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Methods for optimizing station shunting operations

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Abstract

To improve the transportation operations at Ulaanbaatar Railway Joint Venture Company (UBTZ JVC), which plays an important role in the social and economic sectors of Mongolia and is one of the key sectors in transportation, it is necessary to optimize the organization of shunting operations at stations lacking classification humps or yards, reduce inefficient costs, and improve the utilization of technical capacity. It is necessary to reduce the sorting and marshalling shunting operations performed to place wagons arriving for unloading onto branch tracks. Within the scope of this research, an integrated model adapted to local railway operations was developed by synthesizing the principles of movement and resource planning from traffic management theory, the workflow and decision-making structure of process organization theory, and the empirical, data-driven analytical approaches of Grounded Theory. Given that the construction of a classification hump requires substantial capital investment, this research focused on developing an optimization model based on key operational parameters, including train composition, destination stations, unloading duration, movement records, and cost structure. The data processing and analysis were performed in the Python programming environment to obtain quantitative results. The findings demonstrate that reducing waiting costs significantly decreases idle wagon time, shortens wagon turnaround duration, and enhances the utilization efficiency of the rolling stock fleet, thereby improving continuity and reliability in transport operations. In addition, the research identified strategic approaches for improving the process organization of train marshalling and wagon placement on branch tracks, and outlined the primary implementation phases of the proposed system. Potential operational risks- such as interruptions in shunting operations, employee resistance, and challenges in system integration- were also evaluated during the implementation planning stage.

Keywords: Cost, loading and unloading, Shunting operations, Train formation.

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1. Introduction

The Government of Mongolia is planning and implementing measures to increase the volume of mining product extraction, export, and import freight, accelerate industrialization, and establish new sources of energy. In connection with this, the demand for railway transportation has grown rapidly in recent years, reaching a record high of 33.4 million tons of freight transported in 2024. In order to meet the increasing demand in the future, it will not be possible to increase the volume of freight transported without improving the carrying and throughput capacity of the main railway lines, as well as the related technologies and equipment. Therefore, it has become essential to implement measures aimed at increasing the railway line carrying and throughput capacity, constructing a second main line, introducing advanced equipment and new technologies at intermediate stations, reducing train formation time, optimizing shunting operations, and improving coordination between operations. Shunting operations play a key role in ensuring the smooth execution of transportation activities. Optimizing and improving the organization of shunting and loading/unloading technologies, as well as effectively utilizing technical equipment, are key conditions for increasing the profitability of railway transport, reducing transportation costs, and enhancing labor productivity. Shunting operations are classified by the purpose into the following categories: train disassembly, train formation, wagon transfer, pulling, coupling, uncoupling, and others. A partial shunting movement refers to a movement where a locomotive with or without wagons proceeds without changing its direction until it stops. A full shunting movement refers to a movement where a locomotive with or without wagons changes its direction of travel. One full shunting movement consists of two partial movements [1].

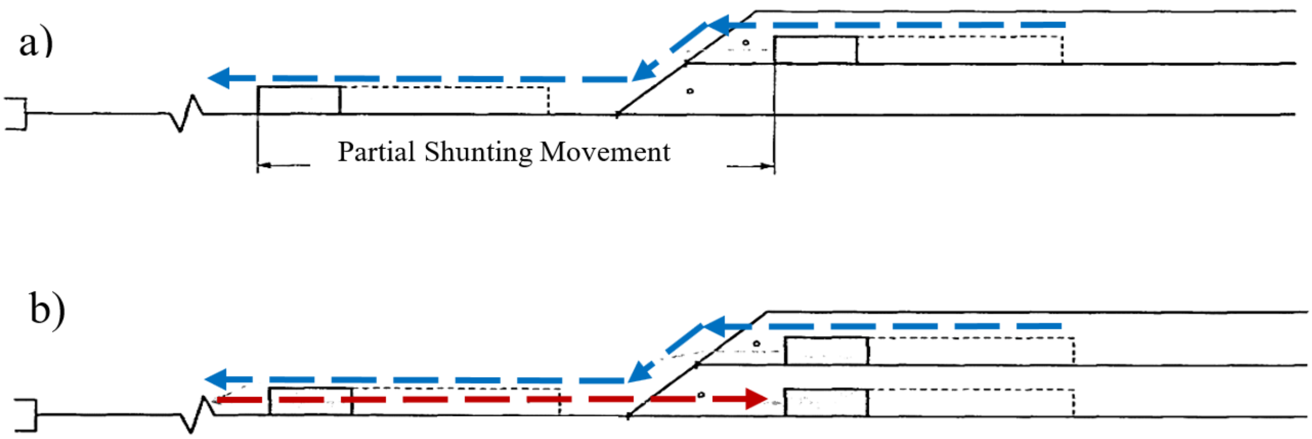

Figure 1.
Diagram of Partial (a) and Full (b) Shunting Movements

In Mongolia, except for Ulaanbaatar station, other stations lack classification humps and classification yards. As a result, shunting operations are carried out using two methods- pulling and pushing- along the shunting tracks, which lead to extended operation times. "The shunting system in railway transportation is a technological process that integrates the operations of multiple sectors, and its optimal organization is essential for improving the efficiency of transport services." Pepevnik and Bogović [2] in foreign countries, at locations with high volumes of wagon flow-where large-scale loading and unloading operations take place- classification stations are established. These stations carry out shunting operations using a comprehensive classification system that includes receiving yards, classification humps, classification yards, and shunting tracks. A classification hump is equipped with automated hump control systems used in classification stations, including retarders, automatic centralized switching devices, systems for automatically controlling the speed of wagon descent, systems for adjusting the rolling speed of separated wagons, remotely controlled hump locomotives, track monitoring systems under the hump, equipment monitoring and diagnostics, and automated control systems [3].

At classification stations on railways of China, to improve the quality of shunting operations, a quality analysis algorithm based on the "intelligent body model" has been applied. As a result, shunting overlaps have been reduced, track utilization has become more balanced, and shunting plans are executed without conflicts [4]. In addition, at Fengtai West classification station of China, the introduction of a big data–based management system has enabled the monitoring of shunting operations based on real-time data [5]. Maschen station, the most productive classification yard in Europe, combines traditional hump yard technology with modern AI, IoT, automated control, and sensor-based intelligent systems. Based on international best practices, studies have been conducted on how to optimally organize train formation at classification yards, offering allocation solutions that consider each wagon's destination, priority, and capacity constraints [6].

