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Enhancing Railways Signaling System Efficiency

Elana Bahmaid, Layan AlEssa, Maha AlThenyan, Nourah AlHudaithi and Shouq AlHawiti
Department of Industrial Engineering and Systems, College of Engineering, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia

Kaouther Ghacham
Laboratory of Metrology and Energy Systems (LR18ES21), University of Monastir, Monastir, 5000, Tunisia

Abstract

Railway capacity ensures effective transportation, supports economic growth and promotes social welfare. With Saudi Arabia witnessing rapid economic growth and urbanization, enhancing the railway system's capacity to meet escalating transportation needs is crucial. This project has investigated and addressed Saudi Arabia Railways delay causes specifically in the North railway passenger line, with the aim of improving capacity and creating a more efficient and reliable transportation system. The project aims to enhance the signalling system of Saudi Arabia Railways by optimizing train spacing which allows for more trains to operate safely on a given track. A simulation model of a part of the railway network was built and implemented using ARENA software. An improved model was made by adding a new marker board to adjust the size of the section. This improved model makes it easier to analyse the various factors that influence the decision to add a marker board, thereby contributing to the overall effectiveness of the train system.

Keywords
ETCS Level 2, Railway Capacity, Signaling System, Simulation, Trains Delay Causes.

1. Introduction
The Vision Realization Programs (VRPs) are the driving force behind Vision 2030, working to bring the vision to life. Each VRP has a specific roadmap with approved delivery plans, focused on meeting specific objectives and key performance indicators within five years. As Vision 2030 evolves to meet the changing needs of Saudi Arabia, the VRPs adapt and align with these needs to ensure Vision 2030 is successfully achieved. The logistics industry plays a crucial role in the Kingdom's current transport system due to its advantageous geographical location on global trade routes and its strong and developing economy. The improvement of railway capacity can contribute to the reduction of delays and the improvement of the overall efficiency and performance of the railway system. In addition, delays can have a significant impact on railway capacity as they reduce the number of trains that can run on a given line. Furthermore, Figure 1 shows the general delay causes that can occur in any railways, in order to identify the areas for improvement and implement strategies to minimize delays and improve overall efficiency.

This project will focus specifically on enhancing the efficiency of the signalling system by studying signalling block systems, which allow railways to run safely and effectively by averting train collisions.

1.1 Objectives
To ensure efficient transport and to promote sustainable economic growth and social welfare, railway capacity plays a crucial role. Increasing rail capacity can help reduce delays and improve overall rail system efficiency and performance.

In addition, delays can have a significant impact on railway capacity by reducing the number of trains that can run on a given line. Therefore, formulating a solution that focuses on identifying and addressing the bottlenecks within the railway infrastructure is the primary objective of this project. Therefore, by optimising the signalling system used in the Saudi railways, the study seeks to reduce unproductive downtime and capacity constraints due to train delays.

2. Literature Review

In this section, an overview of railway delay causes will be considered in terms of the operational arrangement, infrastructure, environmental conditions, and signalling systems. The signalling systems will mainly focus on the levels of the European Train Control System. Additionally, the methods used for optimizing the signalling systems will be discussed as well.

2.1 Railway Delay Causes Overview

The quality of railway transportation holds significant importance in enhancing punctuality, which requires the identification of delay issues, the occurrence of a delay during a train journey can disrupt the efficiency of the railway line. So, to ensure the efficiency of the railway line, the causes of delays in railway passenger transportation have been categorized into four categories, operational arrangements, infrastructure, environmental conditions, and the signaling system.

2.1.1 Operational Arrangements

Stability in the railway system is quite difficult to maintain because train punctuality itself depends on the railway system (Wiarcot et al., 2022). Railway maintenance activities are carried out to decrease the probability of the occurrence of a failure on the components of the railway. The scheduling of maintenance work is important in supporting the normal daily operation of the railway (Buurman et al., 2023).

2.1.2 Infrastructure

Occurring damages in railway structures such as track buckling, and many others, could potentially lead to the failure of key rail infrastructures such as railway bridges and tunnels, which can induce hazardous derailments. These reasons justify that railway infrastructures may cause railway delay (Du et al., 2020).

