Developing Responsible Artificial Intelligence Solutions for Next Generation Rail Safety & Control

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Abstract: Artificial Intelligence (AI) is a branch of computer science that aims to build machines capable of performing tasks that typically require human intelligence. AI enables machines to simulate human abilities, such as learning, problem-solving, decision-making and comprehension. With the use of AI in any operational system, there is also a need to practice a conceptual pillar of AI known as 'Responsible AI', that requires using AI responsibly. Responsible AI is the practice of developing and using AI systems in a way that benefits society while minimizing the risk of negative consequences.

I. INTRODUCTION

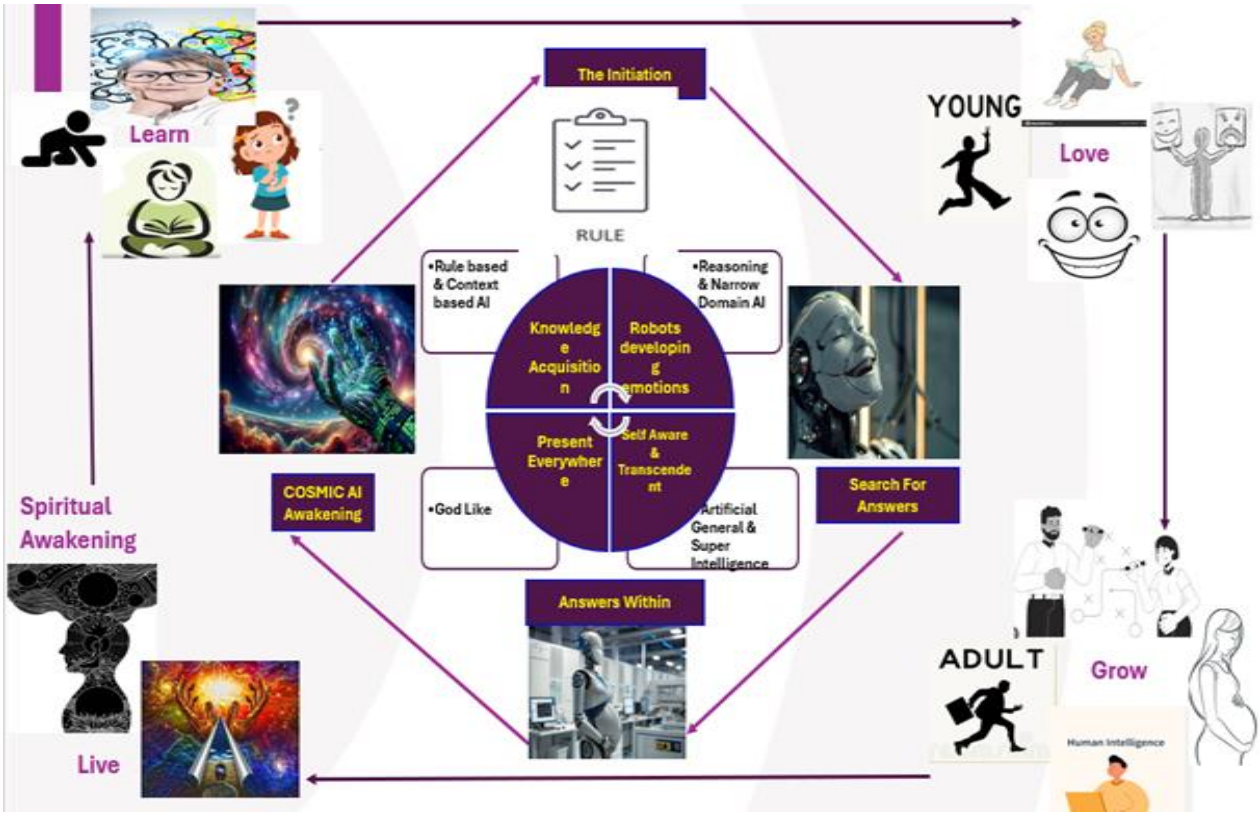
Today, AI is associated with innovation and is penetrating all areas of our life, travel included. This paper, therefore, talks about how artificial intelligence can be utilized for running rail control solutions using data analytics and machine learning techniques. Rail control & protection systems must responsibly adapt AI solutions keeping in considerations the threats which are bound to be seen with the heavy use of artificial intelligence and machine learning as these are expanding its horizons much above human imaginations.