Additionally, methods such as calculating optimal transfer routes using Hamiltonian graphs, applying the Hungarian algorithm to obtain the lowest-cost and time-efficient solutions, and connecting open loops to streamline wagon placement and retrieval operations have been utilized to enhance efficiency and reduce costs [7]. As a result, it was concluded that these approaches can play a crucial role in improving the productivity of wagon transportation, reducing station dwell times, and lowering transportation costs. Ruifan Tang and Lorenzo De Donato of the University of Leeds conducted a systematic review of 141 research articles indexed in Scopus and Google Scholar to assess the influence of Artificial Intelligence (AI) within the railway sector, identifying well-examined subfields, insufficiently explored domains, and prospective directions for further research [8]. Among these studies, only 3 percent focused on shunting operations, with one significant example by Evertjan Peer and Vlado Menkovski, who addressed the Train Unit Shunting Problem (TUSP) by formulating it as a Markov Decision Process (MDP) and solving it using a Deep Reinforcement Learning (DRL) approach [9].

Optimizing railway shunting operations requires an integrated, multidisciplinary approach. In this context, key theoretical foundations include Movement Management Theory [10] Process Organization Theory [11] and Data-Driven Theories [12].

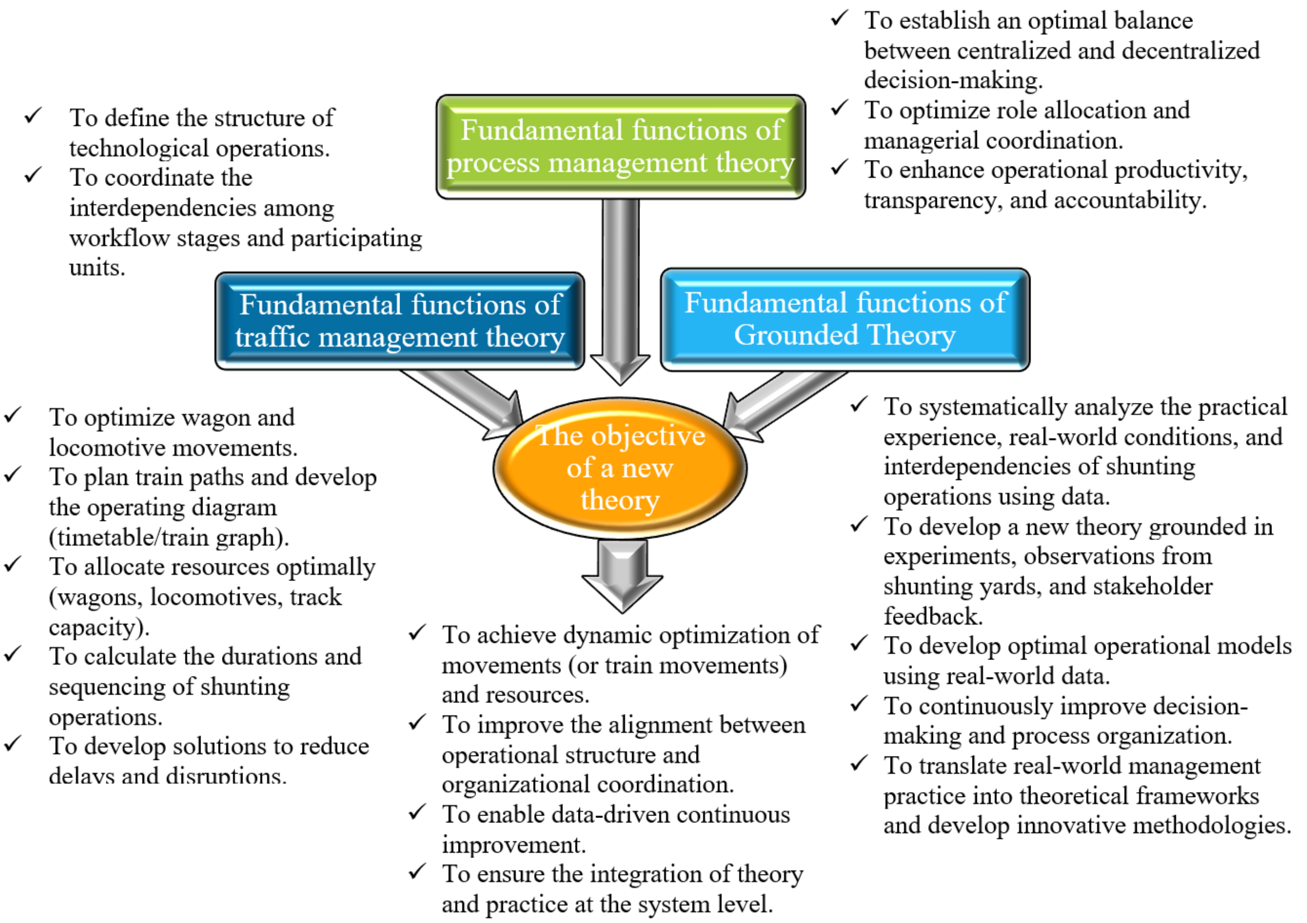

Figure 2.
Integrated Model of Theories for Optimizing Shunting Operations.

By integrating these theoretical approaches, a localized model tailored to national conditions has been developed. This integrated model incorporates the movement and resource planning principles of Movement Management Theory**,** the workflow and decision-making organization of Process Organization Theory, and the experience-based and empirical data analysis methods of Grounded Theory, forming a unified framework for optimizing shunting operations.

2. Methodology

Due to the limited technical capacity- such as underdeveloped track infrastructure, insufficient branch line capacity, and a shortage of shunting locomotives- at major intermediate and loading/unloading stations of UBTZ JVC, challenges have arisen. These include the inability to receive and dispatch trains on time, as well as delays in placing and retrieving wagons from branch lines in a timely manner. The total dwell time of wagons arriving for unloading at a station is equal to the sum of the durations of all operations performed on them; however, it is also important to account for possible idle times between operations. One of the key factors influencing the average idle time of a wagon during a single freight operation is the time spent on shunting operations to classify and position wagons for loading and unloading on branch tracks. As a result, in recent years, the idle time of domestic wagons has shown a steady increase. (Figure 3.).

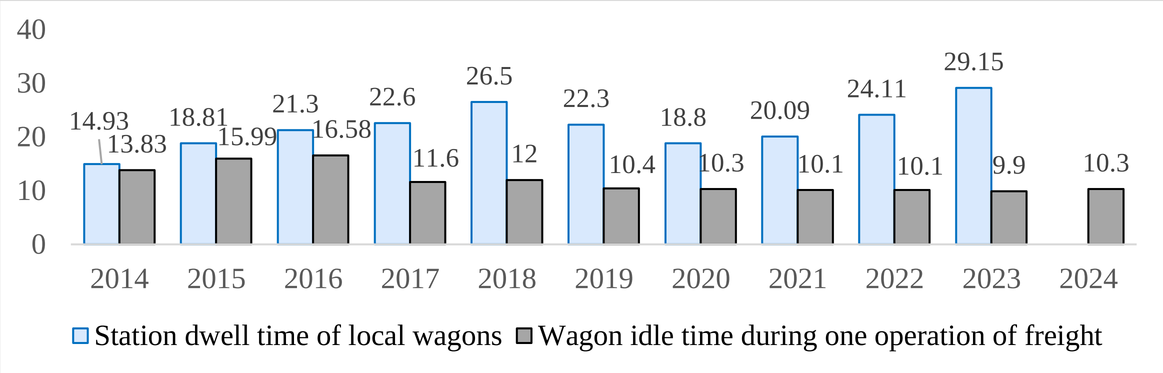

Figure 3.
Wagon Idle Time at Stations (hours).

