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Improving efficiency of long-distance passenger railway traffic planning using the digital twins technology

Andrey Sokolovskiy*

Joint Stock Company “Railway Research Institute” (JSC “VNIIZHT”)

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A B S T R A C T

To increase the efficiency of planning long-distance passenger railway traffic, it is proposed to consider it a decision-making procedure for the synchronous interaction of all organizational units involved in the planning process. Relevant data for tasks at every step of traffic planning has different compositions of input and output points for possible use by other organizational units for their purposes.

Consecutive checks of compliance with the requirements of traffic planning stages are rather labor-consuming. Importantly, the alteration of one parameter of an existing transportation service offer may require rechecking the whole sequence of stages due to altered input parameters for the corresponding stages in the planning process.

Transportation planning efficiency improvements may be accomplished by using digital twins that assume a single cohesive model of data for the entire transportation organization process. This approach provides the use of related “sets” of data at every stage of the planning process for checking new transport service planning alternatives with given parameters, which require significantly less time and effort. Moreover, the abovementioned approach can also be applied to the tasks that require checking of parameter alteration possibilities for the existing transport service offers, which accelerates the checking process for these new conditions’ application possibilities.

1. Introduction

The efficient organization and planning of passenger transportation services are essential for maintaining a smooth and reliable operation. This text focuses on the importance of efficient coordination activities for maintaining passenger traffic on Russian railways. It proposes a solution to increase efficiency and reduce resource intensity and emphasizes the importance of delivering product changes and improvements quickly to win customer trust and loyalty. The article discusses the use of "digital twins" technology as a solution for increasing the speed of information processing in the organization of passenger transport services. The article also introduces the concept of "digital twin" technology and its application in the context of passenger transportation services, emphasizing the need for a unified data model to synchronize the interaction of physical objects and virtual entities that are used to organize passenger transportation. The process of creating

*Corresponding author

Email address: sokolovskiy.andrey@vniizht.ru

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such a model involves determining dependencies between entities, setting boundary conditions for values, and creating an algorithm that can adjust input parameters to fall within acceptable ranges. Ultimately, the goal is to create a system that can quickly determine the possibilities of assigning a train and make adjustments automatically.

2. Passenger transportation process

In this paper, the passenger transportation planning process stands as a research object. All the examples for the research object are provided from the Russian Railways passenger transportation complex. In the Russian Railways' passenger transportation planning process, there are six major blocks (Figure 1):

1. Budget planning;
2. Passenger transportation planning;
3. Train schedule;
4. Infrastructure "service window" planning;
5. Rolling stock turnover schedule; and
6. Traction services plan.

During budget planning, financial targets are set concerning passenger complex performance. The target indicators (KPI) primarily include revenues from the organization of transportation management. The setting of target indicators takes into account the strategic objectives of the "Russian Railways" holding and corporate financial management system. As a result of budget planning, revenue and expense plans should be established. In the following step, this data is allocated to the number of train runs through the directions of the railway network. All these activities are part of the Plan targets for passenger transportation.

Plan targets for passenger transportation (hereinafter, the "Plan") are the offered volume of transport services that should be delivered to the market in order to respond to consumer demand and meet the needs for transport mobility. For its drafting, the data on passenger traffic on the railway network is used. Ultimately, the Plan should determine the number of train runs in various categories, taking into account the structure of trainsets by types of cars for network directions in accordance with the environment of local transport markets. The next step is the train schedule.

It is one of the main documents regulating the operation of railway transport. As the present report is intended for railway experts, there is probably no need to dwell upon the significance of the train schedule, but it is important to highlight its role in the process of planning and organizing railway passenger transportation as the process of managing and synchronizing data flows. Initially, the incoming information about the needs of external and internal customers is used, which should be coordinated and coherent for drafting a train schedule. Subsequently, the possibility of matching the internal resources for the organization of transport services to meet previously defined needs is checked. In practice, drawing up the train schedule implies laying the train paths along the sections that make up all directions of the railway network. Also, it reflects the running time of trains along the sections; on the basis of this data, the train schedule is formed (in fact, not only for the passengers, but in the context of this report, it is important to note that passengers are also the end users of this information). The schedule is not permanent. This is a relatively flexible document, which may change if adjustments are needed due to technologies for infrastructure maintenance, preparation of trains for departure, or delivery of traction services. On Russian railways' networks, the tracks are used mainly for both freight and passenger traffic. Therefore, the train schedule should take into account the intensity of the infrastructure loads on the considered railway sections for all types of traffic. It should also be kept in mind that emergencies may interfere with the abovementioned technological processes, which require adjustments to the current train schedule in order to return to the planned performance indicators.