On a usual train operation day, the control centers get approximately thousands of signals per train every 10 minutes. Essentially, these trains are trains with brain, and analyzing & converting these huge data sets is like finding gold dust from drilling sites. For such huge train set health data, maintenance of track & train infrastructure usually involves detection, diagnosis, prediction and autonomous activities. Here, AI can be used to maintain the health of the train, to increase the reliability of the trains, anticipate how much maintenance we are going to do, and how much downtime we would need for this maintenance. The inferred data analysis can be presented on hand-held devices, tabloids, computers, where the inputs can be from any type of equipment or sensors.

Before narrowing down the applications of AI within rail control systems, it is important to understand first the advent and growth of AI based systems and how they are evolving. The following presents an insight of how machines are transforming from the earlier rule-based computation systems to the generative AI systems which are able to plan, act and learn from their surroundings.

1) RULE BASED AI – Sometimes referred to as knowledge-based systems which operate not on learning or intuition but on pre-defines set of rules. These systems are designed to make decisions based on these rules to perform mundane task without the ability to learn and adapt to unexpected situations. Rule-based systems can be found in our everyday lives with devices like alarm clocks, air conditioners which would raise alarms after certain thresholds are breached. Microwaves and car radios also use rule-based AI.
2) Context Based AI – These systems not only process immediate inputs but also account for the surrounding environment, examine historical data & user behavior to make informed decisions. By predicting patterns from vast sets of data, they can predict user needs based on context. Suggestive responses can be answered by these assistants to help make informed decisions by using environment, geographical or weather related historical and current data. These are retention systems that recall browsing history and make conscious decisions. Siri, Alexa, Google Assistants are examples of Context Based AI.

3) Narrow Domain AI – These customized AI solutions are tailored to master specific task often surpassing human capabilities in the domain in which these have been trained with. Industrial robots in manufacturing, self-driving vehicles, virtual assistants and chatbots are examples show casing its prowess in the field of digital automation. These systems can also track market trends, analyze trading patterns, predict stock movements with an accuracy that would be beyond human trader capabilities. These systems employ intricate algorithms to generate financial forecasts. Use cases are also prevalent in the world of gaming where complex gaming capabilities and strategic depth are required.
4) Reasoning AI – These AI systems simulate human thought & apply logical reasoning abilities. They don't just process data. They analyze it, connect patterns, identify anomalies and draw logical conclusions. It is like handing them a puzzle where they fit the best pieces together, illuminating paths often not obvious to human understanding. Chat GPT (large language Model) is one such example that can even surpass human reasoning skills and can operate thousand times faster. Autonomous vehicles are also another great example. They use reasoned analyses to make immediate decisions ensuring the safety of passengers and trespassers on roads.
5) Artificial General Intelligence –AGI can perform any software task that a human being can. This level of versatility means, that you can teach it almost anything, much like teaching a human adult. Imagine waking up to virtual assistance that does not only play your favorite music or tells you weather but also understands your mood, helps plan your day, helps in cooking and acts as a potential companion. Users might receive guidance from these systems in form of text, speech, thoughts, visual, sensations that only humans can sense. If we augment these systems with ROBOT bodies, the opportunities become boundless, as these robotic systems may perform complex intricate surgeries, assist in rescue missions or perform scientific explorations. AGI can perform any software test that any human can, deduce results and take corrective measures.
6) Super Intelligent AI – These types of AI would improve, adapt and evolve without any human input. This self-improving nature could lead to an exponential growth in incredibly short time. Such unparalleled knowledge can compete with human skills and solve problems currently deemed impossible within the boundaries of human comprehension. This intellectual prowess of machines could be trillions of times more intelligent than human knowledge, thus bringing more risk & threats to human survival with these super comprehensive and powerful AI machines. Concepts that are in the realms of science fiction today might transition into tangible realities.
7) Self Aware AI – These systems could use quantum algorithms to model human consciousness. This could lead to AI's that have an intrinsic understanding of their own internal state, develop conscious and their inter-relation with this vast external world. They could even have a full range of emotions and senses even beyond human experience.
8) Transcendent AI – Such AI systems potentially craft new LIFE forms that can be biological, digital or something very different with tailor made attributes and functionality. Some of these life forms can transform our planet in the most beneficial possible ways by connecting & integrating the consciousness of multiple entities to create awareness and promote growth.
9) Cosmic AI – These AI solutions might possess inter stellar capabilities. Their capabilities could far surpass the capabilities of any science fiction, create massive intelligence networks, might merge with the fabric of the entire universe. These could have deep understanding of physical, meta physical existence of existing universe.
10) God Like AI – AI systems which are present everywhere, powerful and can operate in realms beyond our imaginations harnessing computational powers from parallel realities. These could create all new universes/ realities from existing information.