The majority of cargo imported from China through Zamiin-Uud station consists of containerized goods and construction materials. Most of the imported and domestic cargo is transported in containers and unloaded at stations such as Ulaanbaatar, Tolgoit, and Amgalan.

A cumulative analysis of wagons arriving for loading and unloading at major UBTZ JVC stations from 2010 to 2024 (Figure 4) revealed the following results: Ulaanbaatar station handled 1,604,512 wagons, Tolgoit station 461,204 wagons, and Erdenet station 237,244 wagons. This confirms that substantial unloading operations are carried out at these key stations.

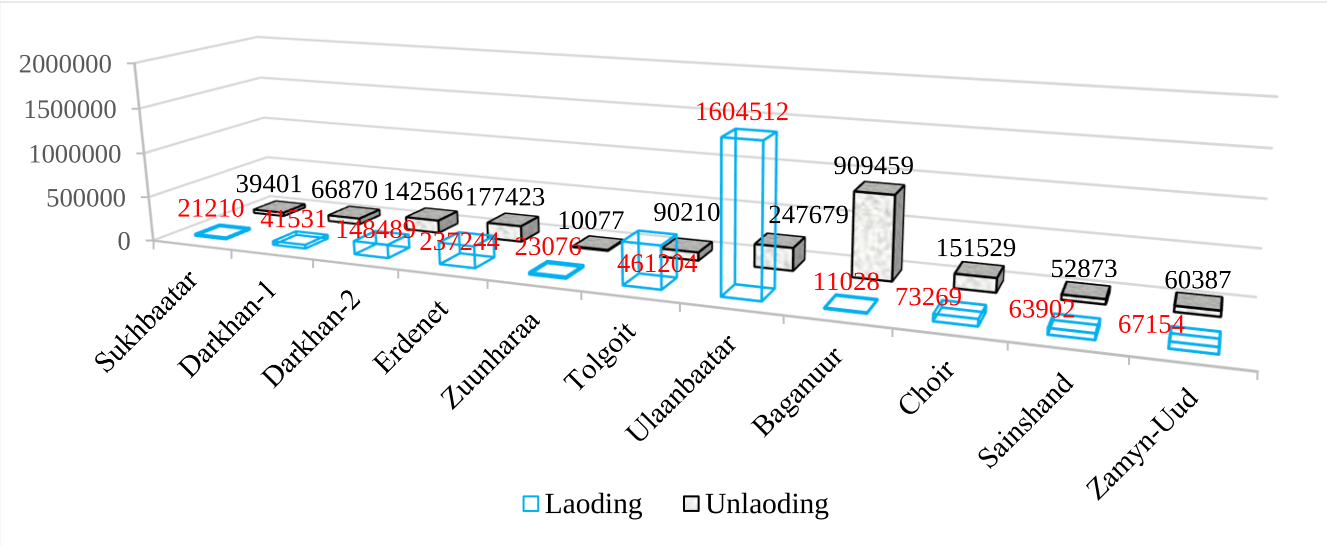

Figure 4.
Analysis of Unloading and Loading at Stations (Wagons)

Among these stations, only Ulaanbaatar station is equipped with a hump and classification facilities for disassembling and forming train consists, and it handles the highest volume of unloading operations. At all other stations without classification humps, loaded wagons arriving at the unloading station undergo technical and commercial inspections while still on the train. After this inspection, shunting locomotives are used to group and arrange the wagons onto unloading branch tracks and receiving tracks by utilizing the station's train arrival and pulling tracks.

The next busiest station in terms of the number of arriving wagons for unloading is Tolgoit station. Since its A and B yards are arranged sequentially, wagons arriving for domestic unloading are mostly handled using the arrival and departure tracks of the yards, with shunting operations carried out through partial and full shunting movements (Figure 5). At Tolgoit station, three main shunting locomotives of the TEM18DM series- numbers 3104, 3102, and 3006- are in operation, and the station has a total of 56 branch tracks. A study was conducted to determine how many shunting operations are required to sort and position the wagons arriving for unloading onto the appropriate tracks based on the receiving party. The results are as follows:

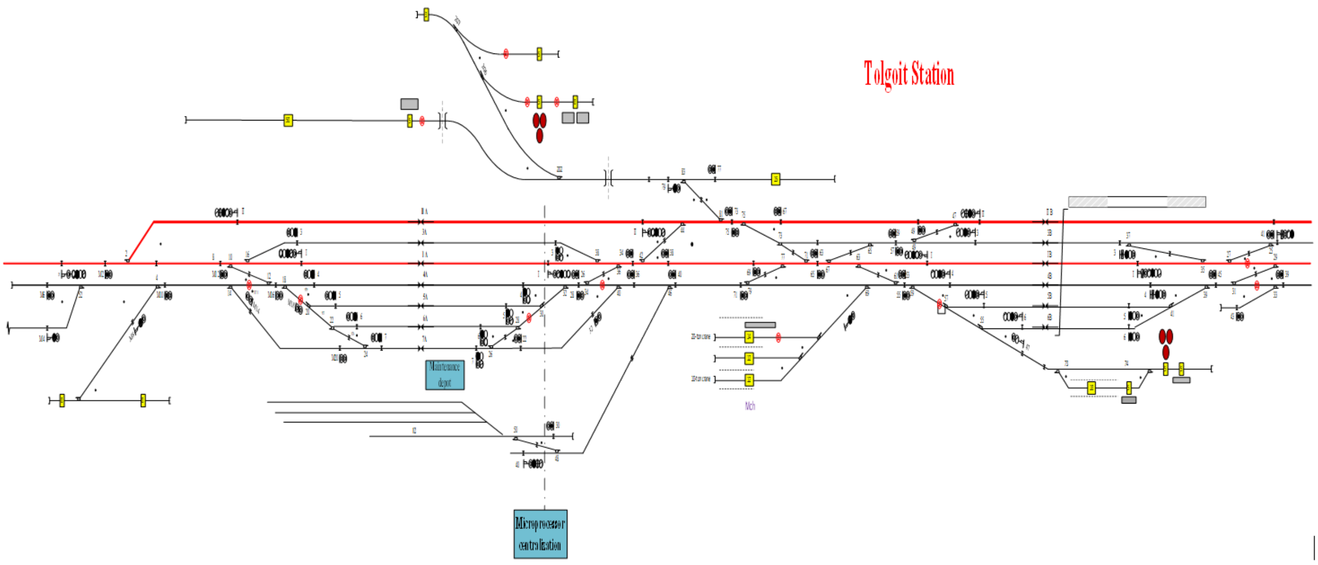

Figure 5.
Track Connecting A and B Yards of Tolgoit Station.

