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Track properties for formation of pick-up trains

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Subject review

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Track properties for formation of pick-up trains

The problem of tracks for formation of pick-up trains, with the analysis and proposal of possible solutions, is considered in the paper. Proposed solutions are derived from the results of simulations, which are based on the information obtained from the Belgrade and Lapovo marshalling yards. it was established that processes realized in these train stations are discrete with stochastic elements, and so the simulation models selected for solving this problem have been adapted accordingly, and have proven to be implementable and efficient. The results obtained show that the current practice in solving this issue has not been appropriate, that it does not provide good results and, hence, that it has to be changed.

Key words:

technical cargo stations, Pick-up train formation methods, number and length of tracks

Pregledni rad

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Karakteristike kolosijeka za formiranje sabirnih vlakova

U ovom radu razmatran je problem kolosijeka za formiranje sabirnih vlakova s analizom I prijedlogom mogucih rješenja. Predložena rješenja zasnovana su na rezultatima provedenih simulacija ciju osnovu predstavljaju podaci dobiveni iz ranžirnih kolodvora Beograd i Lapovo. Procesi koji se realiziraju u tim kolodvorima pokazali su se diskretnim sa stohastickim elementima te su i simulacijski modeli izabrani za rješavanje ovog problema prilagođeni istom, primjenjivi i ucinkoviti. Dobiveni rezultati pokazuju da dosadašnja praksa rješavanja ovog problema nije bila dobra, da ne daje dobre rezultate i da je treba mijenjati.

Ključne riječi:

tehničke teretne stanice, metode za formiranje sabirnih vlakova, broj i dužina kolosijeka

Übersichtsarbeit

Miloš Ivić, Ivan Belošević, Sanjin Milinković, Milana Kosijer, Norbert Pavlović

Eigenschaften von Gleisen für die Formierung von Sammelzügen

In der vorliegenden Arbeit wird das Problem von Gleisen für die Formierung von Sammelzügen analysiert und mögliche Lösungsvorschläge werden gegeben. Die vorgeschlagenen Verfahren beruhen auf den Resultaten durchgeführter Simulationen, die sich auf Daten der Rangierbahnhöfe in Belgrad und Lapovo stützen. Die Abläufe an diesen Bahnhöfen sind als diskrete Prozesse mit stochastischen Elementen identifiziert worden und folglich sind anwendbare effektive Simulationsmodelle für die gegebene Problemstellung angepasst worden. Die erhaltenen Resultate zeigen, dass die bisherige Verfahrungsweise nicht zuverlässig ist, da sie nicht zu zufriedenstellenden Ergebnissen führt, und daher Änderungen vorgenommen werden sollten.

Schlüsselwörter:

technische Güterstationen, Methoden für die Formierung von Sammelzügen, Anzahl und Länge der Gleise

1. Introduction

Either track groups (separate groups or groups that form part of marshalling or marshalling-departure yards) or end parts of marshalling-departure yards, are used in technical freight yards to conduct activities that are needed to form feeder trains. In both cases, requirements relating to the number and length of tracks must be met so as to enable successful completion of the final feeder train forming process. Although known methods, developed a long time ago, are now used in practice for formation of freight feeder trains, i.e. traditional methods (Futhner Method, Special Method, and Japanese Method) and simultaneous methods (elementary, geometrical and triangular methods), the effects of their use have not as yet been fully explored, particularly as to track capacities that are significant for use of an appropriate organisation and technology of work, and the definition of the final yard layout. Inexistence of these data makes it difficult to properly plan and invest in track capacities that are needed to conduct shunting operations in these yards. Considering the complexity and stochastic nature of these processes, simulation is considered to be an efficient procedure that can be used for analysing behaviour of such systems, in order to find adequate solutions.

For that reason, a simulation based study is presented and used in the analysis of complex processes that occur during assembling and forming freight feeder trains, the purpose being to determine indicators significant for the analysis of solutions for a given real-life system, and for appropriate decision making. Indicators analysed in this simulation model, i.e. indicators of highest significance for this paper as they point to possible solutions, are specifically related to the number and length of tracks that are needed for realization of the above mentioned tasks.

During determination of numerical values of these indicators, the emphasis was placed on their functional dependences with respect to the method applied, on the number of intermediate stations served by feeder trains, number of wagons per intermediate station, and number of wagons in the trains formed in the train assembling process. Simulation models used provide results that can be useful not only to the planners and designers, but also to shunting controllers in their everyday work.

2. Current research

Three types of research can be differentiated when considering track capacities necessary for forming feeder trains. In the first group, authors of the papers [1, 2, 3, 10, 14] focus their attention on research aimed at defining the number of tracks needed to apply an appropriate technology (method) for implementing the feeder train forming process, without taking into account any other additional effects. These papers can be regarded as the very beginning of the process aimed at formulating feeder train forming methods. In fact, they formulate and define basic dependencies between the number of intermediate stations and track capacities required.

Detailed studies of some relevant methods were conducted in more recent papers [4, 5, 6 and 12]. Thus the triangular simulation method is analysed in detail in paper [4] where a presentation is given of possibilities for its application in technical freight yards equipped with humps or turnout tracks. The relationship between the number of intermediate stations and the required number of tracks for a single-phase forming of feeder trains is defined in paper [6], while the integer linear programming is used in [12] to establish an optimum train forming plan and the required number of tracks suitable for operating conditions in a particular marshalling yard.

In all these papers, the studies made are based on the theoretical level only, without additional analysis of influence on other, real-life, indicators of this system. That is why it can be said that they represent a good albeit not the final basis for further research.

The second group of authors deals with additional conditions for the application of some methods, based on existing data. This research, presented in papers such as [8, 9, 11], enables a more accurate analysis of effects of the use of individual methods related to the number and length of tracks, prior to actual realization. The effects of simulation method for feeder train forming are presented in papers [9, 11]. Traditional forming methods are described in [8], while a comparative analysis of the use of such methods in real operating conditions is given in [11]. Nevertheless, such research does not point to the type of preventive measures to be taken, which are related to the definition of final solution for crack capacities.

