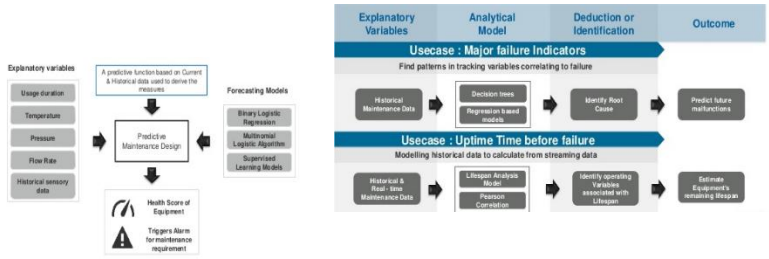
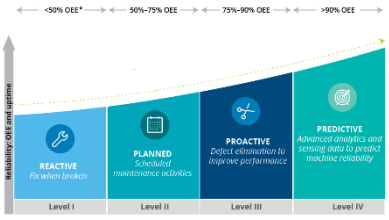
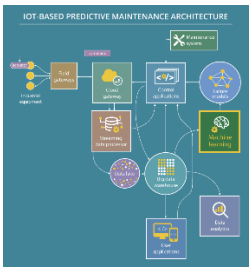
Digital Transformation of Railways – New Way for Railway Control and Command Systems

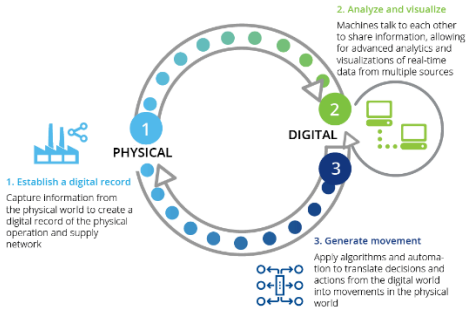
1. **Today Digital intervention means adoption of AI in day to day activities from design to maintenance, installation to operations.** Most importantly is brining Digital Technology driven by AI for safety enhancement. The data for safety and data analytics is gathered from embedded digital sensors on various parts of the trains and the fixed infrastructure like switches, SEJs, Curves, point machines, signals, location boxes, tracks, sleepers, track fixutres/ fittings, Pantograph, SP/ SSPs/ TSS, Bridges – Substructre/ Superstructure), Tunnels, etc capturing the sensory data and developing AI driven actionable Futuristic Train Control and Command Systems. AI helps them to increase their availability, reliability and effectiveness.







With the invent of advanced computing technologies, HI2AI can help Railway to map their networks into a multi dimension 3D model, tracking train location, maintenance status, depot utilisation, extrenal factors like rains/ earth quake, flood, landslides, such a system is termed as 'Digital twin' of that particular Railway network.



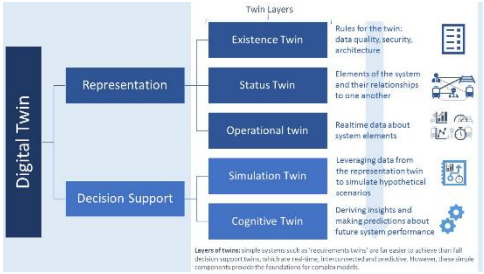


Fig: Digital Twin Concept (Source: Center for Integrated Research, BCRRE, Birmingham University, UK)

When the first electronic interlocking systems was made, many conservative signalling engineers offered heavy resistance to their introduction, primarily because of a lack of confidence in terms of

safety. For them, behaviour and electrical parameters of a vital relay can be seen and measured, the absence of knowledge and a complete understanding of what happens inside the mysterious blackbox of an electronic interlocking and its software create a lack of perceived safety. We all know that safety is not a feeling, but the proven absence of unacceptable risks, however much of the time feelings are important in such decisions. The use of software in critical signalling applications promised cost reduction, lower energy consumption and substantially smaller physical space requirements, but may lead to unsafe conditions due to many safety hazards, known or unforeseen. Fortunately, the application of well-established safety standards and processes of software engineering were able to provide evidence of safety and make the use of computers in railway signalling feasible. These processes now enable us to use SIL4 hardware, running SSIL4 certified software. But those opposing the move, point out vulnerabilities which are present to reject use of AI powered algorithms for Fail Safe system design. As is known, Artificial Intelligence (AI) seems to be the next breakthrough technology in engineering. While existing deterministic programming requires a full understanding of the desired software behavior (which may require months or years of physical system study and modelling), followed by well-designed algorithms and many hours of software coding and testing, whereas AI modelling requires only the basic neural math and huge processing power.