The above figure shows a contrast between the AI development life cycle in the center (inner layer), and the human development cycle as the outer layer in the diagrammatic representation.

To understand the AI stages and lifecycle, it is very important to first understand the human life cycle and the way we are born as babies, descend towards knowing the world and then finally in our late retirement ages plan to move towards spirituality in the pursuit of embracing God and connecting with God. The AI development cycle is also synonymous to the human cycle as initial AI systems were rule-based, which needed guided rule sets, which are now evolving as machines which can self learn, reproduce and understand cosmic origins.

II. AI OVER RAIL CONTROL SYSTEMS

Trains have always been symbols of progress connecting cities and enabling goods transmission promoting business expansion & growth. Today a new revolution is on the way for the railway's community powered by Artificial Intelligence. AI is transforming how rails operate, promising more safer, and smarter ways by which humans commute, opening occasions for more harmonious and comfortable passenger travel experience. From predictive maintenance needs to autonomous train operations, AI is revolutionizing rail operations. Here is a list of applications for the use of AI within the rail sector for better rail control & operations:

1. Digital Assistance – These are conversational AI systems to confirm tickets, to ensure train arrival times, to re-direct passengers to less crowded cab cars, provide station directions. Such assistance software systems can be deployed in tabloids, hand-held devices or even in smart phone apps to provide easy access to real time information.
2. Route Planning and Scheduling-Trained models are utilized here to optimize traffic routes, forecast weather conditions for rail movements and improve train schedules with informed data analytics.

   The current operations suffer difficulties with traffic predictions, time tabling, rescheduling and shunting. To improve such difficult and dynamic conditions, the use of intelligent knowledge-based reasoning and decision making systems have shown better timetabling and predictions across railway lines.
3. Autonomous Trains (Un-manned Driver less URBAN trains)- Autonomous Driver Less Train

(ATO) systems moderate the brake control system and help handle the train speeds, with information being obtained from Radio Block Center (RBC), to handle driver less operations. These driverless systems ensure safe train movements.

