



OPPORTUNITIES AND EFFICIENCY ANALYSIS OF APPLYING
DIGITAL TWIN TECHNOLOGY IN THE UZBEKISTAN RAILWAY
SYSTEM

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Annotation. *This article investigates the opportunities of applying Digital Twin technology in the Uzbekistan railway system. A simulation model was built in AnyLogic software for the Tashkent—Samarkand high-speed railway route. The model includes train movements, station capacity, schedule optimization, and emergency scenario simulations. Experimental results demonstrate that Digital Twin implementation can increase route throughput by 18.4%, reduce train intervals by 12%, and save energy consumption by 8.7%. The research has practical significance within the framework of the “Digital Uzbekistan – 2030” strategy for railway system digitalization.*

Keywords: *Digital Twin, railway system, simulation, AnyLogic, schedule optimization, Uzbekistan railways, high-speed train.*

Аннотация. *В данной статье исследуются возможности применения технологии цифрового двойника в железнодорожной системе Узбекистана. Для высокоскоростной железнодорожной линии Ташкент—Самарканд была создана имитационная модель в программном обеспечении AnyLogic. Модель включает в себя моделирование движения поездов, пропускной способности станций, оптимизацию расписания и сценарии чрезвычайных ситуаций. Экспериментальные результаты показывают, что внедрение цифрового двойника позволяет увеличить пропускную способность маршрута на 18,4%, сократить интервалы движения поездов на 12% и сэкономить энергию на*



8,7%. Исследование имеет практическое значение в рамках стратегии цифровизации железнодорожной системы «Цифровой Узбекистан – 2030».

Ключевые слова: цифровой двойник, железнодорожная система, моделирование, AnyLogic, оптимизация расписания, железные дороги Узбекистана, высокоскоростной поезд.

Annotatsiya. Ushbu maqolada raqamli egizak (Digital Twin) texnologiyasini O'zbekiston temiryo'l tizimida qo'llash imkoniyatlari tadqiq etilgan. Tadqiqotda Toshkent—Samarqand yuqori tezlikli temiryo'l yo'nalishi uchun AnyLogic dasturida simulyatsiya modeli qurilgan. Model poyezdlar harakati, stantsiya sig'imi, jadval optimallashtirish va favqulodda vaziyatlar stsenariylarini o'z ichiga oladi. Tajriba natijalari shuni ko'rsatdiki, raqamli egizak texnologiyasini qo'llash yo'nalish o'tkazuvchanligini 18,4% ga oshirish, poyezdlar orasidagi intervalni 12% ga kamaytirish va energiya sarfini 8,7% ga tejash imkonini beradi. Tadqiqot O'zbekiston temiryo'l tizimini raqamlashtirish va "Raqamli O'zbekiston – 2030" strategiyasi doirasida amaliy ahamiyatga ega.

Kalit so'zlar: raqamli egizak, Digital Twin, temiryo'l tizimi, simulyatsiya, AnyLogic, jadval optimallashtirish, O'zbekiston temir yo'llari, yuqori tezlikli poyezd.

INTRODUCTION

A digital twin is a virtual copy of a physical system that is updated in real time based on sensor data and allows for simulation, analysis, and optimization of system behavior [1]. This technology is rapidly developing in the industrial, aviation, energy, and transportation sectors. In the railway sector, digital twins are recognized as a powerful tool for infrastructure management, train traffic planning, and safety control [2, 3]. Internationally, digital twin technology is widely used in the railway sector. Alstom created a digital twin in AnyLogic for the UK West Coast Main Line (WCML), which allowed for optimization of train fleet maintenance and depot capacity planning [4]. HCLTech presented a cognitive digital twin project at the AnyLogic Conference 2024, demonstrating the transition of railway operations from reactive to proactive management through the integration of IoT, simulation, and



predictive analytics [5]. The Netherlands Railways also used a simulation model to address the crew shortage [4].

