Method for automation of generation of interlocking tables for station traffic control devices

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Abstract. On account of the growing number of railway upgrading projects implemented in Poland, there are numerous problems emerging when they are prepared and performed. While preparing detailed plans and specifications for railway traffic control devices intended to secure traffic at a railway station, one must deal with numerous alterations related to the phasing of the works directly linked with the said equipment. Consequently, the variety of elements subject to change includes the schematic plan and the relevant interlocking tables for railway traffic control systems. The purpose of this article is to discuss the authors’ original method for automation of generation of interlocking tables for station traffic control equipment. The solution to the problem in question is assumed to be a model consisting of two components. One of them is the design part identifying individual objects comprising the railway station being designed. Subsequently, by the application of adequate algorithms, data are implemented in the other model component. Further calculations are performed to generate a list of all possible movements from main signals and shunting signals at the station, these being referred to as railway routes. The method has been verified using the authors’ original computer program. Its first part corresponds to the design process. The station’s track layout is built using the program’s dedicated toolbar combined with an additional database of layers created in computer-aided design software. Next, such a track layout, saved into a dxf file, is imported to a dedicated application where train and shunting routes are generated. The method is verified by checking the routes thus generated against those in the existing interlocking tables by applying an adequate significance indicator. Assuming that basic assumptions of the design process are satisfied, the method in question makes it possible to accelerate the generation of interlocking tables in a secure manner.

Keywords: interlocking tables, schematic plan, railway control devices

Article citation information:


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Received 27 December 2020, Revised 19 January 2021, Accepted 21 January 2021, Available online 18 March 2021
1. Schematic plan and interlocking table

1.1. Introduction

The most important aspect of railway traffic management is the capacity to ensure safety. In pursuit of this goal, various railway traffic safety and control solutions have been developed and improved over the years. Starting from mechanical devices, to relays, to state-of-the-art computerized solutions, railway traffic control systems have always been supported by interlocking tables, the design of which entails large responsibility on account of their high complexity. These tables represent the relationships between individual elements comprising a railway route, i.e., a single trip of a rail vehicle from the start signal to the end signal.

For the sake of improved universality of the process in which interlocking tables are created, the MGLTAB method has been devised for the automated creation of interlocking tables for in-station railway traffic control systems. The method has been adapted to the needs arising from frequent track layout changes, which, in turn, result from the very nature of the requirements and needs defined for the given station. Its main purpose is to automatically generate all railway and shunting routes at a railway signal box. The method proceeds in two stages: design and generation. The first one is intended to create a database of objects, including their properties, that are necessary to complete the second stage. The method is based on the assumption that a specific station’s database is built using a directory of elements that are characteristic of a typical interlocking table. The second stage of the MGLTAB method commences by learning about all the required objects and their properties and proceeds by generating the relevant routes and rail switches.

At individual stages, all crossings are defined using dedicated algorithms of the MGLTAB method. The input data preparation methodology is based on the assumption that certain properties of objects (including temporary naming, choice of object sub-types) are introduced automatically.

1.2. Schematic plan

In order to understand what interlocking tables are, one must first become familiar with the structure and elements of the schematic plan of railway traffic control devices. Based on that plan, all possible routes and all devices inside them are created.

The schematic plan of railway traffic control devices [1] is developed on the basis of the track system layout plan. It depicts the layout of tracks and switch points in a non-uniform scale (1:2,000 longitudinally and 1:500 transversely) and marks the railway traffic control devices as well as train routes. A different type of scale may also be used.

A sample schematic plan has been provided in Figure 1.

With an intent to analyze interlocking tables, one should also define what a railway route is. A railway route is understood as a set of ordered states that should be the states of elements of the railway traffic control equipment which control, secure, and monitor a certain block [3].

There are two kinds of routes that must be taken into consideration in an interlocking table:

a) train route, characterizing the route in which trains run [1],
b) shunting route – a route set for shunting vehicles [1].
Such a set of routes, along with their elements, constitute a complete notation of relationships in play at the given station. It defines the routes which cannot be covered simultaneously and the elements (railway traffic control devices) to be engaged for that purpose. Below is a railway route example (see Fig. 2).

