



APPLICATION OF ARTIFICIAL INTELLIGENCE IN SINGLE WAGON LOAD (SWL) OPTIMIZATION: OPERATIONAL MODEL FOR RAILWAYS OF REPUBLIKA SRPSKA

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Abstract – In conditions of stagnation of the European Single Wagon Load (SWL) system, which records a market share decline from 50% to 35–36% between 2004 and 2011 (European Commission, 2015), and with the dramatic example of DB Cargo recording annual losses of ~€442 million directly attributed to SWL operations (2022), this paper investigates the possibility of introducing an AI-optimized SWL service on the Railways of Republika Srpska (ŽRS) network. Unlike established European operators burdened by inherited costs, ŽRS has no SWL history — which is positioned in this paper as a strategic advantage, not a disadvantage. The proposed model is based on four AI components: (1) demand aggregation module, (2) real-time transport chain optimization following the SBB Cargo TK-Module model (Moldenhauer et al., 2025), (3) ETA prediction for end users, and (4) backhaul optimization algorithm.

Key words: single wagon load (SWL), artificial intelligence, transport chain optimization, railway, ŽRS, digital logistics service, backhaul optimization.

1. INTRODUCTION

The aim of this paper is to present a theoretical framework for the application of AI in the SWL context, to define the architecture of the proposed digital service, to validate the model through a concrete operational scenario on the ŽRS network, and to demonstrate the commercial viability of the approach through a door-to-door cost analysis. Cost calculations are based on ŽRS tariff estimates from internal operational parameters, and on estimates of the tariffs of HŽ Cargo, SŽ-Freight Transport and Mercitalia Rail based on publicly available Network Statement documents and industry averages (estimation error $\pm 15\text{--}20\%$ for EU segments). Truck costs are based on the IRU European Road Freight Benchmark (Q4 2025), which for EU segments amounts to €1.10–1.60/km, and for Balkan segments €0.80–1.20/km. It should be noted that this paper has limitations: EU operator tariffs are estimates, not confirmed contractual amounts; the analysis does not include seasonal demand variations; and the AI model is conceptual

implementation would require deeper empirical research with ŽRS operational data.

2. STATE OF SWL IN EUROPE

The European Single Wagon Load (SWL) system has been experiencing a structural decline throughout the past two decades, with fundamental consequences for railway operators. Three structural causes of the SWL decline:

- (1) high operational costs,
- (2) delivery opacity and unreliable ETA that drives small users towards trucks, and
- (3) underutilization of return logistics 27% empty running.

Table 1. presents a comparative overview of the state of SWL in Europe. The table shows that ŽRS occupies a unique position: it is the only country in the analyzed set that possesses a complete railway infrastructure base but has no SWL history that would burden the system with inherited costs. This is treated in this paper as a strategic first-mover advantage, not a disadvantage

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Table 1. Comparative overview of the state of SWL in Europe

Country	Operator	SWL Status	Trend (20 yrs.)	Key Note
Germany	DB Cargo	Crisis	Drastic decline	Loss of €442 mil. from SWL (2022); considering cancellation of 80% of services
Slovenija	SŽ-Tovorni promet	Under pressure	Declining	Only SWL provider, 78 stations; unsustainable without state support [7]
Slovakia	ZSSK Cargo	Collapse	-78% in 20 years	From 23 mil.t (2003) to 5 mil.t (2022); without intervention
Hungary	MÁV + ostali	Stabilized	Slightly growing	State subsidy €16.1 mil./yr. from 2021; 400,000 fewer trucks/yr
UK	Nema	Discontinued	Nema SWL	Speedlink network shut down 1991; focus on block trains
BiH / ŽRS	Nema	Inactive	Never introduced	Unique potential: infrastructure exists, SWL experience does not burden the system

3. ARCHITECTURE OF THE PROPOSED AI DIGITAL SERVICE

Based on a review of the literature, a modular AI service architecture is proposed that addresses each of the identified structural problems of SWL (Table 2).

Module 1: Demand Aggregation and Predictive Planning

The central challenge of SWL is the coordination of fragmented demand: instead of one client filling an entire train, SWL involves dozens of clients with smaller shipments that need to be coordinated into a

single operationally and financially efficient consist. Traditionally, this coordination was carried out by phone and fax, with delays of 2 to 3 days. The proposed Module 1 uses clustering algorithms (k-means, DBSCAN) to identify geographically and temporally compatible shipments that can be consolidated into a joint collection train. Based on historical demand dynamics data, the module predicts optimal departure times and capacities for each part of the network 48 hours in advance, a period that Moldenhauer et al. (2025) identify as the critical threshold for effective transport chain planning.

Table 2. Architecture of the proposed AI digital service for SWL

AI components	Technical basis	Operating contribution
Demand Aggregation Module	Clustering algorithms (k-means, DBSCAN); predictive demand modeling	Identifies shipments that can be consolidated into a joint train; minimizes wagon waiting time at nodes
Transport Chain Optimization Module (TK-Module)	Graph search (BFS); integer programming; path-based formulation	Calculates optimal train sequences (transport chains) from loading to final destination in real time
ETA Prediction Module	LSTM neural networks; Random Forest regression; historical delay data	Provides clients with accurate estimated arrival time in real time; automatic notifications
Return Logistics Module (Backhaul Matching)	Matching algorithms (bipartite matching); real-time search for available wagons	Matches free wagons with import goods entering through Dobrljin; eliminates empty running
Digital Client Portal	API integration with HŽ/SŽ/Mercitalia Rail systems; automatic generation of CIM documents	Client enters a shipment and receives price and ETA for the entire route in < 60 seconds

Module 2: Real-time Transport Chain Optimization

This is the algorithmic core of the system, directly inspired by the SBB Cargo TK-Module. Moldenhauer et al. (2025) describe how SBB Cargo

transitioned from a rigid system of predefined geographical maps (Leitwege) to dynamic optimization based on a mathematical model that assigns wagons to trains in real time.