4. CCTV for Passengers Safety and Service- People on TRACK can be detected with such systems and can be immediately informed to the controller. Detection zones and the trespasser detection systems applied to stop the train in areas where human movements are prevailing are beneficial for station & track monitoring. These systems analyze passenger density, handle station thefts or UN-ATTENDED BAGGAGE to prevent terror-prone attacks on railway stations.
5. Automatic Track Inspection (ATI) – Railway tracks are critical infrastructure requiring regular monitoring to ensure safety, prevent accidents. ATI can be achieved through cameras and sensor devices on tracks. AI based detection and control mechanisms rely on using a combination of sensors accumulating information which can be of various forms. There are various kinds of sensors handling such rail track monitoring. PIR (Passive Infrared) sensors measure human and animal presence whereas Ultrasonic sensors detect flood levels by measuring time intervals between consecutive waves. Infrared sensors sense cracks between rail tracks. These sensors collect data continuously, and upon detecting any outliers, raise alarms prompting immediate actions to the locomotive driver or the rail authority personnel. With the presence of these sensors, it is conveniently possible to predict whether the 'Track Ahead' is free for the train to pass across the railway track or not, and the same information can then be provided to the train driver in real time helping prevent accidents.
6. Internal Operations- These ensure predictive maintenance by installing multiple sensors on Rail segments to ensure powerful operations which turn trains into rolling data centers. Railway inspections, driver behavior analysis, cab car sanitary conditions and passenger crowd index per train can all be tracked by such sensor units attached on tracks, onboard train units and station platforms.

III. HANDLING RAIL OPERATIONS WITH RESPONSIBLE AI SOLUTIONS

Traditionally, maintenance has been a corrective process, where repairs or replacement start to take place, once a problem or defect comes to the topmost layer and is highlighted. AI has reversed the process by predicting potential issues before they become major problems by analyzing huge data sets. Managing massive rail networks require AI based data analytics for faster, more reliable operation and maintenance of rail tracks. With the advent of AI based solutions, re-inspections and repairs, happen as immediately as possible. In addition, occurrence of minor track faults decrease to a large extent and very less speed warnings are issued due to major track irregularities.

The amplitude of rain movements caused by strong winds can also be studied with the help of AI systems. Technology can improve the new data analysis with raw data collection by AI, including the data for rail body movements, meteorological records and real vibrations, which earlier were collected once a week/month. With machine intelligence, regular reports can be accumulated, with predictive data collection becoming more convenient.