In order to solve this problem, previously developed solutions have been sublimed and additionally improved in this paper. Because of specific approach to the problem, this paper represents the beginning of new research on this topic and, as such, it can be classified into the third group. This assertion will be confirmed through analysis of research results presented in the paper.

3. Description of a realistic system

Feeder trains are a category of freight trains that is used to transport freight by railway. They run along railway sections between two technical freight yards and, at that, they perform operations in intermediate stations based on the principle "leave, take and exchange" wagons. In these intermediate stations, they can perform operations with wagons in one of the following ways:

- take wagons from the initial train composition formed in technical freight yards and leave them at the loading-unloading and handling points in the yard,
- take wagons from the loading-unloading and handling points within the yard and assemble them into a train,
- perform both of the above mentioned activities, first one and then the other.

These operations involving changes in composition require additional manoeuvring operations in intermediate stations, and they greatly affect the rate at which freight transport is operated. At the same time, this work reduces capabilities of railway transport, and affects the quality of railway services. To what extent the operation of railway transport will be hindered will largely depend on the method used to perform the above mentioned operations, and on capacities engaged to implement the method.

In order to achieve the best possible effects, i.e. to speed up the additional manoeuvring work at intermediate stations, the task of technical freight yards is to make appropriate preparations with regard to train composition. These preparations consist in grouping and inserting wagons into the train according to the order of intermediate stations along the route and, to meet this requirement, subsequent wagon sorting must be made after collection of wagons in technical freight yards (cf. Figure 1). This process requires engagement of appropriate track and locomotive capacities, which involves an appropriate organisation and technology of work, i.e. implementation of an appropriate method for the realization of this process.

Methods already mentioned in the paper are normally applied to enable final establishment of feeder trains. Out of these methods, the Futhner method, special method, and Japanese method, belong to traditional methods, i.e. to consecutive feeder train forming methods, while elementary, geometrical and triangular methods belong to simultaneous methods, i.e. to methods involving concurrent formation of several feeder trains. All these methods differ according to the way wagons are grouped via intermediate stations, and also according to possible track capacities engaged to perform this process, and hence according to the effects or results of the overall process.

Some of the crucial questions that are to be answered in this paper through simulation model are related to necessary track capacities and to method use solutions.

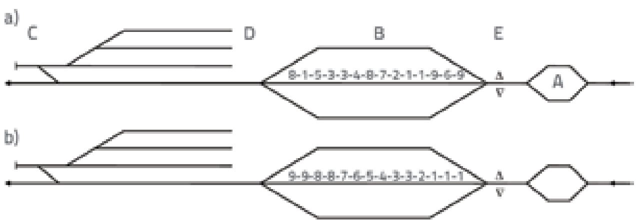

Figure 1. Order of wagons: a) after wagon collection; b) after wagon sorting

Note:

For the final appearance of the feeder train, it is significant to know what is the disposition of wagons as related to the tractive locomotive position (whether wagons should be arranged from the initial intermediate station toward the end station, or vice versa), so that an appropriate organisation and technology can be defined and applied. The answer to this question should be based on achieving minimum train stopping time at intermediate stations, i.e. on ensuring maximum speed of wagon delivery to the loading-unloading position).

3.1. Installations needed for final formation of feeder trains

In addition to track installations for wagon collection and sorting, the installations through which this process is operated are also needed for ensuring final formation of feeder trains (Figure 2). The forming of these installations is quite similar with regard to their structure (content and location), although they can greatly differ according to other typical indicators (form, number and length), which is dependent on the method used for implementation of this process.

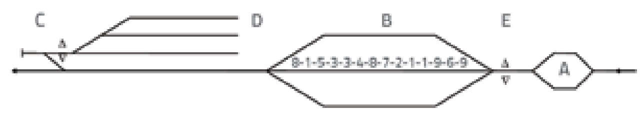

Figure 2. Installations for final formation of feeder trains

Shunting or shunting-departure park tracks are used for collecting wagons for feeder trains. The number and length of such tracks depends not only on train frequency and wagons that are to be moved from the yard, but also on the method applied.

The shunting hump and, very rarely, the turnout track, is used in the process of separation aimed at wagon collection. The shunting hump, turnout track, and modified shunting hump, can be used for sorting operations. At the same time, shunting or shunting-departure park tracks (entire tracks or just final parts of these tracks) are used in this "final sorting". A separate group of tracks, the so called "yard track group", can also be used for small shunting operations.

Newly formed trains usually depart from shunting-departure tracks from which the wagon was pulled out after collection and brought back after sorting, or from a separate departure group of tracks.

3.1.1. General properties of feeder train forming installations based on Futhner method and special method

The number and use of shunting or shunting-departure park tracks, where wagons are collected for feeder trains, is generally related to the number of shunting tasks (each shunting task is related to one track, or several smaller shunting tasks are related to a single track, and each greater task is related to a separate track). Lengths depend on the wagon flow for a given shunting task. The separation process is primarily accomplished via the shunting hump.

The final sorting is conducted at the ends of shunting or shunting-departure tracks or at the yard track group using the turnout track or the modified shunting hump (cf. Figure 3). The use of the ends of shunting or shunting-departure tracks is not rational as it disturbs train departure process and, if these tracks have to be used, the use should be concentrated on less travelled tracks. This is why the yard track group is more often used for feeder train sorting. This group is composed of a number of shorter tracks connected by the turnout track or modified shunting hump. In addition, it is necessary to ensure a good link between the turnout track or modified shunting hump and all tracks from which wagons are taken and on which wagons are left for feeder train forming purposes.

