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November 14, 2024 | Online

Ensuring Rail Safety: KAVACH, a Train Collision Avoidance System (TCAS)

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Agenda

- KAVACH Overview
- PSPAD Implementation
- 3D Co-simulation

Introduction

- Train Collision and Avoidance System (TCAS) is introduced by the Indian Railways' Research Design and Standards Organization (RDSO).
- Design, development, and validation of complex TCAS algorithms are critical: Train crash test involved
- Model based design using MathWorks solutions can ease the process.
- The left shifting using virtual validation: early bugs, cost efficient, early time to market.
- MathWorks solutions for design, development, simulation, and virtual validation: Systematic, efficient, intuitive.

Train Collision : An example

- On 17 June 2024, two trains collided in Darjeeling district in the Indian state of West Bengal.
- A goods train collided with Sealdah–Agartala Kanchanjunga Express, a passenger train near Rangapani railway station.
- 11 people were killed and more than 60 were injured.
- The chairman of the Railway Board said that the operator of the goods train ignored multiple red signals, which might have caused the crash.
- The trains were not equipped with KAVACH, a collision avoidance system designed by Indian Railways.

Kanchanjungha Express train accident June 17 highlights: Goods train rams into express from behind in Bengal, 9 killed

9 dead, over 40 injured as goods train collides with Kanchanjungha Express in West Bengal

Updated - July 17, 2024 05:16 pm IST Published - June 17, 2024 10:36 am IST

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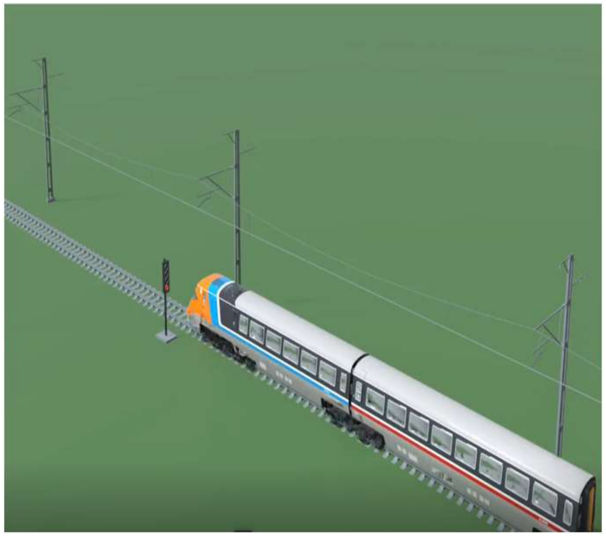
Sealdah Kanchanjungha Express was hit by a goods train in Darjeeling district of West Bengal on June 17, 2024. | Photo Credit: Special Arrangement

Source: https://www.thehindu.com/news/national/kanchanjungha-express-train-accident-highlights-goods-train-west-bengal-new-jalpaiguri/article68299231.ece

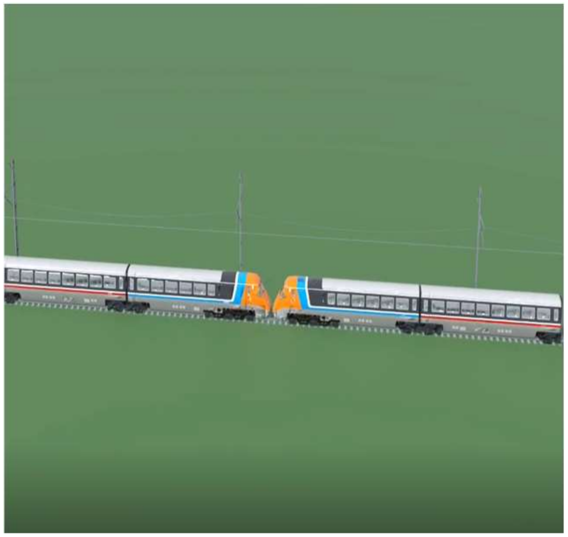
https://en.wikipedia.org/wiki/2024_West_Bengal_train_collision

KAVACH/TCAS Overview

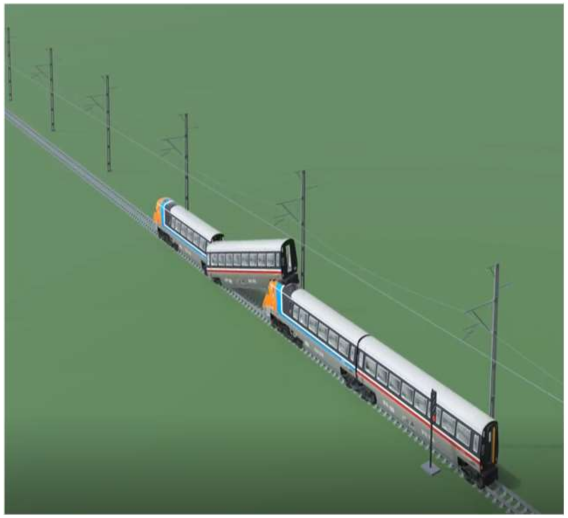
- KAVACH is an Automatic Train Protection system developed indigenously by the Indian Railways' Research Design and Standards Organization (RDSO). It's designed to prevent train collisions and increase safety in train operations across India.
- Some of its Key features are:



Prevention of Signal Passing At Danger (SPAD).