At the B Yard of Tolgoit station, the disassembly of a 49-wagon consist arriving on Train No. 3551 for domestic unloading was analyzed using time-motion analysis to determine the number of minutes spent on shunting operations. (Figure 6.).

№	Operation name	Duration (min)				
		10	20	30	40	50
1	Placing-in wagons into the consist	2				
2	Pull out the consist	5				
3	Placing-in on Yard A tracks		14			
4	Taking-out wagons from the tracks and assembling the consist				18	
Total time		39 minutes				

Figure 6.
Diagram of Train Classification and Formation.

The consist of the train comprised the wagons from the following companies: Podraz– 3/0 loaded cement hoppers, 0/12 empty tank wagons; CHPP-2 JSC– 10/0 loaded open wagons; Teso – 0/6 loaded boxcars; Mongol Trans (MTK) – 0/1 loaded boxcar; MCh – 1/0 loaded boxcar; Barley Root– 1/0 loaded boxcar; Teso – 1/0 loaded boxcar; Interdecision – 0/1 loaded boxcar; Mongol Trans – 1/0 loaded container wagon; MCh – 1/0 loaded container wagon; Mongol Trans (MTK) – 1/3 loaded boxcars; MCh – 6/0 loaded open wagons; Undraga – 1/0 loaded open wagon. (Figure 7.)

Train Consist Sheet DU-1

Train Index:

Train № 3551 **Locomotive Series № 2TE116UD-75** **Driver: B. Munkhtulga** **Train Route No. 934311**

Train Departure : *16 September 2022, 06:20* **Call Time :00:00**

Train Arrival: **6 September 2022, 06:37** **Control Time :00:00**

Marshalling Station : *Ulaanbaatar* **Code :** *84* **Dispatch Track No:** *6*

Destination Station: **Tolgoit** **Code :** *76* **Receiving Track No:** *15*

№	Owner Railway	Wagon Number	Axle Count	Wagon Type	Calculated/Design Length	Freight Name	Freight Weight	Destination Station	Consignee / Receiving Track	Transport Contract Date	Special Notes
1	UBZD	93035913	4	cem	0.95	Cement	73.12	76	Podraz	2022.09.14	
2	UBZD	93037083	4	cem	0.86	Cement	73.44	76	Podraz	2022.09.14	
3	UBZD	93035665	4	cem	0.86	Cement	72.63	76	Podraz	2022.09.14	
4	RZD	50975408	4	tank	0.86	Empty	0	76	Chemical Liquid	2022.09	
5	RZD	54087028	4	tank	0.86	Empty	0	76	Chemical Liquid	2022.09	
6	RZD	54090535	4	tank	0.86	Empty	0	76	Chemical Liquid	2022.09	
7	RZD	54745995	4	tank	0.86	Empty	0	76	Chemical Liquid	2022.09	
8	RZD	54091400	4	tank	0.86	Empty	0	76	Chemical Liquid	2022.09	
9	RZD	54045933	4	tank	0.86	Empty	0	76	Chemical Liquid	2022.09	
10	RZD	54085525	4	tank	0.86	Empty	0	76	Chemical Liquid	2022.09	
11	RZD	51895530	4	tank	0.95	Empty	0	76	Chemical Liquid	2022.09	
12	RZD	53672131	4	tank	0.95	Empty	0	76	Chemical Liquid	2022.09	
13	RZD	54090600	4	tank	0.95	Empty	0	76	Chemical Liquid	2022.09	
14	RZD	51878163	4	tank	0.95	Empty	0	76	Chemical Liquid	2022.09	
15	RZD	50627942	4	tank	0.95	Empty	0	76	Chemical Liquid	2022.09	
16	UBZD	85402162	4	op.wa	1	Coal	65	76	CHPP-2 JSC	2022.09	
17	UBZD	85401677	4	op.wa	1	Coal	68	76	CHPP-2 JSC	2022.09	
18	UBZD	85404473	4	op.wa	1	Coal	70	76	CHPP-2 JSC	2022.09	
19	UBZD	60013216	4	op.wa	1	Coal	65	76	CHPP-2 JSC	2022.09	
20	UBZD	85403053	4	op.wa	1	Coal	67	76	CHPP-2 JSC	2022.09	
21	UBZD	813311	4	op.wa	1	Coal	67	76	CHPP-2 JSC	2022.09	
22	UBZD	812941	4	op.wa	1	Coal	60	76	CHPP-2 JSC	2022.09	
23	UBZD	85402931	4	op.wa	1	Coal	66	76	CHPP-2 JSC	2022.09	
24	UBZD	810366	4	op.wa	1	Coal	64	76	CHPP-2 JSC	2022.09	
25	UBZD	60040557	4	op.wa	1	Coal	60	76	CHPP-2 JSC	2022.09	
26	RZD	28036514	4	Box	1.22	Sugar	67.62	76	TESO	2022.09	Prot
27	RZD	52691474	4	Box	1.27	Sugar	67.62	76	TESO	2022.09	Prot
28	RZD	52452661	4	Box	1.06	Sugar	67.62	76	TESO	2022.09	Prot
29	RZD	29534294	4	Box	1.35	Sugar	67.62	76	TESO	2022.09	Prot
30	RZD	29192390	4	Box	1.35	Sugar	67.62	76	TESO	2022.09	Prot
31	RZD	29220225	4	Box	1.36	Sugar	67.62	76	TESO	2022.09	Prot
32	RZD	52044435	4	Box	1.1	Sugar	60.25	76	MTK	2022.09	Prot
33	UBZD	703603	4	Box	1.27	Others	59.47	76	MCh	2022.09	Prot
34	UBZD	28212090	4	Box	1.26	Grain	59.55	76	Barley Root	2022.09	Prot
35	UBZD	28025393	4	Box	1.1	Others	16.91	76	TESO	2022.09	
36	RZD	98079080	4	cont	1.81	Container	65.45	76	Interdishn	2022.09	
37	UBZD	210682	4	cont	1	Container	48.52	76	MTK	2022.09	
38	UBZD	20001962	4	cont	1.41	Container	55.72		MCh	2022.09	
39	РЖД	29018983	4	Box	1.35	Sugar	60.2	76	MTK	2022.09	Prot
40	RZD	29156502	4	Box	1.35	Sugar	60.2	76	MTK	2022.09	Prot
41	RZD	52044146	4	Box	1.1	Sugar	60.2	76	MTK	2022.09	Prot
42	UBZD	28128593	4	Box	1.1	Sugar	60.2	76	MTK	2022.09	Prot
43	UBZD	60079167	4	op.wa	1	Steel Billet	62.06	76	MCh	2022.09	
44	UBZD	60028164	4	op.wa	1	Rebar	66.4	76	MCh	2022.09	
45	UBZD	85405660	4	op.wa	1	Rebar	61.35	76	MCh	2022.09	
46	UBZD	85402113	4	op.wa	1	Rebar	61.35	76	MCh	2022.09	
47	UBZD	813907	4	op.wa	1	Rebar	61.35	76	MCh	2022.09	
48	UBZD	60073053	4	op.wa	1	Steel Billet	62.06	76	MCh	2022.09	
49	UBZD	60057106	4	op.wa	1	Steel Billet	66	76	Undraga	2022.09	

Figure 7.
Physical Consist Sheet of the Train (Form DU-1).

