Traffic of multi-car trains in marshalling yards

Konstantin Kornienko[1,2*], *Sergey* Kolarzh[3], *Oksana* Pokrovskaya[2,] *Inga* Drozdova, and *Ivan* Olgeizer[1,4]

[1] Rostov Branch of JSC NIIAS, 44/13, Lenina, 344038 Rostov-on-Don, Russia
[2] Emperor Alexander I St. Petersburg State Transport University, pr. 9, Moskovsky 199178 St. Petersburg, Russia
[3] Siberian Transport University, 191, Dusi Kovalchuk, 630049 Novosibirsk, Russia
[4] Rostov State Transport University, squer, 2, Rostovskogo Strelkovogo Polka Narodnogo Opolcheniya, 344038 Rostov-on-Don, Russia

Abstract. Developing rail transport is one of the world's greatest challenges. Rail transport reduces emissions and is the most energy efficient means of transport. An important element of the railways is a hump yard, where rolling stock is formed. The purpose of this article is to describe the mathematical apparatus for calculating the speed of a multiple unit train at a marshalling yard. As a calculation method, the articulated-axis model is used. In this model, the trailer is not seen as a material point, but as several physical bodies. Due to this model, it is possible to simulate multi-carriages moving along heterogeneous profile. It was found that for multi-car trailers the spread of the main co-protection will be lower than for single-car trailers. In addition, as a result of accounting for multi-car trains, the profile requirements are reduced when calculating marshalling yards. The results obtained can be used to design hump yards and automate existing hump yards. Keywords: marshalling yard, simulation, mathematical model, coupling (uncoupling), wagon, basic specific resistance, total specific resistance, resistance from medium and wind, wind load

1 Introduction

One of the most important areas of development for the global community in the long term is the transition from non-renewable energy sources to reduce carbon dioxide emissions into the atmosphere. The key challenge is to reduce the amount of energy required to move people and goods. Based on statistics, rail transport is the most energy-efficient. Therefore, the European Union has adopted a railway transport development programme [1-11].

Freight transport can be divided into two large groups: Block Train Load (BTL) and Single Wagon Load (SWL). BTL is a formation method where all wagons in a train go from one consignor to one consignee to one location. Such wagon formation methods are typical for very large enterprises or in intermodal transport, for example when containerised goods are transported from one port terminal to another by rail.

Single Wagon Load (SWL) is the transport of goods in individual wagons or groups of wagons, where the consignment is smaller than the entire train. SWL is mainly used by small

* Corresponding author: Kkonstantini@mail.ru

and medium-sized businesses. An important element in SWL is marshalling, because it is necessary to dispatch fully-formed trains with maximum load capacity, consisting of wagons of different destination. Statistics show that SWL accounts for only 27% of all rail transport in Europe. The reason for this is the significant time losses for shippers. About 10-50% of SWL delivery time is spent on shunting operations at marshalling yards.

In order to attract customers to rail transport, shunting times need to be reduced and, consequently, shunting times need to be reduced. In this context, the European Union would be interested in the experience of the Russian Federation, which has long been one of the leaders in the development of rail transport. The concept of reducing shunting time has been implemented in our country since the 2000s and a large number of articles have been devoted to it [12-22].

For the development of marshalling yards, it is necessary to increase the automation of marshalling yards. An important element in automation is proper design of a marshalling yard. In the Russian Federation, for the design of marshalling hills, calculated runners with specified parameters are used. Many authors point out that this design approach is not correct. It is necessary to apply simulation modelling. The paper gives a mathematical model of multi-car detachment movement.

2 Methods

The speed of the uncoupling can be calculated using the formula [23-25]:

$$\upsilon = \sqrt{\upsilon_{in}^2 + 2g' * \sum_{i=1}^{n} (l_i * (i_i - W_i))} \tag{1}$$

Here υ_{in} is initial velocity, m/s;

g' is gravity acceleration, considering inertia of rotating masses, m/s^2;

l_i is length of i-th section, m;

i_i is slope of the i-th section, %o;

W_i is total specific resistance of the wagon on the section, N/kN.