The next chronological step is the planning of maintenance "windows" for infrastructure repair works. The organizational structure of JSC "Russian Railways" has a separate stakeholder that is in charge of it; technological processes for infrastructure maintenance are not directly related to the transportation process. Thus, in case of discrepancies, a long re-approval is needed to find new opportunities for these stages' synchronization, ensuring train traffic and the provision of the necessary intervals for the maintenance of tracks.

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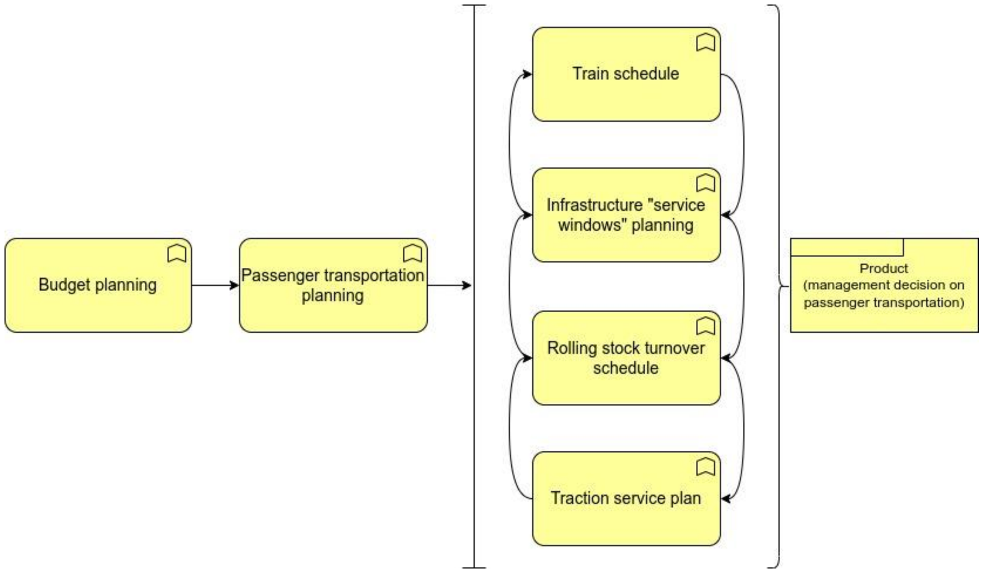

Figure 1. Upper-level passenger transportation process

Another step that requires coordination of activities for maintaining passenger traffic is the planning of rolling stock turnover. There are two types of rolling stock used for passenger intercity transportation on Russian railways: locomotive-traction rolling stock and multiple units (MU). The rolling stock turnover planning differs a lot for each kind of rolling stock. These two types of rolling stock could not be combined or replaced by each other, so, essentially, there should be different rolling stock turnover plans with the goal of delivering a suitable amount of passenger transportation services to the market. One of the conditions for rolling stock turnover mapping is that train formation and turnover locations should have appropriate equipment for rolling stock maintenance and its planning with due regard to standard maintenance terms and intervals. The inability to provide technical work or equip the train for the trip also requires a re-approval of the rolling stock used or the train route.

3. Digital twins

What technological solutions could provide an increase in the speed of information processing for the formation of the final solution for the organization of passenger transport services while increasing the productivity of specialists and shortening the time for the introduction of new transport products to the market? This paper discusses the possibility of solving this problem using the “digital twins” technology.

What is a “digital twin”? There are more than 100 definitions of this concept. The concept of a “digital twin” was introduced by Michael Grieves, a professor at the Florida Institute of Technology [3]. Digital twin technology is a mathematical model of real-world objects that sets conditions and constraints for their possible states. The prerequisites for creating digital twins were the development of the concepts of the “digital production process” and the Industrial Internet of Things (IIoT). The concept assumes equipping production facilities with sensors that allow interpreting changes in the states of system objects and transmitting this data for centralized processing. Matching of the model algorithms, designed in accordance with the technological process, with an array of processed and prepared data can significantly increase the level of responsiveness of the virtual model and reflect on it the changes occurring with real objects on a time scale close to real. Now, there are many interpretations of the concept of “digital twin.” With respect to the issues of JSC “Russian Railways,” the best definition is one given by Tao, Sui, Liu, Qi, Zhang, Song, Gyo, Lu & Nee [4]: “A digital twin is a real representation of all components in the product lifecycle using physical and virtual data, as well as their interactions.”