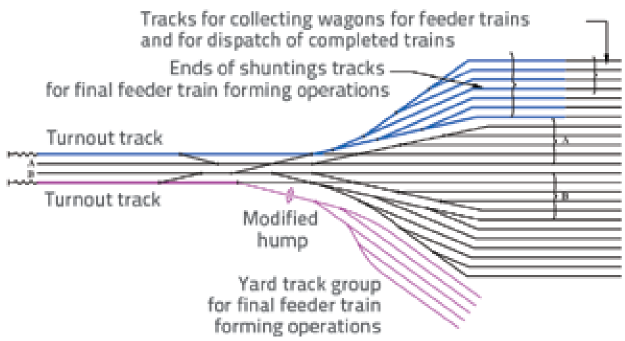

Figure 3. Installations for forming feeder trains according to Futhner Method and Special Method

On the other hand, yard group tracks can somewhat be changed (shape and number of tracks) in accordance with local conditions and needs. Thus for instance these tracks can be shaped as dead-end sidings or as a track group connected by turnouts at both sides [13], or they can be parallel to the turnout track or situated at an angle to this track (cf. Figure 4). The solution involving both-sided track connections is more expensive, but it is more efficient during transfer of newly-formed feeder trains into a separate departure group, especially when it is located parallel to the shunting track group.

In general terms, the yard group can also be used for arranging wagons by loading-unloading points at local goods or industrial stations, and for some other tasks. That is why it is considered to be highly appropriate for shunting yard operations.

3.1.2. General properties of feeder train forming installations based on Japanese method

The Japanese method has been popular in technical freight yards due to a specific track solution. This method requires three shunting tracks, where the final feeder train forming takes place. The tracks must be interlinked with appropriate crossovers (most often with simple crossovers (Figure 5a) or double crossovers (Figure 5b)). Furthermore, all these tracks must have a downward grade of 2.5‰ and must be equipped with track brakes, radars, and axle counters. The central delivery track is usually by 50 to 80 mm higher then the end tracks, so that wagons can easier move to end tracks, depending on their use.

In marshalling or classification yards, such track solutions can be:

- with only one track structure on which the final sorting is operated for all trains,
- with several track structures, where the number of such structures corresponds to the number of feeder trains to be formed at a particular yard,

with several truck structures that are defined depending on the needs and expected effects.

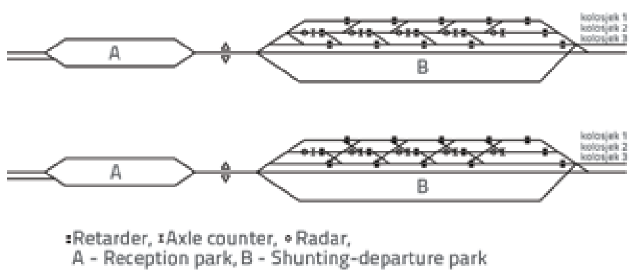

Figure 5. Technical solutions for forming feeder trains by Japanese method: a) with simple crossovers; b) with double crossovers

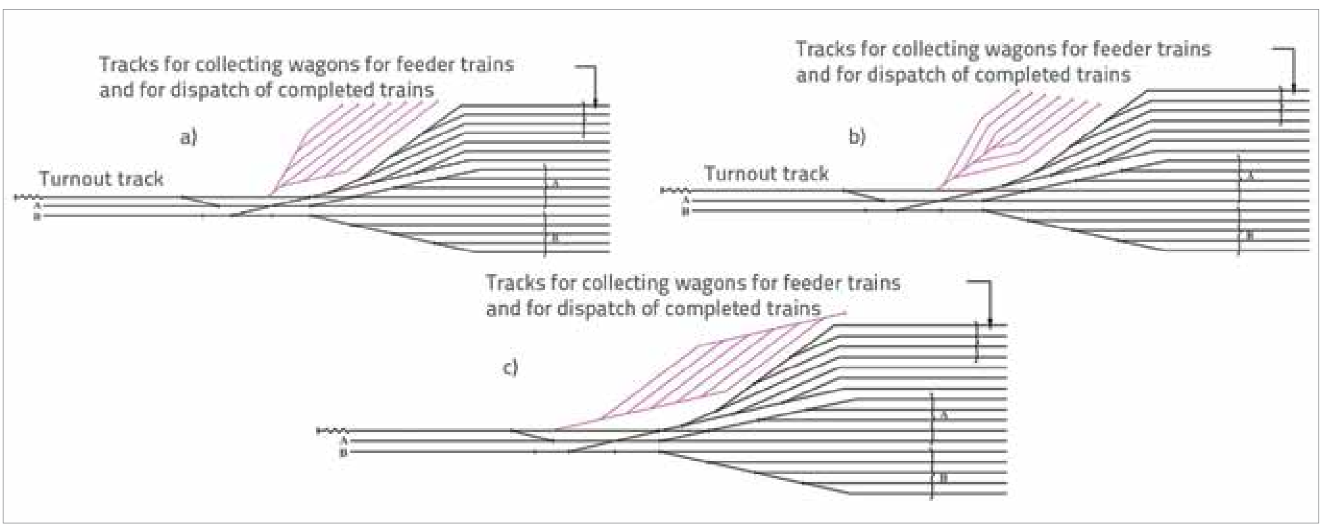

Figure 4. Forms of yard track groups: a) fan; b) fir-tree; c) grating

3.1.3. General properties of feeder train forming installations based on simultaneous methods

When simultaneous methods are used for forming feeder trains, shunting or shunting-departure park tracks are exclusively used in the process of wagon collecting and final sorting according to trains and intermediate stations. The shunting hump is used as a separating and forming facility (cf. Figure 6). The number and use of collection tracks is usually related to the number of intermediate stations, and their lengths depend on the number of wagons that are collected at a particular track. The number of tracks for sorting wagons according to trains and intermediate stations corresponds to the number of newly formed feeder trains, and their lengths correspond to train lengths.