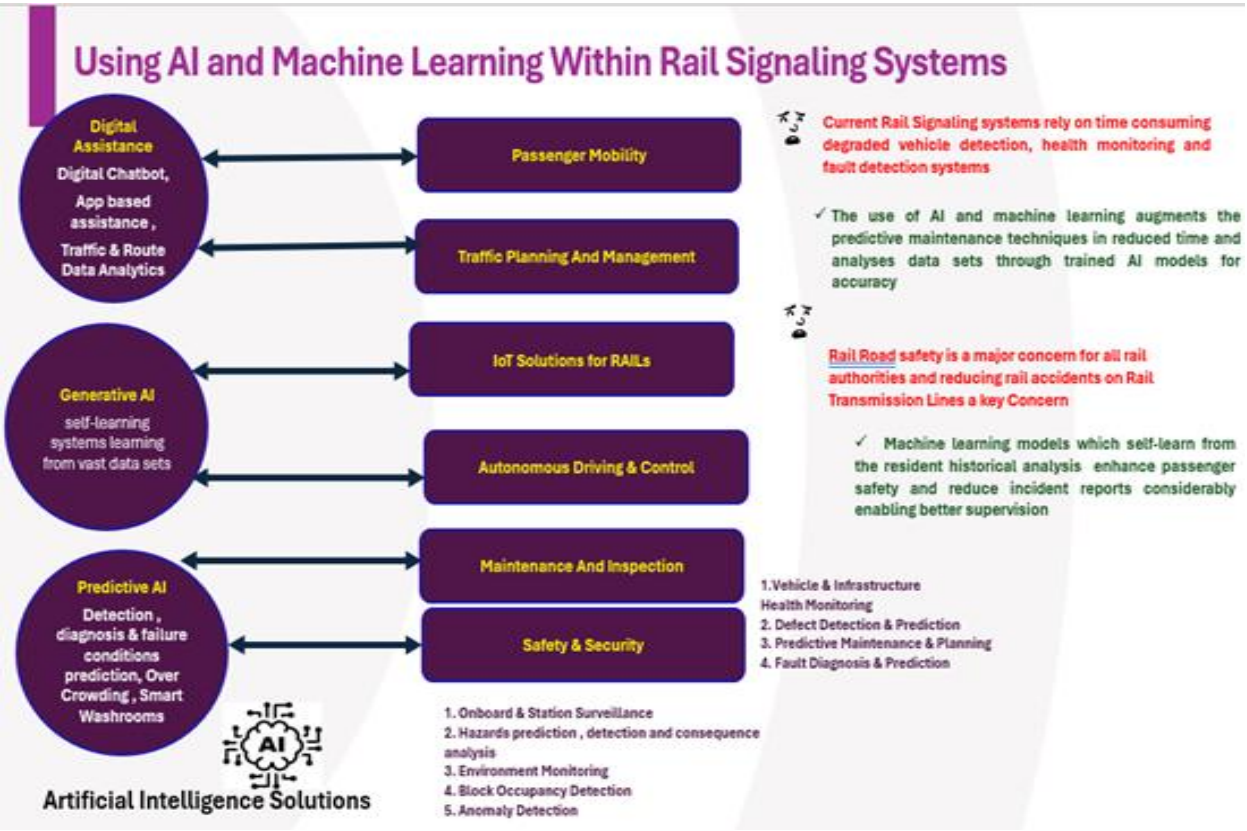
IV. RAIL SAFETY WITH GENERATIVE AI

An AI system has the capability to process vast amounts of real time data accumulated over trains across the country and can alert maintenance teams of abnormal conditions. The maintenance of rails is generally challenging as wires and rails age over a period posing a challenge to maintain safe operations. With the introduction of AI, the number of track incidents are expected to decrease tremendously.

AI systems monitor the conditions of tools and machinery in real time identifying potential issues before they turn into problems. This not only saves time and money but also increases safety at rail construction sites. Machine learning algorithms learn from past incidents and predict potential hazards enabling preventive measures to be put in place.

Artificial intelligence can significantly improve productivity by improving efficiency & reducing time on task that can be automated, which means less guess work and more data driven decisions leading to a higher reduction in cost. Its not just about reduction in

cost but also, AI has the potential to enhance safety. The figure below summarizes how artificial intelligence and machine learning concepts can be utilized in rail signaling systems:



Machine intelligence can predict and issue warnings before problems arise, enabling precise and timely maintenance that keeps the infrastructure of high-speed rail lines in better conditions than when it was first built. The significant amount of data generated in high-speed rail units force rail infrastructure authorities to adopt new technologies such as BIG DATA and AI.

AI's advantage lies in its ability to analyze diverse data, identify potential problem related clues and uncover previously unknown connections within seemingly chaotic data sets. This enables more precise fault identification and prediction. Efficiency also improves with improved safety and fewer incidents occurring on site.

Artificial intelligence based sensors in major trains within the onboard system can become active if the loco driver does not show any activity for certain fraction of seconds so that emergency does not occur, and brakes start to apply. Here are some of the key concerns which can be addressed with using AI responsibly for the betterment of mankind:

Preventing Suicide on Railway Tracks – There remain multiple suicide cases of people committing suicides specially in metro political cities across the world, where people jump on the track causing temporary disruptions. These incidences highlight the importance of safety measures in public transit systems. With the increasing frequency of such events, the integration of AI-driven computer vision systems could be a game-changer. These systems could monitor visual feeds, detect dangerous behaviors, like someone entering restricted areas and immediately inform authorities. This technology would not only enhance safety but could potentially prevent tragedies by enabling rapid intervention. If implemented effectively, this can significantly reduce the response times.

AI driven Rail Car Inspection – AI driven train inspections rely on the outputs obtained from cameras installed in and around the trains which take 360-degree view of the train while entering /leaving rail yards. This helps in identifying what kind of defects the train has. The amount of data that is captured is processed with the existing IT infrastructure and then

pipelined to AI algorithms to identify mechanical flaws and safety issues. This can also require special storage for this huge image data which gets eventually processed by AI engines. Software Defined Storage (SDS) methodologies help define DPUs (Data Processing Unit) which manages data storage resources by removing dependencies on underlying physical storage hardware helping to perform more efficiently, for the challenge of storing high resolution images. As each camera possesses different characteristics in taking pictures, therefore, the challenge for an AI algorithm becomes higher with such a heterogenous set of image data.

