DEPENDENCE OF TRAIN SORTING TIME ON THE TURNOUT TRACK AND DURATION OF SEMI-TRIP

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ABSTRACT

The duration of sorting of the train on the turnout track is determined by the known formula T_{sort} = A•g + B•m. At the same time, the duration of all semi-trips – arrival of the locomotive behind the part of the train, its extension to the turnout track, sorting and reverse pulling of the remaining cars – were calculated according to the formula $t_{s/t}$ = a + bm, which is now replaced by a new method for adjusting the shunting operations. The article presents the results of a study that made it possible to derive a formula for calculating the duration of the sorting of a train on the turnout track based on a different calculation of the duration of semi-trips.

Keywords: railway, turnout track, duration of sorting, duration of semi-trip, calculation formulas.

Background. *Usually, the sorting time of the composition of m cars and g cuts is calculated by the formula T_{sort} = A•g+B•m, where A and B are the coefficients, the value of which is taken depending on the slope of the track of cut motion and the way the maneuvers are organized [1, 2].*

The formula given was obtained from the division of the composition into parts in order to minimize the total duration of sorting [3], but in the derivation of this formula the duration of the semi-trip was determined from the formula $t_{s/t}$ = a+bm (where m is the number of cars in the composition), which in «Methodical instructions on the calculation of time norms for shunting work» was replaced by another. The coefficients A and B are determined by statistical observations.

In this paper, we prove the derivation of a formula analogous to T_{sort} = A•g+B•m, on the basis of the current methodology for calculating the duration of a shunting semi-trip with a theoretical derivation of the coefficients.

Objective. *The objective of the authors is to consider the problem of dependence of train sorting time on the turnout track and duration of semi-trip.*

Methods. *The authors use general scientific and engineering methods, mathematical calculation, comparative analysis.*

Results.

The formula for determining the duration of the shunting semi-trip, given in [1] instead of the formula $t_{s/t}$ = a+bm, looks like this:

$$t_{s/t} = (\alpha_{ab} + \beta_{ab} \cdot m) \cdot \frac{V}{2} + \frac{3,6 \cdot l_{st}}{V}, \text{ sec}, \quad (1)$$

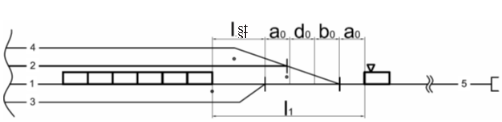
where α_{ab} – coefficient, which takes into account time required for changing speed of motion of a locomotion by 1 km/h at acceleration and braking, in accordance with [1] $\alpha_{ab} = 0,76 \frac{sec}{km/h}$;

β_{ab} – coefficient, which takes into account additional time for changing speed of motion of each car in the shunting train by 1 km/h at acceleration and braking, in accordance with [1] $\beta_{ab} = 0,13 \frac{sec}{km/h}$;

V – permissible speed of motion at maneuvers, km/h;

l_{st} – length of semi-trip, m.

We transform the formula (1):



Pic. 1. Scheme for calculating the duration of maneuvers.

$$t_{s/t} = (\alpha_{ab} + \beta_{ab} \cdot m) \cdot \frac{V}{2} + \frac{3,6 \cdot l_{st}}{V} =$$

$$= \alpha_{ab} \cdot \frac{V}{2} + \frac{3,6}{V} \cdot l_{st} + \frac{\beta_{st} \cdot V}{2} \cdot m = + \cdot l_{st} + \cdot m, \quad (2)$$

where $\alpha = \alpha_{ab} \cdot \frac{V}{2}$, *sec,* (3)

$\beta = \frac{3,6}{V}$, *sec/m,* (4)

$\gamma = \frac{\beta_{ab} \cdot V}{2}$, *sec,* (5)

In general, the duration of maneuvers on the turnout track when dividing the composition into x parts can be determined by the formula:

$T = \sum t_a + \sum t_p + \sum t_s + \sum t_{rp}$, *sec,* (6)

where $\sum t_a$ – duration of idle semi-trips (arrival to seek for parts of the composition), sec;

$\sum t_p$ – duration of semi-trips of pulling of parts of the composition, sec;

$\sum t_s$ – duration of semi-trips of backing of the composition to the sorting tracks, sec;

$\sum t_{rp}$ – duration of semi-trips of reverse pushing back of the composition to the turnout track, sec.

