Modelling and simulation of marshalling yard operation providing semi-continuous speed control

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Abstract

It is a well-known fact that for the last decade the railways in Eastern Europe suffered severe erosion. In the case of freight traffic the decline was made much worse by the closing of inefficient heavy industries which relied on rail to carry the bulk of their raw materials and products. Directive 91/440 of the European Union is designed to help railways attain as a key objective halt the loss of traffic by adopting market strategies. In line with it a study has been conducted to develop an optimal structure for automation of a marshalling yard taking into account specific factors, i.e. light duty, low humping velocity and relatively low cost, giving preference to automation with spot retarders.

1 Introduction

In Bulgaria, marshalling yard subject to automation are light duty with processing capacity of up to 2,000 wagons per twenty-four hour period, or 150 wagons per hour. Thus they can be categorised as medium capacity yards and the theory recommends as appropriate having two retarder positions - a primary one and one in the sorting sidings [1]. The design of the vertical profile used for the presented simulation model is detailed in previous publications [2]. According to this design method the primary retarder position is at the beginning of each sheaf of tracks. The "group" retarders are placed in the classification roads and they provide the "target shooting".
There is one marshalling yard in Bulgaria which has been entirely equipped with ASEA spiral hydraulic retarders. For the first time, installation on both rails has been experimented. The profile was calculated following the principles of continuous speed control. According to this method the first spot retarders are installed ahead of the first separation point. The retarders have been concentrated in two groups along the declivity of the hump and one in the sorting sidings. This method of automation proved to be very effective. The cars are tightly bunched ready for departure in the classification roads which are filled up to 85%. While the design of the profile of sorting sidings has been put into practice on Bulgarian Railways there are still discussions as to what will be the best hump profile so that the optimum can be taken from the spiral retarders. Some considerations are given in the current paper.

2 System simulation

Following the success of the pilot implementation on one marshalling yard Bulgarian Railways tend to speak in favour of ASEA spiral retarders. Factors that contribute to this are drastic reduction of noise pollution compared to beam retarders, zero power consumption and safe operation. As if foreseeing the future and the low demand for freight traffic and sorting Bulgarian Railways have been licensed by ABB Brown Bovery to start manufacturing the clamp unit and bracket for the hydraulic retarders. Thus developing a precise design method for the hump profile becomes very important. The idea of moving the primary retarders further down in the track shelves in order to reduce number of turnings they are exposed to and thus achieving a longer life has been carefully studied. The modelling work is based on the results of a recently conducted study of the primary parameters of car movements through the marshalling yard hump and a new formulation of the aerodynamic drag of individual wagons and mixed groups [3]. The simulation package developed was used to estimate the effect of resistivity of retarders arranged in different locations along declivity of the hump.

2.1 Basic Theory

The mathematical modelling is used to provide the corresponding profile. It is founded on the basic differential equation of movement:

\[ \frac{\partial v}{\partial t} = g'(i - w)10^{-3} \]  

(1)

where:
Depending on the worst-best car category the value of $g'$ is in the range of 9.0 to 9.6 m/s².

Speeds of cars are being calculated at the beginning and end of each section using the basic energy equation:

$$ h_e - h_b = h_i - (h_w + h_r), $$

Or

$$ v_e = \sqrt{v_h^2 + 2g'(h_i - h_w - h_r)}, $$

Where:
- $h_e, h_b$ are the energy heights at the beginning and the end of each section respectively;
- $h_i$ is the car potential energy transformed in kinetic energy as a result of the wagon moving to the next section down the declivity of the hump.
- $h_w, h_r$ are the dissipated kinetic energy for compensating the total aerodynamic, road and retarder resistance.

When calculating the actual speed of each cut during the process of simulation formulae [4] can be further decomposed to derive the speed in next discrete time:

$$ v_j = \sqrt{v_{j-1}^2 - 2g'[w_0 + w_{en} - i]10^{-3} + (h_r + h_p + h_c)}, $$

Where:
- $w_0$ is the volume resistivity of the wagon which has been experimentally defined. The initial data for further calculations are taken from Bulgarian Railways Normative Tables with standard deviation 1.8σ. The type of used wagons on Bulgarian Railways varies widely. The majority are four wheeled wagons (low-sided) and about 30% of them travel unloaded. That's the reason why a four wheeled low-sided wagon weights 25t has been chosen to be the worst car for this study. An eight-wheeled open sided wagon that weights 70t is respectively the best runner. Thus the least resistance of loaded roller-bearing wagon is $w_0=0.5$ kg/t and the highest value used for the resistance of the worst car is 5.0 kg/t.
- $w_{en}$ is the aerodynamic resistance calculated using the formulae:
\[ w_{en} = \frac{\rho F}{2mg} c_t(\alpha) v_R^2 \]  

Where:
\( \rho \) - aerodynamic coefficient of wagons;
\( F \) - front surface;
\( m \) - wagon mass;
\( g \) - gravitational acceleration;
\( c_t \) - air drag, calculated for gravity fed movements taking into account the effect of wind and calculated for a specific wagon length.

