Decision Support System for Managing Marshalling Yard Deviations

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Abstract: The presented studies, research and innovation focus in marshalling yards is on providing adequate responses on standard timings or deviations from the normal timetable. To address the possible deviations in the marshalling yard daily operation, the decision support system called SMART Real Time Management System (RTMY) is developed and introduced in this study. In general, Smart RTMY should give real-time responses to deviations, and decrease the time for making an adequate decision by providing a decision support system with optimal solutions based on selected criteria and optimization objectives. The system is based on the optimization function, which calculates the numerical (influence) value for each wagon in the marshalling yard, and on the developed expert system. The application of SMART RTMY in its current state is verified through the developed web application used by experts from universities and railways. This system should bring a novel solution to the marshalling yard classification and deviation response systems, thus providing a powerful software tool for marshalling yard dispatchers and operators.

Keywords: decision support system; software; marshalling yard; expert system

1 Introduction

Marshalling Yard (MY) is a complex system with many processes that should be properly executed. The main processes in marshalling yard are: Pre-notification of incoming and outgoing trains, Arriving and checking incoming trains, Disaggregating/aggregating trains; Wagon shunting within the yard; Throwing wagons using the hump and/or the locomotive; Checking and departure outgoing trains; Wagon maintenance. These are standard processes and part of the standard and usual daily data flow [1-5]. The common processes are automated on satisfaction level with various IT applications [2]. Besides the developed applications, numerous research solutions address the problems with marshalling yard operations, and all of them are focused on keeping the operations active and removing bottlenecks. In general, the complex problem of managing the marshalling yard can be divided into smaller problems and partially addressed [6]. Considering sorting algorithms the existing literature already covers numerous types, which can be divided into three main categories [7]. The first consists of simple heuristics or rule-based sorting schemes, which can be easily applied in practice. The rule-based sorting schemes can further be divided into sequential (meant to rearrange wagons within a single train) and simultaneous sorting schemes (rearranging multiple input trains into other outgoing trains). The second category of algorithms are the exact methods that try to calculate an optimal solution, similar to the one presented in this research. Lastly, there is a third category of complex deterministic heuristics that tries to solve the sorting problem, by finding a good instead of an optimal solution. These methods are used in most classification activities, but each marshalling yard has some specific properties that should be considered. In general, for the classification of arriving trains all cars should eventually be rolled to the siding that has been assigned to the train they're supposed to depart with. There is usually a problem with capacity of these tracks, so experienced dispatcher or train operator should conduct actions to use mixing tracks for wagon classification properly. The studies [8, 9] presents a solution for these operations by introducing image discrimination theory and different online planning strategies tested using stochastics and deterministic approaches. The first tested strategy assigns tracks to trains on a first-come-first-served basis, while the second strategy uses time limits to determine when tracks should be assigned to departing trains. The research [10] investigates the influence of inbound traffic volume variation and schedule flexibility on classification yard performance. Simulation experiments using YardSYM, a discrete-event simulation model developed for hump classification yard analysis, quantify the interaction of these factors through different yard performance metrics. Simulation results suggest increasing schedule flexibility causes classification yard performance to decline while increasing volume variability has a less pronounced effect.

Expert systems are decision making systems that provide semantic solutions to different problems and are defined by rules and facts. They are a means to share and distribute knowledge [11], acquired directly or indirectly from domain experts of different scientific areas. They not only aid users lacking specific know-how but also provide support and guidance [12], if not even substitutes, for human experts. Therefore, the power of an expert system should be its ability to mimic the human decision process [13]. An example of this kind of system is a solution for the output recommendations with an increased workload of the Baladjar station, presented in [14]. An expert system based on structured technology is introduced and applied to address this issue. Structural technologies are a set of technological techniques that allow you to control the properties of the structure of the station. With these methods, it is possible to bring the structural properties of the station closer to the optimum in any mode of operation. However, studies have shown that introducing "elastic technologies" in practice can increase stations' capacity only in the short-term. For greater efficiency in this direction, it is more advisable to use the technique of structural technologies together with the gradual optimization of the track development of the station.

