort,
W – resistance force.

If the active traction force is greater than zero, the train is accelerating. If the active traction force equals zero, the train is moving at a constant speed. If the active traction force is less than zero, the train is decelerating. The traction force is calculated from the tractive effort diagram using the equation of a line through two points:

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1) \quad (2)$$

Figure 1 below illustrates the traction effort.

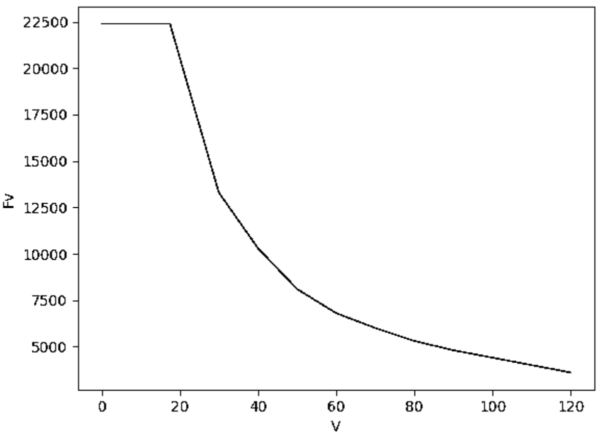

Fig.1. Tractive effort diagram

The resistance of the locomotive was also calculated using the same formula. For each speed range, there is a corresponding value of resistance and traction force. For railway wagons with rolling axle bearings, the following formula is used to calculate specific resistance [2]:

$$w_{ok} = 2.2 - \frac{80}{V+38} + (k + 0.007) \cdot \left(\frac{V}{10}\right)^2 \text{[daN/t]} \quad (3)$$

Where:
k - coefficient that depends on the type of wagon,
V – current speed

Temporary resistances acting on the train include slope resistances and curvature resistances. Tunnel resistances have not been included. The specific resistance of a slope is defined as:

$$w_i = i \text{ [daN/t]} \quad (4)$$

Where:
i – gradient in ‰.

The analytical expression for calculating the specific curvature resistance for curves with a radius greater than 272 meters is:

$$w_k = \frac{650}{R-55} \text{ [daN/t]} \quad (5)$$

Where:
R-radius of curve in meters.

After defining the temporary resistances, the next step is to calculate the fictive slope. This involves calculating the resistance of each individual curve (or just a segment of the curve) located on the observed gradient. Sum all the resistances from the curves and transfer the data to the fictive slope resistance. The resistance of the gradient section w_{i1}, with curve resistance w_{k1} on it, is equal to the resistance of the gradient without the curve w_{i2}, where:

$$w_{i2} = w_{i1} + wk_1 \text{ [daN/t]} \quad (6)$$

By combining all the given formulas, the calculation of small increments in time and distance is achieved, with speed as a variable parameter. The speed value is increased by 0.1 km/h for each case. The time increment is defined as:

$$\Delta t = \frac{\Delta v}{2 \cdot (|F_{va}(v)| + \frac{|F_{va}(v+\Delta v)|}{2})} \text{ [s]} \quad (7)$$

Where:
$F_{va(v)}$ - Specific active traction force for initial speed
$F_{va(v+\Delta v)}$ - Specific active traction force for the initial speed with a speed increment

Distance increment is defined as:

$$\Delta l = \frac{(2 \cdot v + \Delta v)}{2} \cdot \Delta t \text{ [m]} \quad (8)$$

Where:
v- starting speed
Δv – speed increment
Δt – time increment

Once the speed reaches the maximum value input by the user, or the train reaches the last point where brakes are applied - regardless of whether the maximum speed has been reached - the calculation stops. The sum of all small distance increments represents the total distance traveled from the start to the braking point. Similarly, the sum of all small time increments represents the total travel time from the start until the train reaches the braking point.

After reaching the braking point, the next step is calculating the braking distance. Braking Distance is the distance the train travels from when the train driver makes a full-service brake application to when the train stops [3]. Braking distance small increment calculation include:

$$\Delta l = \frac{4.13(v_{1+\Delta v}-v_1)}{\mu\cdot\delta\cdot\beta+w_{okavg}+w_{i2}}\,[\mathrm{m}] \qquad (9)$$

Where:
$v_{1+\Delta v}$ – initial speed with speed increment,
v_1 – initial speed,
μ – adhesion coefficient,
δ – braking weight percentage,
β – pressure coefficient,
w_{okavg} – average specific resistance of railway wagons between the initial speed and the initial speed with increment,
w_{i2} – fictive gradient resistance

The distance for which the brake pressure is fully developed must be included, along with the distance the train travels during the driver's reaction time. This is calculated using the basic formula for distance traveled over time at a given speed. The final step involves generating graphical speed/distance curves, which represent the total distance covered during acceleration, any constant speed phase (if applicable), brake preparation distance, and braking distance.

3. INPUT PARAMETERS

The input parameters include all variables used in the equations. For testing the model, infrastructure data from mainline track number 109, covering the section from station Batočina (km 3+405) to station Jovanovac (km 22+335), was utilized. Locomotive data was sourced from the tractive effort diagram of locomotive 661. Remaining variables were directly entered into the Python environment for calculation.

4. TESTING PYTHON MODEL

Two tests were conducted using the Python model, and the results were later compared with Open Track. Below are the input data for Python Test 1:

- Speed: 80 km/h
- Train mass: 1000 t
- Braking weight percentage: 100%
- Adhesion coefficient: 0.14
- Speed increment: 0.10 km/h
- Pressure coefficient: 5.60

Python 1 output data:

- Distance to braking point: 18 286 m
- Time to braking point: 18.81 min
- Braking distance: 589 m
- Braking time: 0.69 min
- Braking point speed: 73 km/h
- Constant speed distance: 0 m

The following figure 2 shows the output.