2. **Train Collision Avoidance System –Upgradation of #KAVACH** from Train Collision Protection System to Autonomous Train Control, Protection and Management system using state of the art AI & Quantum based technologies were discussed to evolve into autonomous train operation. was discussed. Thus, use of AI shall be both in (i) Safety related systems (predictive maintenance of assets, intrusion detection system, train traffic management and optimisation system) and (ii) #Safety_Critical systems (#Train_location_detection system, #interlocking_systems, #ATS & #ATP. Introduction of Artificial Intelligence (#AI) algorithms if on one hand can bring lot of #optimization but, there shall always be additional safety risks. Methodology of introduction and #mitigation of the safety risks were discussed.

(A) Indian Railways have to adopt #Digital Twin technology from #Design to #Health_Monitoring to #Operations to develop next Generation #KAVACH++ as a next generation train control, operations, protection and management system for achieving multiple times enhancement in #throughput, #safety_integrity_levels & #Operational_Optimisation.

(B) Digital Twin brings induction of various sensors for monitoring asset condition, /status, data acquisition, data storage and analytics to learn about internal and external risks and also how to mitigate them using advanced and certified AI algorithms as per Global standards so as to enable identifying train location accurately (100% True positive) requiring huge data processing which may require Railways own quantum computation resources to make full use of advanced AI techniques. Thus, it is possible to achieve fail safe #SIL4 safety integrity which currently need months/ years of field trials as per EN standards, thus eliminating time overruns.

(C) Thus, instead of using non standard AI algorithms which do not confirm to any of the global standards like #ISO42001/2003, #IEC5338, #IEC38507, #IEC22989:2022, #IEC_TR24208 and very new EN standard of #EN50716, which has now superseded EN 50128 AND EN 50657. The EN 50716 now encompasses detailed guideline about using AI / ML algorithms along with Cyber Security in the safety critical system software designing and testing. Adherence to these standards, enables Safety integrity, data integrity, robust and OT Cyber Secured design. AI powered Digital Twin based next generation KAVACH++ shall definitely improve RAMS, accuracy, predictive safety to eliminate any impact of safety hazards in better way making rail transport highly fail safe and secure, as it shall be possible to predict potential risks beyond simple signaling rules like abnormal train behaviour, track conditions, dangerous weather conditions etc.

(D) Digital twin based modern train control, command and protection system shall incorporate #Smart design, #Delay / fault prediction, #Advance train scheduling, #Creating efficient train paths, #Centralized traffic control with AI Algorithms demonstrating #Trust & #accountability, Safety & reliability., Regulatory compliance, #Market acceptance, #Accuracy & #robustness, #unbiasness and #Data privacy

Thus, even if AI can't solve every problem in the world, but it can solve many problems better and cheaper than using deterministic programming used so far in Modern Signalling systems. Quantum Twin, on which HI2AI built on this platform opens a new opportunity for a new Train Control and Command framework, wherein the throughput of existing Railway network of Indian Railways can go up by ten times and providing much higher safety integrity levels as a part of Quantum Twin can now be equipped with a range of sensors, including GPS, inertial navigation, odometers, radar, Lidar, cameras, ultrasonic and acoustic monitors, generating a massive amount of data. By analysing and combining this data can help in predicting accurately as train positioning, which can be feed into the ATP, ATO and thus docking undocking of Autonomous train PODs, subject to compliance to a India made Global standards.

AI can be trusted to take control of a safety critical system.