Regarding the presented studies, research and innovation activities focus on providing adequate responses on standard timings or on deviations from the standard timetable. Special attention is given to deviations from decision making processes in marshalling yards. Different types of deviations are presented in [6, 15, 16] and can be summarised as the following: Deviations of the incoming train – later (delay) or earlier than timetable plan; Deviations of the outgoing train - later (delay) or earlier than timetable plan; Deviations in personal resources – lack of train driver or other staff for operations in MY; Deviations in individual wagons modification; Unexpected repair or breakage of sections of rail line; Unexpected repair or breakage of wagons; Deviations or incorrect weight of incoming trains or wagons; Priorities in cases of congested infrastructure or other priority policies; Extraordinary requests; Not defined deviations. All deviations can be grouped related to four factors: time, the present state of infrastructure, personal resources, and additional cargo operators' demands. The main factor is time, which is why the first two above deviations are also one of the consequences of all other deviations. Each deviation has causes, consequences of deviations, decisions that need to be realized, and consequences of selected decisions.

To address the possible deviations in the marshalling yard daily operation, the SMART Real Time Management System (RTMY), i.e., decision support system is developed and introduced in this study. In general, Smart RTMY should give real time responses to deviations, and decrease the time for making an adequate decision by providing support system with optimal solutions based on selected criteria and optimization objectives. This means the system is based on past experience (past interactions) and includes additional yard operational parameters (static and dynamic – content-based systems). Furthermore, the proposed solution is based on the optimization function, which calculates the numerical (influence) value for each wagon in the marshalling yard and the developed set of expert system rules. The expert system represents a hybrid decision support system because it includes rules and calculated influence factor to propose solutions. Therefore, SMART

RTMY should bring novel solution to the marshalling yard classification and deviation response systems, thus providing a powerful software tool for marshalling yard dispatchers and operators.

2 The Overall System Architecture

Smart RTMY is a decision support system represented by the developed web application (https://tehnogenijalci.rs/smartvis/). The web application is open and free to use. However, the application is still in the testing phase, and responses from different experts are required to improve it in future work. It is composed of visualization and an optimization module. The other developed modules are supporters (security, data exchange and transformation modules) or providers (e.g. data input module). The visual representation module displays the current status of the marshalling yard to the user, based on manually entered data acquired from a specific marshalling yard. In addition, this module will also display the future state of the marshalling yard based on input data and the optimal marshalling process planning results. The optimization or marshalling process planning module implements an expert system based on the optimization function and expert knowledge acquired from the Popovac (Serbia) marshalling yard.

The developed expert system is a Decision Support System or Decision Making System that provides instructional data to the marshalling yard dispatcher or operator. To properly define the functional and technical requirements of the SMART RTMY, Unified Modeling Language (UML) is used [17]. UML diagrams are created for all specific marshalling yard and software requirements and used to develop software modules. There are nine selected types of deviations in decision making processes in marshalling yards, and they can be described as use cases in UML. They are modelled and presented in Fig. 1. To properly model deviations and data included in marshalling yard management systems, additional parameters are defined as static (yard connections, layout data, operative times, equipment) and dynamic (data flow, restrictions and deviation) and presented in [18]. This is standard data already applied in marshalling yard operations. Finally, the data and object model were created and used as the basis for making the Decision support system application. The data model is expressed through a developed relational database, and the object model was developed using MVC (Model – View - Controller) pattern [19]. The database structure was defined with separate tables for trains, wagons, sidings, timetables, traffic directions, and users [18]. Database defines the structure of a Marshalling yard data model on which the object model depends, and it includes all requirements and limitations restricting the use of freight transport in the marshalling yard and freight transport that will be processed in the marshalling yard.