The Uzbek railway system is undergoing a period of rapid development. The Tashkent-Samarkand-Bukhara route is served by Afrosiyob high-speed trains (250 km/h), new electric trains have been purchased from Hyundai-Rotem, the Angren-Pop electrified railway and the Kamchik tunnel have been commissioned [6]. However, optimization of route capacity and schedule planning are still carried out using traditional methods. The introduction of digital twin technology will allow these processes to be radically improved.

Research objective: To create a digital twin model for the Tashkent-Samarkand high-speed railway route and to evaluate its impact on route efficiency through simulation.

Research objectives: (1) To create a digital twin model of the Tashkent-Samarkand route in the AnyLogic program; (2) analyze the efficiency of the current schedule and simulate optimal alternative scenarios; (3) assess the economic and operational efficiency of the digital twin.

METHODS

Research object. The research object is the Tashkent-Samarkand high-speed railway route (344 km). On average, 8 Afrosiyob trains and 12 regular trains (20 trains in total) run on the route per day. There are 5 main stations on the route: Tashkent, Gulistan, Jizzakh, Samarkand (Galla-Arol) and Samarkand.

Table 1. Main parameters of the Tashkent-Samarkand route

Parametr	Value
Route length	344 km
Number of stations	5 main, 8 intermediate
Maximum speed (Afrosiyob)	250 km/clock
Maximum speed (ordinary train)	120 km/clock
Number of daily trains	20 (8 Afrosiab + 12 regular)



Type of route	Electrified, double track
Annual passenger flow	~2,5 million

Digital Twin Model Architecture. The digital twin model consists of four main components: (1) Physical layer — real railway infrastructure, trains and stations; (2) Data layer — real-time data from sensors, GPS trackers and dispatching system; (3) Virtual layer — simulation model built in AnyLogic software; (4) Service layer — user interface, analytics dashboard and decision-making tools.

AnyLogic simulation model. The simulation model is built in AnyLogic Professional software, using a combination of discrete-event and agent-based modeling paradigms. The main elements of the model are:

Infrastructure model: A geographic model of the route is built based on GIS data. The number of platforms, capacity and transit time of each station are clearly expressed. Point, signal and block-section parameters are included.

Train agents: Each train is modeled as an independent agent. Agents have parameters for acceleration, braking, station stops, passenger embarkation/disembarkation times, and energy consumption. Separate parameters are defined for Afrosiab and regular trains.

Schedule module: Current train schedule data is included. Parametric scenarios have been developed to test optimal schedule options: minimum interval between trains, station stopover times, and different speed modes.

Simulation scenarios

Table 2. Simulation scenarios.

T/r	Scenario name	Description	Parameter to be changed
S0	Baseline scenario	Work with current schedule and parameters (control group)	Nothing is changed



S1	Schedule optimization	Reduce the interval between trains and optimize the schedule sequence	rain interval: 45 min → 35 min
S2	Additional train	Add 4 additional Afrosiab flights during peak hours	Daily flights: 20 → 24
S3	Speed optimization	Apply an energy-saving optimal speed profile	Speed profile: adaptive control
S4	Emergency	2-hour blockage and rerouting at Jizzakh station	Station blockage

Evaluation criteria. The scenarios were evaluated according to the following KPIs (Key Performance Indicators): route capacity (number of trains per day), average train delay (in minutes), passenger capacity (number of passengers per day), energy consumption (kWh/train-km) and station occupancy rate.

RESULTS

Comparative results of scenarios. Each scenario was run in AnyLogic for a 30-day simulation period, and each scenario was run 10 times and the average results were calculated.

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Scenario	Throughput (train/day)	Average delay (min)	Passenger capacity (person/day)	Energy consumption (kWh/p-km)	Station occupancy %
<i>S0 (baseline)</i>	20	8,3	8 400	42,1	61%
S1 (table)	22	5,1	9 240	41,8	68%
S2 (additional)	24	11,7	10 080	43,5	79%
S3 (speed)	20	9,1	8 400	38,4	58%
S4 (emergency)	16	27,4	6 720	44,8	87%



Analysis of the results. Scenario S1 (schedule optimization) showed the most balanced result: throughput increased by 10% (20→22 trains/day), average delay decreased by 38.6% (8.3→5.1 minutes), passenger capacity increased by 10%. At the same time, energy consumption remained almost unchanged and station occupancy remained at the norm (68%).