With the collected images, the engineers create training models, which give near re-usable data.

It has several applications in Rail Yard Management and the defects picked up by these cameras (which might or might not be seen by the mechanical car engineer) can enable in capturing defects in Open DOORS, bottom sides of train brakes, trespasser detection, track foreign object detections.

Crowd Monitoring and Enhanced Security at Stations – This system works as "digital eyes on the ground" pin pointing safety and security issues as they arise. It involves predictions based on historical crowd data to forecast crowd patterns and enhance the overall traveler experience.

AI Sprinkler Systems – There have been a recent trend in trying some AI powered sprinkler systems which would first detect if there is fire outage in the rail station, and if so, the camera sensors would detect within seconds of passing over the detection zone, and then also issue commands for water sprinklers to be started over the hazardous areas. These AI powered sensors first detect the presence of unwanted elements (like fire), and not only learn from the situational data, but also take corrective measures, which for any human to achieve in such a short span of time, is near impossible, also saving injuries which could have been caused because of the incidence.

AI Health And Safety Management Solution – Hazardous Area Monitoring

For increasing rail safety and security, there are various problems to be addressed which are related to object detection, incident analysis or station security and to solve these problems computer vision & image processing techniques can be used in the procedure of anomaly/object detection. There are various expert systems getting implemented which combine the rule based and case based reasoning systems. Neural networks and Natural Language Processing is used widely for accident report processing and analysis.

AI Powered Trains

As AI technology continues to evolve, its impact on railways will only grow exponentially. The number of tracks irregularities, speed reductions, strong wind indications and track & train anomalies can all be detected with sensors & devices fitted on the wayside and onboard trains. Engineers are launching AI powered autonomous trains used for navigating intricate rail networks without human at the helm, increasing safety and efficiency, reducing energy consumption and delays.

V. FUTURE TRENDS IN RAIL INDUSTRY WITH AI

The railway industry is undergoing major transformation and Onboard and wayside deployments require exceptional ruggedness. To cater to these tough needs, its vital to list what the future trends in railways would improve, and how we can adapt to new technological needs and still maintain safe transportation ensuring passenger safety, comfort and enhance user experience. The following best practices might help transform the existing systems with wise categorization and deployment of AI based rail solutions, and help the rail signaling engineers deduce better AI models, compact, user-friendly digital assistance for passengers, and ensure safer train commutes:

Smaller AI models for a Smarter Future

Small models are really going to make a larger impact as compared to Large Language Model (LLM). Running these giant LLM models are cost-centric whereas smaller models deliver high performance with significantly lower computation power. This offers additional benefit of better performance in comparison to large language models breaking the misconceptions that "bigger is always better". Smaller, leaner, purpose-based models bring meaningful results which can be trained and deployed in fraction of cost as they are highly adaptable. With smaller AI models,

companies can even reduce their carbon footprints with less energy consumption. With smaller task specific models, these models can outperform the capabilities as showcased by large language models.
Computer Vision and Analysis – Computer vision and analytics provide powerful information that creates a safe environment for passengers such as breakdown detection & track anomaly detection.