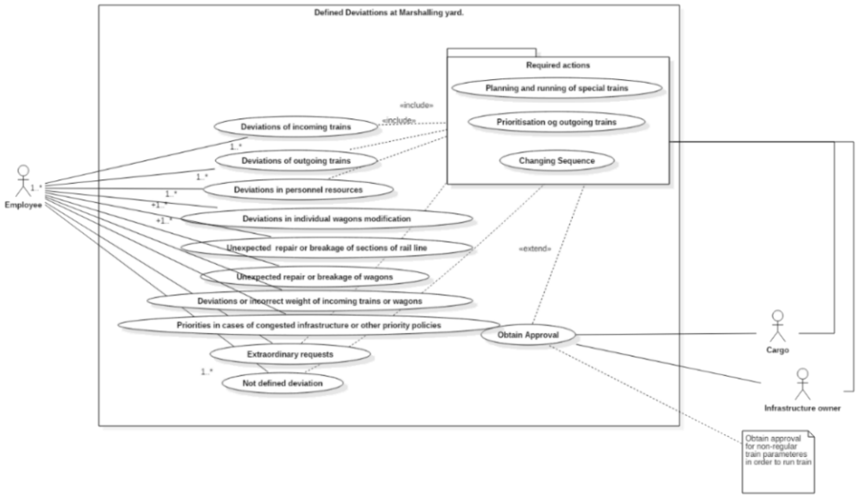


Figure 1

Use case diagram of defined types of deviations in the marshalling yard

The defined composition of the database, allows input and processing of all the described deviations and inputs or outputs. In addition, static and actual data from marshalling yard Popovac, Serbia was inserted into the database for further manipulation and processing.

To conclude, the Smart RTMY system uses the following:

- Material: Marshalling yard data from Popovac, Serbia; Expert knowledge gained from university and marshalling yard staff;
- Methods: Numerical Optimization; Expert system based on rules and facts; Relational database for data manipulation; MVC framework for application development

3 The Methodology

Smart RTMY complex structure enables a complete overview of the marshalling yard infrastructure and adequate real-time response by applying its developed modules. The visualization module can display status of the marshalling yard to the user, based on data entered manually or the possibility of showing data acquired automatically from a railway information system in the future upgrade. In addition, it displays the current snapshot of the marshalling yard infrastructure (warehouse, repairing station). Based on the security level, visual representation is differently formed for different users, e.g., dispatchers or marshalling yard operators [18].

The visualization module receives data from the database as statical and optimized data (from the optimization module) and shows it to the user. It also enables data manipulation by using web app forms dedicated to yard elements (e.g., wagons, sidings, trains). Every modification of the data is reflected in recreating the data process, which creates a distinct visual representation of yard elements and inserts changes to the database. Furthermore, the database regularly makes replications using automatic DBMS service due to the possible errors in yard elements classification, which can be reverted to the previous verified state.

The module was developed using the following technologies: Front End – JQuery (standard, generally known JavaScript library) and D3.js (Data-Driven Documents); Back End – Currently, cakePHP is used as the main platform framework. It is important to mention that application works in a closed environment due to the railway regulations, but with the possibility to share data over secured connections.

The optimization module is created to control the classification of the trains (wagons) in the marshalling yard, and its overall composition is presented in Fig. 2. The diagram(s) are created by using adapted Structured Analysis and Design Technique - SADT [20]. Data analysis includes (P1) a static and dynamic dataset.