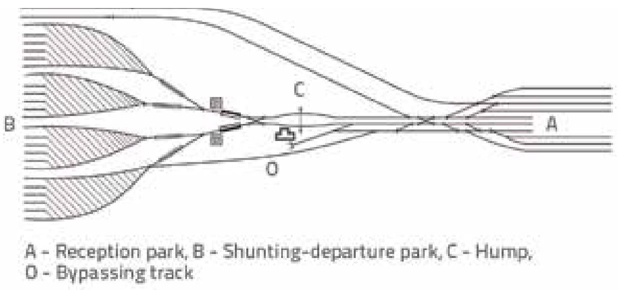

Figure 6. Installations for forming feeder trains by simultaneous method

3.2. Technical requirements for implementation of individual feeder train forming methods

Technical requirements for implementation of individual methods that are used for forming feeder trains are directly related to these methods. This is why a brief account of their functioning is given in this paper.

3.2.1. Brief presentation of the Futhner method

The Futhner method is the oldest feeder train forming method. It was named after its author Harry Futhner who first applied it in 1880 at the Liverpool train station which had a small number of tracks and where manoeuvring work was operated with great difficulty.

According to Futhner, by two separations and two subsequent connections of wagons or groups of wagons on feeder train forming tracks, wagons can rapidly be arranged into groups for the number of stations (intermediate stations) which corresponds to the square of the number of tracks available for this manoeuvring work. This means that the following dependence exists between the number of groups, i.e. the number of intermediate stations, and the number of manoeuvring tracks for arranging groups by intermediate stations:

$$m = n^2, or\ n = \begin{cases} \sqrt{m}; \sqrt{m} \in N \\ \lceil \sqrt{m} \rceil + 1; \sqrt{m} \notin N \end{cases} \qquad (1)$$

where:

m - number of intermediate stations for which the feeder train is formed,

n - number of tracks for final wagon regrouping-sorting according to the order of intermediate stations.

To facilitate understanding of essential characteristics of this method, a general feeder train forming example is given. It involves train groups for "m" intermediate stations, while the forming itself is conducted by means of "n" tracks.

<u>The following procedure is used:</u>

Wagons collected from the shunting or shunting-departure track are first brought to the turnout track and then the process of sorting according to target stations is conducted. During the first sorting, wagons for intermediate stations 1; n+1; 2n+1; ...; to m-n+1 are left at the first track, wagons for intermediate stations 2; n+2; 2n+2; ...; to m-n+ are left at the second tracks and so forth up to the wagons for intermediate stations n; 2n; 3n; ...; m which are left at the n track (if n = √m). This ends the first process of wagon separation by tracks. After that, wagons from individual tracks are connected and moved to the turnout track in preparation for the second sorting process. In this sorting process, all wagons from the group for one intermediate station are left at one track, for the second neighbouring intermediate station at the second track, and so on until the wagon is reached with the serial number of the intermediate station that is adjacent to the station for which wagons have already been sorted. In this case, such wagons are added – sorted to that track (Example: wagons for intermediate stations 1; 2; ...; up to n are left at the first track, wagons for intermediate stations n+1; n+2; ...; up to 2n are left at the second track, and so on until wagons for intermediate stations m-n+1; m-n+2; ...; up to m, which are left at the nth track). In this way, all wagons from the feeder train are ordered according to the sequence of intermediate stations, but at different tracks. The next activity is to conduct the second connection process by tracks, so that the wagons are fully arranged according to the sequence of intermediate stations. In this connection process, it is important to know that the order similar to the previous one must be respected. Thus, if in the first connection process the sequence was from the first to the nth track, i.e. from the nth to the first track, then the same sequence must be used in the second connection process.

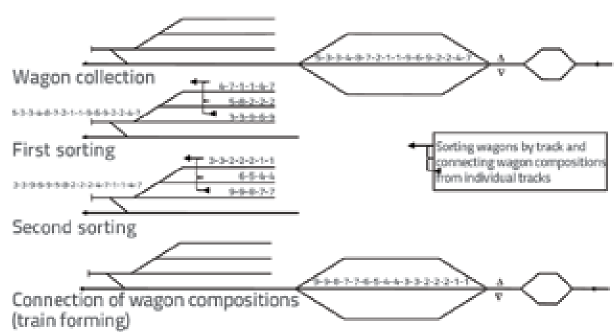

Figure 7. Feeder train forming by Futhner method

An example of feeder train forming by phases, for the case of three tracks where collection is made for nine intermediate stations, is presented in figure 7.

3.2.2. Brief presentation of the Special Method

The Special Method for feeder train forming is also applied at yards with a limited number of tracks. In this method, there is no dependence between the number of tracks and the number of intermediate stations by which wagons are grouped. Unlike the Futhner method, it can be applied for any number of tracks.
To facilitate understanding of essential characteristics of this method, here also a general feeder train forming example is given. It involves train groups for "m" intermediate stations, while the forming itself is conducted by means of "n" tracks (case m>n).

The following procedure is used:
Wagons collected from the shunting or shunting-departure track are first brought to the turnout track and then the process of sorting according to target stations is conducted. During the first sorting, wagons for intermediate stations from 1 to n-1 are left at the corresponding tracks, while all other wagons are moved to the nth track. This is followed by the first process of assembling wagons from individual tracks, starting from the nth track, via the n-1-th to 2, and by their moving to the turnout track in preparation for the second sorting process. In this sorting process, all wagons from the groups for intermediate stations from 2 to n-1 are grouped and arranged according to their order, and all are left at the first track where wagons for the first intermediate station are already positioned. These wagon groups at the first track are complemented by wagons for

