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APPLICATION OF ARTIFICIAL INTELLIGENCE TECHNIQUES TO REDUCE THE LOADING OF THE MARSHALLING YARD

Summary. The article is devoted to the development of an expert system for the output of recommendations with an increased workload of the Baladjar station. A significant increase in the private wagon fleet has changed the system of organizing the work of the Azerbaijan Railways, the technology of the stations and the duration of station operations have changed. Problems arising from the uneven reception of trains have become more frequent. Due to this process of operation, the station load is increasingly exceeding the optimal value. Sometimes, with increased loading, the wrong manager solution further complicates the operation of the station. In the article, to reduce the loading level of the station, it is proposed to use methods of structural technology. According to the loading rate of the station, an expert system for displaying recommendations has been developed to select the right solution.

Keywords: marshalling yard, workload, arrival yard, departure yard, tracks, expert system.

Introduction

In connection with the economic development of the republic in recent years, many enterprises have purchased private freight wagons. This led to a significant increase in the private wagon fleet of Azerbaijan Railways and changed the system of organizing their work. The technology of work of stations and the duration of station operations have changed, the number of low-tonnage cargos has increased, a need occurred to send prefabricated group cargo to a large number of senders, and so on. All this significantly increased the volume of shunting operations, as well as the duration of ineffective downtime of freight wagons (waiting time for processing and loading-unloading operations) at the stations. To eliminate these shortcomings, the organization of train traffic carried out according to the "firm schedule" (hard train lines of the train timetable). However, in many railway sections, the filling level of the "hard schedule" is 50%, which increases the duration of inefficient downtime of locomotives and reduces their productivity.

An increase in the duration of ineffective downtime and the volume of shunting operations, as well as a decrease in the productivity of locomotives, affect the uneven flow of trains to technical stations. Uneven reception of trains during freight traffic affects not only the quality of service for cargo owners, but also the efficiency and reliability of the station. Inequalities in the train reception interval lead to inefficient downtime between receiving, handling, sending, feeding to loading and unloading sites, etc., as well as uneven loading of shunting diesel locomotives, an increase in the reserve of production powers (throughput and processing capacity) and the need to attract additional personnel. All these negative factors reduce the power of stations. The power of stations can be increased by reconstructing the station tracks (construction of new roads, switches, etc.). However, the reconstruction method requires a large capital cost [1, 2, 3].

Problem statement

The problems arising from the uneven reception of trains are organizational in nature and related to the technology of the stations. One of the solutions to these problems is “elastic (structural) technology”. Structural technologies are a set of technological techniques that allow you to control the properties of the structure of the station. Using these methods, it is possible to bring the structural properties of the station closer to the optimum in any mode of operation. Studies have shown that the introduction of "elastic technologies" in practice can increase the capacity of stations only in the short term. Since, a long-term increase in power with these methods then leads to a decrease in power. For this reason, such methods not often used in practice. For greater efficiency in this direction, it is more advisable to use the method of structural technologies together with the gradual optimization of the track development of the station. It is proposed to carry out such optimization in four directions: parametric, functional, structural and systemic.

The feasibility of implementing all four directions is determined by the effectiveness of each of them. Actions in each direction are implemented sequentially. To increase the efficiency of the applica-

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tion considered optimization directions, it is necessary to use an additional method – the method of structural technologies. Experiments have shown that it is more expedient to apply this method together with parametric and functional directions of optimization [1, 4, 5].

Methods of changing the technology of work to reduce the load of the station

The regulation of the station is based on a change in the distribution of power between the elements by changing the technology of work. Changing the power distribution of elements carried out in two available technological ways: account of the transfer of throughput or track capacity.

The capacity of station tracks can be adjusted by changing the specialization of the tracks. This method is carried out by receiving and processing trains on tracks intended for other operations (cargo, wagons, destinations, etc.). A feature of the method is a gradual change in the specialization of tracks with the subsequent restoration of the existing station technology. The limitation of this method is the lack of free tracks for receiving trains. At large technical stations, if necessary, they change the specialization of yards to regulate train capacity. For example, depending on the situation, receiving trains to the departure yard, putting up trains ready to send to the arrival yard, etc.