![Fig. 1. Poznań PoD junction – schematic plan of railway traffic control devices [2]](image)

![Fig. 2. Example of a train route starting at signal F [4]](image)

### 1.3. Interlocking table

Interlocking tables are used to represent the location and state of the devices engaged in a train or shunting route in a legible manner. They are created with reference to the schematic plan of the given railway station (see Fig. 1). Interlocking tables are included in the internal documentation of railway traffic control systems, and they are intended for train dispatchers to safely manage traffic at the railway station from signal boxes.
An interlocking table consists of the upper section, known as an interlocking table header, and the lower section is referred to as a table of locks. The interlocking table header contains the type and number of internal control and block devices, while the table of locks indicates the locks and mutual relationships between the devices [1].

The sample interlocking table (see Fig. 3) illustrates all routes managed at the Poznań PoD junction, organized under the upgrading project for line 351 between Poznań and Szczecin.

Fig. 2. Interlocking table example [2]

2. Method presentation

2.1. Requirements

The fundamental assumption behind the method discussed in this paper is that a station’s interlocking tables for railway traffic control devices can be generated automatically on the basis of input data on the given site’s existing track system.

The track system elements represented by the input data are divided into particular object types having generic and specific characteristics. There are appropriate relationships between objects. All objects are included in a database of objects specific to the given site. In order to prepare the database (simplified schematic plan) in the way of the method in question, one uses a ready set of objects with pre-defined generic characteristics. In subsequent steps, the objects are assigned types and specific characteristics.

One should assume that the database provides a sufficient range of information about the railway traffic control system. The most important stage of work is designing a simplified track system, where every single error has consequences to the subsequent phases of the
interlocking table generation process. For this very reason, simplification of the rules/principles applicable to the design stage is one of the preconditions for a positive final assessment of the automation method.

The method’s fundamental assumptions are as follows:
- the method can be used independently of the manufacturer of station systems,
- the relevant process consists of two parts: first comes the design part, aimed at preparing the database of objects at the station, followed by the second, generation phase, when the database is used to create all the possible routes,
- the goal is to generate all the possible train and shunting routes at the station without defining any additional special conditions,
- the number of elements is limited, i.e., the table designing stage should be simplified as much as possible,
- one must develop algorithms describing specific processes performed under the method,
- it is necessary to standardize the requirements that could become applicable in the foreseeable future when, for example, a new railway instruction manual on interlocking tables is released,
- the model produced using the proposed method will allow the analysis and verification to be performed with reference to the existing interlocking tables in order to validate the method,
- the method should make it possible to expand the database with further new elements, i.e., signal indication tables, switch point tables, etc.

Figure 4 provides a schematic diagram of the method implementation. It consists of 4 basic sub-processes, each having the algorithms which define them. The first process is the preparation of a set of data (not otherwise noted) characterizing the schematic plan designed. The next step in the method assumes that the necessary data concerning blocks of adequate objects are organized. In the third process, the object data are read out, and object types are assigned to appropriate tables. In the last step, safeguards are first generated for respective objects, and then all possible train and shunting routes are generated for the station. The sequence of actions assumed in the method is of utmost relevance if a satisfactory outcome is to be achieved.

2.2. A formal description of track system elements

In order to present the MGLTAB method correctly, one should first prepare a model being the outcome of the modeling process at the same time [5]. The modeling process, on the other hand, is a set of activities aimed at creating a tool (model), the examination of which determines the very rationale of the research [6]. The goal of the examinations performed using the MGLTAB method is to analyze and verify the correctness of the formal description and of the consequential interlocking tables generated against the required state (real tables).