SN	Applications	Use Cases
1.	AI powered Designing of stations	Advanced data analytics tool is applied alongwith AI algorithm on many parameters like size of stations, capacity of passenger to be handled considering passenger growth in next 40 years, access to and fro station, passenger evacuation plan, no of platforms, no of trains to be handled per hour (futuristic demand forecast), passenger sitting, amenities, use of humanoids.
2.	Survey of new lines using Ray sat/ LiDAR/ Drone / Geo tech etc surveys	Alignment control points, weather/ disaster resilient rail line design based on various surveys, speed potential, train length, type of traffic to carry, throughput requirement in future
3.	Automatic Customer Services Upgradation	AI assisted Humanoids/ Robots can learn from passenger behaviors and help them in resolving constraints faced, feedback, easing congestion points, addition/ deletion of passenger facilities
4.	Digital Twin Modelling for Train Operations	For existing sections: Creation of mathematical model based on existing railways system – mapping of all fixed/ rolling stock/ human resources/ train time tabling, speed restrictions etc For new sections: Throughput requirement, type of traffic, headways, passenger load, train stoppage, enroute and depot maintenance scheduling, allocation of rolling stock, advance alerts and warnings for likely maintenance, operation hiccups
5.	Locomotive Driver Advisory System based on AI modeling with or without AR/ VR support	Train simulator to alert upcoming congestions, traffic / engg speed restrictions based on internal and external factors like maintenance failures, weather, land slides, track intrusion etc. AR/ VR support for fault rectification in the online / working environment with predictive

		analysis of likely locations based on previous operations, maintenance availed and history of the competence of maintainers, parts, shops etc
6.	IT/ OT Cyber Security	To restrict/ stop cyber attacks on OT systems for train operation related activities using live AI models
7.	Predictive Integrated Maintenance of Assets	Digital Sensor based data acquisition from fixed and rolling assets (sensors to be embedded in the parts inside, undergear, on track, S&T, OHE – 3D printed), prediction of its futuristic behavior vis a vis current running to support alerts about unsafe failures/ situations or traffic disruptions.
8.	AI powered MOR activity	AI tools with LRM support for end to end MOR activity
9.	Reduced complexity with simplified and interoperable interfaces	Reduced complexity with simplified and interoperable interfaces, eliminate dependency on OEMs for parts of critical items and improved flexibility. Creation of Digital twin of each product, system and create 3 D Engg model with advanced metallurgical component based 3D design and printing of import substituted critical components as identified to cut downtime, improved performance, lesser OPEX and better flexibility.
10.	Autonomous Train Operations	Complete automation of entire train operations including formation (docking) undocking of trains based on passenger volumes at a station, enroute in motion docking facilities
11	**Design for Kavach** As a part of its vision statement, Indian Railways have identified provision of TCAS (Kavach) as one of the mission items to be completed by Mar 2030 on HDN and HUN sections (30000 Rkms) and further on balance portion in next 3-5 years and in nearly 15000 Locos and Trains sets/ Self propelled vehicles Kavach works need urgent completion on the railways. the commissioning of the system is taking place slowly at stations. This is due to two factors – (i) Excessive time taken in the preparation of design & drawing papers and Station RFID localization plan.	HI2AI has developed an AI powered system, in which highly technical complex system design processes of Kavach-TCAS works are carried out its AI algorithms whose LLM has been trained on data acquired from Indian Railways station data for and doing lot of local customization, testing and interface design and incubation using AI powered design optimization has been done, in afew hours in place of months or so 1. Rather in a way, it can be treated as a strategy to move various data which can only be acquired from field trials , by using AI powered LL Models resulting in moving from Field to Lab using accredited software simulations and AI powered applications for design by accredited IRSE licensed Designer, verifier as a part of design Optimization, in which one station work can be reduced in a few days instead of 20-30

	(ii) Non availability of an independent lab for testing and certification of Kavach, due to which issues like interfacing and interoperability, RAMS testing is not being done affecting field implementation.	days to design, generate and verify by IRSE Licensed engineers like Kavach Design and Smart Data format for Tag/TIN Layout, Kavach TOC, RFID tag data and Tag profile data

Future challenges

To be fully autonomous, intelligent trains must be equipped with sensors and have AI calculation capacities. Moreover, as previously noted, automated trains need optical sensors and cameras to detect obstacles on tracks. In the last few years, India's critical infrastructure and digital assets are under relentless attacks by state-sponsored hackers. Cyber-attacks warfare bypass traditional security systems: Old methods of data and online security are rapidly becoming obsolete as the capabilities; resources and geographic spread of professional attackers now far exceed that of most organizations; for example, universally used random number-based encryption systems and current public key algorithms are no longer any match to the new compute powers and cryptanalytical methods. As per the latest reports, majority of encrypted data relies on RSA-2048 and a quantum computer with 4099 qubits will break it in a few minutes. For strategic organisation like police force, defence etc. such risks breaching data security, shall be very harmful to the national security as well.