During the operation of the station, there are cases when the load of the station exceeds the optimal value. Since such cases are non-standard, the methods of solving them are not specified in the instructions, the process of the station and other regulatory documents of the station. To overcome non-standard situations, it is necessary to standardize these types of cases. It is possible to classify situations that occur at stations by the amount of bandwidth utilization:

1. Station operation at low load (to 50 %);
2. Station operation at average load (51-75 %);
3. Station operation at full load (76-100 %).

The first case is standard. In this case, the station operates as usual; the dispatcher in accordance with regulatory documents and instructions performs all operations. No further action is required. Case 2 is considered partially non-standard, making the work of the station more difficult. In this case, some additional measures are required. In the third situation, the station utilization reaches its maximum value. In this case, in order to bring the station to its normal state, it is necessary to make optimization decisions based on structural technologies [6, 7].

In this case, in order to reduce the load level of the station, it is recommended to implement the following solutions:

a) Transfer mobile equipment (shunting locomotives, loading and unloading mechanisms, etc.) from one section of the station to another. By increasing the number of such vehicles, several operations of the transportation process can be performed simultaneously. This allows increasing the throughput and processing capacity of this section of the station;

b) Regulation of the distribution of teams and individual workers between work areas ("flexible use of staff"). When loading a specific section of the station, the problem can be eliminated by sending one of the work teams to the area. Also with constant inefficient downtime of freight wagons for technical and commercial inspections in parks, it is more expedient to create an additional mobile team. This measure will reduce inefficient downtime of trains waiting to be processed.

c) Changing the specialization of arrival and departure tracks. To increase the capacity of the station, it is possible to accept trains on free departure tracks or put ready-made trains on the tracks for arrival.

d) The possibility of occupying lead tracks and tracks for the movement of single locomotives. When arrival and departure tracks are busy, trains are allowed to be accepted to lead tracks and tracks for the movement of single locomotives. In some cases, stretch tracks (at dead-end stations), connecting tracks (on non-public tracks, tracks between the station and facilities, between park tracks, etc.) can be used to park trains waiting for processing.

If the above solutions cannot reduce the load on the station, it is necessary to go to the following solutions:

e) Use of free ends of tracks. To maximize the use of station capacity, it is possible to divide the received trains into several groups and place them at the free ends of the tracks. This method will free up the track for the next train. However, to separate the train, additional shunting work will be required.

f) Changing the specialization of yards. If the configuration of the station and the location of the yards allow, then it is possible to reduce the load on the station by changing the specialization of arrival and departure yards. For example, the number of wagons accepted at the station at the same time can be increased by combining two yards (arrival and departure) and using them as one arrival-departure yard. It is also possible to receive trains in the departure yard or place trains ready for departure in the arrival yard.

g) Use of station loading and unloading tracks. If the station receives a large number of freight wagons from all directions and all arrival and departure tracks are busy, it is possible to place trains in the loading and unloading tracks. Thanks to this method, the processing capacity of the station can be increased.

The implementation of the above measures will increase the throughput and processing capacity of the station. The station will return to normal. The dispatcher will then continue to operate the station in accordance with the instructions.

If, after the implementation of all the above measures, the load of the station continues to increase and reaches its maximum value, then at the next stage the use of structural technology is not considered appropriate. In such cases, it is necessary to reduce the number of trains arriving at the station. To do this, the station dispatcher informs the dispatcher serving the railway section about this, which in turn temporarily stops approaching trains at neighboring stations. Moreover, the higher authorities are informed about the artificial delay of trains on the railway network.

Thus, non-standard situations arising during the operation of a dispatcher can be solved by applying the methods of structural technology and brought to a standard situation.

In order to properly select one of the above measures by the dispatcher and their practical solutions, an expert system should be developed. With the help of this system, according to the degree of loading of the station, you can select the desired situation and make decisions for implementation.

In non-standard cases, the use of an expert system will allow the dispatcher to reduce the time for making management decisions, increase the performance of the station and increase throughput. In the first step, initial data is entered into the system. The initial data include the occupancy rate of individual tracks or yards, the number of shunting locomotives, loading and unloading machines and mechanisms, as well as the number of technical and commercial inspection teams, etc. At the second stage, based on preliminary data on suitable trains, the loading speed of the station is estimated. In order to optimize the operation of the station, the congestion of tracks and yards is analyzed separately to determine a set of solutions. The third stage is the decision-making process. If the station load is equal to or less than 75%, the station operation in normal mode and no additional measures are required. In this case, the work is regulated by the standard solutions of the dispatcher. If the station load is more than 75%, then the expert system gives recommendations for reducing the station load [8, 9].