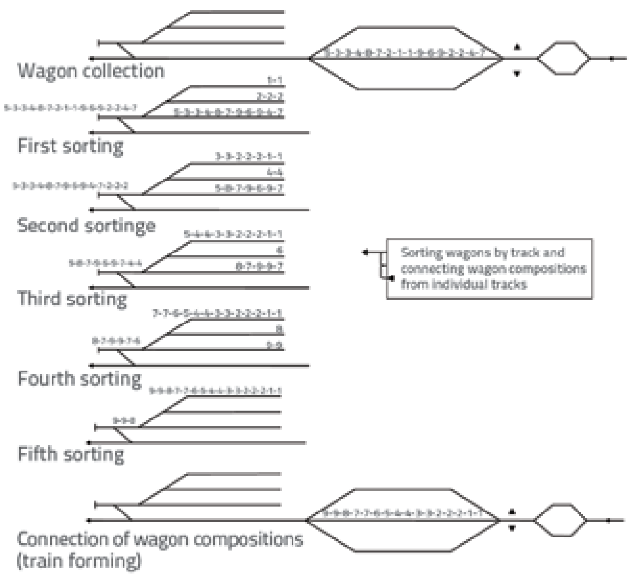

Figure 8. Feeder train forming by Special Method

the nth intermediate station, while wagons are distributed to other tracks in the following sequence: wagon for the intermediate station n+1 at the second track, wagon for n+2 at the third track and so on until the n-1 track where wagons for the intermediate station 2(n-1) come, while wagons for 2n-1 station come to the nth track, and so on until the mth intermediate station. Now the wagon grouping by tracks resumes starting from the nth track to 2, and they are moved to the turnout track in preparation for the third sorting process, which is similar to the preceding one. This process continues until wagons for the final intermediate station have been classified.
In case m £ n, the total distribution of wagons by intermediate stations is conducted in the first sorting operation, so that only the wagon grouping (connection by tracks) remains.
To facilitate understanding of the feeder train forming by phases, as based on this method, an example with three tracks, on which wagon collection is made for nine intermediate sections, is given in Figure 8.

3.2.3. Brief presentation of the Japanese Method

The technology for final feeder train sorting by means of the Japanese Method does not depend on the number of track structures contained in the system of these yards, but rather on the technical track solution, i.e. on the use of crossovers (simple crossovers (Figure 5a) or double crossovers (Figure 5b)). Here it is important that in each track group the central track assumes the role of delivery track, while two end tracks are used for wagon collection by intermediate stations. This is why both end tracks must have the number of parts that corresponds to the maximum number of intermediate stations at a distribution section for which feeder trains are formed (e.g. in Figure 9, there are 10 parts at end tracks (5 on each track) on which feeder train forming is possible for ten intermediate stations). The method of wagon forming or wagon collection at sections, and by intermediate stations, depends on crossovers used:

- if simple crossovers are used, then the use of parts at end tracks must correspond to the order of intermediate stations (on one side 1, 2, ..., 5, and on the other 6, 7, ..., 10, or on the one side 1, 3, ..., 9, and on the other 2, 4, ..., 10);
- if double crossovers are used, then the use of parts at end tracks can be arbitrary.

This solution enables wagon sorting and grouping according to appropriate intermediate stations in a single classification effort, so that this phase is followed solely by grouping according to the order of intermediate stations.
In the end, we could state that this solution is generally characterized by an increase in investment due to use of additional crossovers and track brakes, while on the other hand significant savings are made by shorter downtime of wagons.

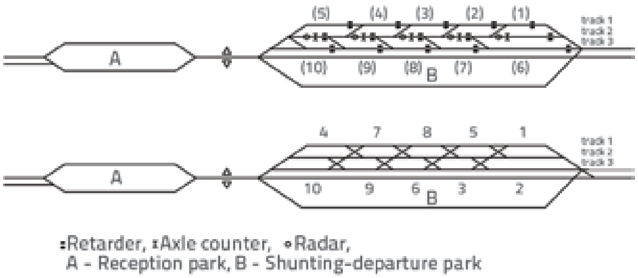

Figure 9. Track use during feeder train forming by Japanese method a) for solution with simple crossovers; b) for solution with double crossovers

3.2.4. Brief presentation of the Simultaneous Method

The simultaneous method for feeder train forming is used for simultaneous or concurrent forming of several feeder trains to enable timely departure of trains from the marshalling yard so that all wagons contained in such trains can be delivered on time to appropriate intermediate stations, and to appropriate loading-unloading points. This method was first used on French railways during the World War I in 1917 when several trains had to be formed to supply food for the military. Today, it is especially significant in cases of a rigid timetable of freight trains, i.e. in cases of the so called "agreed transport".

An another point that makes this method quite different from traditional methods is operation of the final train forming via the hump, at the shunting or shunting departure track group, which is not possible in case of traditional methods, i.e. at the yard track group using turnout track. Furthermore, an efficient use of simultaneous method requires an appropriate timetable adjustment and a better qualified manoeuvring personnel. In this method, wagons for feeder trains are collected according to appropriate intermediate stations for all trains together, at the same track. This means that wagons for all first intermediate stations, for all second intermediate stations etc., are gathered together at the same previously defined track, regardless of the fact that they belong to different trains, or rail lines, or rail line sections.

The final feeder train forming process begins simultaneously for all trains, when a sufficient number of wagons is collected for all trains that are to depart from the marshalling yard. When simultaneous method is used, the required number of tracks for wagon collection depends on the number of intermediate stations [8, 9]. The connection between the number of groups i.e. the number of intermediate stations (m) served by feeder trains, and the required number of shunting tracks (k) where wagons are collected using the geometrical methods, and assuming that no additional shunting other than separation of collected wagons is conducted, is shown in the following expression:

$$m_{max} = 2^k - 1 \tag{2}$$

$$k = \begin{cases} \dfrac{\log(m^{stv}_{max} - 1)}{\log 2}; & \dfrac{\log(m^{stv}_{max} - 1)}{\log 2} \in N \\ \left[\left| \dfrac{\log(m^{stv}_{max} - 1)}{\log 2} \right|\right] + 1; & \dfrac{\log(m^{stv}_{max} - 1)}{\log 2} \notin N \end{cases} \tag{3}$$

where:

m_{max} – maximum number of intermediate stations served by a single feeder train,

m^{stv}_{max} – maximum real number of intermediate stations served by one of feeder trains formed at the yard,

k - number of marshalling tracks on which wagon collection is operated.