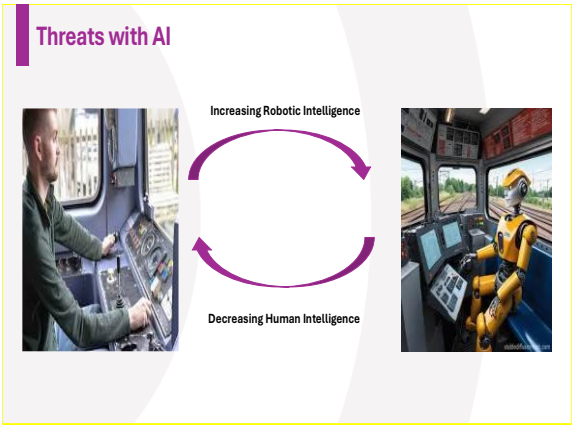
Hybrid Traffic Management with AI – Over the past decades, the railway traffic density increased, trains got faster, operational modes became more diverse. These changes have made traffic management more complex. The rail timetables are becoming increasingly complex because of extensive rail operations and railway line sharing. The scope of modifications of rail routes is burdening the rail operators in the event of accidents, and to restore timetables is therefore becoming complex and tedious for rail operators to manage. Time table management and other rail operations require advanced skills to be possessed by these rail operators. With the present day crunch of experienced rail operators in major countries, the use of machine learning AI to automatically calculate recovery plans for disrupted timetables is the need of the hour. Hybrid Traffic Management AI works by studying the recovery plans created by experienced rail operators for disruptive time tables. The results from Hybrid machine learning based AI models are then validated by the conventional rule-based models which creates ideal time table management proposals.

Inspection Robots and Intelligent Maintenance for Railway Vehicles
Intelligent robots fitted with high-speed cameras quickly collect information about vehicle bottom and unreachable areas like detecting bogies in all directions. After collecting high-definition images of vehicle components, the robot can identify vehicle faults by deep learning and feature recognition algorithms. This information can be transmitted in real time with wireless network control centers to request service support.

VI. THREATS WITH AI

AI can bring plethora of opportunities for automation, statistical analysis and predictive maintenance techniques, but, at the same time, it is also important to keep in mind the threats that Artificial Intelligence bring along with it. We as humans, must understand these threats, and work towards eliminating them. The following presents some of the threats which AI might bring in the times to come:

Decreasing Human Jobs
AI capabilities are increasingly rising whereas HUMAN capability development is slow and to an extent getting stagnated often bringing lethargy. AI may not take your Job but the people using AI will definitely have an impact in retaining their jobs. With such a dynamic environment, continuous learning and adaptation is the only way to bring survival of the human presence with the expanding machine intelligence. The MINDSET SHIFT needs to be made – “AI would progressively make my life positive, and I myself would learn a lot from the discoveries made by AI”. Some jobs will disappear for sure but we need to understand the need for increasing HUMAN intelligence at the same pace to compensate for the weaknesses of your GENIOUS COLLEAGUE (AI). Humans therefore need to keep that knowledge of what to ask from AI, how to formulate the prompts, what context to be provided and how to evaluate results. AI can be very productive some times, and at times be as stupid to answer simplest of prompts.



Too much Machine Control
To generate co-ordeal environments of operation between human and the machine and help both humans and the machines grow together, it is very much necessary to keep “HUMAN-IN-LOOP” along with autonomous train operations and define clear responsibilities for both the machine and human. If such a balance is not maintained, AI could prove to be

a potential threat to human existence rather than being a convenient colleague and gradually, humans may experience a sharp decrease in brain power use because of the lethargy being brought by too much reliance on machine intelligence.

VII. SUMMARY

Rail undertakings rely on legacy equipment, standard practices and known inter-operability standards which are followed by all rail suppliers. Revolutionizing the rail operations with the use of upcoming technologies like AI would require significant considerations, careful examination of data sets and a deep understanding of the core need of the rail units. With so many AI solutions already available in the market, it becomes even more difficult to deploy the most significant solutions with minimum negative impacts in production keeping in account also the human factors while maximizing the use of machines. This is not the age of just using AI, but using AI responsibly.

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SHRUTI KHATRI. An MTech in information technology, with 15+ years of experience working with rail control & protection systems, defense & aerospace & safety critical systems with vivid interest in project & process management, quality driven approach to system design and development with an inclination towards generating software systems keeping human needs as the most vital ingredient