Application of an expert system to derive correct solutions

In this work, the block diagram (Fig. 1) was implemented during the development of the expert system for the conclusions of recommendations using the example of the Baladjar marshalling yard. Baladjar is the main marshalling yard of Azerbaijan Railways and plays a key role in organizing train flows to the three main directions of the country. The station has 3 yards (arrival, classification, departure) located parallel to each other. In the arrival yard 9, the departure yard 12, the classification 31 tracks. Loading and unloading operations are carried out in the freight yard of the station. The station serves 5 shunting locomotives. Four teams carry out technical and commercial inspections. The developed expert system will make it possible to make the right decision in non-standard cases.

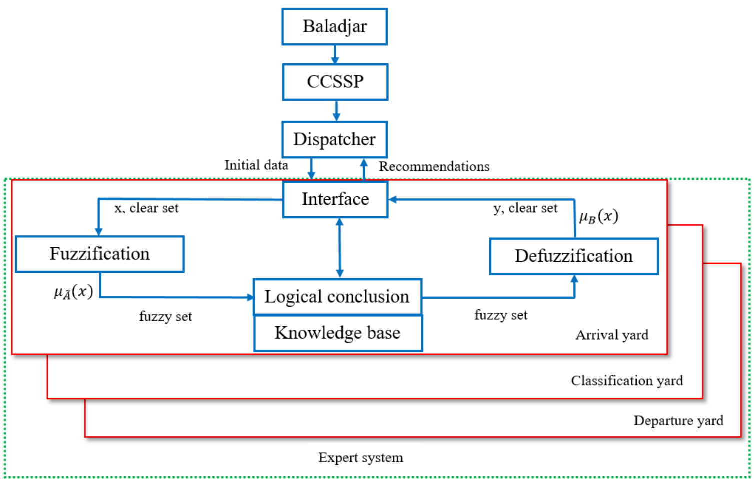

Fig. 1. Block diagram of the expert system of the Baladjar

Expert system model on based on fuzzy logic, it is a set of production rules written in the natural language of qualitative concepts of specialists. Fuzzy expert systems allow not only taking into account uncertainty, but also providing the opportunity to model reasoning based on the experience of specialists. The central control system of the station parameters (CCSSP) reads the data and provides this data to the dispatcher. Then the dispatcher enters the obtained data into the expert system and starts the processing mechanism. Fuzzification is the transformation of a clear set of input data into a fuzzy set, determined using the values of the membership functions. The purpose of the fuzzification step is to establish a correspondence between the specific numerical value of the individual input variable of the system and the value of the membership function of the corresponding term. Input $\{x_1, x_2 \ldots x_n\}$ where n - is the number of parameters, are values obtained from the central control system. Then happens linguistic evaluation of each parameter according to the set in the system membership functions. For example, for input variables when loading the receiving fleet, we can take: the level of track occupancy (low - 0....50 %, medium - 40...75 %, high - 70....100 %), train arrival intensity (low - 0...2 trains per hour, medium - 2...4 trains per hour, high - 4...10 trains per hour), the number of processing teams (below the norm - 0...1, normal - 1...2, above the norm - 2...4), number of shunting locomotives (below the norm - 0...1, normal - 1...2, above the norm - 2...4). After that, the clear set of input parameters turns into a fuzzy set $\tilde{A}$ and is used as linguistic variables in the logical rules of the knowledge base. The knowledge base contains production rules that have left- and right-hand parts:

IF $X_1=A_{l1}$ *AND* $X_2=A_{l2}$ *AND...AND* $X_n=A_{ln}$ *THEN* $Y_1=B_{l1}$ *OR* $Y_2=B_{l2}$ *OR...OR* $Y_n=B_{ln}$

IF $X_1=A_{n1}$ *AND* $X_2=A_{n2}$ *AND...AND* $X_n=A_{nn}$ *THEN* $Y_1=B_{n1}$ *OR* $Y_2=B_{n2}$ *OR...OR* $Y_n=B_{nn}$

The number of rules for the receiving park with the above input variables is 81. Defuzzification is the inverse transformation of a fuzzy set into a clear set B. Thus, the system values are the probabilities of conclusions of the recommendations $\{y_1, y_2 \ldots y_n\} \in Y$, where j - is the number of recommendations.