The shunting operation was carried out from the B yard to the empty arrival/departure tracks of the A yard, using both partial and full shunting movements to sort and classify the wagons into 9 different receiving branch tracks according to the recipients. A total of 39 minutes was spent on this operation.

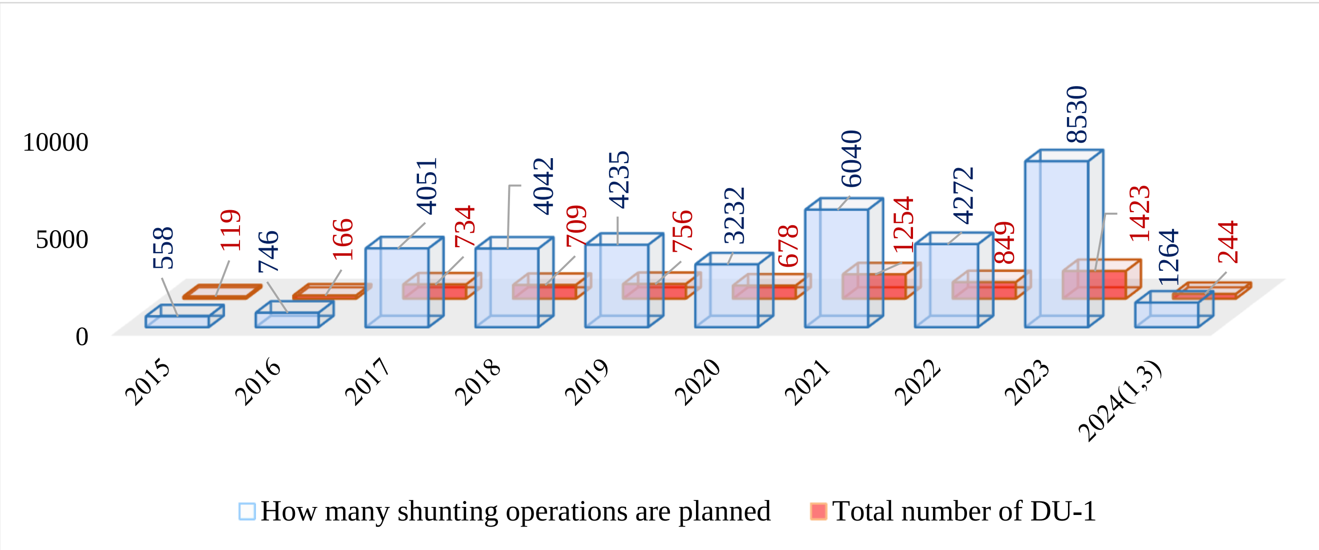

Figure 8.
Study on the Physical Consist Sheets of Trains Arriving for Unloading at Tolgoit Station.

A study was conducted on 6,932 physical consist sheets (Form DU-1) from 2015 to 2024 at Tolgoit station to determine how many times shunting operations were performed to sort and position wagons onto the appropriate unloading tracks. The results showed a total of 36,970 shunting operations, indicating that on average, wagons arriving in a single train are sorted and rearranged 5 to 6 times. (Figure 8.)

To position wagons for unloading on branch tracks, shunting operations must be carried out by grouping them according to the unloading branch track, recipient, and type of cargo. These operations require considerable time and result in high labor costs for the shunting crew. The cost associated with one hour of shunting operations is presented in Table 1.

Table 1.
Cost of one hour of Shunting Operations.

Hourly consumption of the shunting brigade		Purpose	Price / MNT/
Cost of materials for one hour of shunting locomotive operation		Total Cost	149236
Shunting brigade	Hourly wage or payment of machinists	Shunting locomotive driver	15248
		Assistant shunting locomotive driver	11402
	Hourly wage or payment of train shunting operators	Train compiler with YI Rank	13188
		Assistant train compiler with IY rank	11127
		Freight train receiver	10167
	Total		210368

To reduce shunting operations at the station for placing wagons arriving for domestic unloading onto branch tracks, lower the costs of shunting locomotives and crews, utilize resources efficiently, accelerate wagon turnaround, minimize wagon idle time, increase economic efficiency, and improve the processing capacity of the station, it is necessary to properly group and organize trains at the initial loading station. Since constructing a classification hump requires significant investment, it is advisable to implement the following measures by making use internal resources.

1. At loading stations, organize train formation by categorizing loads according to the destination station, receiving branch track, zoning within the branch track area, and the capacity of the branch track (unloading section). (Figure 9.)
2. Divide the branch tracks located on both sides of the main line of UBTZ into zones and organize loading operations at the loading stations according to these zones to reduce shunting operations. (Figure 9: Zone I, Zone II)
3. Enhance the loading and unloading technology of the 2nd workshop of the transshipment department at Zamiin-Uud station. (Figure 10)
4. Renew the zoning of station branch tracks by regrouping and coding them, among other measures. (Figure 11).