The duration of semi-trips of arrival to take parts of the composition ($\sum t_a$) can be determined by the formula:

$\sum t_a = t_a^{av} \cdot x$, (7)

where t_a^{av} – average duration of a semi-trip of arrival to take parts of the composition, sec.

The duration of semi-trips of pulling of the parts of the composition ($\sum t_p$) is equal to:

$\sum t_p = t_p^{av} \cdot x$, (8)

where t_p^{av} – average duration of a semi-trip of pulling of parts of the composition, sec.

The duration of semi-trips of pulling of the composition to the sorting tracks ($\sum t_s$) is:

$\sum t_s = t_s^{av} \cdot g$, (9)

where t_s^{av} – average duration of a semi-trip of pushing back, sec.;

g – number of cuts in the sorted composition.

The duration of semi-trips of reverse pushing back of the composition to the turnout track ($\sum t_{rp}$) is determined by the formula (taking into account the return of the locomotive after the installation of the last cut):

$\sum t_{rp} = t_{rp}^{av} \cdot g$, (10)

where t_{rp}^{av} – average duration of a semi-trip of reverse pushing-back of the composition to the turnout track, sec.

The average duration of a semi-trip of each type can be determined by the formula:

$t_{s/t}^{av} = \alpha + \beta \cdot l^{av} + \gamma \cdot m^{av}$, (11)

where l^{av} – average length of a semi-trip, m;

m^{av} – average number of cars with this type of a semi-trip.

The average length of a semi-trip (l_{av}) is defined as the half-sum of its minimum (l_{min}) and maximum (l_{max}) length:

$$l_{av} = \frac{l_{min} + l_{max}}{2}, \text{ m.} \quad (12)$$

To determine these quantities, let's consider the scheme in Pic. 1.

The sorting technology in the example under consideration is as follows: the sorted composition is on the track 1, the shunting locomotive is on the turnout track 5. The composition is sorted in three appointments into three tracks: 2, 3, 4. The power of the appointments in the composition is assumed to be the same and is for each of the three appointments m/3. The shunting locomotive drives to track to take the first part of the sorted train, the first trains on each track are put on a distance $m_i \cdot l$, where l is the length of the car, m_i is the number of cars from the sorted train to be installed on the i-th tracks, i.e. each cut is installed immediately at the end point and does not move during the sorting process. Further, tracks 2, 3, 4 are filled in the direction of the turnout track. Thus, after the end of sorting, the assigned appointments are at the beginning of the sorting tracks. This method gives the minimum duration of shunting operations.

Hence:

1. For $\sum t_a$ (semi-trips of arrival):

The first semi-trip is done to the head of the train (Pic. 1):

$l_a^{min} = l_1 = 2 \cdot a_o + d_o + b_o + l_{st}$, m, (13)

where l_1 – length of the 1-st semi-trip of arrival, defined by the formula:

$l_1 = 2 \cdot a_o + d_o + b_o + l_{dp}$, m, (14)

here a_o – distance from the junction of the frame rail to the center of the turnout switch, m (a_o = 15 m);

b_o – distance from the center of the turnout switch to the end of the track crossing, m, (b_o = 15 m);

d_o – length of the straight insert, m, (d_o = 12,5 m);

l_{dp} – distance from the center of the turnout switch to the distance post, m (l_{dp} = 37 m);