The key mathematical problem is formulated as a throughput optimization problem: maximizing the number of successfully routed requests subject to segment capacity constraints (weight, length) and time windows (pickup/delivery time). Moldenhauer et al. (2025) demonstrate that a path-based formulation, instead of column generation or flow-based approaches yields good results for SWL because transport chains are relatively short (3–6 blocks). In testing, a greedy strategy misses 7–12% of shipments compared to the optimized model when train capacities are tight. In the ŽRS context, this module would manage synchronization between 5 collection stations (Zvornik, Sočkovac, Dobo, Banja Luka, Prijedor) and optimize the stop sequencing to minimize the total train formation time.

Module 3: ETA Prediction and Client Transparency

A RailNetEurope survey (2025) shows that users of railway information systems cite inaccurate ETA as the primary problem, with explicit demands for automatic notifications. For small and medium-sized exporters considering the switch from trucks to rail transport, this lack of transparency is often the deciding factor keeping them with road haulage. The proposed Module 3 uses LSTM neural networks and Random Forest regression on historical delay data (including data on border procedures at Dobrljin, which are particularly variable) to generate probabilistic ETA predictions. Minbashi (2024) demonstrates the application of a similar approach for delay prediction at marshalling yards, with improved accuracy compared to a deterministic approach. Clients automatically receive notifications when ETA changes by more than one hour.

Module 4: Return Logistics Optimization

The fourth module addresses the problem of empty running which, according to global estimates, accounts for 27% of all freight miles. For ŽRS, this is a particularly relevant problem because a wagon that unloads in Italy or Slovenia must somehow

return — either empty or with new cargo. The module uses bipartite matching algorithms for real-time identification of import goods entering BiH/RS through Dobrljin whose characteristics (wagon type, weight, destination) match available wagons. The same principle that Aboutalib & Agard (2024) apply to LTL freight consolidation is here adapted for railway wagons: the AI system does not wait for a client to contact ŽRS, but proactively offers free wagons to clients with import shipments.

4. OPERATIONAL SCENARIO: COLLECTION TRAIN ZVORNIK → DOBRLJIN

In order to validate the proposed model, a concrete operational scenario was developed that illustrates the functioning of the AI service under real ŽRS network conditions. The scenario was selected to encompass all key elements of the proposed architecture: multiple collection stations, heterogeneous wagon types, different final destinations and a cross-border passage.

The scenario includes a collection train formed from shipments from 5 stations on the ŽRS network, with a loading date of 1 June 2026. All shipments were ordered for loading at 07:00 on handling tracks. Border exit at Dobrljin (HŽ Cargo), selected to maximize the distance covered on the ŽRS network (~315 km for the longest segment). The alternative exit at Šamac was rejected as it would reduce the ŽRS segment to ~80 km, which would significantly reduce operator revenue. Total consist: 18 wagons (11 Eas + 7 Rgs), 740 tonnes. Duration of the ŽRS segment from departure at Zvornik to handover to HŽ at Dobrljin cca 15 hours. Without AI coordination, the same train would require 2 to 3 days of administrative preparation and coordination between stations.

5. COMPARATIVE ANALYSIS: ŽRS AI MODEL vs. TRADITIONAL SWL

Table 3. compares the key parameters of the proposed ŽRS model with the traditional SWL approach that led DB Cargo to crisis, illustrating the concrete advantages of the AI-optimized approach.

Table 3. Comparison: ŽRS AI model vs. DB Cargo traditional SWL model

Parametar	DB Cargo (Germany) — traditional model	ŽRS (prijedlog) — AI-optimizovani model
Annual SWL loss / subsidy cost	Cca €442 mil. loss from SWL (2022); €172.6 mil. state subsidies (2023/24)	No state subsidies, business model based on AI cost optimization
Transport chain planning	Partially digitized; historical legacy of manual processes; rigid	AI TK-Module: real-time optimization based on the SBB Cargo model; dynamic capacity allocation
Client transparency	ETA unreliable; clients cite lack of transparency as main reason for switching to trucks	Digital portal: price and ETA for the entire route in < 60 sec.; automatic notifications
Return logistics / empty running	27% of all wagon-km empty running; minimal systematic optimization	AI backhaul matching: automatic pairing of free wagons with import goods through Dobrljin
Marshalling yard operation costs	High fixed costs; shunting loco. not optimized; frequent empty running	AI optimization of shunting sequences; Dobož as a smart hub cost reduction cca 40%
Target segment	All users; overly broad network; unprofitable segments burden the system	Selective focus: only routes where rail is commercially competitive

6. CONCLUSION

The Railways of Republika Srpska should not treat SWL a return to the past, but as an innovative logistics service that, with AI support, is capable to offer transparency, predictability and a competitive price for small and medium sized exporters on long European corridors, something that massive state subsidies to DB Cargo have failed to achieve.

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