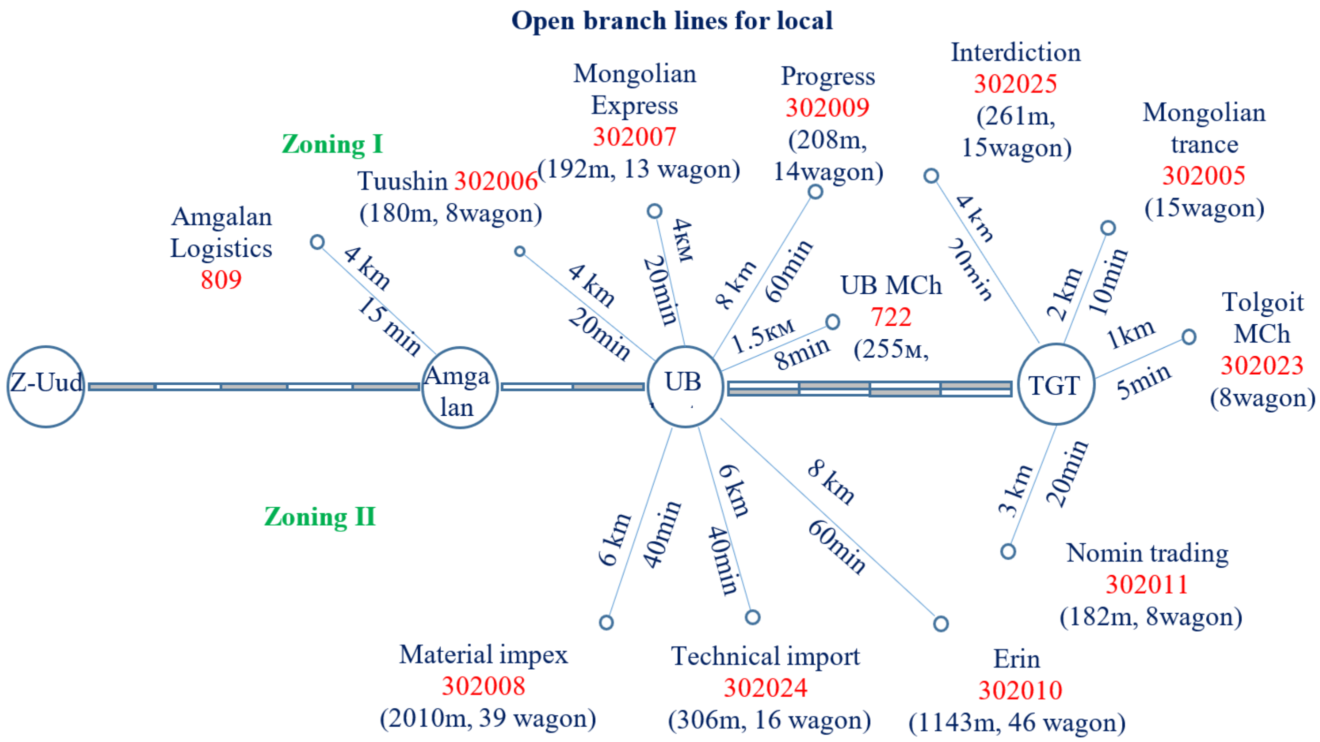

Figure 9.
Train Formation Sequence by Destination Station, Receiving Branch Track, and Unloading Section from Zamiin-Uud Station.

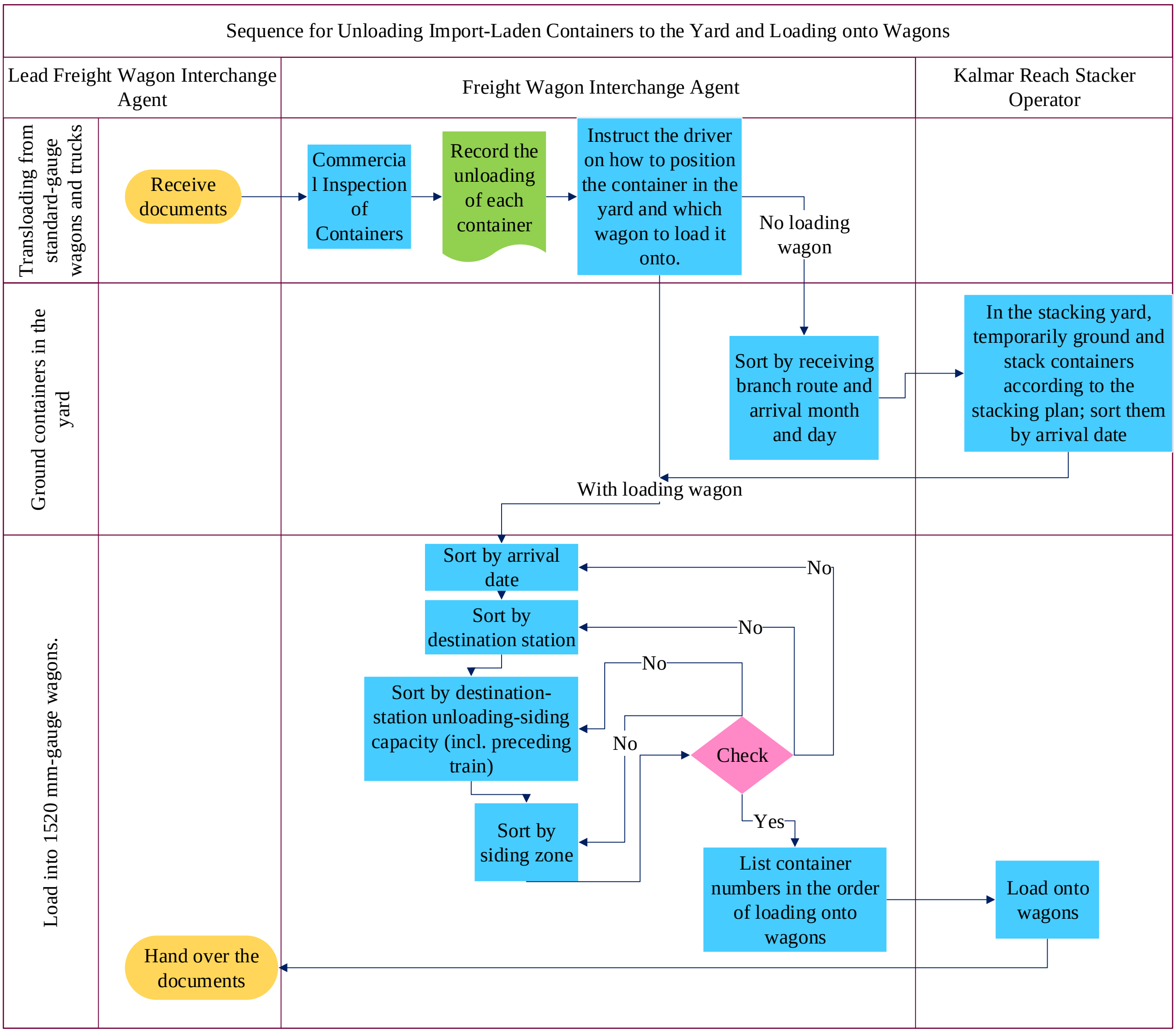

Figure 10.
Diagram of the Process for Unloading Imported Loaded Containers onto the Yard and Loading onto Wagons

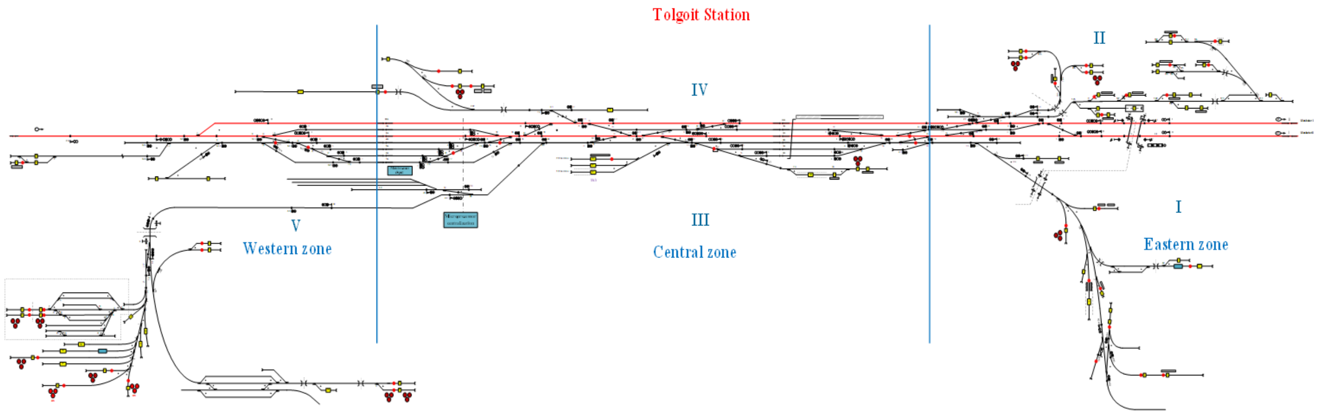

Figure 11.
Reclassification of the branch tracks at Tolgoit Station into three zones and five groups.