Without an appropriate description, it is not possible to demonstrate the correctness of the automated table generation method. In the consecutive points of this section, the model assumed under the method for automated generation of interlocking tables has been described in formal terms. This description comprises the following elements:
- breakdown of the sets of all elements should be found on a simplified schematic plan,
- functions of mapping of the characteristics and types specific to individual elements of the set, which are necessary to make the track system structure detailed enough,
relationships between the elements of the set, which determine, among other aspects, the possibilities for arranging routes, sideways runs, and many other required relationships. Examples of the elements of the assumed formal description have been provided in the consecutive sub-sections.

Fig. 3. Schematic representation of the method for automation of the generation of interlocking tables for station traffic control equipment [by the authors]
2.2.1. Sets of routes and rail switches

Elements of the set of routes and rail switches have been described in this section. In accordance with the applicable regulations Bląd! Nie można odnaleźć źródła odwołania., railway routes can be divided into two basic types, as shown in Figure 5.

![Diagram of railway routes](image)

Fig. 4. Breakdown of railway routes [1]

Where the given description concerns computer devices, one assumes that the routes are organized, and thus a set of all the $P_Z$ routes can be noted as follows:

$$P_Z = \{P_{ZP} \cup P_{ZM}\}$$

(1)

where it comprises a total of all train and shunting routes managed at the given station.

Each separate route consists of individual elements characterizing its path, flank protection, and overlap. This route is composed of the following elements: switches, main signals, shunting signals, isolated sections, level crossings (or passageways), locks.

A set of switches comprises a sum of two subsets according to the equation below:

$$Z = \{Z_C \cup Z_T\}$$

(2)

Subset $Z_C$ can be noted as a sum of subsets of all possible signals with their characteristics defined in the figure:

$$Z_C = \{Z_{C0} \cup Z_{CS}\}$$

(3)

where $Z_{C0}$ is the subset of generic characteristics.

$$Z_{C0} = \{Z_{000} \cup Z_{001} \cup Z_{010} \cup Z_{011} \cup Z_{100} \cup Z_{101} \cup Z_{110} \cup Z_{111}\}$$

(4)

Their quantity is given by the number $n^k$ Where $n$ is the number of characteristics in a single group, and $k$ is the number of groups of characteristics defining rail switches.

Subset $Z_{CS}$ contains the specific characteristics of the rail switch object, i.e., its name and coordinates (x, y).

$$Z_{CS} = \{Z_N \cup Z_{WSP}\}$$

(5)
Subset \( Z_T \) defines the element type, which is simply a rail switch in this case. It is possible that the range of rail switches is extended on account of their type, using this method. Since the approach assumes simplification of the applicable rules, no additional distinction between rail switches is made considering whether they occur on the route, as well as given their flank protection and overlap. Such a distinction should be made in the process of automatic generation of interlocking tables in the course of the track system analysis.

2.2.2. Functions for mapping characteristics and types

In order for specific objects to be assigned specific types, adequate functions must first be defined. The first function assigns a type to each object, and the type then determines whether or not it belongs to a particular set:

\[
F_T: O \rightarrow Type_O
\]

(6)

where:

\[
Type_O = \{ Z_T, S_T, Tm_T, Wk_T, K_T, Kon_T, B_T, P_T, D_T \}
\]

(7)

Another function enables values of coordinates \((X, Y)\) to be assigned to an object:

\[
F_{\text{Coord}}: O \rightarrow (X,Y)
\]

(8)

where \(X \in R\) and \(Y \in R\). The \(F_W\) function concerns all objects and determines the nature of the model’s geographic structure in the MGLTAB method.

The following function assigns names to objects:

\[
F_N: O \rightarrow (N_O)
\]

(9)

where \(N_O = \{ Z_N, S_N, Tm_N, Wk_N, K_N, Kon_N, B_N, P_N, D_N \}\)

The functions which define the generic characteristics of a rail switch object, as noted in a binary system, can be represented as follows:

\[
F_{\text{CZW}}: Z_{Co} \rightarrow \{ z_1, z_2, z_3 \}
\]

(10)

where:

- \(z_1\) – turn in facing point movement, and \(z_1 \in \{0,1\}\),
- \(z_2\) – direction of side movement, and \(z_2 \in \{0,1\}\),
- \(z_3\) – basic state “+”, and \(z_3 \in \{0,1\}\).