A large proportion of wagons are discharged on hills as part of multiple-car detrains. A multiple wagon train can be represented as a group of wagons, each of which has its own characteristics. The wagons are interconnected by means of a coupling device, which can be represented as a completely non-stretch thread. The basic specific resistance of a multi-car detachment can be found using the following formula:

$$w_O^{\text{coup}} = \frac{\sum_{i=1}^{n} (w_O^i * m_i)}{m_{\text{coup}}}, \tag{2}$$

where w_O^i defines basic specific resistance of the i-th wagon in the uncoupling, N/kN;

m_i is mass of the i-th wagon in the uncoupling, t;

n is number of wagons in the uncoupling, pcs.;

m_{coup} defines uncoupling mass, t.

The forces acting on the trailer are almost never constant values. Consequently, formula (1) can be used if the distance travelled is short, i.e., simulation models with a defined small step can be used. A sorting slide consists of many sections with different gradients. When calculating the movement of multiple wagons, each wagon can drive on a section with a different gradient. This complicates the mathematical model of movement. In the 1970s, an articulated-axis model of the trailer's movement was proposed to simplify the mathematical model of movement. The main feature of this model is to calculate the speed of the trailer as a physical body consisting of several wagons. To do this, an equivalent gradient is substituted in formula (1), which is calculated using the following formula:

$$i_{\mathrm{EKV}} = \sum_{j=1}^{n} \left(q_j \sum_{k=a_j}^{b_j} i_k \right), \tag{3}$$

where n is the number of wagons in the uncoupling;

q_j is specific axle load of the j-th wagon:

$$q_j = \frac{m_j}{\mu_j m_O}, \tag{4}$$

here μ_j is a number of axles of the j-th wagon;

a_j is the number of the first axle of the j-th wagon in the overall axle array:

$$a_j = 1 + b_j - \mu_j, \tag{5}$$

here b_j is the number of the last axle of the j-th wagon in the overall axle array:

$$b_j = \sum_{c=1}^{j} \mu_c, \tag{6}$$

here μ_c is the number of the c-car axles;

i_k – is the actual gradient along which the k-th axis moves at the displacement ΔS, ‰:

$$i_k = \frac{\sum \left(i_p l_p \right)}{1 * \Delta S}, \tag{7}$$

where ip, lp define the gradients and lengths, respectively, of the profile elements on which the k-th axle of the coupling moves at the displacement ΔS.

3 Results

Based on formula (2), increasing the number of wagons in a coupling will reduce the dispersion of the basic drag characteristics of the coupling. With an increase in the number of wagons in the trailer, the RMS deviation and dispersion will decrease. In this case the average value of the basic specific resistance in case of increase in the number of wagons of the same weight category does not change, but is a constant value. The increase in the weight of the trailer causes the expectation of the standard unit resistance to decrease, and the spread of the distribution parameters also becomes smaller.

If the trailer consists of wagons of different weight classes, all parameters of the distribution change.

When wagons of different weight categories are processed the mathematical expectation depends on the number of wagons in the coupling. When the number of wagons in the carriage increases, the mathematical expectation of the basic specific resistance of the carriage decreases. This is due to the fact that the average number of high-capacity wagons with low basic resistance to a wagon movement and high value of unit mass increases.

The dependences of mathematical expectation, standard deviation and asymmetry on the number of wagons in the carriage can be approximated by a hyperbolic curve. The distribution coefficient, as is done for trailers of the same weight category, cannot be distinguished, as the structure of the wagon flow has a great influence on this coefficient.

An increase in the number of wagons in a coupling leads to a decrease in all the parameters of the distribution. If the number of trailers is large, the gamma distribution of the basic specific resistance to wagon movement can be replaced by the normal distribution.