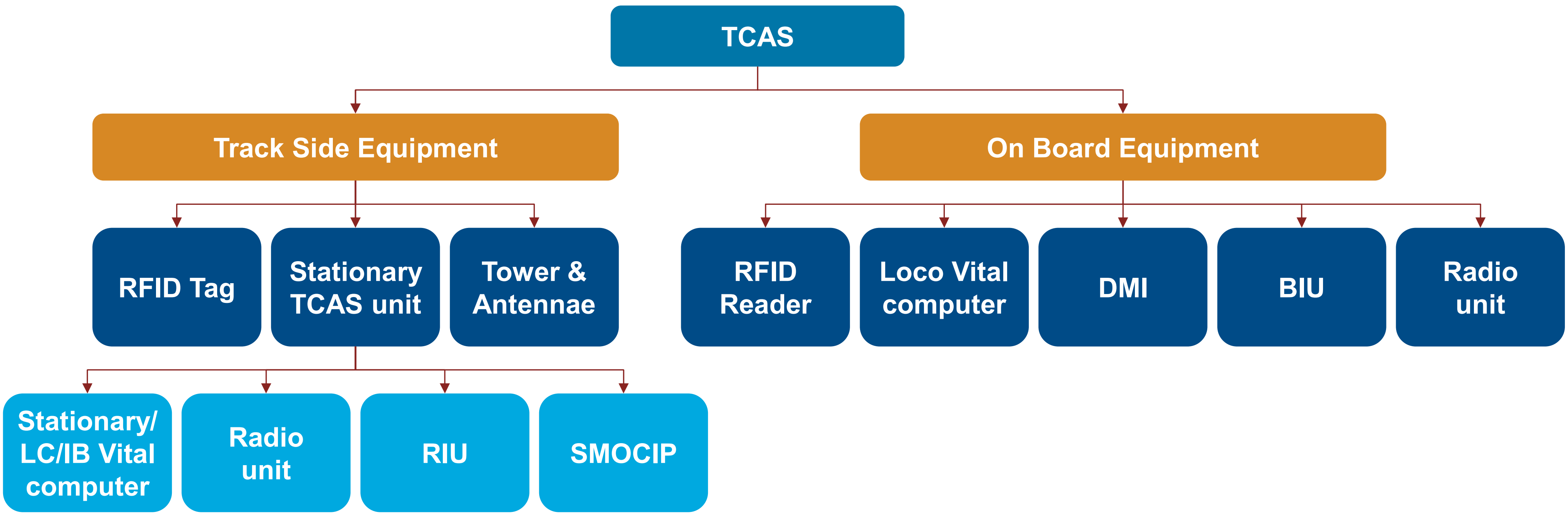
Head-on Collisions



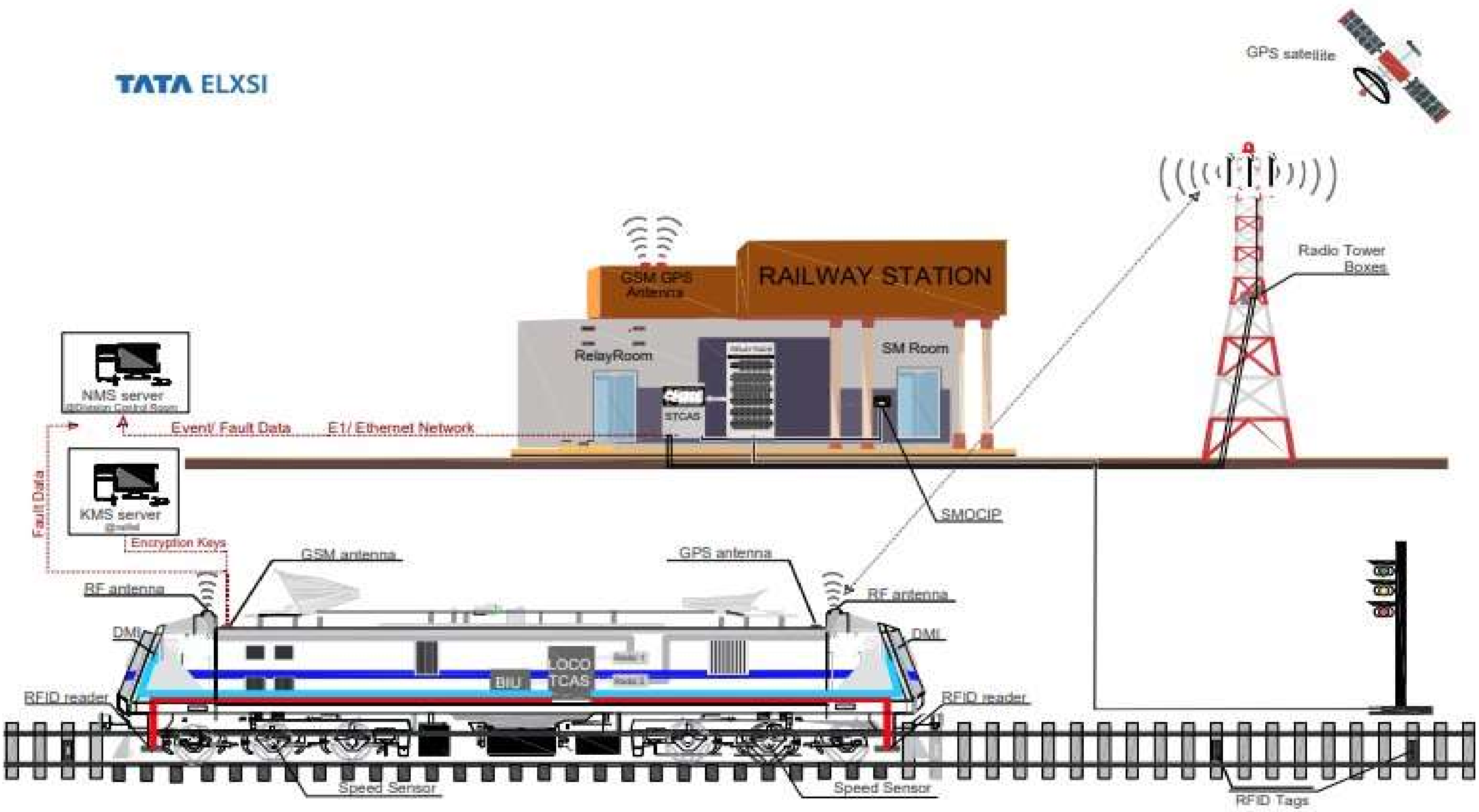
Rear End Collisions

TCAS/KAVACH Architecture

Train Collision Avoidance System (TCAS), an indigenous Automatic Train Protection (ATP) system to prevent accidents by automatic application of brakes in case of Loco Pilot fails to do so.



Communication of KAVACH/TCAS



Features Implemented:

Prevention of Signal Passing At Danger (SPAD).

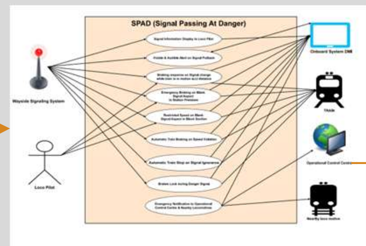
Prevention of Over speed: Section Speed, Train Speed

Line-side signal display in the cabin for improved visibility in foggy conditions and at higher speeds

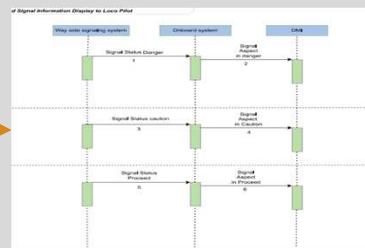
SOS Messages

Development Lifecycle

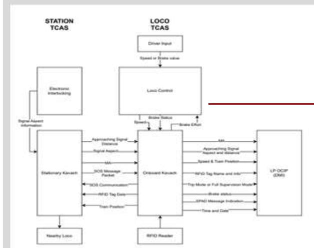
SyRS (System Requirements Specifications)



