

Simulation of Hump Performance in Railroad Classification Yard

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Synopsis

The paper presents methods for simulation and examination of the performance of a classification yard, including both manual and computer-aided methods. Presented methods are applicable to the simulation and examination of full range of yards of different types and sizes including manually operated as well as highly automated classification yards.

1. Introduction

During the process of hump yard design as well as after designing is completed, an examination of basic hump yard characteristics is inevitable. This examination can be done by car motion simulation which results in a velocity head diagram and time-distance plot construction. Motion of both single cars and longer cuts can be simulated, although longer cuts can be approximated as single cars of unusual length. Each car or cut can be treated as a mass point represented by its center of gravity. The cars' motion simulation can be done by both manual and computer-assisted methods. In the following sections one manual method and one computer-assisted method for car speed and time simulation are described.

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2. Graphical Method of Speed and Time Simulation

The initial datum for simulation of the car velocity is a graphical model of the hump profile with the plot of the car energy head line.

The theoretical formulas for the calculation of the car energy head are derived in [8]. The practical construction of the energy head line starts with plotting the zero line from the value of the car velocity head at the breakaway point horizontally until the reference point lying in the classification track*.

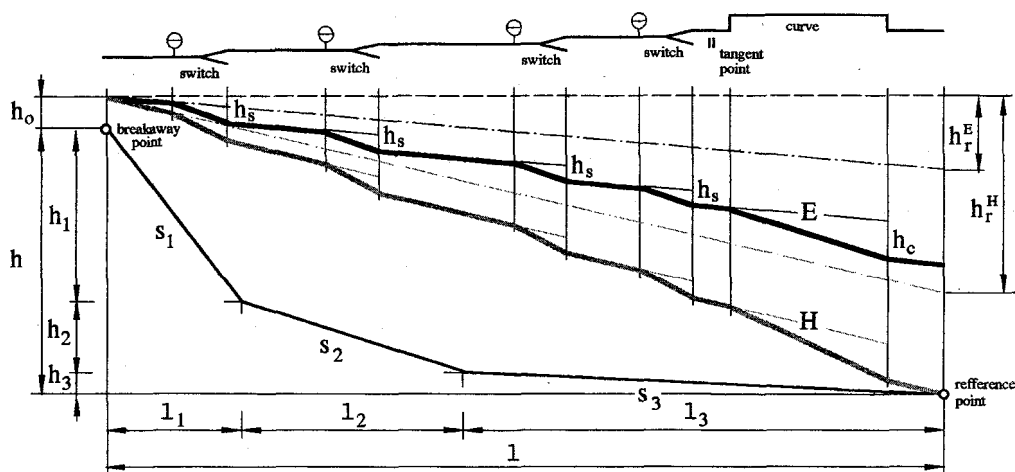


Figure 1: Velocity head lines of an easy and a hard rolling cars

Subtracting the car energy loss caused by the rolling resistance vertically at the end of the zero line yields a point, representing the theoretical energy head of the car at the reference point. The line connecting this point with the beginning of the zero line can be thus called a *theoretical line*. The slope of the theoretical line in ‰ corresponds to the mean rolling resistance of the car in N/kN . The real energy head line keeps this slope except for the track sections where the car is exposed to track resistance (switches and curves). The energy head line in this section has a steeper slope due to the additional energy loss caused by the resistance of switches and curves.

* Usually 100 m beyond the tangent point

When the construction of the energy head line is accomplished, the car velocity head and thus also the car velocity at any point of the track can be determined. The velocity-distance line can be derived from the energy head line and the track profile by means of a velocity parabola.

A velocity parabola is a curve expressing the car energy head as a function of its velocity. The car energy head is defined as $h=v^2/2g'$, which is the equation of the parabola. The current of this curve can be determined either numerically by calculating several energy heads corresponding to the selected velocities or graphically.

Also the time-distance line can be derived from the energy head line and the track profile. The track profile is divided into small sections and the times of travelling through these sections are computed. Suppose that a section of the track Δl and the energy head line in this section are given (Figure 2). The velocity corresponding to the energy head in the middle of the section can be considered as an approximate mean velocity*. This mean velocity can be determined from the energy head by means of the velocity parabola. Time Δt required for the traversing the track section can be calculated from the length of the track section and the mean velocity as:

$$\Delta t = \frac{\Delta l}{v_m} \quad [s] \quad (1)$$

where

Δl = length of the track section in m ,

v_m = mean velocity in the track section in m/s .

Equation (1) can be also expressed as:

$$\frac{\Delta l}{\Delta t} = \frac{v_m}{"1"} \quad (2)$$

Here number "1" becomes a pole distance in m .