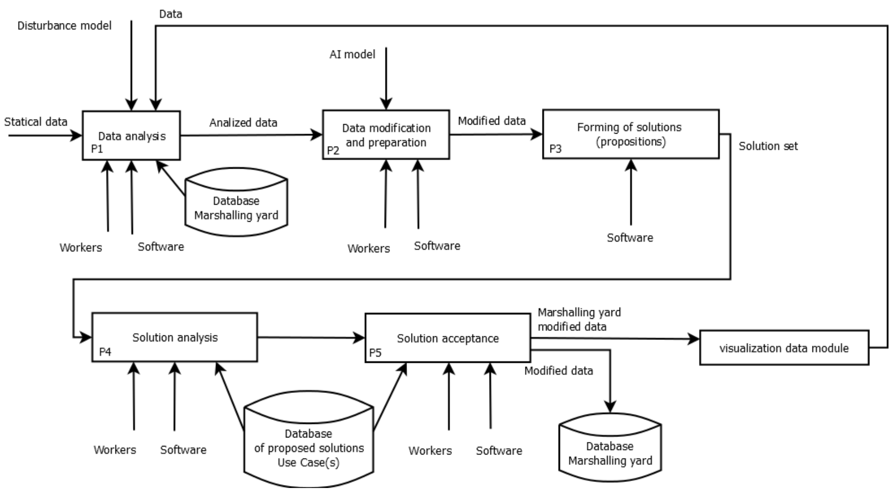


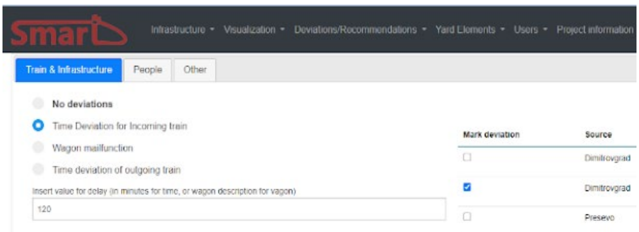
Figure 2

Optimization module of the Decision support system

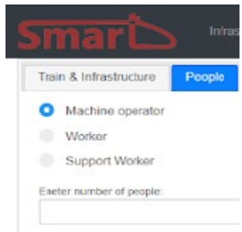
The disturbance model presented in the scheme is currently under development, but its behaviour should be controlled like in the workflow systems, i.e., these should represent workflow interruptions. Furthermore, the disturbance model should encompass interruptions not defined in the system as deviations, i.e., unknown deviations. The decision system contains software solutions and manual progress monitoring (marshalling yard experts), defined in a scheme by "Data Modification and Preparation" – P2, "Forming of solutions" – P3, "Solution analysis" – P4. P2 includes an intelligent system that controls the input dataset processing. The P2 process outputs data in a numeric-readable form (arrays, matrices) and process P3 creates human-readable data (presented in Fig. 3c) in a state of the solutions, which goes to P4 for the final verification (software can make wrong conclusions). In the process of "Solution(s) acceptance" – P5, solutions are finalized, modified marshalling classification is stored in the database for the next iteration, and new data is sent to the visualization module for display.

In the developed application, deviations are defined as:

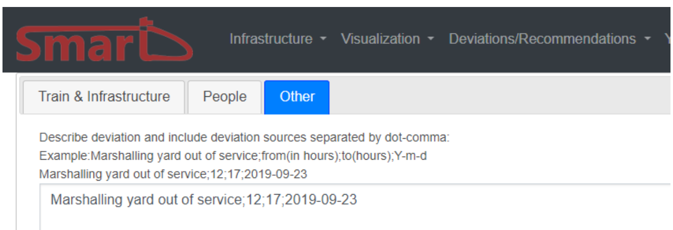
- D1 - Train & Infrastructure, which includes Time deviation for incoming and outgoing trains and Wagon Malfunction (Fig. 3a)
- D2 - People (characterized by a shortage of people): Machine operator, Worker, Support worker. (Fig. 3b)
- D3 – Other generally refers to marshalling yard out of service (Fig. 3c)



