Mine Automation and Data Analytics

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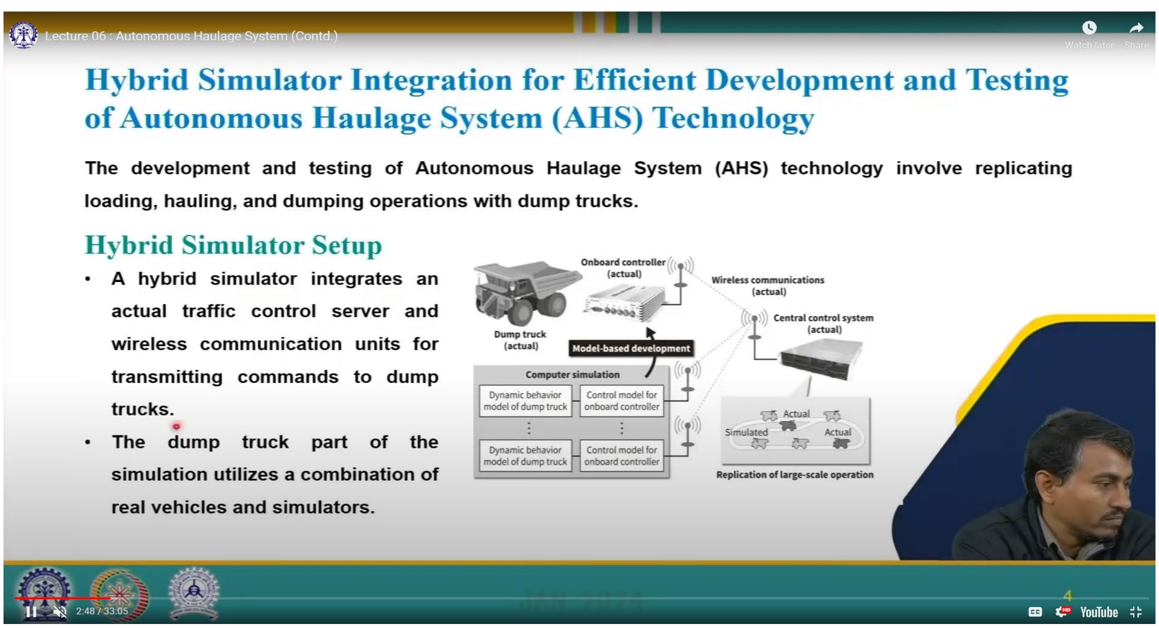
Week-2

Lecture-6

Autonomous Haulage System (Contd.)

Welcome back to my course mine automation and data analytics. So today we will cover in this lecture the second part of the autonomous haulage system. So, in this lecture, we are going to cover the following: First, we will discuss hybrid simulator integration for efficient development and testing of automated haulage systems. Then second, comprehensive test site configuration for an automated haulage system and third, different levels of systems in an automated haulage system. Then we will discuss the potential challenges of an autonomous haulage system in the mining industry. We will also discuss the risk management practices in the autonomous haulage system.

So let us focus on the hybrid simulator integration for efficient development and testing of autonomous haulage system technology. So, the development and testing of autonomous haulage system technology involve replicating, loading, and dumping operations with dump trucks.