With suitably selected scales the relationship of the equation (1) can be graphically expressed by the similarity of two right angled triangles. The former has altitudes v_m

* Mean velocity lies in the middle of the time rather than in the middle of length.

and number "one" drawn in selected scales, the latter has altitudes Δl and Δt . When the corresponding altitudes are parallel, the hypotenuses of the triangles are also parallel and the hypotenuse of the triangle with right angle sides Δl and Δt shows the current of time as a function of the length of the given track section*.

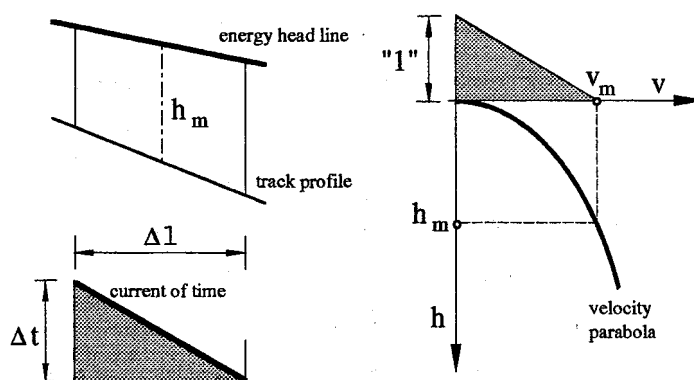


Figure 2: Construction of the time-distance line

Before the construction of the time-distance line starts, the appropriate scales of used terms must be determined. Suppose, the scales of the following terms are denoted as:

length: $l = 1 \text{ m}$, scale = $x \text{ mm}$;

time: $t = 1 \text{ s}$, scale = $y \text{ mm}$;

velocity: $v = 1 \text{ m/s}$, scale = $m \text{ mm}$.

Because the above mentioned triangles are similar, it holds:

$$\frac{x \cdot \Delta l}{y \cdot \Delta t} = \frac{m \cdot v_m}{"1"} \quad (3)$$

As $v_m = \Delta l / \Delta t$, the relationship among the scales is:

$$\frac{x}{y} = \frac{m}{"1"} \quad (4)$$

* In reality, the time of the uniformly accelerated motion has a curve current. In a short track section, for simplification, however, this curve current of time can be substituted with an abscissa.

Three of these scales can be selected and the fourth one must be calculated. If, for instance, the scales m , x and y are selected, the pole distance can be calculated as:

$$"1" = \frac{m \cdot y}{x} \tag{5}$$

For the construction of the time-distance line the hump profile is divided into several sections which are shorter in those parts of the profile, where the energy head changes dramatically and are longer in those parts where the changes are slow. In every section the mean energy head is found and from it, by means of the velocity parabola, the mean velocity is determined. The time-distance line can then be drawn as a set of mutually connected abscissas parallel to the lines connecting the pole distance with the corresponding velocity in the velocity parabola. The procedure of time-distance line construction is evident from Figure 3.