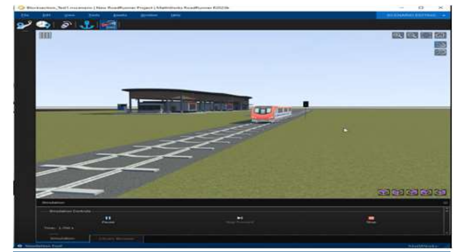
Use case Diagram



Sequence Diagram



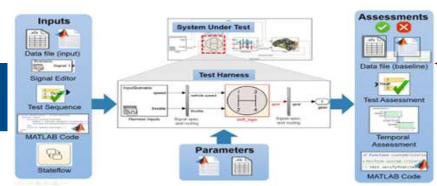
Low Level Requirements



3d simulation

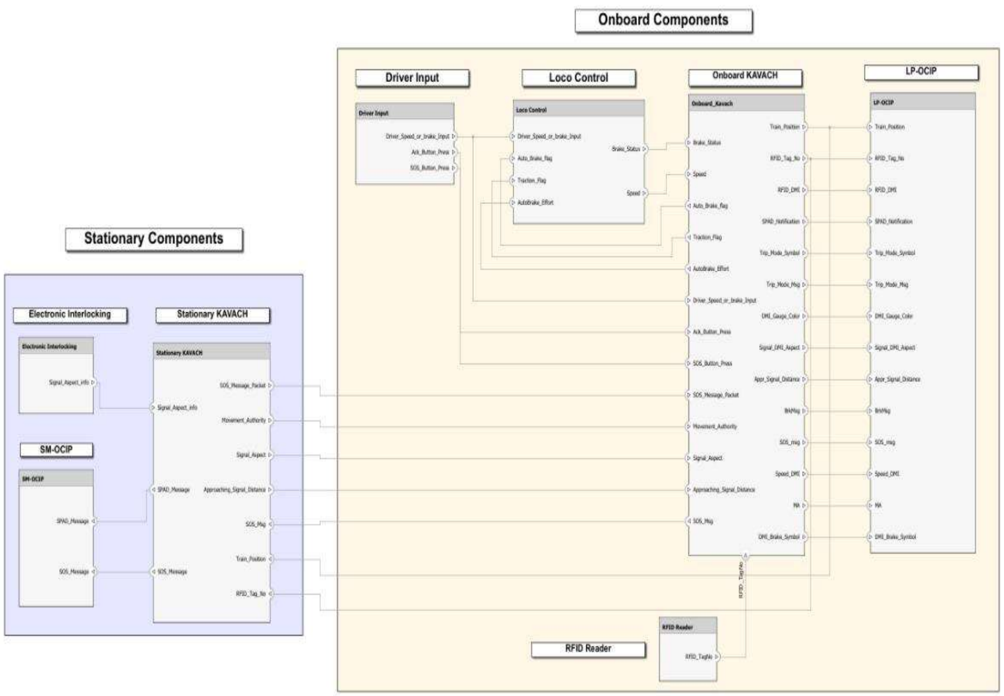
Control model

Function Testing



Model Based Systems Engineering

- Engineers use model-based systems engineering (MBSE) to manage system complexity, improve communication, and produce optimized systems.
- Developed architecture and sequence diagram using System Composer.
- System Composer enables to analyze requirements, to create architecture diagrams, and produce requirement specifications and interface control documents (ICDs).



System Composer Architecture

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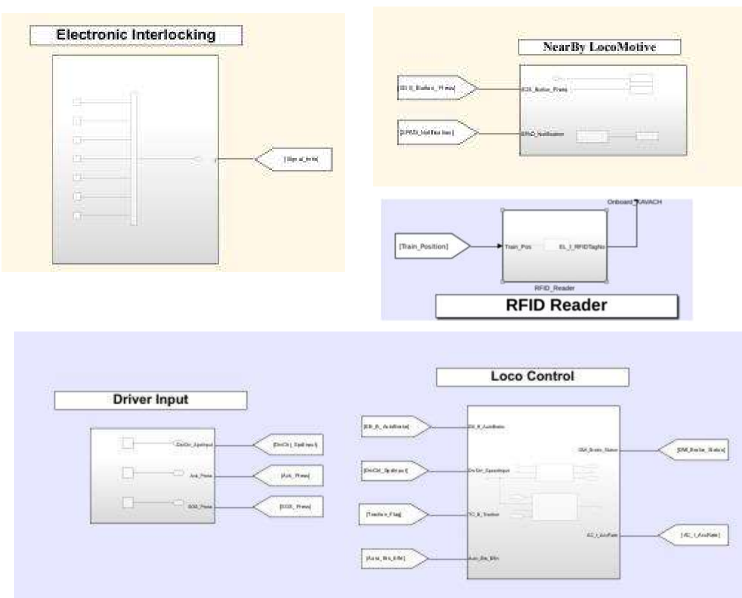
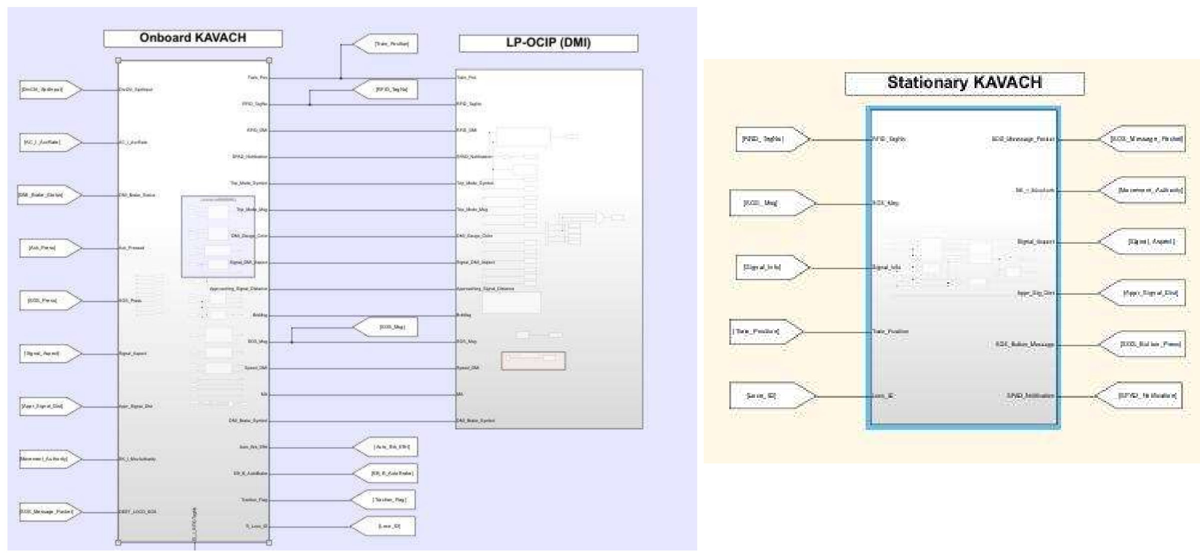
Control Algorithm and Plant Model Development

- Plant Models: Electronic Interlocking, Nearby Locomotive, Loco Control, Driver Input
- Control Models: Stationary KAVACH, Onboard KAVACH, RFID Reader, LP-OCIP (DMI),