Within the scope of the study, a data-driven mathematical model was developed to optimize the train formation process. The model takes into account key parameters such as train consist, destination points, unloading time, movement records, and cost structure. It was implemented and tested using the Python programming environment. For cost optimization, a total of 474 containers across 20 trains were analyzed during the shunting operations in March 2025. (Preliminary data are presented in Appendix A.) Using actual shunting operation data from that period, the study assessed the potential for cost savings within the train formation and marshalling system (optimization calculations are included in Appendix A). The key aspects are as follows:

2.1. Modeled Framework

Within the scope of the study, the shunting operations of the station were modeled based on the following main processes:

- Train Formation Optimization Model: To reduce the number of shunting movements required by grouping wagons according to each receiving branch track.
- Delivery Model: To optimize based on the number of trips to deliver wagons to each receiving branch track, the utilization time of locomotives, and the costs associated with waiting and stopping.

2.2. Mathematical Formulation

2.2.1. Shunting Operations

$$M = \sum_{i=2}^{n} \delta(c_i \neq c_{i-1}) \quad (1)$$

Here: M— Number of required shunting operations

c_i— Code of the receiving branch track for wagon i

2.2.2. Cost Functions

Classification Cost: $$C_{class} = M * t_{op} * c_{loco} \quad (2)$$

Here: t_{op}- Average duration of one shunting operation (minutes)

c_{loco}- Locomotive cost per minute (MNT)

Cost of Placing on Branch Track: $$C_{delivery} = \sum_{j=1}^{n} B_j * C_{trip_j} \quad (3)$$

Here:B_j- Actual Delivery Cost

C_{trip_j}- Cost per Delivery

Waiting Cost: $$P = \sum_j W_j * T_j * r \quad (4)$$

Here:W_j- Number of wagons that entered waiting

T_j- Time spent by one wagon in waiting (hours)

r- Hourly penalty rate: 900 MNT (MNT per wagon per hour)

2.2.3. Calculation Algorithm

2.2.3.1. Classification Algorithm

- Check wagons sequentially;
- Consider every change in the receiving branch track as a shunting operation;
- As a result: Total number of shunting operations and Efficiency Score = Ideal number / Actual number (the ratio of the theoretical minimum number of shunting operations required—at least one per branch track—to the actual number performed).

2.2.3.2. Algorithm for Placing Wagons on Branch Tracks

- Group and deliver wagons according to each receiving branch track;
- Calculate locomotive travel time plus unloading time;
- Waiting cost = waiting time × waiting tariff, applied if the previously placed wagon has not yet been unloaded.

2.2.4. Performance Metrics

Classification Efficiency: $$\text{Efficiency} = \frac{\text{Number of Branch Tracks}}{\text{Number of Shunting Operations}} \quad (4)$$

Cost per Wagon: $$\text{Cost per Wagon} = \frac{C_{total}}{N_{wagon}} \quad (5)$$

ROI and Payback: $$ROI = \frac{S-I}{I} * 100\%, \qquad Payback = \frac{I}{S} \quad (6)$$

Here: *S*- Annual Savings Amount

I- Investment

3. Results

Based on the calculation results, optimizing train formation can achieve cost savings of 30-40%. Specifically:

Cost savings from optimized train formation

- Current: 156 shunting operations for 20 trains
- Optimized: 95 shunting operations (a 39% reduction)
- Resulting savings: 2,135,000 MNT

Reduction in Waiting Costs

- Current: 2,340,000 MNT in fees
- Optimized: 0 MNT in fees
- Savings: 2,340,000 MNT (100% elimination)

Increase in Locomotive Efficiency

- Current: Due to improper train formation and inefficient shunting operations
- Optimized: Properly formed trains with optimized delivery
- Savings: 13,222,000 MNT (29% reduction)

- Cost per wagon: 112,782 MNT → 75,491 MNT (a saving of 37,291 MNT per wagon).

Table 2.
Total System Savings.

Cost Type	Initial (MNT)	Optimized (MNT)	Savings (MNT)	Saving %
Category	5,460,000	3,325,000	2,135,000	39.1%
Locomotive	45,678,900	32,456,789	13,222,111	29.0%
Payment	2,340,000	0	2,340,000	100.0%
TOTAL	53,478,900	35,781,789	17,697,111	33.1%

By reducing waiting costs by 2,340,000 MNT, wagon idle time was decreased by 2,600 hours. This reduction shortens the wagon turnaround time, improves the utilization efficiency of the rolling stock fleet, and enables continuous transportation operations.

Inefficient allocation of time and costs in train formation and wagon placement on branch tracks is one of the main factors reducing the efficiency of railway transportation operations. To address this, a data-driven systematic methodology and organizational reform are required. An optimization strategy should be implemented step-by-step based on the correct algorithms, performance monitoring, and continuous improvement. Initially, a pilot level evaluation should be conducted, followed by identifying the key stages for successful system-wide implementation. (Figure 12)