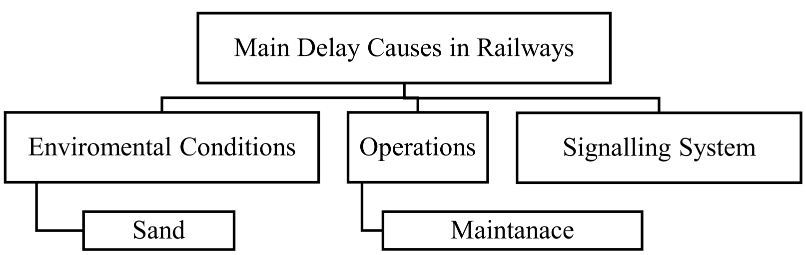

Figure 1. General delay causes

2.1.3 Environmental Conditions

Sand dune is an example of the environmental conditions since the sand accumulation on railway tracks is considered a major challenge that significantly affects the safety of the railway sector and leads to reduced train speeds which results in railway delay (Almujibah et al., 2022).

2.1.4 Signalling System Overview

Signaling system is responsible for overseeing railway traffic and ensuring that trains are consistently kept at a safe distance from one another to avoid accidents that cause delays (Cansu et al., 2023).

The recommended standardised signalling system, known as the European Train Control System, can be used. The basic idea is that a track is divided into several blocks or sections. Each block is sized to accommodate a train stopping within it, and only one train will be present within it. In addition, each block consists of an entry marker board and an exit marker board, and trains are moved between blocks under the control of a signalling system.

2.1.4.1 ETCS Level 1

ETCS Level 1 is a spot transmission train control system and a cab-signalling system that relies on a conventional Trackside Train Detection system which known as (TTD), that transmits the status of the railway to external systems interlocking and control center. Axle counters and track circuits are considered the main components of the TTD system (Qiu et al., 2014).

2.1.4.2 ETCS Level 2

ETCS level 2 is a radio-based train control system that relies on conventional TTD systems for train integrity and track vacancy detection. ETCS level 2 provides bidirectional communication between Infrastructure and vehicles using the radio communications network and Global System for Mobile Communication-Railway which known as (GSM-R) (Ranjbar et al., 2022). In addition, level 2 represents a cab signalling system with continuous speed supervision linked with a dynamic braking system and an optional dependence on external signals (Mikulčić & Mlinarić, 2021). In ETCS level 2 as shown in Figure, the information transmission is by radio. The movement authority and track description are displayed directly in the cab for the driver, so lineside signals are no longer needed and Balises are used as positioning beacons to help the train determine its position via sensors (Qiu et al., 2014).

2.1.4.3 ETCS Level 3

Finally level 3 is a moving block signalling system which combines the benefits of continuous speed supervision and a train integrity monitoring system (Mikulčić & Mlinarić, 2021). As shown in the Figure 2 in ETCS level 3 the train integrity checking is done by the train itself, so track circuits are no longer needed, and Balises are used to update position information and transmit position and integrity data back to the interlocking via GSM-R. In level 3 The minimal distance between the two trains depends on the speed and braking distance of the second train (Qiu et al., 2014). Moreover, ETCS Level 3 is currently under development.

3. Methods

Simulation systems for the core system and an application system of the railway signalling system have become important tools for its development, application, and maintenance. As far as the functions of the simulation system are concerned, there are many kinds of simulation systems for the signalling system such as ARENA software.

4. Framework of the study

The primary purpose of the current study is to formulate a solution focused on identifying and addressing the bottlenecks within the railway infrastructure. This initiative seeks to optimize the signalling employed system. As a direct outcome, the study endeavors to reduce unproductive downtime and capacity constraints attributed to train delays.

Figure 2 represents the flow of reaching the solution, the flow starts with collecting and analyzing received data, then

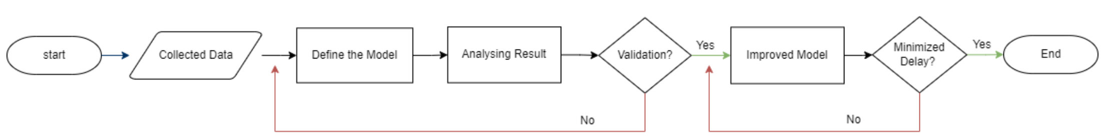

Figure 2: Problem Solution Flowchart

manually defining the model and constructing it using ARENA software. After simulating the model, the SIMAN summary report will show the results to analyze and validate it to decide if it matches the manual solution, so changes can be implemented to complete the improved model. The improved model is the process of assigning the main modification of the real situation to determine the amount of minimized delay and to make sure that the utilization for the scenarios will be evaluated and validated.

