**Evaluation of Traction Efficiency for the Tashkent Metro Train Formation with a Trailer Car and Motor Cars   
81-717/81-714**

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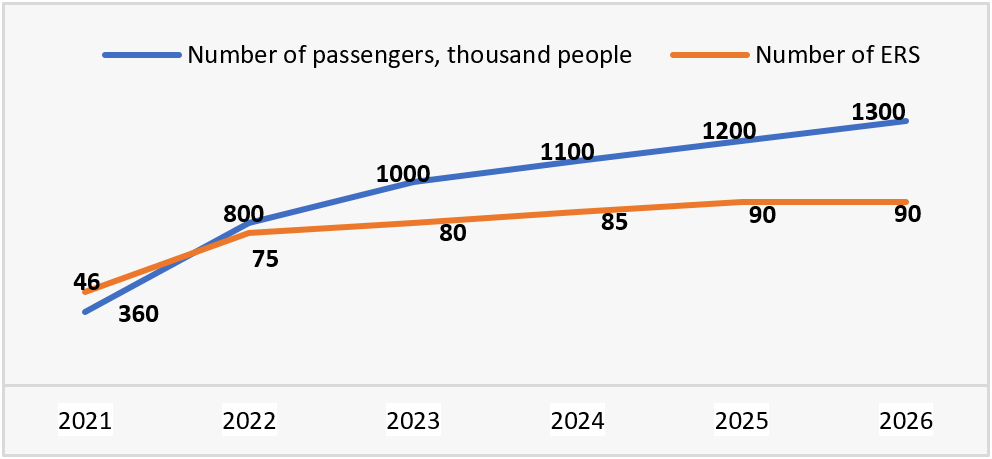
**Abstract.** This study examines a potential method for increasing the traction and operational efficiency of the Tashkent Metro by adding a trailer car to the 81-717/81-714 motor car set. Traction characteristics were modeled based on a mathematical representation of the observed track profile, traction force, and movement resistance. The results demonstrate that the proposed change in train composition enhances the ability to navigate complex sections of the urban railway and optimizes operations. Research methodology the traction efficiency of the train was evaluated using a mathematical model that includes parameters of traction engines, axle loads and track profiles. The research is carried out in difficult areas, including open spaces, where the requirements for traction characteristics are increased. The main results showed the simulation of the effectiveness of the new train with a trailer solution in difficult areas, which ensures increased operational efficiency. The results obtained can be used to further optimize the formation of trains, which will reduce the burden on infrastructure and increase the economic efficiency of subway operation in the face of current challenges.

**Keywords:** Tashkent Metro, traction efficiency, train composition, trailer car, mathematical modeling, traction force, track profile, urban railway, infrastructure optimization