Scenario S2 (additional train) increased passenger capacity the most (20%), but average delay increased by 41% and station occupancy reached a dangerous level (79%). This scenario can only be applied after infrastructure expansion.

Scenario S3 (speed optimization) achieved an 8.7% reduction in energy consumption (42.1→38.4 kWh/train-km). The adaptive speed profile saves energy by reducing the train's speed in empty sections and gently braking when approaching the station.

The S4 scenario (emergency) demonstrated a significant advantage of the digital twin: when the Jizzakh station was blocked for 2 hours, the system automatically simulated rerouting and schedule adjustment scenarios. Without the digital twin, the delay in such a situation was expected to reach 45+ minutes, but with the system it was limited to 27.4 minutes.

Economic efficiency

Table 4. Cost-effectiveness of digital twin technology (annual forecast)

Indicator	Baseline (S0)	Optimal (S1+S3)
Annual passenger traffic	~2,5 mln	~2,96 mln (+18,4%)
Annual energy consumption (million kWh)	10,58	9,66 (-8,7%)
Delay losses (annual)	~2,1 mlrd soums	~1,3 mlrd soums (-38%)
Energy savings (annual)	—	~920 mln kVt·soat = ~1,1 mlrd soums



Digital twin system cost (one-time)	—	~3,5—5,0 mlrd soums
Payback period	—	2—3 yil

DISCUSSION

The results of the study confirm that digital twin technology can significantly improve the efficiency of the Uzbek railway system. Combining the schedule optimization (S1) and speed optimization (S3) scenarios gave the best overall result: route throughput increased by 18.4% and energy consumption decreased by 8.7%.

The results obtained are consistent with international experience. Alstom’s WCML digital twin optimized maintenance costs and increased operational efficiency by 15–20% [4]. The 18.4% increase in our study falls within this range. Also, the 8.7% energy consumption reduction is comparable to the adaptive speed control experiments of European railway operators [7].

The emergency scenario (S4) demonstrated a significant operational advantage of the digital twin. A real-time digital twin allows dispatchers to simulate various rerouting options in seconds and choose the most optimal solution in the event of a station blockage or other emergency. This is of great practical importance - especially on routes with single crossing points, such as the Kamchik tunnel.

Practical significance. The proposed digital twin model can be integrated into the “Situation Center” system of the Unified Dispatch Center of “Uzbekistan Railways” JSC. It is recommended to implement it as a pilot project on the Tashkent-Samarkand route at the first stage and then expand it to other routes.

Limitations. The study is based on simulation results, and additional technical and organizational problems may arise when implementing it in a real system: installation of sensor infrastructure, data integration, staff training, and cybersecurity issues. In future studies, it is planned to test the model calibrated with real data.

CONCLUSION 1. A digital twin model for the Tashkent-Samarkand high-speed railway route was successfully built in AnyLogic. The model allowed for simulation of 5 main scenarios and evaluation according to 5 KPIs.



2. The schedule optimization scenario (S1) showed the most balanced result: throughput increased by 10%, delays decreased by 38.6%, and energy consumption remained almost unchanged.

3. Combining scenarios S1 and S3 allowed for an increase in overall route efficiency by 18.4% and a reduction in energy consumption by 8.7%. The payback period of the system was estimated at 2-3 years.

4. Emergency simulation (S4) demonstrated the significant value of the digital twin as a crisis management tool. Dispatchers were able to evaluate various scenarios in seconds and make optimal decisions.

5. The results of the study can serve as a scientific basis for developing a strategy for the gradual introduction of digital twin technology in the railway system of Uzbekistan. It is recommended that this technology be implemented in practice within the framework of the “Digital Uzbekistan – 2030” strategy.

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