Figure 1 shows the distribution curves of the basic specific resistance for single-car and multi-car trailers.

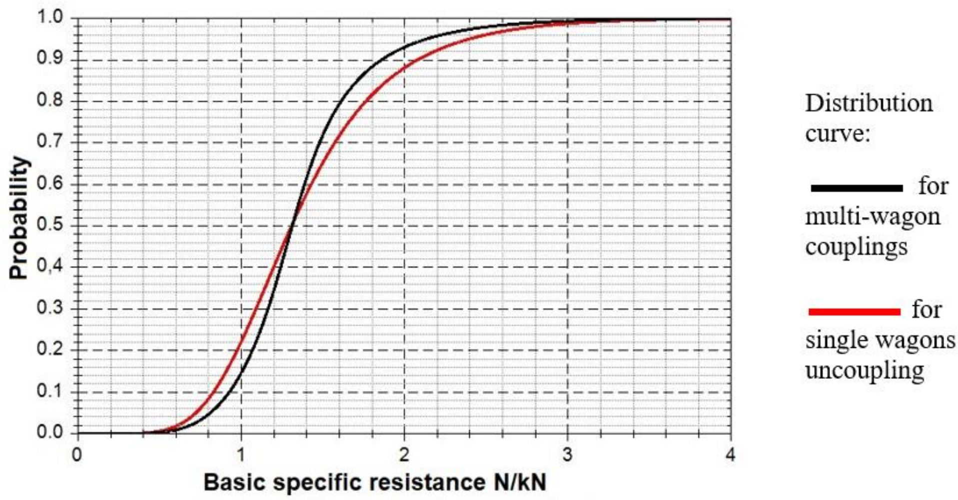

Fig. 1. Distribution curves of the basic unit resistance for multi-car and single-car trailers of mixed weight category.

The following conclusions can be drawn from Figure 2:

The distribution of the basic unit resistance is greatly influenced by taking into account the structure of wagon and trailer traffic. This influence is especially noticeable on the dispersion and asymmetry of the distribution, since these parameters decrease when the probability of occurrence of multi-car trains increases.

The distribution curve constructed by taking into account the wagon and detrainer structure differs from the curve for single wagon detrains. Consequently, the structure of wagon and uncoupling flow must be taken into account when calculating marshalling yards.

For the research the simulation model of movement of the uncoupling in the marshalling yard, constructed on the basis of Sort Park 1, was used. Modelling was made for a way of marshalling yard. The length of marshalling yard was taken as 950 metres. The actual and normative profile for the track is shown in Figure 2, with a continuous and dashed line, respectively.

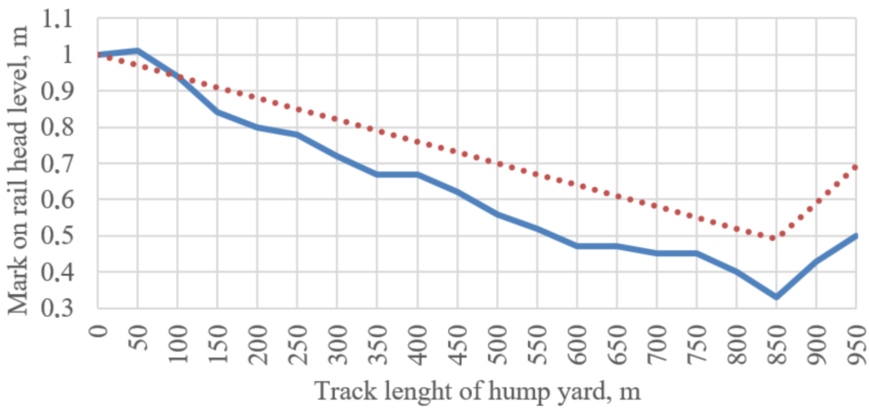

Fig. 2. Track profile of the marshalling yard.