For condition monitoring of passenger trains and their geospatial display, Research Center “Express” of JSC “VNIIZHT” developed

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a complex “digital twin of the passenger train” [5], which processes and transmits quantitative and qualitative data on the condition of the operating train to the dispatcher in a near-real-time mode. Technologically, the solution aggregates data collected from various sources, processes it, and presents it to the dispatcher in a single window (super-app) mode. The data flow is processed “from bottom to top.” At the same time, planning and organizing passenger traffic do not require a fast lifting of data “from bottom to top,” but rather a process that is executed in line with a single data model at every stage, where selected input parameters for all stages are checked automatically. In the future, complementing this scheme with prompts for the dispatcher on possible options of the transport offer for approval at all stages would further increase the speed of hypothesis testing and management decision-making.

4. Unified data model

The development of a unified data model requires the analysis of arrays of data on the objects and results that appear at every stage of the process. It is required to highlight the main characteristics, primary keys, and secondary attributes. Also, interconnections should be defined for the characteristics of objects. For instance, “Budget” is determined as the result of budget planning; “number of train runs” is the result of Plan targets for passenger transportation; “train schedule” is the result of the train timing process; “schedule of infrastructure maintenance works” is the result of maintenance “windows” planning; and “traction services as defined by the schedule” are the result of the plan of traction and locomotive crews’ services. An enlarged data model of the passenger transportation planning and organization process is shown in Figure 2.

In order to create a single data model that could synchronize the interaction of physical and virtual objects in the real world, in accordance with the definition of the “digital twin” technology, the problem of linking the defining characteristics of the entities of each of the stages of the process with other entities of this process should be solved. For example, there is the cost of one train run, which depends, among other things, on the type of service (high-speed, international, etc.) and the number of cars in the trainset (or MU). Also, a known factor is the budget limit for the organization of passenger transportation. Thus, these attributes for the entity “number of train routes” become external keys or external defining characteristics. When creating a single data model, it is necessary to build such dependencies on all entities that arise as a result of the process of planning and organizing passenger transportation.

When the chains of dependencies of the characteristics of the entities of the process are determined, the boundary conditions of the values of the characteristics that satisfy the conditions of admissibility for the purpose of the train should be determined. This includes such logical restrictions as the limit of the train length, the capacity of railway network sections, the type of traction used on sections of the train route, etc. When the software package for

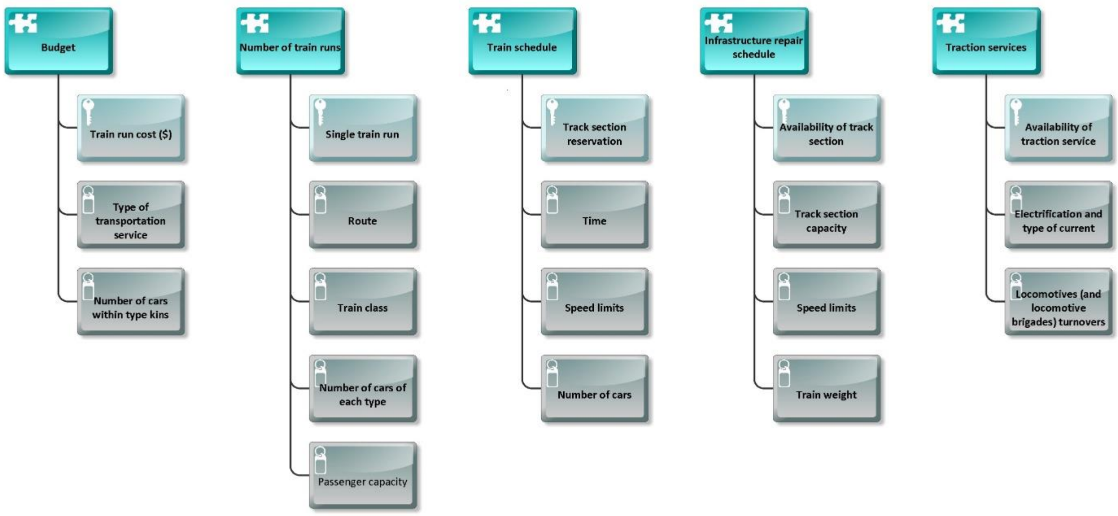

Figure 2. An enlarged data model of the passenger transportation planning and organization process

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planning and organizing passenger transportation is able to operate on such data, the system will be able to determine very quickly the possibilities of assigning a train by checking that the specified parameters match certain value boundaries. At the same time, at this stage, the system will be able to give the operator only "YES-NO" responses to the entered parameters to check the possibility of assigning a train.