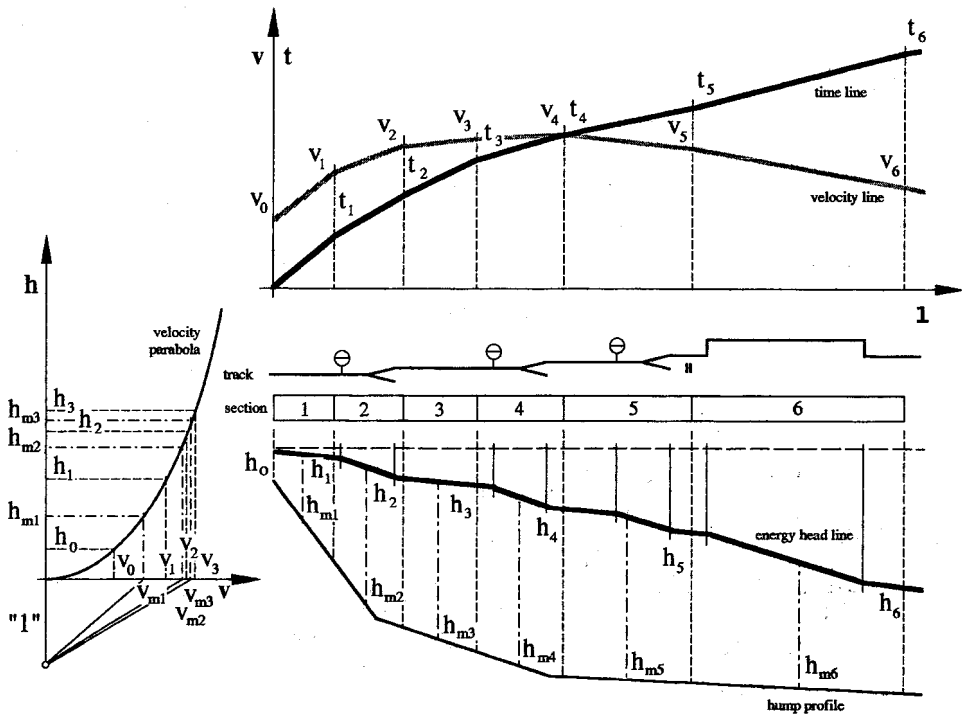


Figure 3: Graphical method of car velocity and time simulation

This method can also be used for a simulation of velocity and time of a group of cars rolling down the hump as a single cut. The initial datum is here a hump profile modified in such a way that the real gradients are substituted by theoretical gradients which include resistance of curves and switches. By means of this modified profile the theoretical profile along which the center of gravity of the whole cut moves, can be constructed. In the following passage, the procedure of the theoretical profile construction is described.

Two identical modified profiles are drawn, shifted horizontally by the length of the reference cut. The profile drawn on the left side represents the track along which the head of the cut moves, and the profile on the right side represents the track of the cut's end. The vertical distance of lines of both profiles shows the elevation of the front and the back parts of the cut at any point of the track. If an abscissa of the same length as the length of the cut is drawn parallel with the horizontal axis of the plot, then the line connecting the left end of the abscissa with the elevation distance between the front and back parts of the cut plotted over its right end represents the theoretical gradient along which the cut center of gravity is currently moving. For the construction of the theoretical profile, the modified real profile is divided into a set of sections. These sections should not exceed points of change of gradient and their length should be selected according to the desired accuracy of the plot. In the middle of each section the mean elevation between the front and the back parts of the cut can be found. Partial gradients determined from these mean elevations in the above mentioned way, connected together, yield the theoretical hump profile along which the cut center of gravity moves.

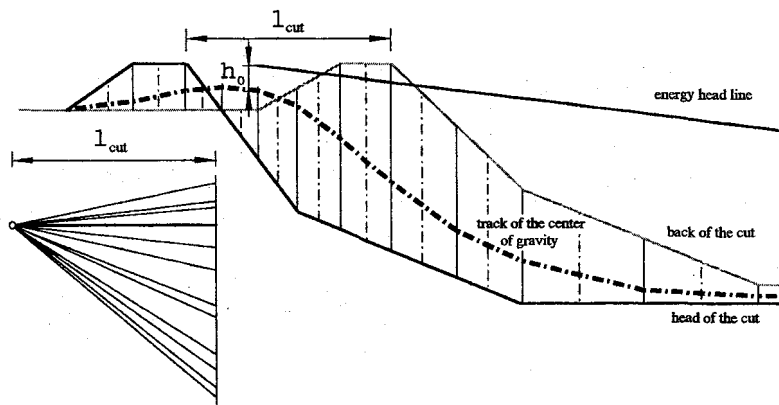


Figure 4: Construction of the theoretical hump profile for a group of cars

From this theoretical hump profile and from the cut energy head the velocity line as well as the time-distance line of the cut can be constructed by the same methods as for a single car.

This method gives a quick and easy-to-survey result of the speed and time current of a car rolling down the designed hump and is suitable for graphics software of personal computers. It, however, has one disadvantage which is in the fact that this method considers car resistance as constant. This may cause some inaccuracy in the final shape of the time-distance line. For more accurate computations numerical computer assisted methods are recommended.

3. Numerical Method of Speed and Time Simulation

The graphical method of speed and time simulation described in the previous section is sufficient enough for fast and practical screening of characteristics of already existing hump yards, or for preliminary calculations for the design of a newly projected hump yard. However, for scientific computations of automated yards, especially in the case when a great number of different design variants are to be worked out, this method is neither precise nor fast enough and should be substituted by a numerical computer assisted method which enables one to comprehend all influences acting on the rolling car or cut.

The determination of the speed and time current of the cut rolling down the hump as a function of the distance consists in the solution of the differential equation:

$$a = \frac{d^2 l}{dt^2} \quad [m/s^2] \quad (6)$$

This equation can be solved by a step method of the approximate integration by means of equations:

$$v_i = \sqrt{v_{i-1}^2 + 2a \cdot \Delta l} \quad [m/s] \quad (7)$$

$$\Delta t = \frac{2 \Delta l}{v_{i-1} + v_i} \quad [s] \quad (8)$$

where

v_i = car velocity at the end of the i -th step in m/s ,

v_{i-1} = car velocity at the beginning of the i -th step in m/s ,

Δl = length of the step in m ,

Δt = time of traversing the distance Δl in s .