a) Train & Infrastructure deviation form



b) People deviation form



c) Others deviation form with filled deviation – out of service

Figure 3

Web forms (Smart RTMY) for entering marshalling yard deviations

To control the data flow based on the defined deviations and to find the optimal solutions, decision support system application (SMART RTMY) based on the developed expert system is applied. The Expert system is based on the marshalling yard dispatcher and operators' experience and it is included as a set of rules and facts. The optimization function (calculated influence factor) is part of the expert system as a numbering tool that presents the current influence on the specific wagon and/or train to the marshalling yard classification. The two elements of the expert system can be separated and work independently. Currently, the expert system is developed by using an if-then set of rules and predefined parametric sentences (similar to parametric queries in relational databases) that simulate standard operator's responses, but it will be transferred to the experta package (https://experta.readthedocs.io/) in the future versions. The developed system contains standard rules for operating wagons and their classification, used for many years in the marshalling yards. The expert system is good up to a point, or up to a number of rules and their capabilities to respond to the marshalling yard requirements. The expert system should provide correct answers for the D2 and D3 deviations because these two are standard, and responses are uniform and straightforward. It is more complicated for deviation D1, which includes trains and wagons. Rules can be set, but sometimes it is required to optimize wagon classification and to properly distribute wagons to an adequate siding (outgoing train, for the service, etc.). The logical/mathematical model is defined and described in the following section to respond to this possible complex situation.

Wagons are defined as matrices elements in Wagons matrix (W_M [S x N]) – Sidings are rows, and positions are columns. Wagons dimensions are standard, and for the marshalling yard infrastructure definition, it is enough to know the starting position of each wagon, and its dimension. Another defined matrix is positional wagon matrix (P_{WM} [S x N]) which relates to each wagon in W_M and it defines wagons dimension and position which relates to siding length, and all values are transformed between [-1:1]. Siding length is defined as 100%. Each wagon length defines a percentage of that length, which is reflected to real numbers, up to 1. These matrices represent a current snapshot of the marshalling yard infrastructure and wagon distribution, i.e. if a wagon is re-positioned, the positional matrix is changed. If wagon leaves the station, it can be (is) deleted from both matrices. One note, timetable influence on the matrix is defined by adding virtual or physical incoming (-1) and outgoing sidings for outgoing trains (1). This feature of the proposed classification enables "bubble" sorting for wagons before they hit the yard, allowing proper reaction for train time deviation.

We introduce the new category called temporary trains with influence factor between -1 and 1 – They are virtual trains positioned on each siding, and its vector T_{WM} contains rows from W_M matric, i.e., individual siding. When temporary train reflects incoming or outgoing trains, then we changed category, or influence on -1 (not yet in the station), or 1 (in the station, scheduled for departure). Each siding is influenced by the marshalling yard rules, which can be changed. The influence factor on each is defined according to the current timetable for the marshalling yard and sidings definition (incoming, outgoing, mixed, or service). These values defines the marshalling yard operator or dispatcher. To add a time variable temporary train factors are multiplied with the time factors from the timetable. This factor is from [-1:1], and it reflects the time schedule of trains coming [-1:0] or scheduled for departure [0:1] the station. Factor for temporary trains already in the station, e.g., on classification yards, are set to values defined for the train they belong to or the trains they will be added.

To form a Decision support system, the function (1) which defines the wagon influence on the station operation is expressed by space matrices and vectors for trains and timetable:

$$W_M = \begin{bmatrix} W_{1,1} & \cdots & W_{1,n} \\ \vdots & \ddots & \vdots \\ W_{s,1} & \cdots & W_{s,n} \end{bmatrix};$$

$$P_{WM} = \begin{bmatrix} P_{1,1} & \cdots & P_{1,,n} \\ \vdots & \ddots & \vdots \\ P_{s,1} & \cdots & P_{s,n} \end{bmatrix};$$

$$T_{WM} = \begin{bmatrix} T_{1,1} & \cdots & T_s \end{bmatrix};\ C_T = \begin{bmatrix} C_{1,1} & \cdots & C_s \end{bmatrix}$$

$$W_{Pi,j} = \prod_{\substack{i=1,s \\ j=1,n}} W_{Mi,j} \times P_{WMi,j};\ \ T_{Ci,j} = \prod_{i=1,s} T_{WMi} \times C_{Ti};$$