In order for such a system to become a full-fledged "digital twin" and be able to adjust instead of an operator the set of values for the process entity that does not meet the requirements of the train assignment possibility, it is necessary to create an algorithm that would first determine the available range of values for the entity for which compliance with the requirements was not obtained and then submit it to the input for verification a new set of input parameters, taking into account adjustments to fall within the acceptable range of values. Then, the operation must be performed a certain number of times until a match is found to the permissible ranges of values for all entities of the process, or all combinations of data are sorted out and an answer is given about the impossibility of meeting the established requirements.

Since the operations listed above are currently performed by specialists of various structural divisions manually (partially or completely), it is possible to predict the main increase in labor productivity and efficiency of the planning and organization of transportation due to inter-structural interactions marked with red arrows in Figure 3, which will significantly affect the speed of the entire chain of managerial decision-making and, as a consequence, increase the speed of response to changes in market conditions. This is a prerequisite for increasing the attractiveness and competitiveness of railway transportation services in the transport market.

5. Conclusions

"Digital twin" technology can be adapted for the tasks of planning and organizing passenger transportation by rail. The introduction of "digital twins" technology will allow smooth interaction between structural units involved in the process of planning and organizing passenger transportation based on a single data model. Smooth interaction eliminates the bottlenecks and allows for an increase in labor productivity and the efficiency of the planning and organization of passenger transportation, which will have a positive impact on the ability of rail transport to meet market fluctuations. The technological basis of the achieved effect is the digitalization of the technological processes of the industry and the building of relationships between the characteristics of the entities of the processes among the various structural units involved.

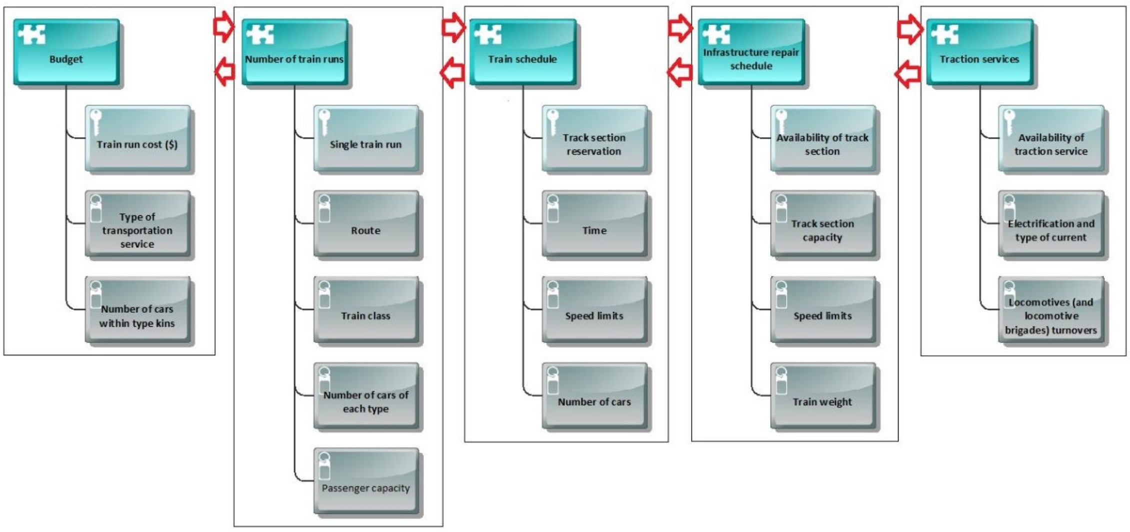

Figure 3. Interactions between entities of the passenger transportation planning process to synchronize data structures for unified data model

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Further research on the possibilities of using "digital twin" technology in passenger transportation management tasks on railway transport involves targeted consideration of the interrelations of the characteristics of a limited number of process entities in order to work out the mathematical apparatus for solving the formulated problem for them.

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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