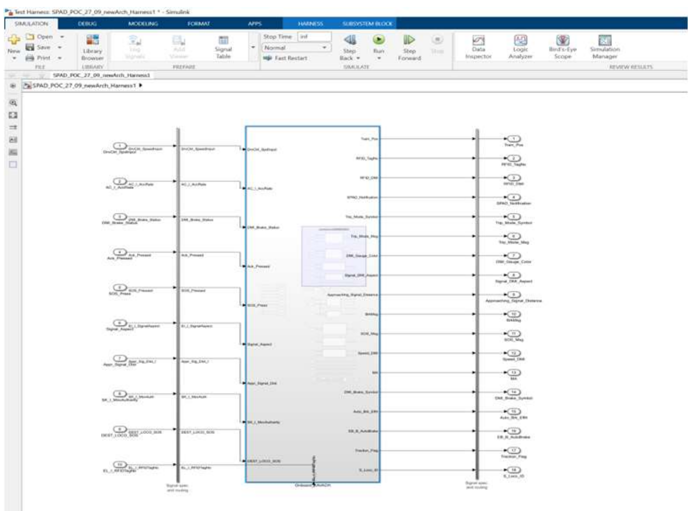
KAVACH Plant Model



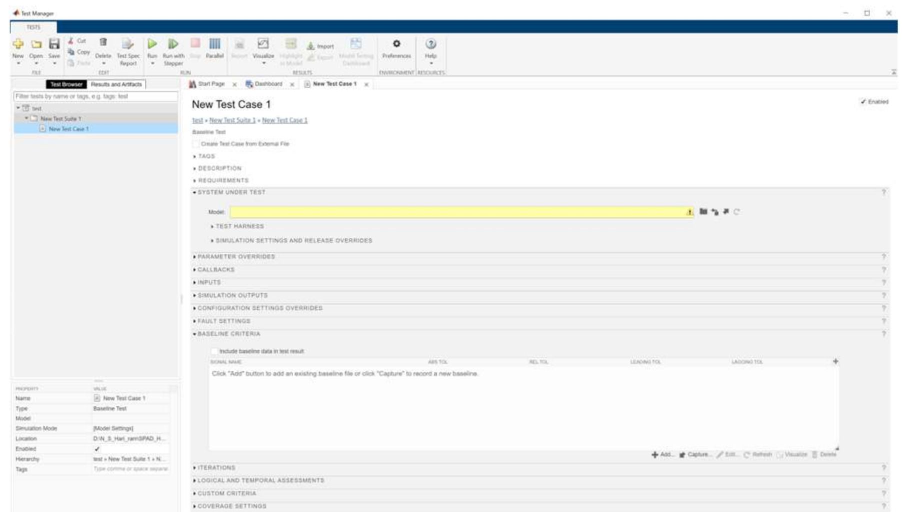
KAVACH Control Model

Unit Testing and Integrated Testing

- The control models are divided into units like Onboard KAVACH, Stationary KAVACH and performed Model In Loop (MIL) Testing.
- Control Models are integrated and connected with Plant model and performed integrated Model In Loop (MIL) testing.
- Test Harness, test case creation and testing are performed using Simulink Test.



Test Harness



Test Manager

Model/Code Coverage Analysis

- Structural coverage analysis/code coverage analysis, provides a measure of the extent to which software code has been exercised under specific test conditions.
- Simulink Coverage performs model and code coverage analysis metrics such as decision, condition, modified condition/decision coverage (MCDC), and relational boundary coverage to assess the effectiveness of simulation testing in models.
- We have achieved 100% coverage for the model.
- This is done to comply with the Rail Safety Standards