A general principle on the basis of which wagon collection for feeder trains is operated according to the simultaneous method is shown in Table 1.

Table 1. General principle for wagon collection by tracks for intermediate stations of individual feeder trains

Track No. [k_i]	Intermediate station numbers for all sections for which feeder trains are formed [m_{is}]	General principle for wagon collection by tracks for intermediate stations	
1 2 3 4 5	1 3 5 7 9 11 13 15 17... 2 6 10 14 18 ... 4 12 ... 8 ... 16 ...	$m_{1,s} = 2^0 + 2*(j-1)$ $m_{2,s} = 2^1 + 4*(j-1)$ $m_{3,s} = 2^2 + 8*(j-1)$ $m_{4,s} = 2^3 + 16*(j-1)$ $m_{5,s} = 2^4 + 32*(j-1)$	i = 1, ..., k j = 1, ..., N s = 1, ..., m^{stv}_{max}
k_i	2^{k_i-1}...	$m_{i,s} = 2^{i-1}(1+2*(j-1))$	$m_{i,s} \leq m^{stv}_{max}$

The feeder train collection and forming process based on the simultaneous method can easily be described through the following example, assuming that:

- five feeder trains are formed (A, B, C, D and E),
- each train has wagons for no more than nine intermediate stations according to sequence that can be numbered with numbers 1, 2 ..., 9 and, at that, these intermediate station numbers represent groups of wagons that are sent to intermediate stations designated by that number. This means that each wagon gets its own (not written) designation corresponding to the intermediate station to which wagons are sent and to the train by which they are sent.
- four shunting tracks, marked with k_1, k_2, k_3 and k_4, are used for wagon collection,
- wagons in train to be separated are distributed by intermediate stations as shown in Figure 10.

Figure 10. Order of wagons by intermediate stations in the train to be separated

During the separation process (Figure 11), wagons for all first, third, fifth, seventh and all ninth intermediate stations, for all five trains, are collected at the first track. Wagons for all second and sixth intermediate stations for all trains are collected at the second track, while wagons for all fourth intermediate stations are collected at the third track, and wagons for all eighth intermediate stations are collected at the fourth track.

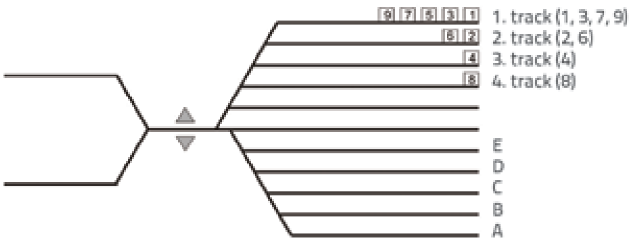

Figure 11. Wagon collection order at shunting tracks according to corresponding intermediate stations after train separation from Figure 10 (first phase of feeder train forming using the simultaneous method)

The forming process starts as soon as a sufficient number of wagons for all feeder trains are collected. Wagons collected are first pulled out from the first track and shunted in such a way that wagons for first intermediate stations of individual trains are turned to separate tracks (from A to E), separately for each train. Wagons for the third and seventh intermediate stations are turned to the second track, from fifth intermediate stations to the third track, and wagons for all ninth intermediate stations join wagons located at the fourth track (Figure 12).

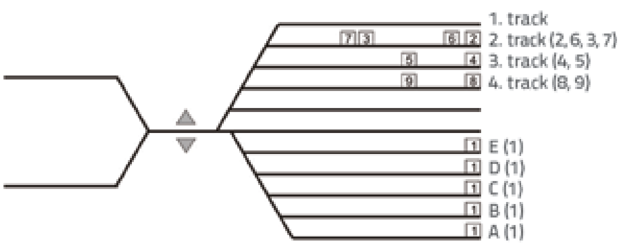

Figure 12. Wagon collection order at shunting tracks according to corresponding intermediate stations after wagon separation from the first track (second phase of feeder train forming using the simultaneous method)

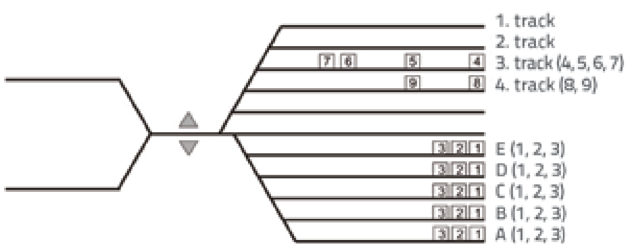

Figure 13. Wagon collection order at shunting tracks according to corresponding intermediate stations after wagon separation from the second track (third phase of feeder train forming using the simultaneous method)

Once the wagon shunting from the first track is completed, the process continues by shunting wagons from the second track (Figure 13). Wagons from the second track are shunted in such a way that they are turned, for second and third intermediate stations, to separate tracks from A to E, according to individual trains, while wagons for all sixth and seventh intermediate stations of all trains are separated, together, at the third track. During this time, the wagons from the fourth track do not move. The process logically continues (Figure 14) by first pulling out wagons from the third track and shunting them toward individual trains, on tracks from A to E (phase 4), and then from the fourth track (phase 5). Nevertheless, it is also possible to take out wagons from the fourth track and join them with wagons from the third track (phase 4), and then they are together shunted toward individual trains, on tracks from A to E (phase 5). In this way, all feeder trains are formed by individual sections and by the order of sections at tracks from A to E.
(Note: These alternatives do not affect the track length and will therefore not be analysed in greater detail)

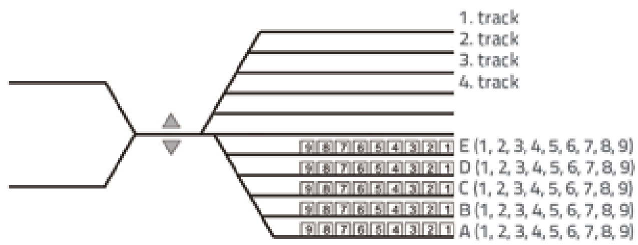

Figure 14. Final feeder train forming

The previous example clearly shows that we need four tracks for separating wagons for feeder trains during the composition separation process, i.e. wagon collection in shunting or shunting departure park, as there are nine intermediate stations at one section that are served by feeder trains, or no more than nine wagon groups that can be found in these trains. As the number of intermediate stations rarely exceeds ten, twelve, and only exceptionally fifteen to twenty, this means that the assumed number of shunting tracks at which wagons should be collected for feeder trains in the process of composition separation and forming is not great, ranging from three to four, or maximum five.