5. Results and Discussion

This section will be divided into five parts starting from the numerical results ending by the improvement results.

5.1 Numerical Results

The study is focused on the section one that have the longest distance equal to 77.281 kilometers. Hereinafter, the solution of the actual situation and our improved model.
The main difference between the actual model (called developed model) and the improved one is the increased number of marker boards.

The added marker board is located when train speed's reach a stable flow. The simulation was performed manually and with the ARENA software.

ARENA report shows that the improved model with one additional marker board has no waiting time at any hold as shown in Figure 3, which means that the optimized model has been reached.

Inputs Values	
Entities	5 Trains
Interarrival Time	20 Minutes
Velocity	80-200 Km/hr
Distance	0.169- 62.857 Km

ARENA Software →

Output Values		
	Developed Model	**Improved Model**
Minimum	0.07838 Hours	Zero
Maximum	0.31351 Hours	
Average	0.19594 Hours	

Figure 3: Comparison Between the Developed and Improved Models

The improved model helped to specify the factors that will affect the decision of determining the appropriate number of additional marker boards. The factors that must be considered when developing the whole railway network from Riyadh to Hail are the time between trains' arrival, the number of entities, the distance between marker boards, and the velocity of the train.

5.2 Validation

For validation the hand simulation has been used to ensure that there is an agreement between the manual simulation and the SIMAN reports as shown in Figure 4 and Figure 5.

Time in Each Section							
Start to MB1	Section 1 MB1-MB2				MB2-MB3	MB3- End	
0.006175	0.0078625	0.03576923	0.05379412	0.314285	0.070455	0.001075	0.00105625

Total Time of Section 1= 0.41171085 Total Time of MB3-End= 0.00213125

Arrival Time	Train 1		Train 2	Train 2 Waiting Time	Train 3	Train 3 Waiting Time	Train 4	Train 4 Waiting Time	Train 5	Train 5 Waiting Time
Time Until MB1	0		0.333333333		0.66666667		1		1.333333333	
Time to Exit Section 1	0.006175		0.339508333	0.078377517	0.67284167	0.156755033	1.006175	0.23513255	1.339508333	0.313510067
	0.41788585		0.8295967		1.24130755		1.6530184		2.06472925	
Time to Exit Section 2										
	0.48834085		0.9000517		1.31176255		1.7234734		2.13518425	
Time to Exit the Model										
	0.4904721		0.90218295		1.3138938		1.72560465		2.1373155	

Figure 4: Manual Simulation

TALLY VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Observations
Tally 1	.14892	(Insuf)	.07838	.19594	5
Train 1.VATime	.00000	(Insuf)	.00000	.00000	5
Train 1.NVATime	.00000	(Insuf)	.00000	.00000	5
Train 1.WaitTime	.15676	(Insuf)	.00000	.31351	5
Train 1.TranTime	.49043	(Insuf)	.49043	.49043	5
Train 1.OtherTime	.00000	(Insuf)	.00000	.00000	5
Train 1.TotalTime	.64719	(Insuf)	.49043	.80394	5
Hold 2.Queue.WaitingTime	--	--	--	--	0
Hold 1.Queue.WaitingTime	.19594	(Insuf)	.07838	.31351	4
Request 1.Queue.WaitingTime	.00000	(Insuf)	.00000	.00000	5

DISCRETE-CHANGE VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Final Value
Train 1.WIP	1.5140	(Insuf)	.00000	2.0000	.00000
Hold 2.Queue.NumberInQueue	.00000	(Insuf)	.00000	.00000	.00000
Hold 1.Queue.NumberInQueue	.36672	(Insuf)	.00000	1.0000	.00000
Request 1.Queue.NumberInQueue	.00000	(Insuf)	.00000	.00000	.00000

OUTPUTS

Identifier	Value
Train 1.NumberIn	5.0000
Train 1.NumberOut	5.0000
System.NumberOut	5.0000

Simulation run time: 0.08 minutes.
Simulation run complete.