Arrival to take the last part of the composition:

$$l_a^{max} = l_1 + l_p \cdot \frac{m}{x} \cdot (x-1), \text{ m.} \quad (15)$$

Average length of semi-trip of arrival:

$$l_a^{av} = l_1 + l_p \cdot \frac{m}{2} - l_p \cdot \frac{m}{2 \cdot x}, \text{ m.} \quad (16)$$

In case of semi-trips of arrival m = 0 and from (11) it follows:

$$\sum t_a = (\alpha + \beta \cdot (l_1 + l_p \bullet \frac{m}{2} - l_p \bullet \frac{m}{2 \cdot x}) + \gamma \bullet 0) \bullet x =$$

$$= (\alpha + \beta l_1 + \beta l_p \frac{m}{2}) x - \beta l_p \frac{m}{2}. \quad (17)$$

2. For $\sum t_p$ (semi-trips of pulling):

Pulling of the first part of the composition:

$$l_p^{min} = l_1 + l_p \cdot \frac{m}{x}, \text{ m.} \quad (18)$$

Pulling of the last part of the composition:

$L_p^{max} = l_1 + l_p \cdot m$, m. (19)

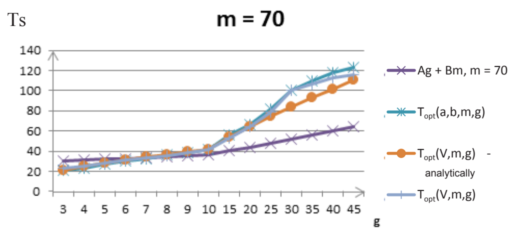
Average length of semi-trip of pulling:

$$l_p^{av} = l_1 + l_p \cdot \frac{m}{2} + l_p \cdot \frac{m}{2 \cdot x}, \text{ m,} \quad (20)$$

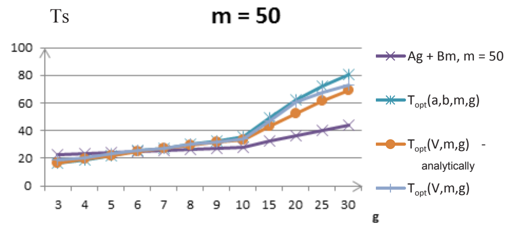
$$m_p^{av} = \frac{m}{x} \text{ (part of the composition),} \quad (21)$$

$$\sum t_p = (\alpha + \beta \bullet (l_1 + l_p \bullet \frac{m}{2} + l_p \bullet \frac{m}{2 \bullet x}) + \gamma \bullet \quad) \bullet x$$

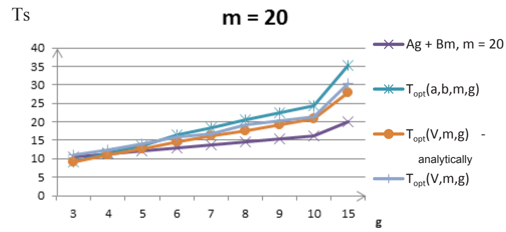
$$= (\alpha + \beta l_1 + + \beta l_p \frac{m}{2}) x + \frac{m}{2} + \gamma m. \quad (22)$$



Pic. 2. Duration of maneuvers on the turnout track, m = 70 cars.



Pic. 3. Duration of maneuvers on the turnout track, m = 50 cars.



Pic. 4. Duration of maneuvers on the turnout track, m = 20 cars.

3. For $\sum t_s$ (semi-trips of pushing back):

Pushing back of the last cut of the part of the composition:

$$l_s^{min} = l_g + l_p \cdot \frac{m}{g}, \text{ m,} \quad (23)$$

where l_g – distance from switch points of the turnout switch, leading to the turnout track, to the extreme (far) distance post of the sorting tracks (in Pic. 1 coincides with l_1).