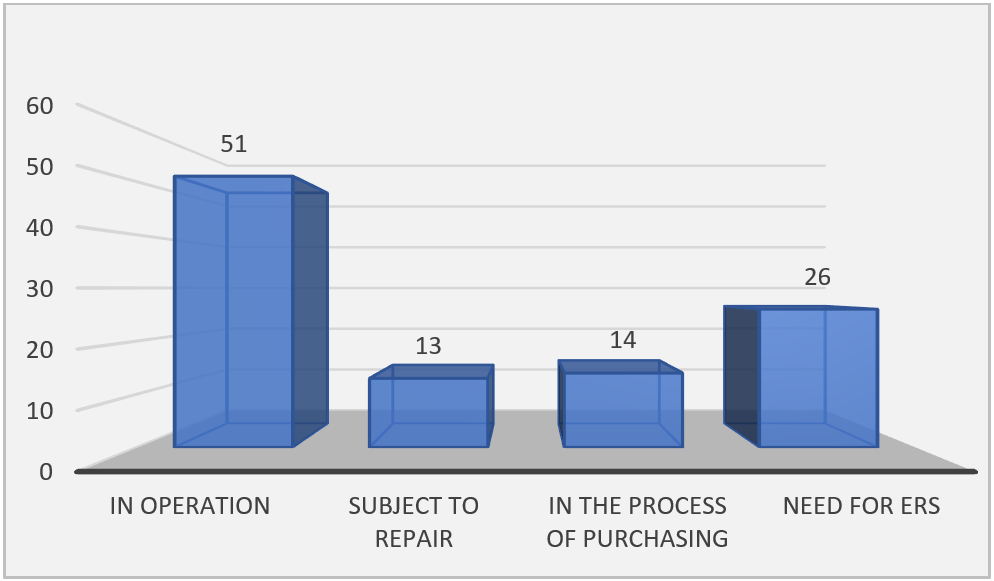
**INTRODUCTION**

Over the past few years, the Tashkent Metro has faced several challenges due to the significant increase in passenger traffic. Currently, this number reaches 1 million people per day, posing a significant challenge for the smooth operation of the system, see Figure 1. One of the main issues is the wear and tear of the rolling stock, as insufficient attention has been given to updating the fleet for a long time. Despite attempts to purchase new trains from Russia, the shortage of rolling stock continues to be a major obstacle to efficient metro operations, see Figure 2.

Due to the above circumstances, one of the possible solutions is to change the existing composition of metro trains, namely, the addition of a trailer car to the train consisting of four motor cars of type 81-717/81-714. This approach involves improving traction characteristics and increasing operational efficiency, which is relevant for optimizing the system's operation in the face of growing passenger traffic and the need to reduce wear on existing rolling stock [1].

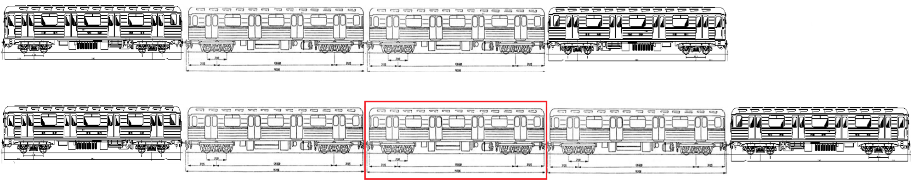


**FIGURE 1.**  The need for rolling stock due to the increase in passenger traffic



**FIGURE 2.** The need for rolling stock

Due to the above circumstances, one of the possible solutions is to change the existing composition of metro trains, namely, the addition of a trailer car to the train consisting of four motor cars of type 81-717/81-714, see Figure 3 [2]. This approach involves improving traction characteristics and increasing operational efficiency, which is relevant for optimizing the system's operation in the face of growing passenger traffic and the need to reduce wear on existing rolling stock [3-4].

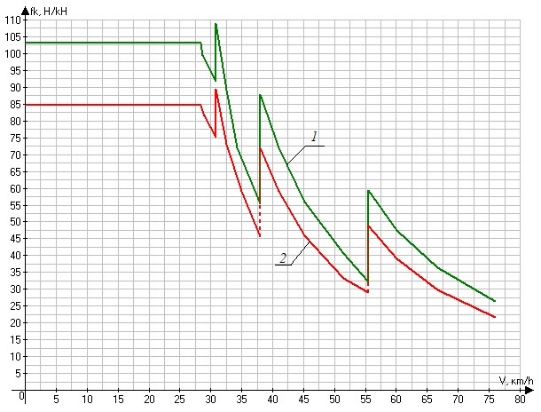


**FIGURE 3.**  Сomposition of rolling stock

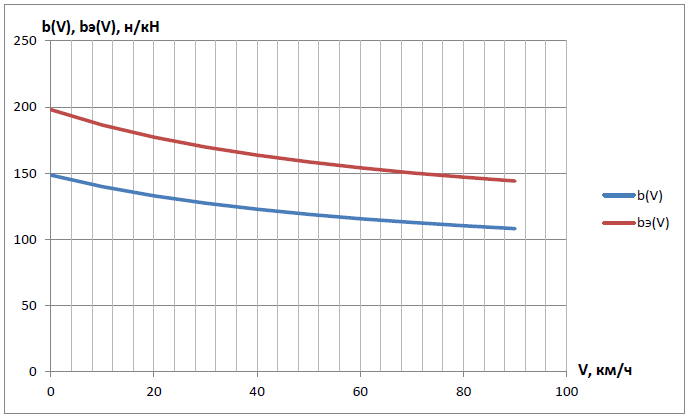
**MATERIALS AND METHODS**

In order to assess the traction efficiency of a subway train consisting of four 81-717/81-714 motor cars, we constructed a mathematical model of the existing train. At the first stage of our work, we checked the adequacy of this model, which allowed us to verify its accuracy and correctness for future calculations, see Figure 4 [7-8].