2.2.3. Relationships envisaged in the method

There can be specific relationships between elements of different types as well as of the same type, and they may affect the notation of interlocking tables. The method is based on the assumption that the relationships characterize the sets of object types. An example of a relationship between two objects of the rail switch type has been provided in this section. The characteristics which affect relationships between objects include coordinates, turn, direction, etc.

One of them is the track crossover relationship \((PZ)\), defining where one track is switched to another, whose set can be noted as follows:

\[
PZ = \{pz(Z_1, Z_2), pz(Z_3, Z_4), ..., pz(Z_i, Z_j)\}
\]

(11)

where:
− \( pz(Z_1, Z_2) \) is a relationship between rail switches \( Z_1 \) and \( Z_2 \),
− \( pz(Z_1, Z_2) \) is a relationship between rail switches \( Z_3 \) and \( Z_4 \),
− \( pz(Z_i, Z_j) \) is a relationship between rail switches \( Z_i \) and \( Z_j \).

The above relationships represent two different rail switches, and consequently, \( i \neq j \).

The track crossover relationship characterizes the \( Z_T \)-type objects, i.e., rail switches, including fictive switches.

### 3. Method verification

#### 3.1. Subject of analysis

In order to verify the method in practice, the train and shunting routes previously generated (including on-route and flank protection rail switches) were compared with regard to the sites situated on line 351 between Poznań and Szczecin. The selected sites are as follows:

− Poznań PoD junction (Jeżyce),
− Poznań Wola junction,
− Kiekrz station,
− Rokietnica station,
− Szamotuły station,
− Pęckowo junction,
− Wronki station.

When preparing for the analysis of the generation results obtained, the following conditions were adopted:

− for comparison purposes, all train and shunting routes included in the interlocking tables have been selected,
− for train routes, all rail switches in the main set route and in flank protection are subject to analysis,
− for shunting routes, all rail switches in the main set route are subject of analysis, as per [1]: “The block of a shunting route is the main set route. Where it is reasonable, overlap and flank protection may be used”,
− overlaps have been disregarded,
− derailers have been disregarded,
− coupling between rail switches and between a rail switch and a derailer has been disregarded.

The database of objects using the simplified schematic plan of railway traffic control devices was developed in the AutoCAD software. Using a dedicated toolbar (see Fig. 5), a schematic diagram of the track layout at the selected stations was prepared.

**Fig. 5.** Toolbar with railway traffic control objects [by the authors]
A sample schematic diagram of a site that constitutes the foundation for creating a database of objects built using the method in question is presented in Figure 6.

![Figure 6. Simplified schematic plan of the Poznań PoD site [by the authors]](image)

### 3.2. Results generated

Train and shunting routes were generated for the aforementioned sites using the proposed method. The follow-up analysis concerned the number and types of the routes thus generated with reference to actual interlocking tables. Another group of facilities subject to analysis comprised all rail switches in the main set route and in flank protection. Other elements, such as the overlap, were not analyzed on account of the limitations of the tool proposed. Nevertheless, it should be noted that it is, by all means, possible that the application is extended with new features in line with the assumptions of the method.

The drawings below depict the results of the generation process performed in the MGLTAB tool against the real-life tables. The first one shows the number of routes thus generated, while the second one – the number of conforming rail switches in the main set route and in flank protection for specific sites.

![Figure 7. Number of routes [by the authors]](image)

The above figure shows that, in terms of numbers, there is considerable similarity between the generated routes (red) and the real ones (blue). The minor differences result from not having generated any routes pertaining to the overlap variant, which was not considered in
the analysis. The next figure (Fig. 8) shows a comparison of the number of all rail switches functioning within the movements analyzed, including their correct positions. In both cases, no derailers were included since they were not taken into consideration due to the tool’s limitations. However, the method assumes that they can be generated at adequate positions. The differences result from the fact that some redundant rail switches have been entered while being generated in MGLTAB. An entry is assigned to the main set route and the flank protection at the same time, which can be undone once an appropriate filter is created. During the analysis, some entries missing from the actual tables were also found for cases that required them. This confirms the superiority of the automation method over the manual filling of interlocking tables.