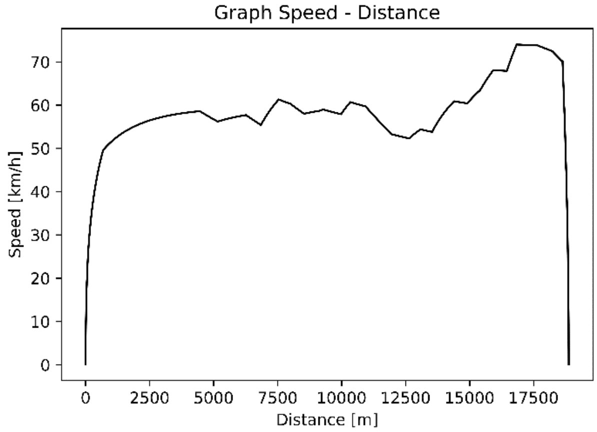

Fig.2. Python test 1 - speed/distance graph

Python test 2 input:

- Speed: 80 km/h
- Train mass: 600 tones
- Braking weight percentage: 100%
- Adhesion coefficient: 0.14
- Speed increment: 0.10 km/h
- Pressure coefficient: 5.60

Python test 2 output:

- Distance to braking point: 18 164 m
- Time to braking point: 15.20 min
- Braking distance: 711 m
- Braking time: 0.77 min
- Braking point speed: 80 km/h
- Constant speed distance: 2 752 m

The following figure 3 shows the output.

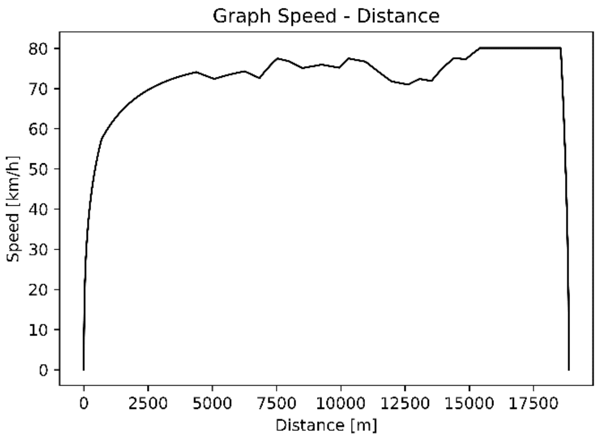

Fig.3. Python test 2 - speed/distance graph

5. TESTING OPEN TRACK MODEL

The testing in Open Track utilized the same parameters as the Python model to ensure consistent comparison. All necessary data were included, and the OpenTrack Test 1 output data is as follows:

- Distance to braking point: 18 322 m
- Time to braking point: 18.97 min
- Braking distance: 553 m
- Braking time: 0.61 min
- Braking point speed: 73 km/h
- Constant speed distance: 0 m

The following figure 4 shows the output.

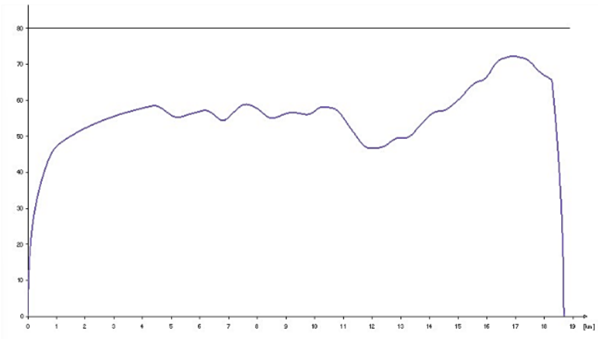

Fig.4. Open Track test 1 - speed/distance graph

Open Track test 2 output data:

- Distance to braking point: 18 207 m
- Time to braking point: 15.64 min
- Braking distance: 668 m
- Braking time: 0.70 min
- Braking point speed: 80 km/h
- Constant speed distance: 2 766 m

The following figure 5 shows the output.

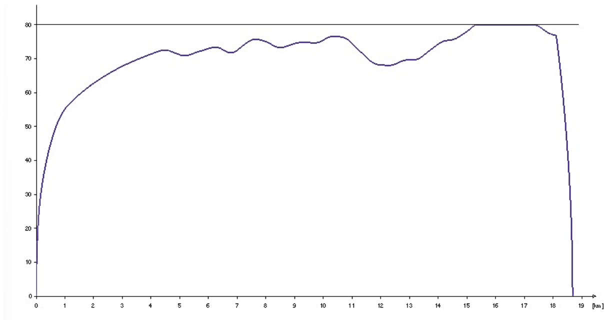

Fig.5. Open Track test 2 - speed/distance graph

6. CONCLUSION

The core objective of this research is to accurately approximate the movement results of a railway vehicle, aiming to determine the maximum thresholds the train can reach during the design phase. The accuracy of the data obtained from this program was validated through a comparative analysis with data from OpenTrack. The program demonstrated a high degree of precision, despite some resistances being omitted. The models illustrate how changes in one parameter affect the train's movement. By incorporating additional parameters, the program would depict the train’s movement along the section with substantially higher accuracy. This model serves as a tool for engineers, enabling them to estimate key data without needing to create complex datasets.

REFERENCES

[1] Zdenka Popović, Osnove projektovanja železničkih pruga, Beograd, 2004

[2] Dimitrije Dinić, Vuča vozova, Beograd, 1986

[3] David Barney, David Haley, George Nikandros, Calculating train braking distance, Proceedings of the 6th Australian Workshop on Safety Critical Systems and Software (SCS'01), Brisbane, Australia, 2001