Summary

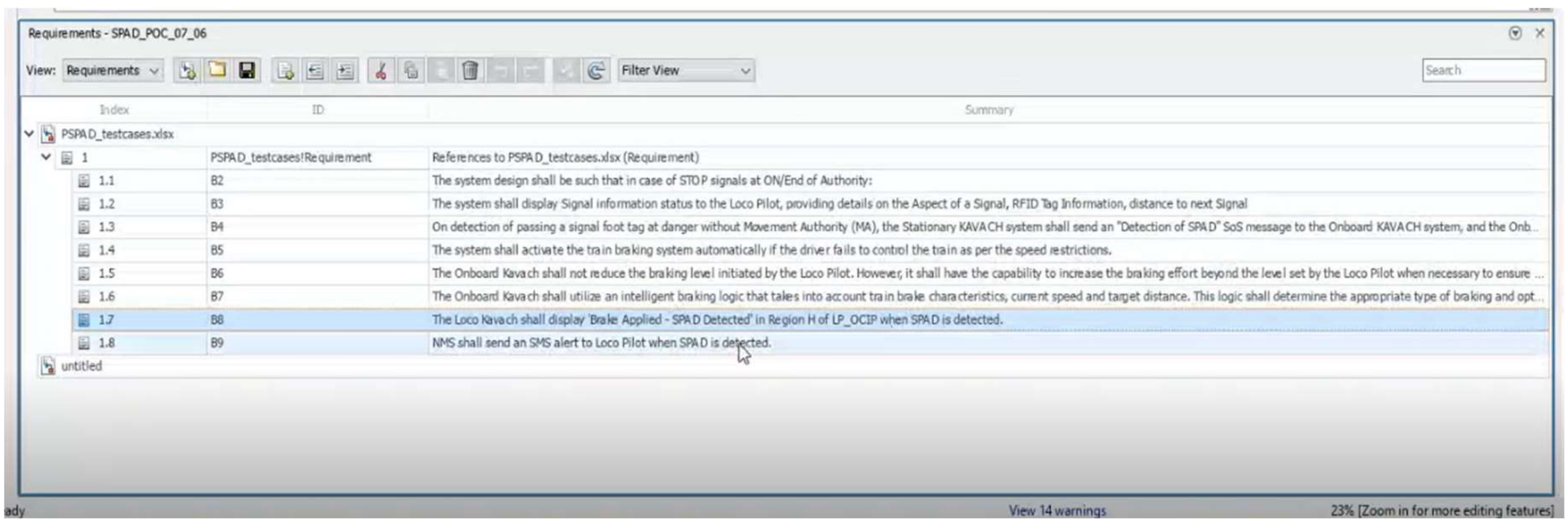
Model Hierarchy/Complexity

		Decision	Condition	MCDC	Test Objective	Proof Objective	Test Condition	Proof Assumptio
1. SPAD_POC_23_09_newArch	146	100%	100%	100%	NA	NA	NA	NA
2. . . . KAVACH	145	100%	100%	100%	NA	NA	NA	NA
3. . . . . . . Driver_Input		NA	NA	NA	NA	NA	NA	NA
4. . . . . . . Electronic_Interlocking		NA	NA	NA	NA	NA	NA	NA
5. . . . . . . LPOCIP_DMI	4	100%	100%	100%	NA	NA	NA	NA
6. . . . . RFID TAG Display DMI		NA	100%	NA	NA	NA	NA	NA
7. . . . . Compare To Constant28		NA	100%	NA	NA	NA	NA	NA
8. . . . . Compare To Constant29		NA	100%	NA	NA	NA	NA	NA
9. . . . . Compare To Constant30		NA	100%	NA	NA	NA	NA	NA
10. . . . . Turn_Out_Distance	2	100%	100%	NA	NA	NA	NA	NA
11. . . . . Compare To Constant		NA	100%	NA	NA	NA	NA	NA
12. . . . . . . Loco_Control	25	100%	100%	100%	NA	NA	NA	NA
13. . . . . Accel_Decel	11	100%	100%	100%	NA	NA	NA	NA

KAVACH P-SPAD Model Coverage

End to End Traceability

- Bi-directional traceability shall be maintained from System requirements to Integration Test artefacts.
- Requirement toolbox will support to link requirements to MATLAB code, System Composer or Simulink models, and tests.
- The toolbox analyzes the traceability to identify gaps in implementation or testing.
- When requirements change, linked artifacts are highlighted, and we can determine the upstream and downstream artifacts affected using a traceability diagram.



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Simulink Visual Design: DMI, Controls & Virtual Track layout

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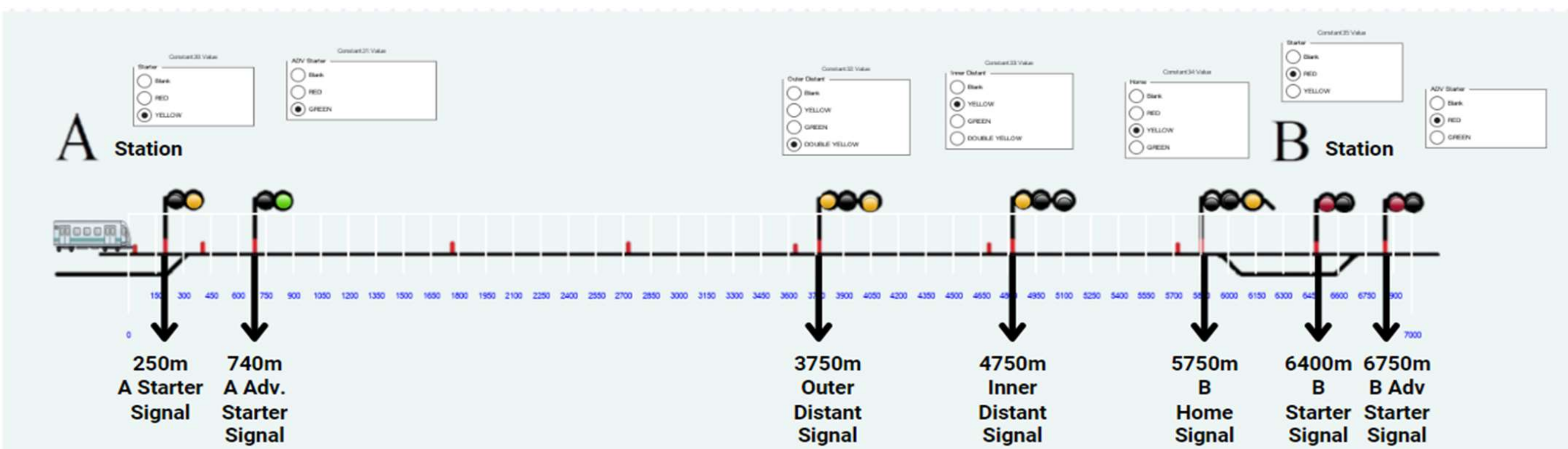
Virtual Track layout