![Fig. 8. Rail switches in appropriate positions in all real and generated routes [by the authors]](image)

### 3.3. Verification of results

In order to verify the conformity of the routes and rail switches generated using the described method, a chi-squared test for independence was performed with regard to the two groups subject to examination, i.e., real-life tables and results of the MGLTAB-based generation process. The generated routes were verified depending on the results obtained from two different sources and should provide an answer to the question if, assuming an adequate level of confidence, the described method is credible and delivers results consistent with real-life interlocking tables.

For this purpose, the chi-squared test for independence should be performed, having formulated the following hypotheses:

- \( H_0 \): the variables are independent (i.e., the results coincide regardless of whether the tables are real-life tables or MGLTAB-generated),
- \( H_1 \): the variables are not independent (there are differences in the results depending on whether the tables are real-life or MGLTAB-generated).

In subsequent steps, cross-tables were presented for two problems:

- problem 1: number of routes,
- problem 2: number of correctly generated rail switches in routes.
The respective values were calculated according to the following formula:

$$\chi^2 = \sum_{i=1}^{k} \sum_{j=1}^{r} \frac{(n_{ij} - \hat{n}_{ij})^2}{\hat{n}_{ij}}$$ \hspace{2cm} (12)

Tables containing the values needed for correct summation and calculation of the $\chi^2$ coefficient has been provided on the next page.

Table 1. Cross-table for problem 1 of the number of routes

<table>
<thead>
<tr>
<th>NUMBER OF ROUTES $\frac{(n_{ij} - \hat{n}<em>{ij})^2}{\hat{n}</em>{ij}}$</th>
<th>Poznań Jeżyce PoD</th>
<th>Poznań Wola</th>
<th>Kiekrz</th>
<th>Rokietnica</th>
<th>Szamotuły</th>
<th>Pęckowo</th>
<th>Wronki</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-life tables</td>
<td>0.012992151</td>
<td>0.01850394</td>
<td>0.084</td>
<td>0.000454</td>
<td>0.013789</td>
<td>0.00433</td>
<td>0.0133</td>
</tr>
<tr>
<td>MGLTAB</td>
<td>0.013550287</td>
<td>0.019298859</td>
<td>0.088</td>
<td>0.000473</td>
<td>0.014381</td>
<td>0.00452</td>
<td>0.0138</td>
</tr>
</tbody>
</table>

Table 2. Cross-table for problem 2 of the number of rail switches in routes

<table>
<thead>
<tr>
<th>NUMBER OF CORRECT RAIL SWITCHES IN ROUTES $\frac{(n_{ij} - \hat{n}<em>{ij})^2}{\hat{n}</em>{ij}}$</th>
<th>Poznań Jeżyce PoD</th>
<th>Poznań Wola</th>
<th>Kiekrz</th>
<th>Rokietnica</th>
<th>Szamotuły</th>
<th>Pęckowo</th>
<th>Wronki</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-life tables</td>
<td>0.095275776</td>
<td>0.064960756</td>
<td>0.058</td>
<td>0.087047</td>
<td>0.186474</td>
<td>0.01732</td>
<td>0.0614</td>
</tr>
<tr>
<td>MGLTAB</td>
<td>0.099368769</td>
<td>0.067751433</td>
<td>0.06</td>
<td>0.090787</td>
<td>0.194485</td>
<td>0.01807</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Having established the relevant values for the two groups examined (for every station), one obtains the following $\chi^2$ coefficients:

$$X_1^2 = 0.301139817$$
$$X_2^2 = 1.164872329$$

On account of the assumed level of significance of $\alpha = 0.025$, the level of confidence of $1 - \alpha = 0.975$, and the number of degrees of freedom being derived from the following formula: $N-1 * M-1$ (product of rows -1 and columns -1), the critical area of $< 1.2373; \infty$ was established. The test values do not belong to the critical area, which is why one should assume the zero-hypothesis implying independence of the routes and of the number of rail switches in real-life tables as well as in those generated in MGLTAB. Consequently, it can be concluded that, with the confidence level of 97.5%, the routes as well as their rail switches in the main set route and in flank protection coincide for the sites subject to examination.