The effect of a following relative wind is substantially equal and opposite to that arising from a head wind. In general, the resistance produced at the rear of a wagon is much less than at the front due to the fact that while a wedge of pressure is built up in advance of the vehicle, the space at the rear is filled with swirling air of indeterminate pressure, the resultant suction being comparatively small. In marshalling yards, with a degree of approximation \( c_t \) can be expressed as a periodical function of the angle between the wind direction and the direction of travel [3]. Fourier series if applied give the multiple components for the cosine of this angle:

\[ c_t = K \sum_{n=0}^{\infty} a_{2n} \cos(2n\alpha) \]

\( K \) is equal to one, only for bad runners it takes the value of 1.2.

\( v_R \) is the resultant velocity of the car taking into account the wind speed \( v_w \) and the relative angle between the wind direction and the longitudinal axis of the section traversed:

\[ v_R = \sqrt{v_{av}^2 + v_w^2 \pm 2v_{av}v_w \cos \beta} \]

The average wagon speed for the middle section of the hump of a light-duty yard as from the Normative Tables [4] is 3m/s.

\( h_{r,p,c} \) is the energy loss due to curve, point and retarder correspondingly. The braking energy per turn of the ASEA retarder is \( A=10kJ \) if the speed of the vehicle is in excess of the retarder limit [5]. The wagon energy height will be adjusted by:

\[ h_r = A \frac{n_o}{q} \]
depending on the number of axles \( n_0 \) and wagon mass \( q \). The minimum driving resistance of the hydraulic retarder in case of low wagon speed is as low as 400J per turn. The maximum entrance speed is 6m/sec and the pre-set value of exit speed can vary from 1.5m/sec to 4.0m/sec.

2.2 Simulation model

SIMSCRIPT has been chosen as a software package to simulate the operation of a marshalling yard in order to exploit the advantages that discrete-event simulation can offer for modelling train movements. In a discrete-event simulation the system is described in terms of logical relationships that cause changes of state at discrete points in time rather than continuously over time. The main modelling elements of SIMSCRIPT are process objects and resources. The process objects are dynamic objects which experience a sequence of actions throughout their life in the model. Resources are passive elements of the model used to describe an object which is required by the process objects. If the resource is not available when required, the process object is placed in a queue and made to wait until the resource becomes available. The simulation algorithm is shown on fig. 1.

![Diagram](https://via.placeholder.com/150)

**Figure 1: Simulation programme**

All the parameters associated with the movements of each wagon part of the simulation are considered process objects by the system. Resources constitute permanent entries for each simulation and values are associated in the beginning of each simulation via a dialog box. Those include hump profile, track elements - points, retarders and their relative location, etc. An important parameter of each marshalling yard is the humping velocity. Taking into account that the aim of the study is not to achieve a greater capacity but a maximum throughput with minimum initial funding the humping velocity 0.8m/sec is considered. In practice, the number of wagons in each cut is found to be of Gauss probability distribution. Single car cut is most probable while the probability of seven car cuts is close to zero. The speed curves up to the clearance markers in the sidings derived from the simulation of a humping list consisting of two single car cuts - a
good eight-wheeled runner following a bad four-wheeled wagon in case of a 3m/sec head wind are shown in fig.2:

![Figure 2: Hump and speed profile](image)

Analyses conducted to compare the results with the output files of previous simulation in PASCAL7.0 have proved very supportive to the idea of providing semi-continuous speed control with passive hydraulic retarders for light duty yards instead installing expensive network of retardation equipment along the declivity of the hump. The inclusion of the new knowledge on the aerodynamic drag of individual wagons though has influenced the design of the hump profile. In order to achieve the required performance the original hump profile as from [2] requires slight amendments. The profile shown on fig.2 consist of the following sections listed in descended order from the top of the hump:

Table 1. Sections of hump profile

<table>
<thead>
<tr>
<th></th>
<th>Length [m]</th>
<th>Gradient [°/100]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>II</td>
<td>105</td>
<td>13</td>
</tr>
<tr>
<td>III</td>
<td>30</td>
<td>8.5</td>
</tr>
<tr>
<td>IV</td>
<td>97</td>
<td>1.0</td>
</tr>
</tbody>
</table>
3 Conclusions

Studies of humping dynamics are fundamentally important for all phases of a marshalling yard project including optimisation of a system at implementation phase. A discrete-event simulation in SIMSCRIPT of a marshalling yard of low to medium processing capacity has been presented in this paper. The simulation results are used to amend the hump profile and retarder locations in order to achieve economically efficient marshalling yard. Preliminary tests carried out with double rail installation of ASEA retarders in Sindel marshalling yard in Bulgaria were encouraging in respect of entrance speed which can be overrun by very heavy cuts without degrading normal operation. The intention is to use the results of this modelling for future design of marshalling yards in Bulgaria.

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References