- To show case the scenarios of KAVACH-SPAD POC, TE team designed a controllable Track layout.
- In this track, signal or Movement Authority will be manually controllable.
- It showcases the absolute block section and signals between **Station A, Station B** and tracks.
- **The Signal aspects (RED,YELLOW,GREEN,DOUBLR YELLOW).**
- **Signals for Departure** are **Starter** and **Advance Starter** Signals.
- **Signals for Reception** are **Outer Distant, Inner Distant** and **Home** Signals.



Driver Machine Interface

DMI shall consist of suitable arrangements and buttons/ switches for display/operation of following functions implemented in our PoC:

1.Communication Indication & SOS operation by the loco pilot.

2.Signal aspect display.

3.Display of modes of loco operation

4.Current speed

5.Movement Authority (MA)

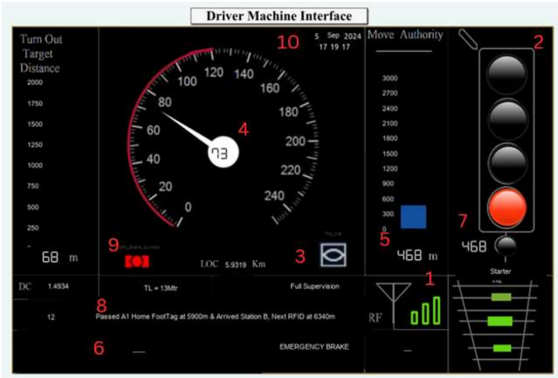
6.Alarm generation and SPAD Message indication.

7.Showcasing the signal distance, name of the signal and signal aspect.

8.RFID Tag info

9.Brake info

10.Time and date.