Figure 5: SIMAN Report for Developed Model

5.3 Simulation outputs

The framework is divided into three parts starting with the input which contains the Excel file that includes the distance between two consecutive marker boards to develop the model that mimics the real situation. Processing the input will start with building the railway model at ARENA simulator using different modules such as the advanced transfer modules which are related to the transportation field. The improved model and the simulation report will be the main output of this project. Additionally, the improved model will aim to enhance the capacity and minimize the delay while the simulation report will help us to study the important indicators such as total waiting time, entity number in, and entity number out.

The network map which represents part of the whole North railway line starting from Riyadh to R1 (R1 is an area between Riyadh and Majmaah) as shown in Figure 6.

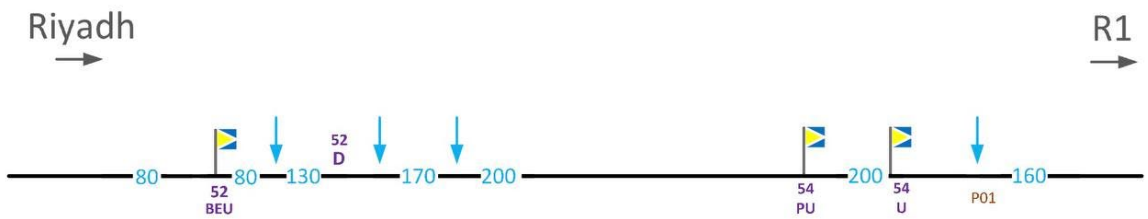

Figure 6: Riyadh to R1 Map

The map determines the specific location for each marker board in addition to the speed change points. Using this information, the distance has been calculated to help construct the model. Figure 7 represents the model of the current railway situation from Riyadh to R1.

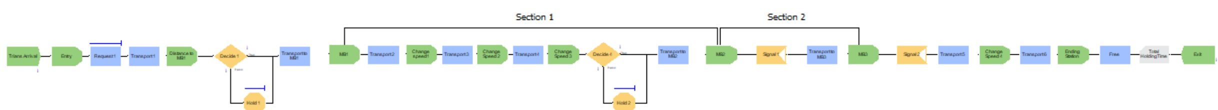

Figure 7: Developed Model

A create module represents the trigger of the railway track, the entity represents the train which is created with an interarrival time of 20 minutes and a maximum of 5 trains. Taking into account that the entity will be created only if the number of trains waiting in the first hold queue equals zero, to avoid train clustering in one point. The stations are used to address a physical or logical location such as the Entry, Changing Speed, and the Marker Board. Moreover, the distance between stations is specified in the distance spreadsheet module. The transport module is responsible for transferring the train from one station to another at a specified velocity. A transport module requires a request module to assign a transporter to an entity and requires a free module to release the transporter. The decide module checks if the stations are empty, if not the train will wait at the hold until a signal. A signal module is responsible for giving the held train a sign so it can enter the section. The record module is used to collect the total waiting time at each hold module. The trains will exit through the dispose module.

5.4 Proposed Improvements

To address the relationship between the waiting time of trains and adding additional marker boards, the improved model was constructed as shown in Figure 8.

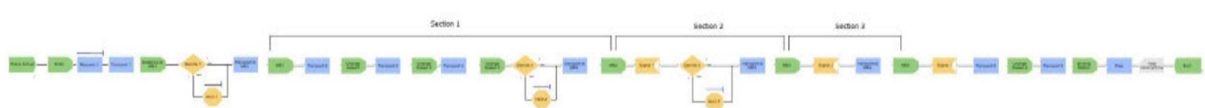

Figure 8: Improved model

6. Conclusion

In conclusion, enhancing the Saudi railway signalling system is crucial for improving the overall safety, efficiency, and reliability of the railway network in the country. The project has investigated several key delay causes that Saudi railways faces, the main focus was on enhancing the signalling system which is one of the critical root causes of delay. By enhancing the signalling system, the number of trains that can run safely on a given track can be increased by optimizing train spacing. This helps to alleviate congestion, accommodate growing passenger demands, and enhance the overall capacity of the railway network.

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