Acceleration of a car can be calculated as:

$$a = \frac{g'(s - r)}{1000} \quad [m/s^2] \quad (9)$$

where

g' = conversion gravitational acceleration in m/s^2 (see [8], p.54),

s = gradient of the track in ‰,

r = relative resistance of the car in N/kN .

This acceleration consists of several components dependent upon many factors which can be grouped into two main groups:

1. Components dependent on the track conditions:

- Force of the gradient of the track,
- Curve resistance,
- Switch resistance,
- Rolling resistance (bearing resistance depends partly on the distance from the place where the car was standing for some time, and air resistance may change as a result of possible different intensity and direction of wind between the crest of the hump and the classification tracks area).

2. Components dependent on the velocity of the cut:

- Air resistance,
- Rolling resistance (rail resistance, bearing resistance, air resistance),
- Breaking resistance of the retarders.

In regard to the number of factors influencing the humped cut, the program for computation of the velocity line and the time-distance line consists of a corresponding number of subprograms elaborating the influences of the single factors. These subprograms are then unified in the main general program. The simplified flowchart of the main program is presented in Figure 5.

The single factors are elaborated in the following way:

Cuts

From the initial data (number of cars in a cut, number of axles, load per axle, etc.) all quantities requisite for further computation are determined at the beginning of the program. They are: total length of the cut, distance of the outermost axles, weight of the cut, position of the center of gravity, and rotational head correction factor.

Grades

Grades are the basic data for calculation of acceleration or deceleration ensuing from the track gradient. At the beginning of the computation the position of the front axle, or if need be, the position of the front buffer of the cut is supposed to be at the crest (breakaway point) of the hump and during the computation this position moves step by step down the hump until it reaches the target on the classification track. During each step, the program calculates the force acting on each axle dependant on the load per axle, and on the gradient on which the axle currently occurs. The sum of the single forces then represents the total force acting on the center of gravity of the whole cut as a result of the influence of the track gradient. From this total force and the mass of the cut, the acceleration of the cut caused by track gradient is determined.

Curves

In contrast to grades, the program considers curve resistance acting on each cut rather than on each axle. From the distance of the outermost axles the crucial wheel base for computation of the curve resistance is determined. During curve resistance computation the program distinguishes three possibilities: the cut is entering the curve by its front axle, the cut occurs on the curve in its whole length, and the cut is leaving the curve by its back axle. Only in the second case the program presumes the full

influence of the curve resistance. In the first and the third cases the program considers only its part proportional to the part of the wheel base occurring on the curve. The sum of curve resistances acting on all cars of the cut is recalculated into the deceleration and added to the cut's acceleration caused by the grades.