4. Model results

The internal structure and form of the simulation model used in individual feeder train forming methods, are directly dependent on objectives that have been set. Basic objectives set in this paper can be reduced to the following task: the simulation method is used to determine the following for parameters that have been specified in advance:

- number of tracks needed for collecting wagons for feeder trains formed in the yard,
- number of tracks needed for final forming-sorting wagons for feeder trains,

- track lengths needed for implementation of planned processes,
- adequate solution (location and layout of installations) for realization.

These problems have usually been solved based on experience and intuition, without systematic analyses aimed at taking appropriate actions [7]. Consequences of such approach are seen as negative effects only after the realization or construction of the yard, i.e. soon after the start of its operation. A modern approach to this problem implies a different methodology which involves:

1. Setting the initial number of tracks for collecting wagons for feeder trains in the yard to a realistic value.
2. Setting the initial number of tracks for final forming of feeder trains in the yard to a realistic value.
3. Setting the structure of feeder trains to be formed into a wider perspective taking into account the number of wagons in the train, number of intermediate stations, and wagon distribution by intermediate stations.
4. Repeating the experiment which involves changing the train structure and number of intermediate stations.
5. Monitoring the way the change in train structure and in the number of intermediate stations influences the system parameters under study.

In order to build such a simulation model, appropriate parameters have been defined. They correspond to real conditions of track groups for small shunting, and to real conditions of wagon distribution by intermediate stations, at any railway network. These parameters are:

- Five tracks in the shunting or shunting-departure park serving for the collection of wagons for feeder trains;
- five tracks in the departure or shunting-departure park serving for forming five feeder trains;
- 30; 35; 40; 45 and 50 wagons in the train;
- 5; 7; 9; 10; 13 and 16 intermediate stations with real distribution of wagons by intermediate stations, as obtained from the Belgrade marshalling yard and Lapovo marshalling yard, which form part of the network operated by the Serbian Railway Authority.
- rather than presenting full results, the authors present only the summary of results relevant for dimensioning (definition of the number and length) of track capacities where wagons are collected for feeder trains, and for their final forming-sorting by trains and intermediate stations.

The indicators relevant for system functioning include the number and length of tracks needed for successful application of the method under study and, at that, track lengths are expressed as the number of wagons that can be placed on a given track. These results are presented in Figures 15, 16 and 17, and in Tables 2 and 3. The information relating to the length of tracks for collecting wagons for feeder trains in case of traditional methods (Futhner Method and Special Method) and to track lengths for final forming-sorting of feeder trains in case of Simultaneous Methods are not graphically presented, as they correspond to the lengths of such trains.

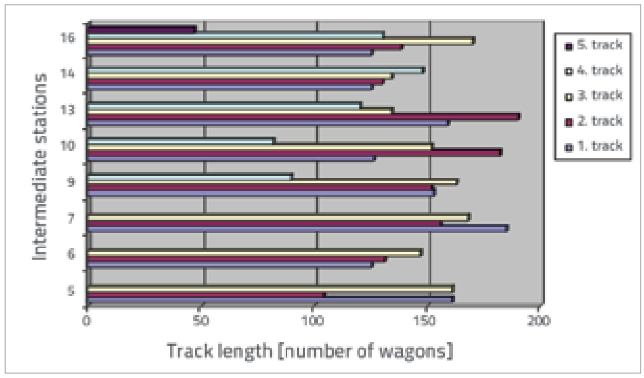

Figure 15. Track lengths needed for wagon collection (Simultaneous Methods)

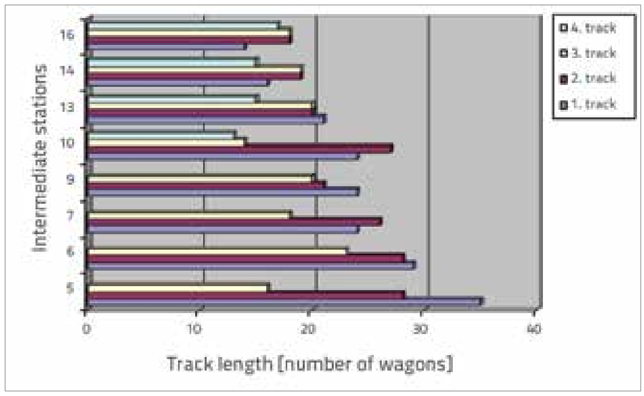

Figure 16. Track lengths needed for final forming-sorting of feeder trains (Futhner Method)

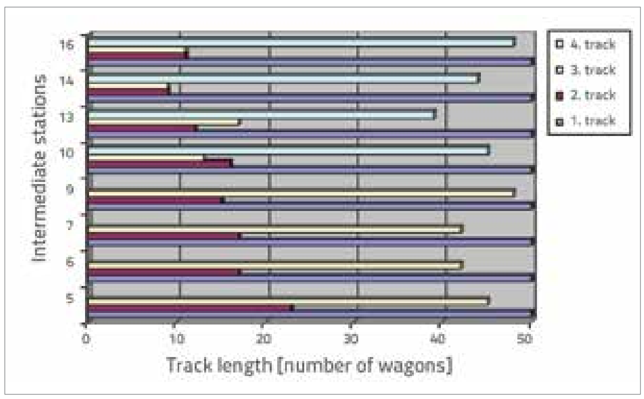

Figure 17. Track lengths needed for final forming-sorting of feeder trains (Special Method)

Output results can be summarized as follows:

- The use of any feeder train forming method requires two track groups; the first one is used for collecting wagons according to trains (traditional methods), or according to intermediate stations (simultaneous methods), while the other one is used for final completing – sorting of feeder trains according to the order of intermediate stations served by such trains.