$$W_I = \prod_{\substack{i=1,s \\ j=1,n}} W_{Pi,j} \times T_{Ci} \tag{1}$$

This operation returns the value from [-1:1] for each wagon in the matrix. Therefore, the reaction importance for each wagon is presented to the user. For example, if some wagon needs to be re-positioned to the outgoing or mixed siding because of the timetable schedule, he will get a high influence factor. Multiple wagons can have an influencing factor close to or equal to one. Still, for each wagon in the expert system, a description is introduced and attached to the influence factor by using the following function (2):

$$W_{EI} = \prod_{\substack{i=1,s \\ j=1,n}} W_{Ii,j} \times E_{xi,j} \tag{2}$$

Ex is a matrix (3) of wagon properties already described in the system, based on an already known timetable for the marshalling yard and the yard infrastructure. The matrix Ex also includes wagons in a timetable, which are defined for future arrival, which is essential if we want to create a temporary train in the virtual incoming siding.

$$E_x = \begin{bmatrix} E_{1,1} & \cdots & E_{1,n} \\ \vdots & \ddots & \vdots \\ E_{s,1} & \cdots & E_{s,n} \end{bmatrix}; E_{i,j} = \begin{bmatrix} Time\ scheduled: Time\ format \\ Temporary\ train\ id : Integer \\ Wagon\ operational\ status: 0\ or\ 1, \ldots \end{bmatrix} \tag{3}$$

Finally, the influence matrix for all existing wagons is formed and applied in the expert system, which gives the marshalling yard operator possible actions based on the defined deviations in the application. The rules and facts define the expert system, but one important addition is created. This addition refers to the set of parametric sentences with parameters like train number, wagon id, and incoming time, which can be replaced by the actual values based on the expert system recommendation. When the expert system creates suggestions/recommendations, it uses the parametric sentences and changes the values of parameters with the recommended ones, as presented in included examples. The optimization model (influence factors) is one of the inputs for the expert decision on wagon classification. It is essential to mention that this part of the system is currently under development, so most of the rules are now defined in the PHP as a set of if-then statements and will be transferred to the "experta" python package. The python library Experta is used for building expert systems and is strongly inspired by CLIPS [21, 22], which means that different notations are used to describe rules implemented in the system. An expert system is written as a program capable of pairing up a set of facts with rules to those facts and executing some actions based on the matching rules. Facts are the basic unit of information of Experta (generally for any expert system). Rules have two components, LHS (left-hand-side) and RHS (right-hand-side). The LHS describes (using patterns) the conditions for executing the rule (or firing). The RHS is the set of actions to perform when the rule is fired. With expert systems like experta, the program flow should not be defined explicitly. The knowledge (Rules) and the data (Facts) are separated, and the Knowledge Engine is used to apply the knowledge to the data. The rules for static data are defined as is, meaning that these rules are defined descriptively, i.e., if a worker is not available for work, call another worker, or if nobody is available, then make different scheduling. For dynamic data, rules are made differently, and for example, the wagon data is currently defined as object notation:

- Wi=(wagon={wagon_id=unique_value,sidings_id=unique_value,train_id =unique_value,positional_data=temporary_value,calculated_matrix=Wi,j ,descriptive_matrix=WEi,…})
- Ti=(train={train_id=unique_value,sidings_id=unique_value,wagons=[wa gon_id_list],...})
- Si=(siding={siding_id=unique_value,siding_type=unique_value,...})

The same notation is performed for the sidings and trains. Because temporary trains are introduced, each wagon is classified as part of a train, as a collection object. The wagon definition provides complete information for the wagon and it contains data from the relation database and calculated data. From the current defined Decision support system (not yet transferred to experta, but defined in the required form), the marshalling yard operator can analyze suggestions and analyze matrix pattern for every station wagon and the incoming or outgoing train.

To see how the Smart RTMY system works in its current state, two examples are presented, one for incoming train delay and one for interruption of yard working hours.