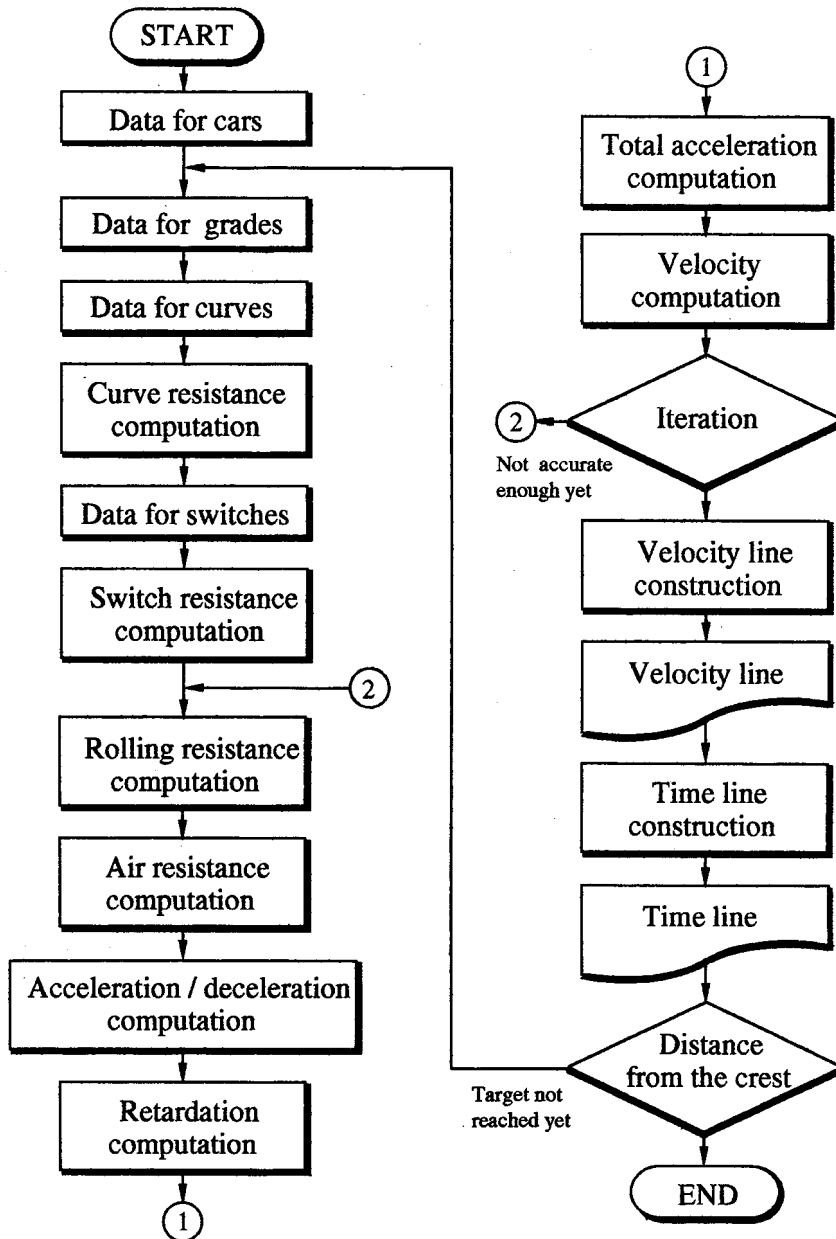


Figure 5: Flowchart of the main program for speed and time simulation

Switches

The influence of switches on the motion of a humped cut can be computed in the same way as the influence of curves. Besides the resistance of the switch curve, however, also the resistance of strike must be taken into consideration.

Rolling resistance

The bearing resistance as well as the rail resistance can be considered as constant or variable, according to the desired accuracy of the computation. The procedure of computation is analogical to the computation of the forces from the gradient. The total rolling resistance is then recalculated into the deceleration and added to the acceleration already determined .

Air resistance

The wind velocity can be considered as dependent on the distance. The intensity of wind can be supposed to fall during a cut's rolling down the hump. The computation should also include the wind direction which can change considerably, particularly in the case when the cut is humped to the outermost classification track. The air resistance is computed iteratively considering the influence of velocity of the cut as well as the changes in wind direction and intensity as a function of the distance from the hump crest. The final air resistance is then recalculated into deceleration and added to the acceleration already determined.

Retarding

One of the most important parts of the program is the simulation of the retarder operation, which depends on the car velocity. In every step the position of each single axle of the cut is observed and only axles which occur within the retarder during the whole step are included into the computation. For each axle the braking force is determined as a function of the current speed and the load per axle. If at the same time more than one axle occurs in the same retarder, the braking force depends on the number of axles currently retarded. In more accurate computations, also the variable rolling resistance should be taken into consideration.

Carrying out all above mentioned computations results in the current of cut's acceleration as a function of the distance from the hump crest. From this acceleration

the velocity of the cut as a function of distance can be determined by equation (7) modified into the form:

$$v_i = \sqrt{v_{i-1}^2 + (a_{i-1} + a_i) \Delta l} \quad [m/s] \quad (10)$$

In the first step the humping speed v_0 is taken as the initial velocity. For the terms dependent on velocity, the previous velocity v_{i-1} can be selected as a basis for the first approximation. Its value can then be calculated with more precision by the iterative process until two consecutive values differ from each other less than preselected divergence.

From the current of velocity the current of time as a function of the distance from the crest can be determined by the equation:

$$t_i = t_{i-1} + \Delta t \quad [s] \quad (11)$$

4. Conclusion

Both methods of speed and time simulation are based on the presumption that all forces acting on a moving cut can be considered as relative forces calculated per a unit of car's weight and can thus be expressed in N/kN or in ‰.

The graphical method gives a quick and easy-to-survey result of the speed and time current of a car rolling down the hump and is sufficient for fast and practical screening of characteristics of already existing hump yards, or preliminary calculations for the design of a newly projected hump yard.

For scientific computations of automated yards, especially in the case when a great number of different design variants are to be worked out, the numerical computer assisted method is recommended.

There are several other problems related to speed and time simulation in a hump yard which are not considered in this analysis, for example: time separation between consecutive cuts at switches, retarders and tangent points, hump yard profile examination, and maximum humping velocity determination to mention but a few.

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