Average ambient air temperature for the month of March +5°C. Wind speed 5 m/s. The angle between the wind direction and the axis of the section of track along which the trailer is moving is taken to be 180 degrees (the wind blows towards the movement of the trailer).

The trailers were released with a park braking position at a speed of 3 m/s. The weight of each car in the trailers was selected to be the same. The first trailer (red line) is a single-car trailer. The second trailer (blue line) consists of 5 wagons. Figure 3 shows the relationship for wagons weighing 85 tonnes.

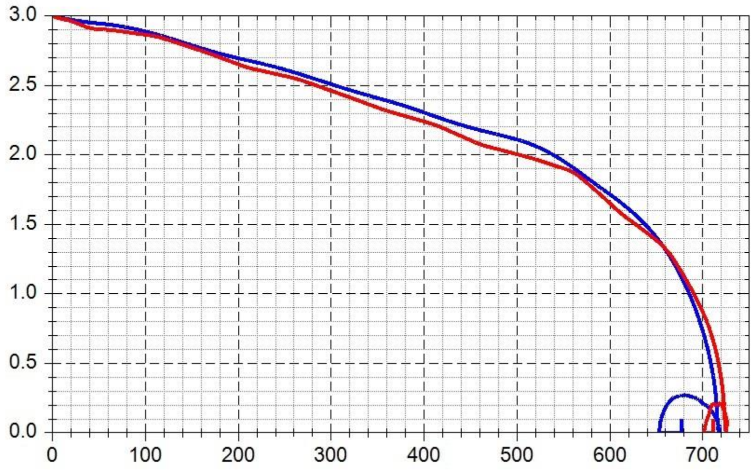

Fig. 3. Dependence of travel speed on distance travelled for wagons weighing 85 tonnes.

Based on Figure 4, it can be concluded that changes in the longitudinal profile also have a significant impact on the movements of multi-car trailers. On the curve of single wagon trailers it is possible to notice sharp changes in speed, due to the change in acceleration, when the trailer enters a section with a different gradient. Due to the fact that the multi-car trailer is on different sections at the same time, the change in its acceleration is noticeably smoother.

4 Discussion

The following conclusions can be drawn from the results of the study:

- The paper presents the results of the study of the influence of wagon and trailer traffic on the distribution of the specific resistance to the movement of trailers. It was found that the weight category of the wagons has a significant impact on the distribution. When the number of heavy wagons is increased, the dispersion of the distributions decreases. As a result, the probability of occurrence of runners with increased or decreased total resistivity decreases.
- The received conclusions testify to impossibility of calculation of a marshalling complex by means of mathematical formulas only. For the designing of marshalling yards it is necessary to apply a method of simulation, which will take into account a big number of variable factors and will have a higher accuracy in comparison with a mathematical calculation. Besides that, it is possible to make experiments on such models which is an undoubted advantage when calculating the economic effect of the planned modernisation and when choosing equipment for the equipment of a marshalling yard.
- The distortion of the hump profile has a significant effect on the speed of the trailers. The lower the total specific resistance of the trailers, the greater the influence of distortion. Trailer units with low total resistance must be released from the slide with special care. Due to the strong profile sagging, it is impossible to determine the exact position of such trailers along almost the whole length of the marshalling yard.

Further research should be aimed at developing methods to calculate hump marshalling yards, taking into account the number of wagons in a trailer.