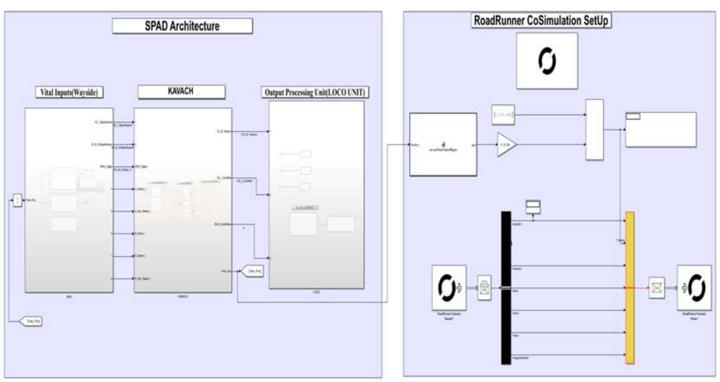


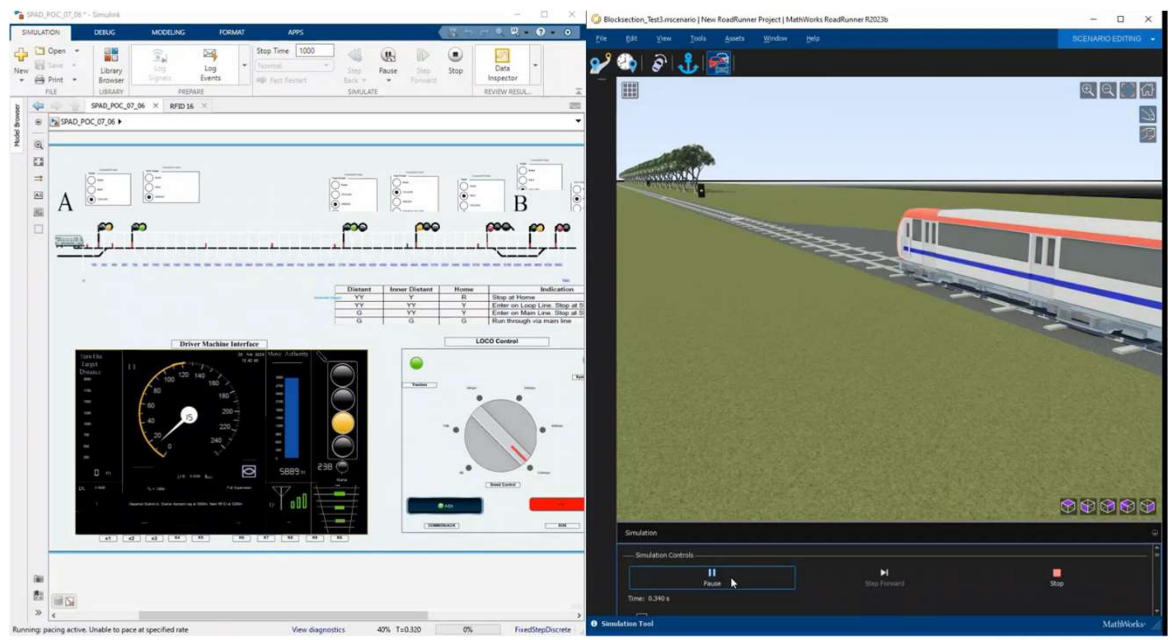
Designed DMI in Simulink Designer

Ideal DMI Suggested by RDSO

3D Virtual Testing: Roadrunner

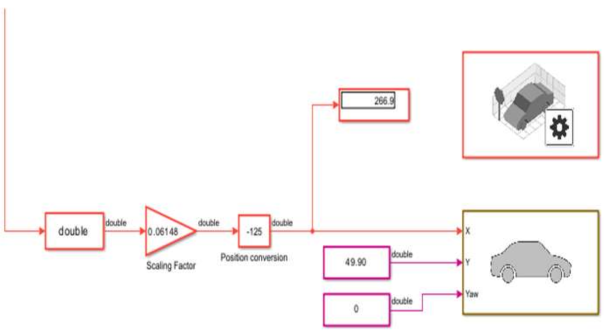
- Scene creation using assets such as rail extrusions.
- Using asset import feature of Roadrunner, we created custom train vehicle mesh in blender and imported that in roadrunner.
- Successful linking of the model using Roadrunner Scenario, Roadrunner Scenario Reader and Writer blocks.
- Manipulation of train movement through the above blocks

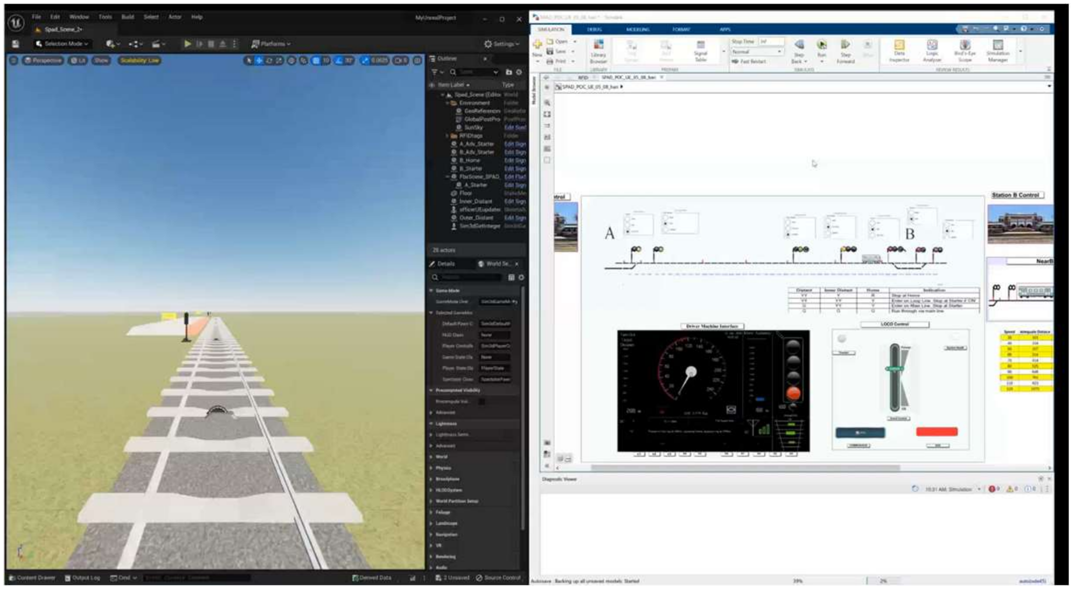




3D Virtual Testing: MATLAB Co-Simulation with Unreal Engine

- Unreal Engine is 3rd party 3D simulation software which is commonly used in sync with Simulink for automotive applications.
- Here we successfully linked the model using Simulation 3D Scene Configuration block.
- Also, Manipulation of train movement through Simulation 3D Vehicle with Ground Following block was done by using suitable scaling factor.
- Connection of signal aspect from Simulink to unreal engine was also done using Simulation 3D Message Set block





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Conclusion and Future works

- Developed control model for KAVACH Prevention of SPAD system with both onboard and stationary systems separated.
- Control Model are integrated together with the Plant Model and tested in both 2D and 3D test layouts.
- 100% coverage obtained for integrated model using system requirement and its linked test cases.
- Possibility of MathWorks tools in Rail domain explored.

Future Works:

- Head-on and Rear end collision feature implementation
- Signal aspect change in MathWorks Roadrunner
- Code generation and Hardware implementation.

MathWorks Products Used

- System Composer (Model based System Engineering)
- Simulink (Control Algorithm)
- Simulink Requirement (Perform traceability with DOORS requirement and Simulink blocks)
- Simulink Test (MIL and SIL testing)
- Simulink Coverage (MCDC, Execution and Decision coverage)
- Simulink Check (For Model advisor check)
- Simulink Visual Design (KAVACH DMI Design, Virtual Track Layout)
- Simulation 3D toolbox (for 3D co-simulation)
- Vehicle Dynamics Block set (for sim3d message set/get)
- Roadrunner (Realtime 3-D simulation with Animation)

Future toolbox usage scope:

- Embedded Coder
- Simulink Design Verifier
- Simulink Fault Analyser
- Polyspace

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Thank you

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