A fuzzy set represents a dependence of a $\mu(x) = \mu_{\tilde{A}\to B}$ (y) as a function from the output variable y. Thus, the conclusions of the recommendations are identified with a probability assessment. Such a logical output system is called Mamdani-Zade system. The choice of an odd model of the Mamdani type is due to the fact that that the rules of the knowledge base are transparent and intuitive, then as for Sugeno models, it is not always clear what linear dependencies "inputs - output "must be used and how to obtain them [10-12].

Causal relationships between parameter values and with non-standard situations are formalized in the form of a set of fuzzy logical rules. Format the base inference rule "if - then" is called fuzzy implication. For example, fragments when loading the receiving park look like this. Input data display:

OCCUPANCY RATE OF TRACKS (%) = 60
TRAIN ARRIVAL INTENSITY = 6 TRAINS PER HOUR
NUMBER OF SHUNTING LOCOMOTIVES = 2
THE NUMBER OF PROCESSING TEAMS= 2

Fuzzification (Selecting the appropriate membership function term for each input variable):

OCCUPANCY RATE OF TRACKS (%) = HIGH
TRAIN ARRIVAL INTENSITY = HIGH
NUMBER OF SHUNTING LOCOMOTIVES = NORMAL
THE NUMBER OF PROCESSING TEAMS = NORMAL

Defuzzification and derivation of solutions:

THE NUMBER OF TRACKS FOR TRAIN ACCEPTANCE IS LOW (NTTAL) - RELIABILITY 100%

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IF NTTAL = LOW
DISPLAY ("RECOMMENDATION: CHANGE THE SPECIALIZATION OF DEPARTURE TRACKS")
SO_THAT, "THERE ARE FREE TRACKS IN THE DEPARTURE YARD"

....

IF NTTAL = LOW AND THERE ARE NO FREE TRACKS IN THE DEPARTURE PARK
DISPLAY ("RECOMMENDATION: TAKE A TRAIN TO THE TRACK FOR MOVEMENT OF SINGLE LOCOMOTIVES ")
SO_THAT, "TRACK FOR SINGLE LOCOMOTIVES ARE FREE"

....

IF NTTAL = LOW AND THERE ARE NO FREE TRACKS IN THE DEPARTURE PARK AND TRACK FOR SINGLE LOCOMOTIVES ARE NOT FREE
DISPLAY ("RECOMMENDATION: PUT THE TRAIN ON THE LEAD TRACK")
SO_THAT, "LEAD TRACK IS FREE"

....

IF NTTAL = LOW AND THERE ARE NO FREE TRACKS IN THE DEPARTURE PARK AND TRACK FOR SINGLE LOCOMOTIVES ARE NOT FREE AND LEAD TRACK IS NOT FREE

DISPLAY ("RECOMMENDATION: REMOVE THE PROCESSING TEAM FROM LESS LOADED YARD OR TEMPORARILY FORM AN ADDITIONAL")
SO_THAT, "TRAINS A WAIT PROCESSING"
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The introduction of this system at the Baladjar station yielded positive results. On fig. 2. a fragment of one of the graphs for reducing workload when using the system is given. As can be seen from the graph, in the period 22:00 – 03:00, with the help of the recommendations of the expert system, the workload of the receiving fleet decreased significantly (before 22:00 and after 03:00, the recommendations of the expert system coincided with the decision of the dispatcher).

Fig. 2. Graph of changes in workload when using the expert system

Conclusions

In terms of practical importance, the developed system will cope with the increase in workload, increase performance and to some extent increase the capacity of the station (Fig. 2). Translate non-standard situations arising in the operation of the station into standard ones by implementing structural technology methods. The use of an expert system will make it possible to make the right decision, which will allow the dispatcher to reduce the time for making management decisions. It is also possible at an early stage to estimate the increasing probability of station loading when the input parameters change in real time.

From the point of view of scientific significance, the advantages of an expert system based on fuzzy logic are as follows:

- Maintaining the development of a quick prototype of an expert system with subsequent complexity of functionality;
- Fuzzy logical model is more user-friendly than similar mathematical model based on differential equations;
- The fuzzy set method allows you to include qualitative variables in the analysis, operate on fuzzy inputs and linguistic criteria;
- Fuzzy models are easier to implement than classic control algorithms.