4. Conclusions

Based on the results obtained in the study, one can conclude that the automation method proposed by the authors allows for all potential railway and shunting routes to be generated for a station being designed in accordance with specific pre-assumptions. The dedicated “Blocks” toolbar was used to successfully design a simplified track layout. Then, by means of an application originally developed by the authors, routes were generated along with all the main set route and flank protection rail switches. A comparison with real-life tables made it possible to analyze the results and to confirm the legitimacy of the method.
Certain limitations imposed on the method resulted from the limited number of verified processes (and consequently also of objects). Therefore, the authors propose that further research should concentrate on the following:

− creating a design environment that would be even more user-friendly in terms of the nomenclature of objects and automatic assigning of layers, and consequently also types, to specific objects,
− automatic naming of objects,
− adding overlap dependence,
− checking redundant measures of flank protection in existing main set routes and flank protection,
− adding a track circuit and rail switch circuit type object,
− adding a crossing type object,
− adding a block type object,
− adding a derailer type object,
− attempting to implement the method in other less popular CAD programs,
− possibility of obtaining data from formalized schematic plans and generating a simplified track layout plan,
− attempting to propose to and convince the infrastructure operator, i.e., PKP PLK, that the relevant requirements pertaining to the notation of interlocks should be formalized in order that they fully conform to the needs of railway professionals and, at the same time, show designers of railway traffic control devices how the notation of interlocks should be prepared.

References
1. Technical guidelines for designing railway traffic control equipment Ie-4 (WTB-E10).
Metoda automatyzacji tworzenia tablic zależności stacyjnych urządzeń srk

W związku z rosnącą liczbą modernizacji linii kolejowych w Polsce pojawia się dużo problemów podczas przygotowania i realizacji tych zadań. Podczas przygotowania projektu wykonawczego dla urządzeń sterowania ruchem kolejowym, które zabezpieczają ruch na stacji kolejowej dochodzi do wielu zmian, które związane są z fazowaniem robót w urządzeniach sterowania ruchem kolejowym (dalej srk). W związku z tym zmianie ulegają również następujące elementy: plan schematyczny oraz tablice zależności kolejowych systemów srk. Celem artykułu jest przedstawienie autorstwnej metody automatyzacji generowania tablic zależności urządzeń srk. Założeniem rozwiązania problemu jest model składający się z dwóch głównych składników. Jednym z nich jest część projektowa, w której znajdują się obiekty wchodzące w skład projektowanej stacji kolejowej. Następnie za pomocą odpowiednich algorytmów zostają one zaimplementowane jako dane w drugim składniku modelu. Kolejne obliczenia służą wygenerowaniu wszystkich możliwych jazd z pod semaforów i tarcz manewrowych występujących na stacji czyli tzw. przebiegów kolejowych. Sprawdzenie metody zostanie wykonane za pomocą autorskiego oprogramowania. Pierwsza część składa się z procesu projektowania. Model układu stacyjnego powstaje dzięki dedykowanym pasku narzędzi wraz z bazą dodatkowych warstw w programie komputerowego wspomagania projektowania. Następnie taki układ torowy zapisany w postaci pliku z rozszerzeniem dxf zostanie odczytany do dedykowanej aplikacji, w której dojdzie do wygenerowania przebiegów pociągowych i manewrowych. Weryfikacja metody polega na sprawdzeniu z odpowiednim wskaźnikiem istotności wygenerowanych przebiegów z istniejącymi w rzeczywistych tablicach. W efekcie opracowania przedstawionej metody przy spełnieniu podstawowych założeń procesu projektowania można przyspieszyć generowanie tablic zależności w sposób bezpieczny.

Słowa kluczowe: tablice zależności, plan schematyczny, urządzenia sterowania ruchem kolejowym