To obtain traction, current, and braking characteristics of the train, we used the parameters of the traction electric motor wagon, as well as data on power consumption and axle load distribution. Based on the data for the formation of numerical calculations, digital maps were formed, which, at each polygon, allowed modeling the behavior of the train on a different part of the track, taking into account the uphill, slippery sections of the track, as well as calculating the current consumption and heat generation, see Figure 5.



**FIGURE 4.** Traction characteristics of a train composed of a trailer car (2) and a motor car train (1)



**FIGURE 5.** Braking performance under mechanical brking

The profile of the Tashkent Metro track that is maximum complex was utilized as a starting point of the traction calculations. Also careful consideration was given to various parts of the track that pass through open places where the train is not passing a tunnel. This adds more demands on the traction attributes of the train [5-6].

**DESCRIPTION OF THE MODEL**

In order to assess the traction performance of a train formation, a mathematical model resolving on the equations of train moving is applied. Various highly significant parameters are considered in this model, such as the traction force, resisting moving force, mass of train, and the contribution that each individual car would have on the whole dynamic characteristic [9].

The traction force is the key part of the calculation and should surpass the resistance towards movement of the train. To make a more realistic evaluation of the movement dynamics, it is required to consider the variations in the movement speed of the electric train as based on applied traction force and the resistance of movement. The equation for changing the velocity of a train can be written as a differential

(1)

≥ 0 is the specific traction that is applied at time t to accelerate train; ≥ 0 is the specific braking that is applied at time t to decelerate the train; s(t) is the position of train; v(t) is the velocity; m is the mass of train, w(s(t), v(t)) is the specific resistance to movement of the composition which is the combination of the resisted mechanisms such as the rolling resistance, and the aerodynamic resistance and resistance on the curves and is defined in the form given as

(2)

in which , , are empirical coefficients depending on the kind of the track and rolling stock; v is the speed of the electric train; r is a second coefficient which considers the caveat of resistance on the curves.

The model enables you to consider all the important factors connected with resistance in a reasonable manner in the context of defining the necessary traction force to provide stable and efficient train running.

Traction characteristic of the electrical train is the highest value of the traction force, which can be derived by the traction motors at a definite speed. All traction motors have an estimated thrust force depending on the power and the rotational speed. This measure is needed to decide on how many traction motors to have in order to deliver the required traction force that can counter the resistance of the motors at a specific speed. The computed traction force (of a single traction motor) of this kind of electric train could be done by using a formula as follows:

(3)

in which is the thrust force of a single traction motor calculated; is the power of traction motor.

The mass of an electric train is composed of the mass of the motor and trailer wagons, and also mass of passengers. Now, how about calculating mass of each type of wagon?

Tare weight of a single motor wagon , ton. The number of passengers in motor car is estimated as:

, (4)

in which is the average weight of one passenger (0,07 ton); is the number of passengers in the motor car.

Thus, the total mass of the motor car with passengers will be equal to

. (5)

Mass of car trailer is calculated in the same way

, (6)

in which, the number in the trailer car.