REFERENCES

1. Козаченко, Д. Н. & Горбова, А. В. Определение расчетных объемов работы железнодорожных станций в условиях изменения структуры вагонопотоков. *Сборник научных трудов Днепропетровского национального университета железнодорожного транспорта.* Вып. 10. 2015 с. 50-56 [In Russian: Kozachenko, D.N. & Gorbova, A.V. 2015. Determination of calculated volumes of work for railway stations in the condition of cars flow changing, *Collection of scientific papers of the Dnipropetrovsk National University of Railway Transport.*]

2. Dong, Li. Research on the passing capacity of Heavy Haul Railway Technical Station [D]. 2015. Southwest Jiao Tong University

3. Jaehn, F. & Rieder, J. & Wiehl, A. Minimizing delays in a shunting yard. *OR Spectrum.* 2015. Vol. 37(2), P. 407–429

4. Guo, R. & Guo, J. & Xie, G. Optimizing model of a railroad yard's operations plan based on production scheduling theory. *Transactions on The Built Environment.* 2016. No. 162. P. 1743–3509.

5. Gestrelius, S. & Dahms, F. & Bohlin, M. Optimisation of simultaneous train formation and car sorting at marshalling yards. In: *5th International Seminar on Railway Operations Modelling and Analysis Rail Copenhagen*. 2013.

6. Gestrelius, S. & Aronsson, M. & Joborn, M. & Bohlin, M. Towards a comprehensive model for track allocation and roll-time scheduling at marshalling yards. In*: RailLille 2017 — 7th International Conference on Railway Operations Modelling and Analysis*. P. 1153-1172

7. Boysen, N. & Fliedner, M. & Jaehn, F. & Pesch, E. "Shunting yard operations: Theoretical aspects and applications." *European Journal of Operational Research.* 2012. 220 (1). P. 1–14.

8. Лаврухин, А. В. Формирование интеллектуальной модели функционирования железнодорожной станции при выполнении поездной работы. *Наука и прогресс транспорта, Днепропетровский Национальный Университет железнодорожного транспорта*. 2015. No. 1(55). P. 43-53. [In Russian: Lavrukhin A. V. Formation of an intelligent model of the functioning of the railway stations when performing train work. *Science and progress of transport, Dnepropetrovsk National University of Railway Transport*]

9. He, S. & Song, R. & Chaudhry, S. Fuzzy dispatching model and genetic algorithms for railyards operations. *European Journal of Operational Research.* 2000. No. 124(2). P. 307–331.

10. Jackson P. *Introduction to expert systems.* England. Harlow: Addison - Wesley. 1998. 526 p.

11. Manafov E. K. The use of a fuzzy expert system to increase reliability of diagnostics of axle boxes of rolling stocks. *Scientific Journal of Silesian University of Technology. Series Transport.* 2020. Vol. 107. P. 95-106. Available at: https://doi.org/10.20858/sjsutst.2020.107.7.

12. Штовба С.Д. 2007. Проектирование нечетких систем средствами MATLAB. Москва: Горячая линия-Телеком. [In Russian: Shtovba S.D. 2007. Designing fuzzy systems with MATLAB. Moscow: Hotline-Telecom. ISBN 5-93517-359-X].

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Е. МАНАФОВ

ЗАСТОСУВАННЯ МЕТОДІВ ШТУЧНОГО ІНТЕЛЕКТУ ДЛЯ ЗМЕНШЕННЯ ЗАВАНТАЖЕННЯ СОРТУВАЛЬНОЇ СТАНЦІЇ

Анотація. Стаття присвячена розробці експертної системи для отримання рекомендацій для станції Баладжар з підвищеним навантаженням. Значне збільшення приватного вагонного парку викликало зміни у системі організації роботи Азербайджанських залізниць, технології роботи станцій і тривалості станційних операцій. Почастішали проблеми, пов'язані з нерівномірним прийомом поїздів. Через такий процес роботи навантаження станції все більше перевищує допустиме значення. Також, в умовах підвищеного навантаження, неправильно прийняті диспетчером рішення ще більше ускладнюють роботу станції. Для зниження рівня завантаження станції у статті запропоновано використовувати методи конструкційної технології. Відповідно до швидкості завантаження станції розроблена експертна система відображення рекомендацій для вибору правильного рішення.

Ключові слова: сортувальна станція, навантаження, парк прибуття, парк відправлення, колії, експертна система.