- Tracks on which the wagon collection process is operated by means of traditional methods have uniform lengths which correspond to train lengths, while in case of simultaneous methods these lengths are markedly non-uniform and they primarily depend on the intensity of traffic flow, and much less on the number of intermediate stations the trains are serving (Figure 15).
- The number of tracks on which wagons are collected by means of traditional methods corresponds to the number of feeder trains that depart from these stations, while

Table 2. Simulation results for 30 wagons in a train

Methods applied		Simultaneous				Futhner				Special			
Number of int. stations		5	9	10	16	5	9	10	16	5	9	10	16
TBK	n	3	4	4	5	5	5	5	5	5	5	5	5
	s	5	5	5	5	3	3	4	4	3	3	4	4
	Σ	8	9	9	10	8	8	9	9	8	8	9	9
SBK	$n_1(n_2)$	5(4)	7(5)	6(5)	8(6)	5	5	5	5	5	5	5	5
	$s_1(s_2)$	5	5	5	5	3(2)	3(2)	4(3)	4(3)	3(2)	3(2)	4(3)	4(3)
	Σ	10(9)	12(10)	11(10)	13(11)	8(7)	8(7)	9(8)	9(8)	8(7)	8(7)	9(8)	9(8)

Table 3. Simulation results for 50 wagons in a train

Methods applied		Simultaneous				Futhner				Special			
Number of int. stations		5	9	10	16	5	9	10	16	5	9	10	16
TBK	n	3	4	4	5	5	5	5	5	5	5	5	5
	s	5	5	5	5	3	3	4	4	3	3	4	4
	Σ	8	9	9	10	8	8	9	9	8	8	9	9
SBK	$n_1(n_2)$	8(6)	10(6)	11(7)	12(7)	5	5	5	5	5	5	5	5
	$s_1(s_2)$	5	5	5	5	3(2)	3(2)	4(3)	4(3)	3(2)	3(2)	4(3)	4(3)
	Σ	13(11)	15(11)	16(12)	17(12)	8(7)	8(7)	9(8)	9(8)	8(7)	8(7)	9(8)	9(8)

Marks used in the above tables are defined as follows:

TBK - theoretical number of tracks needed for collecting and sorting wagons during formation of feeder trains, taking into account the fact that their length is not limited

SBK - real number of tracks needed for collecting and sorting wagons during formation of feeder trains and, at that, their individual length is limited by operational reasons (number of wagons on a track must be realistic and such that it does not disturb efficient functioning of processes or provoke inappropriate solutions)

n - number of tracks needed for collecting wagons for feeder trains ($n=n_1(n_2)$)

s - number of tracks needed for sorting wagons by intermediate stations and feeder trains ($s=s_1(s_2)$)

n_1 - number of tracks needed for collecting wagons for feeder trains in case the limited length principle is applied, and tracks are used according to their initial purpose

n_2 - number of tracks needed for collecting wagons for feeder trains in case changes in organisation of track use (change of track use) are applied

s_1 - number of tracks needed for sorting wagons by intermediate stations and feeder trains in case the track on which the wagon collection was made is not used for final sorting

s_2 - number of tracks needed for sorting wagons by intermediate stations and feeder trains in case the track on which the wagon collection was made is used for final sorting in simultaneous methods this number is dependent on the number of intermediate stations and track lengths. Considering that track lengths in simultaneous methods are markedly non-uniform and that they exceed the limits of acceptable use, the theoretical number of these tracks must be increased for these tasks so as to reach acceptable limits of use, and to achieve uniformity goals. At the same time, the number of tracks for wagon collection using simultaneous methods can be reduced through an appropriate organisation of work in the final train forming process, which implies the use of tracks that have been freed up. This greatly increases the number of tracks in this phase (data in Tables 2 and 3).

- Tracks on which the final feeder train forming process is operated via traditional methods are characterized by markedly non-uniform lengths, unlike tracks on which simultaneous methods are used, where these lengths are uniform and correspond to train lengths. In Futhner method, the length of tracks is more uniform when compared to the Special Method where this is not the case (Figures 16 and 17). In Special Method, track lengths are markedly non-uniform and, at that, the first and the last track are of a more uniform but markedly greater length compared to central – inside tracks, whose length is also uniform (Figure 17).
- The total number of tracks for the collection and final forming of feeder trains can be reduced through an appropriate organisation of work in the processes under study, which implies use of tracks that have been freed up.
- Current principle according to which in case of the simultaneous method the number of tracks on which the wagon collection for feeder trains is related to the number of intermediate stations is difficult to apply and is unacceptable for the standpoint of practical use (excessive track lengths), and should therefore be redefined.
- Data presented in this paper have so far been insufficiently considered and underused in the selection of final solutions, although their role could be quite important in that segment.

5. Conclusion

Based on research conducted in this paper, and the corresponding analysis of results, the following conclusions can be made:

- Regardless of the method used, the process of feeder train forming can be relatively easily modelled and simulated by means of any programming language.
- Results of the model used show the real situation with regard to the use of analyzed methods, and point to a number of errors in the current design and operation of technical freight yards. That is why these results can be used as an additional argument for making significant technical and investment decisions during the design and operation of either new or renovated technical freight stations.
- Significant new indicators as to the use of these methods can be developed by broadening the base of input elements, and through additional analyses. A separate report (study) should be prepared in that respect.
- The establishment of this model has created favourable conditions, and has given an additional encouragement, for the participation of wider public and the authors themselves in the further development of the model through future study of this or other similar problems.

Acknowledgments

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