Pushing back of the entire part of the composition for setting its first cut:

$$l_s^{max} = l_g + l_p \cdot \frac{m}{x}, \text{ m,} \quad (24)$$

$$l_s^{av} = l_g + l_p \cdot \frac{m}{2x} + l_p \cdot \frac{m}{2g}, \text{ m,} \quad (25)$$

$$m_{min} = \frac{m}{g}, \quad m_{max} = \frac{m}{x}, \quad m_p^{av} = \frac{m \cdot (g+x)}{2gx}, \quad (26)$$

$$\sum t_s = \left(\alpha + \beta \bullet \left(l_g + l_p \bullet \frac{m}{2x} + l_p \bullet \frac{m}{2g} \right) + \gamma \bullet \frac{m \bullet (g+x)}{2gx} \right) \bullet g =$$

$$(\beta l_p + \gamma) \frac{mg}{2x} + + (\alpha + \beta l_g) g + (\beta l_p + \gamma) \frac{m}{2}. \quad (27)$$

4. For $\sum t_{rp}$ (semi-trips of reverse pushing):

Return of the locomotive after backing of the last cut:

$l_{rp}^{min} = l_g$ m, (28)

$$l_{rp}^{max} = l_g + l_p \cdot (\frac{m}{x} - \frac{m}{g}), \text{ m,} \quad (29)$$

$$l_{rp}^{av} = l_g + l_p \cdot \frac{m}{2x} - l_p \cdot \frac{m}{2g}, \text{ m,} \quad (30)$$

Table 1

Coefficient A_1

l_g, m	V, km/h		
	15	25	40
100	0,99	0,80	0,81
150	1,39	1,04	0,96
200	1,79	1,28	1,11
250	2,19	1,52	1,26
300	2,59	1,76	1,41
350	2,99	2,00	1,56
400	3,39	2,24	1,71
450	3,79	2,48	1,86
500	4,19	2,72	2,01

Table 2

Coefficient B_1 at V = 15 km/h

g, cuts	m, cars						
	10	20	30	40	50	60	70
1	0,23	0,19	0,18	0,17	0,16	0,16	0,16
5	0,49	0,40	0,37	0,36	0,35	0,34	0,33
10	0,68	0,57	0,52	0,50	0,48	0,47	0,47
15		0,69	0,63	0,61	0,59	0,58	0,57
20			0,73	0,70	0,68	0,66	0,65
25				0,78	0,75	0,74	0,73
30					0,82	0,81	0,79
35						0,87	0,86
40						0,93	0,91
45							0,97

Table 3

Coefficient B_1 at V = 25 km/h

g, cuts	m, cars						
	10	20	30	40	50	60	70
1	0,19	0,16	0,15	0,14	0,14	0,13	0,13
5	0,40	0,32	0,30	0,28	0,27	0,26	0,26
10	0,55	0,45	0,41	0,39	0,37	0,36	0,36
15		0,54	0,49	0,47	0,45	0,44	0,43
20			0,57	0,54	0,52	0,50	0,49
25				0,60	0,57	0,56	0,55
30					0,63	0,61	0,60
35						0,66	0,64
40						0,70	0,69
45							0,73

Table 4

Coefficient B_1 at V = 40 km/h

g, cuts	m, cars						
	10	20	30	40	50	60	70
1	0,20	0,17	0,15	0,15	0,14	0,14	0,13
5	0,40	0,32	0,29	0,27	0,26	0,25	0,25
10	0,55	0,44	0,39	0,37	0,35	0,34	0,33
15		0,53	0,47	0,44	0,42	0,41	0,40
20			0,54	0,50	0,48	0,46	0,45
25				0,56	0,53	0,51	0,50
30					0,58	0,56	0,54
35						0,60	0,58
40						0,64	0,62
45							0,66

$$m_{min}=0,\ m_{max}=\frac{m}{x}-\frac{m}{g},\ m_p^{av}=\frac{m}{2x}-\frac{m}{2g}, \qquad (31)$$

$$\sum t_{rp}=(\alpha+\beta\bullet(l_g+l_p\bullet\frac{m}{2x}-l_p\bullet\frac{m}{2g})+\gamma\bullet(\frac{m}{2x}-\frac{m}{2g}))\cdot g=$$

$$=(\beta l_p+\gamma)\frac{mg}{2x}+(\alpha+\beta l_g)g-(\beta l_p+\gamma)\frac{m}{2}. \qquad (32)$$