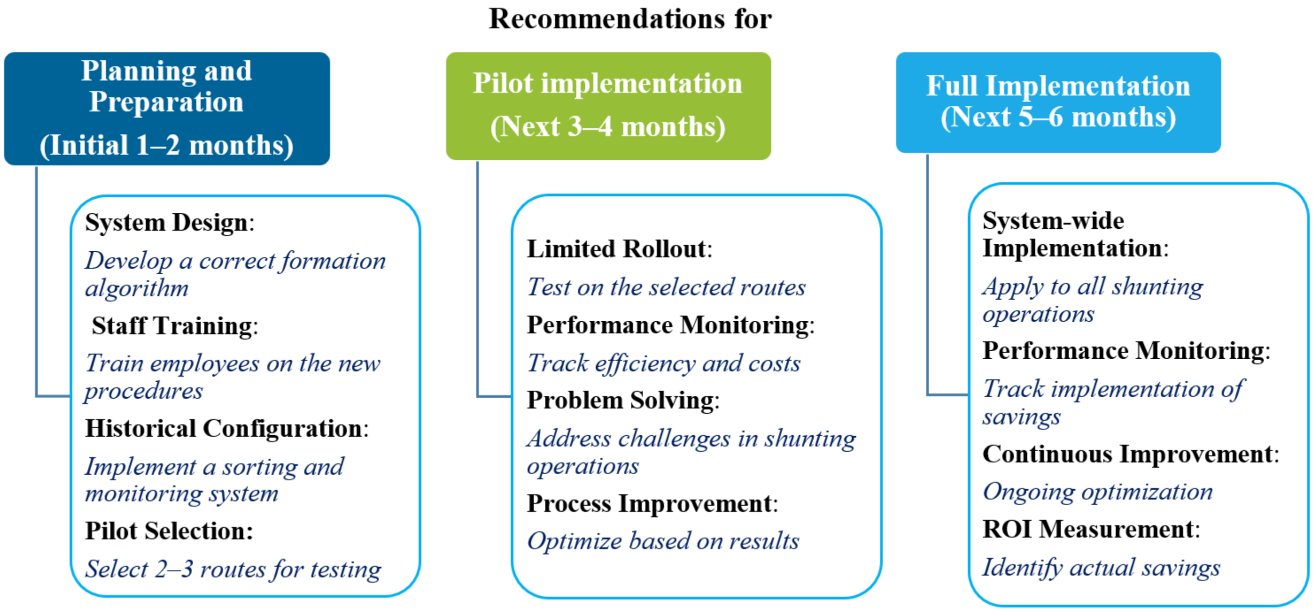

Figure 12.
Implementation Stages.

By optimizing the organization of shunting operations, the following results can be achieved:

1. Formation efficiency: Target 95%+ (currently 60-70%)
2. Reduction of payment costs: Target over 90% elimination
3. Cost savings: Target over 30% reduction
4. Shunting operation time: Target over 35% reduction in grouping and formation time

The introduction of new technology in shunting operations is an important step toward improving railway efficiency, safety, and productivity. However, it is necessary to foresee potential risks and plan appropriate measures accordingly. Risk analysis aims to identify internal and external factors that may affect the transition process and daily operations, as well as determining strategies to minimize their impact.

During the implementation of the new system, operational risks- such as interruptions in shunting operations, employee opposition, and challenges with system integration- may arise. (Figure 12)

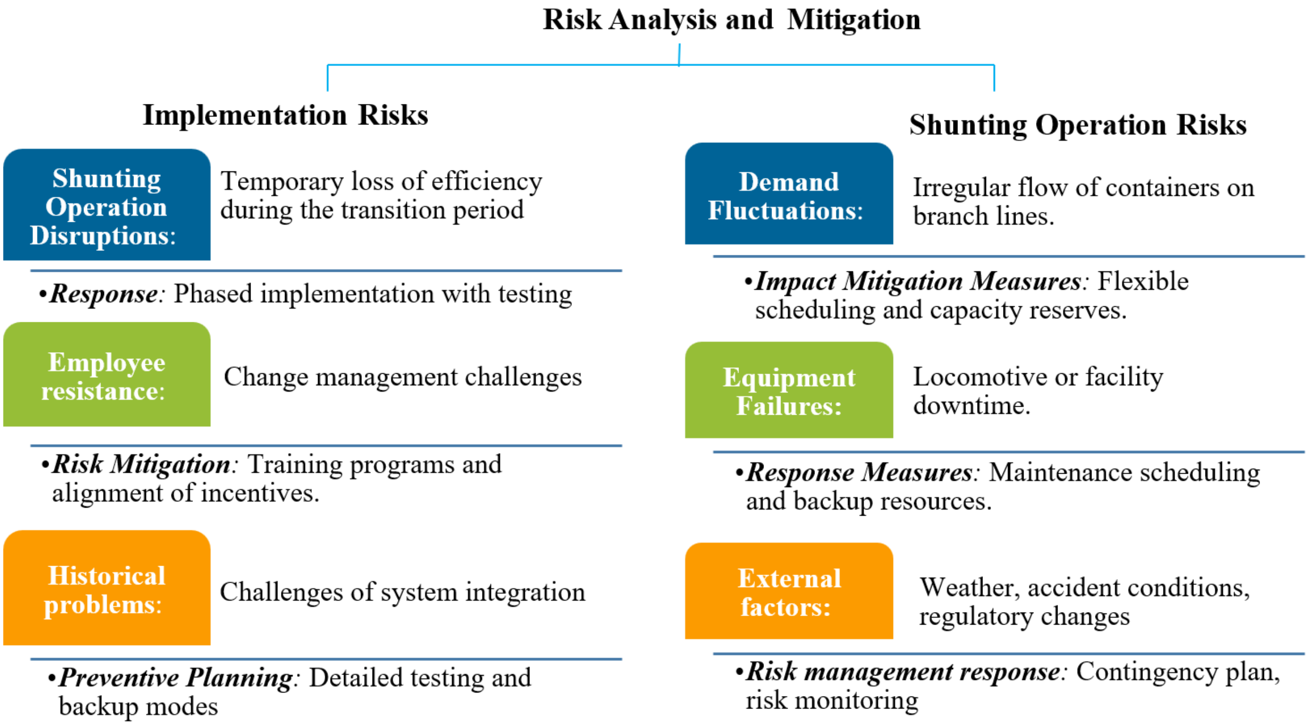

Figure 13.
Potential Risks During Implementation.

Therefore, UBTZ JVC should implement this optimization gradually by planning and executing comprehensive measures such as skills development training for employees and preparing contingency protocols. Additionally, operational risks- including fluctuations in supply and demand, equipment failures, weather conditions, and regulatory changes- must be anticipated. It is essential to establish flexible organizational arrangements, maintenance systems, and pre-plan measures to address emergency situations.

4. Conclusion

By optimally planning loading operations in accordance with destination stations, zoning of receiving sidings, and unloading track capacity; organizing branch tracks with proper coding; and improving the transshipment technology at Zamiin-Uud station, it becomes possible to enhance the utilization of shunting locomotives at the station and reduce the idle time and marshalling duration of domestic wagons.

By optimizing the organization of shunting operations, it is possible to increase formation efficiency by 20-25%, achieve cost savings of 30%, reduce payment costs by 90%, and decrease shunting operation time by 35%. Therefore, optimizing train formation and marshalling processes offers a significant opportunity to enhance shunting efficiency and lower operational costs.

Based on the research analysis, implementing the optimization has proven to be highly effective in terms of financial performance, operational efficiency, and in risk management, while also enhancing competitiveness. It is also easy to manage and feasible to implement. Therefore, further expanding and applying this optimization solution is an important step toward making a significant contribution to the development of the sector.

The introduction of new technology in shunting operations is an important step toward enhancing railway efficiency, safety, and productivity. However, it is necessary to foresee potential risks that may arise and plan appropriate countermeasures in advance. Risk analysis plays a vital role in identifying internal and external factors that could affect both the transition process and daily operations, as well as in determining strategies to reduce their effects.

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