Total weight of one trailer car

(7)

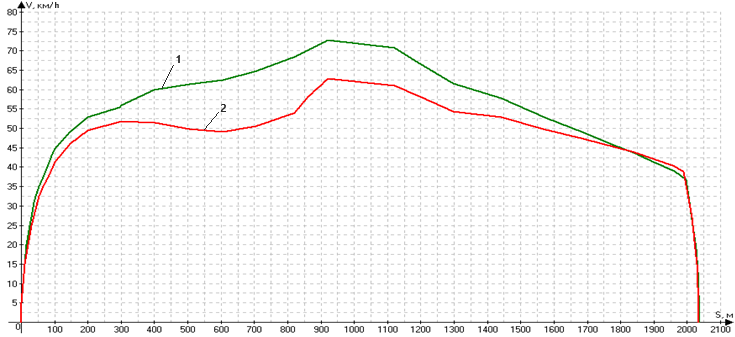
For the entire train consisting of motor and trailer wagons, the total weight is calculated using the formula

. (8)

**RESULTS**

After recalculating the mass of the train, considering the changed composition, it is essential to verify that the thrust force calculated for the new train mass does not exceed the previously calculated thrust force for the old composition. This step is crucial to ensure that the tractive force is sufficient to guarantee efficient movement of the train.

After checking the adequacy of the model for the existing train, a model was developed for the new formation with a trailer car. Using the obtained data on the characteristics of the new train, similar calculations of traction characteristics for this formation were carried out. The main object of the calculations was the passage of the train through the calculated ascents on the selected track profile, see Figure 6. This allowed us to identify how effectively the new composition will cope with profile changes and possible operational difficulties [10].



**FIGURE 6.**  The curves of movement of a train with a trailer car *(2)* and a motor car train *(1)*

**CONCLUSIONS**

The calculations and analysis of the traction characteristics of the Tashkent Metro train, consisting of four 81-717/81-714 type motor cars and a trailer car, showed that the proposed change in composition has a number of advantages in conditions of growing passenger traffic and deterioration of existing rolling stock. The simulation carried out on the basis of a real track profile confirmed the possibility of efficient passage of a train with a trailer car through difficult sections of track, which contributes to improving the operational efficiency of the subway.

At the same time, future studies are planned to take into account the influence of various climatic conditions (rain, snow, temperature changes) on the traction efficiency of the train. These factors can significantly affect the adhesion of wheels to rails, especially in open sections of track, which requires additional analysis to accurately assess the behavior of the train in extreme conditions.

The results obtained can be used to further optimize the formation of trains, which will reduce the burden on infrastructure and increase the economic efficiency of subway operation in the face of current challenges.

**FUTURE SCOPE**

The results of the traction efficiency of the train set of the Tashkent Metro a motor car (81-714 and 81-717) with a trailer car are the reference point of the corresponding researches and investigations. There is still a possibility of upgrading the current study by doing another research with other factors taken into account, which would then make the metro more sustainable and efficient in its work. Future directions of the work are the following.

Another point used by the study was to point out that there was need to conduct a study on how the climate can affect the traction efficiency like effect of rain, snow and changes of temperature among other factors. Further development stage of the research should contain development of models with consideration of the described variables to define the wheel-rail adhesion, in a case with the open sections of a railway, specifically, ensuring the stable characteristics under the different weather conditions.

In the future, there should be simulation of these systems to determine their impacts on the energy consumption, and the dynamics of train.

Further studies of hybrid or mixed motor-trailer offers would lead to optimal arrangements of different routings. Comparative simulation of these arrangements must be carried out to provide a balance between the passenger carrying capacity and traction under performance.

This would give an indication on maintenance strategies since this would give the quantification of the impact which the proposed composition would give to the wear of the rolling stocks. Wheels and motors should model the wear in further research so as to enhance services life of the equipment.

It is necessary to perform a full-cost benefit study in order to add trailers cars. New research needs to be done to determine the savings that will be made in terms of reduced infrastructure load and maintenance against cost of implementation in the future.

Mult-train interactions simulation: This would reduce the schedule and capacity as much as the multi-train functions are concerned. We should carry out another analysis on the total effects of the proposed composition to the metro operations.

The introduction of the trailer cars might also result in the noise and vibration. It is also advisable to ensure that in the future a research must be carried to study such effects and suggest measures to create solutions to minimize the impact on both passengers and the environment.

These lines of investigation can be seen as a roadmap upon which the soundness, resilience, and long-term-efficient nature of the Tashkent Metro can be enhanced even further addressing both productive and eco-related concerns.

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