The total duration of the sorting of the composition by backing when it is divided into x parts:

$$T=\sum t_x+\sum t_p+\sum t_s+\sum t_{rp}=$$

$$=\left(\alpha+\beta l_1+\beta l_p\frac{m}{2}\right)x-\beta l_p\frac{m}{2}+\left(\alpha+\beta l_1++\beta l_p\frac{m}{2}\right)x+$$

$$+\beta l_p\frac{m}{2}+\gamma m+\left(\beta l_p+\gamma\right)\frac{mg}{2x}+\left(\alpha+\beta l_g\right)g+\left(\beta l\ +\gamma\right)\frac{m}{2}+$$

$$+\left(\beta l_p+\gamma\right)\frac{mg}{2x}+\left(\alpha+\beta l_g\right)g-\left(\beta l_p+\gamma\right)\frac{m}{2}=$$

$$=2\left(\alpha+\beta l_1+\beta l_p\frac{m}{2}\right)x+\gamma m++\left(\beta l_p+\gamma\right)\frac{mg}{x}+2\left(\alpha+\beta l_g\right)g \qquad (33)$$

or

$$T=2\left(\alpha+\beta l_1+\beta l_p\frac{m}{2}\right)x+\gamma m+\left(\beta l_p+\gamma\right)\frac{mg}{x}+2\left(\alpha+\beta l_g\right)g,\ \text{sec.} \qquad (34)$$

The first derivative on x:

$$\frac{dT}{dx}=2\left(\alpha+\beta l_1+\beta l_p\frac{m}{2}\right)-\left(\beta l_p+\gamma\right)\frac{mg}{x^2}; \qquad (35)$$

The second derivative is a positive value, so the minimum of the function T is reached at the point:

$$x=\sqrt{\frac{\left(l_p+\right)mg}{2\left(+l_1\right)+l_p m}}. \qquad (36)$$

The formula (36) determines the optimal number of parts of the composition by the criterion of the minimum duration of its sorting by backing on the turnout track.

Substituting (36) in (34), we obtain the minimum duration of maneuvers:

$$T=2\sqrt{2\left(\alpha+\beta l_1+\beta l_p\frac{m}{2}\right)\left(\beta l_p+y\right)mg}+$$

$$+2\left(\alpha+\beta l_g\right)g+\gamma m,\ \text{sec.} \qquad (37)$$

Formula (37) can be represented as follows:

$$T=A^{'}g+B^{'}m++C'\sqrt{mg}, \qquad (38)$$

where $A^{'}=2\left(+l_g\right)=\alpha_{rt}\cdot V+\frac{7,2}{V}l_g$, (39)

$$B^{'}==\frac{\beta_{rt}\cdot V}{2}, \qquad (40)$$

$$C^{'}=2\sqrt{2\left(\alpha+\beta l_1+\beta l_p\frac{m}{2}\right)\left(\beta l_p+\gamma\right)}=$$

$$=2\sqrt{2\left((\alpha_{rt}\bullet\frac{V}{2})+(\frac{3,6}{V})l_1+(\frac{3,6}{V})l_p\frac{m}{2}\right)\left((\frac{3,6}{V})l_p+\frac{\beta_{rt}\bullet V}{2}\right)}. \qquad (41)$$

As seen from the formulas (39)–(41), the values A', B' do not depend on g and m, and the value C' depends on m.