References

1. *European transport strategy 2011-2021 D4.1 Identification of relevant information about train classification process and marshalling yard sorting methods*
2. Li Chou-Huai, Lou Dau-Hua, Chu Lei, Chu Bo-Hua, IFAC Proceedings Volumes **14(2)**, 2391-2394 (1981) https://doi.org/10.1016/S1474-6670(17)63825-4
3. M. Mezitis, V. Panchenko, M. Kutsenko, A. Maslii, Procedia Computer Science **149**, 288-296 (2019) https://doi.org/10.1016/j.procs.2019.01.137
4. A. Motraghi, Research in Transportation Economics **41(1)**, 76–83 (2013) doi:10.1016/j.retrec.2012.10.001
5. Ž.A. Zoran, European Journal of Operational Research **85(3)**, 504-514 (1995) https://doi.org/10.1016/0377-2217(92)00129-9.
6. C. Zhang, Seventh International Conference on Natural Computation, 1270–1274 (2011)
7. C. Zhang, Y. Wei, G. Xiao, Z. Wang, J. Fu, Proceedings of Second International Conf. on Transportation and Traffic Studies, 285–290 (2000) https://doi.org/10.1061/40503(277)45
8. S. Zarecky, J.Grun, J. Zilka, Transport Problems **3(4)**, 87-95 (2008)
9. L. Zhang, M. Jin, Z. Ye, H. Li, D. Clarke, Y. Wang, Transportation Research Record: Journal of the Transportation Research Board **2608**, 125-133 (2017) https://doi.org/10.3141/2608-14
10. I. Belošević, Comput. Aided Civ. Infrastruct. Eng. **33(3)**, 220–242 (2018)

11. V. Medvedev, I. Teslenko, S. Karasev, MATEC Web of Conferences **216**, 02013 (2018) https://doi.org/10.1051/matecconf/201821602013.
12. N. Kovalenko, A. Borodin, E3S Web of Conferences **164**, 03010 (2020) https://doi.org/10.1051/e3sconf/202016403010
13. D. Kozachenko, V. Bobrovskyi, Y.A. Demchenko, J. Mod. Transport. **26**, 189–199 (2018) https://doi.org/10.1007/s40534-018-0161-2
14. M. Mezitis, V. Panchenko, M. Kutsenko, A. Maslii, Procedia Computer Science **149**, 288-296 (2019) https://doi.org/10.1016/j.procs.2019.01.137
15. V. Bobrovskyi, D. Kozachenko, A. Dorosh, E. Demchenko, T. Bolvanovska, A. Kolesnik, Transport problems **11(1)**, 147-155 (2016) https://doi.org/10.20858/tp.2016.11.1.14
16. J. Prokop, Sh. Myojin, Memoirs of the Faculty of Engineering, Okayama University **27(2)**, 41-58 (1993)
17. J. Prokop, Sh. Myojin, Memoirs of the Faculty of Engineering Okayama University **27(2)**, 59-71 (1993)
18. N.N. Vasin, V.U. Kurinskiy, Kompyuternaya Opt **25**, 185–188 (2005)
19. S.M. Kovalev, A.M. Liashchenko, Aktualnyie voprosyi sovremennoy nauki **30(2)**, 17–26 (2013)
20. A.N. Shabelnikov, N.N. Lyabakh, Y.M. Gibner, Proceedings of the Third International Scientific Conference "Intelligent Information Technologies for Industry" (IITI'18). Advances in Intelligent Systems and Computing **875** (2019) http://doi-org-443.webvpn.fjmu.edu.cn/10.1007/978-3-030-01821-4_31
21. A.N. Shabelnikov, N.N. Lyabakh, N.A. Malishevskaya, Proceedings of the Third International Scientific Conference "Intelligent Information Technologies for Industry" (IITI'18). Advances in Intelligent Systems and Computing **875** (2019) http://doi-org-443.webvpn.fjmu.edu.cn/10.1007/978-3-030-01821-4_32
22. K. Kornienko, S. Bessonenko, I. Tanaino, VIII International Scientific Siberian Transport Forum. TransSiberia 2019. Advances in Intelligent Systems and Computing **1115** (2020) https://doi.org/10.1007/978-3-030-37916-2_63
23. S. Bessonenko, K. Kornienko, I. Tanaino, MATEC Web of Conferences **239**, 03002 (2018) https://doi.org/10.1051/matecconf/201823903002
24. K. Kornienko, S. Bessonenko, MATEC Web of Conferences **216**, 02012 (2018) https://doi.org/10.1051/matecconf/201821602012