Example 1: Suppose we state the problem of incoming train (40600) one hour deviation (Fig. 3a). In that case, possible solutions based on the Smart RTMY can be:

Option 1: If train 40600 is going to be processed first, it means that processing and shunting of train 56921 can start at 15:28 and it can leave station with 53 minutes delay and leave the yard at 16:21. This mean that workers and shunting locomotive for next operation can start at 16:31.

Option 2: If train 56921 is going to leave station according to the plan, processing will be from 02:27 until 03:30 and processing for the train can start at 03:40 and will be finished at 05:38. This means that workers and shunting locomotive for next operation can start at 05:48.

Example 2: Suppose we state the problem of Marshalling yard out of service from 12 to 17 hours on a specific date. We first need to enter it into adequate web form (Fig. 3c), like: Marshalling yard out of service;12;17;2019-09-23. In that case, possible solutions based on the developed Smart RTMY can be:

Option 1: Train 56921 is going to be processed from 17:00 until 17:53. Train 45003 is going to be processed from 18:03 until 20:01. It can leave yard at 20:01. Train 44707 is going to be processed from 20:11 until 22:09. It can leave yard at 22:09.

Option 2: Train 56921 is going to be processed from 17:00 until 17:53. Train 44707 is going to be processed from 22:19 until 00:17. It can leave yard at 00:17. Train 45003 is going to be processed from 00:27 until 02:25. It can leave yard at 02:25.

Option 3: Train 45003 is going to be processed from 17:37 until 18:30. Train 56921 is going to be processed from 18:40 until 20:38. It can leave yard at 20:38. Train 44707 is going to be processed from 20:48 until 22:46. It can leave yard at 22:46.

Option 4: Train 45003 is going to be processed from 17:37 until 18:30. Train 44707 is going to be processed from 22:56 until 00:54. It can leave yard at 00:54. Train 56921 is going to be processed from 01:04 until 03:02. It can leave yard at 03:02.

Option 5: Train 44707 is going to be processed from 17:00 until 18:58. Train 56921 is going to be processed from 19:08 until 21:06. It can leave yard at 21:06. Train 45003 is going to be processed from 21:16 until 23:14. It can leave yard at 23:14.

3.1 Methodology Discussion

The presented solution defines novel approach for the marshalling yard deviation response, and it is based on the expert system application. The Smart RTMY is composed of two main parts, which can be completely individual and work independently. The first part is defined as a mathematical marshalling classification model that defines the influence factor for each wagon on the siding, including incoming and outgoing wagons. This exact value reflects the ones stated in the [7, 8], but with a different approach. The calculation is different because this research is focused on wagon influence factor, and mentioned studies on the position of the wagons on the yard. The second part represents expert system currently defined as if-then rules, and facts already prepared for import in the experta python package. In general, machine learning replaces expert systems in many fields. Still, in this case, the later represent a good approach because it can reflect marshalling yard operator experience, and the rules can be constantly upgraded. The system is currently in the testing phase, and the results are promising (found in the web application). Future work on improving the expert system (e.g., implementing machine learning) should be conducted to make the system work with a significant confidence factor.

Conclusion

The decision support system should provide the marshalling yard operator an overview picture of the current snapshot of the marshalling yard and provide information on possible actions which can be performed in the case of deviations, or even in other situations like the energy optimization described in [23, 24], or for wagon and track maintenance described in [25-27].

It is important the mention the possible benefits of Smart RTMY for the railway network structure of the Europe. The support for integration with railway information systems will be developed to provide the opportunity to obtain inbound and outbound traffic data automatically from external sources, but this requires a lot of additional effort and is planned for the future work. In developing support for integration with railway information systems the focus will be on data exchange following industry standards such as TAF TSI and RailML. Additional information may be collected depending on the data available from the railway information system, such as traffic information for the next 24 hours (or another defined period). With such data the information system could offer information about estimated waiting and marshalling time to railway officials planning freight transport.

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