Formula (38) can be represented in a more conventional form:

$T_{sort}=A_1g+B_1m$, (42)

where $A_1=A'$,

$$B_1=B^{'}+C'\sqrt{\frac{g}{m}}=\gamma+C'\sqrt{\frac{g}{m}}=\frac{\beta_{rt}\bullet V}{2}+C'\sqrt{\frac{g}{m}}.$$

Taking into account expressions (39) – (41), the coefficients obtained are:

$$A_1=\alpha_{rt}\cdot V+\frac{7,2}{V}l_g,\ \text{min/cut}. \qquad (43)$$

$$B_1 = \frac{\beta_{rt} \cdot V}{2} + 2\sqrt{2\left((\alpha_{rt} \cdot \frac{V}{2}) + (\frac{3,6}{V})l_1 + (\frac{3,6}{V})l_p \frac{m}{2}\right) \cdot \left((\frac{3,6}{V})l_p + \frac{\beta_{rt} \cdot V}{2}\right)} \cdot$$

$$\cdot \sqrt{\frac{g}{m}}, \text{ min/car.} \quad (44)$$

Thus:

$A_1 = f(\alpha_{rt}, V, l_r)$;

$B_1 = f(\alpha_{rt}, \beta_{rt}, V, m, g)$;

$T = f(\alpha_{rt}, \beta_{rt}, V, l_g, m, g)$.

α_{rt}, β_{rt} – *normative coefficients given in [1], essentially reflect the technical characteristics of the shunting locomotive. The dependence on them is shown above.*

At fixed α_{rt}, β_{rt} *and* l_g $T = f(V, m, g)$, *i.e. optimum duration of maneuvers on the turnout track by the backing method is analytically deduced using formula (1) depending on m and g.*

The results of calculations using formula (38) for V = 15 km / h and fixed m are shown in Pic. 2–4 (l_g *= 94.5 m). In the notation for these figures:*

Ag+Bm – duration of maneuvers, calculated on the basis of statistical coefficients in accordance with [1];

T_{opt}*(a, b, m, g) – optimal (at optimal value x) the duration of maneuvers, calculated as the sum of semi-trips, based on the formula* $t_{s/t} = a + bm$;

T_{opt}*(V, m, g) –optimal duration of maneuvers, calculated as the sum of semi-trips, based on the formula (1),*

T_{opt}*(V, m, g) – optimal duration of maneuvers, obtained analytically by the formula (38).*

Table 1 shows the values of the coefficient A_1 *depending on the speed at maneuvers (V) and the length of the neck of the sorting park (*l_g*). Tables 2–4 show the values of the coefficient* B_1 *depending on the speed at maneuvers (V), the number of cars (m) and cuts (g) in the composition. Tables 1–4 were compiled at standard values of* α_{rt}, β_{rt}.

Conclusion.

Analysis of the results *shows the following:*

For m > 50 and g < 10 all four approaches give almost identical results, for m = 20 the results are the same for g <5;

With the number of cuts greater than the indicated values, are the most significantly different from the others, the results obtained according to the traditional formula $T_{sort} = A \cdot g + B \cdot m$, *these results are significantly lower than those obtained by semi-trips calculations;*

With a long sorted composition (m = 50, m = 70) and a significant number of cuts (g> 10), the analytically derived formula gives a longer sorting time than a formula derived from statistical data (taking into account the calculation of duration of semi-trips on the optimized formula, described in [4]), and with increasing g this discrepancy grows;

For a small length of the composition (m = 20), the analytically derived formula gives results that practically coincide with the optimized formula (1), and is smaller than in calculating the duration of a semi-trip by the formula $t_{s/t} = a+bm$. *All discrepancies increase with increase of the number of cuts.*

Thus, the analytically obtained formula $T_{sort} = A_1 \cdot g + B_1 \cdot m$ *gives results close to those obtained in calculating the duration of sorting by semi-trips in a wide range of values of m and g, and at the same time allows to quickly obtain the desired result (without calculating the duration of each semi-trip).*

The result can be used to quickly check the calculated values of the duration of the shunting operation, which, along with calculating the semi-trip duration [4], is realized in the simulation modeling of station operation in the AnyLogic environment [5–11].

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Article received 06.05.2016, accepted 18.06.2016.