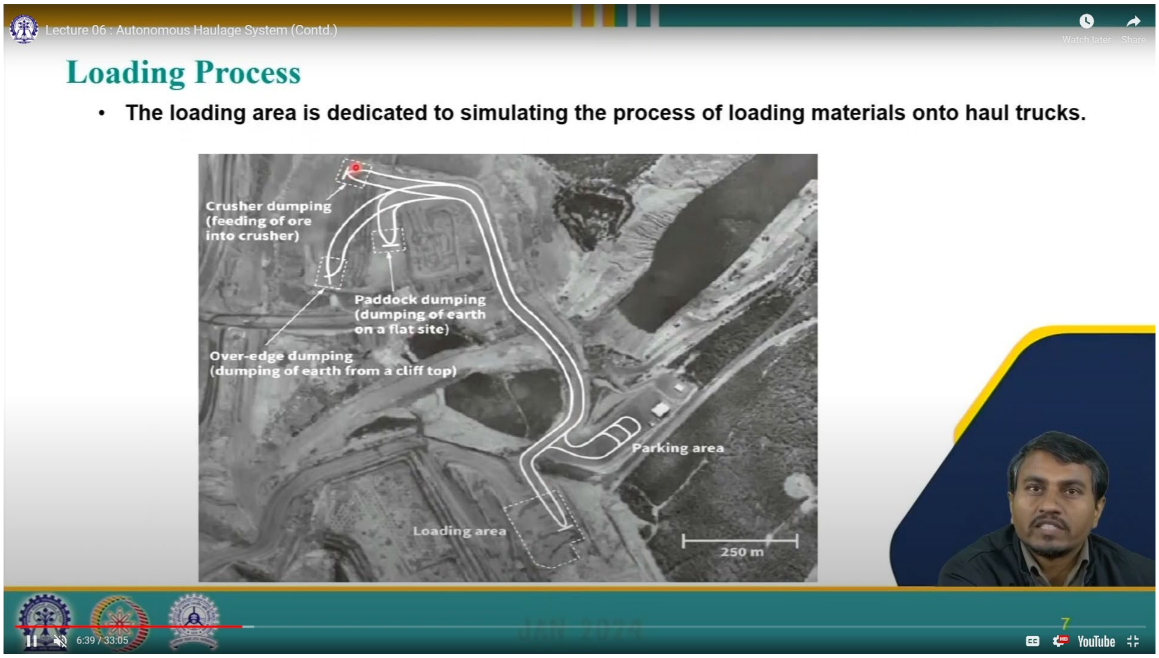


Hybrid simulator setup-A hybrid simulator integrates an actual traffic control server and a wireless communications unit for transmitting commands to dump trucks. So, the dump truck part of the simulation utilizes a combination of real vehicles and simulators. So here is an example. Here is the real dump truck, and here we have some simulated vehicles. So, with the actual vehicles, actual dump trucks, and simulated vehicles, they are basically working in this particular mine environment. This is a replication of the mine environment. So, there is one actual central control system, there is a wireless communication system, and there is an onboard controller. So, this particular hybrid simulator basically works for model-based developments. So, this computer simulation helps with the dynamic behavior model of the dump truck and the control model for onboard controllers with different setups.

Model-based development-So onboard controller control logic is created using a model-based development method. So, the control model is initially developed on the simulator and then directly protected by the onboard controller, reducing development time. So, this is a real simulation. It can be scalable at any point in time. So, this hybrid simulator can replicate and test mining operations with around 100 vehicles by modeling them as virtual dump trucks. This scalability enables thorough testing and validation of automated haulage system technology in various mining scenarios. Early-stage traffic control testing. A combination of actual and virtual dump trucks is used for early-stage testing of traffic control. So, this approach ensures the safety of real vehicles during testing while providing comprehensive insights into system functionality. So let us focus on comprehensive test site configuration for simulating and evaluating mine site operations.

Test site configuration-The test site is organized into specific zones to replicate mine site operations. It includes one loading area and three distinct dumping areas. Sequential operation replication-The site is designed to faithfully evaluate the sequence of operations observed at a mine site. So, this encompasses the loading, hauling, and dumping phases.

So let us see the loading process-The loading area is dedicated to simulating the process of loading materials onto haul trucks. So here in this area, we have a dedicated loading area, and three dumping areas are designated. One is crusher dumping, the feeding of ore

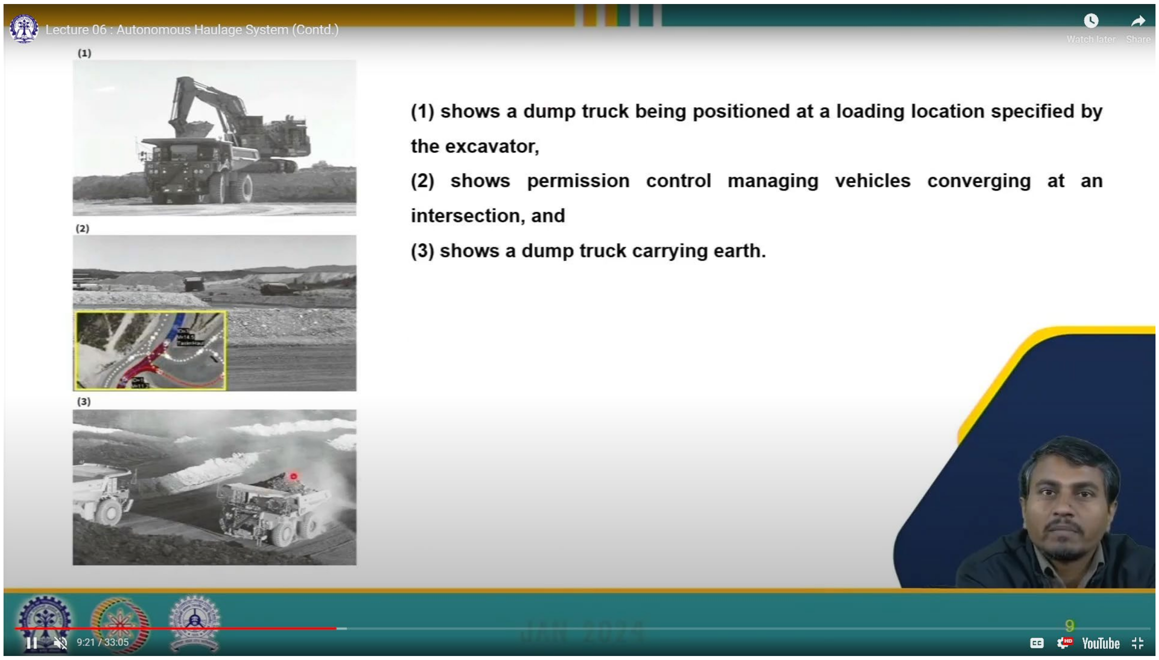


into the crusher. Second is over-edge dumping, dumping of earthen materials from the cliff top, and third is the paddock of dumping, dumping of earthen material on the flat side. There is another side that is a parking area where the vehicles will park during their ideal time or maybe during their maintenance time. So, this is basically the route map for testing the configurations.

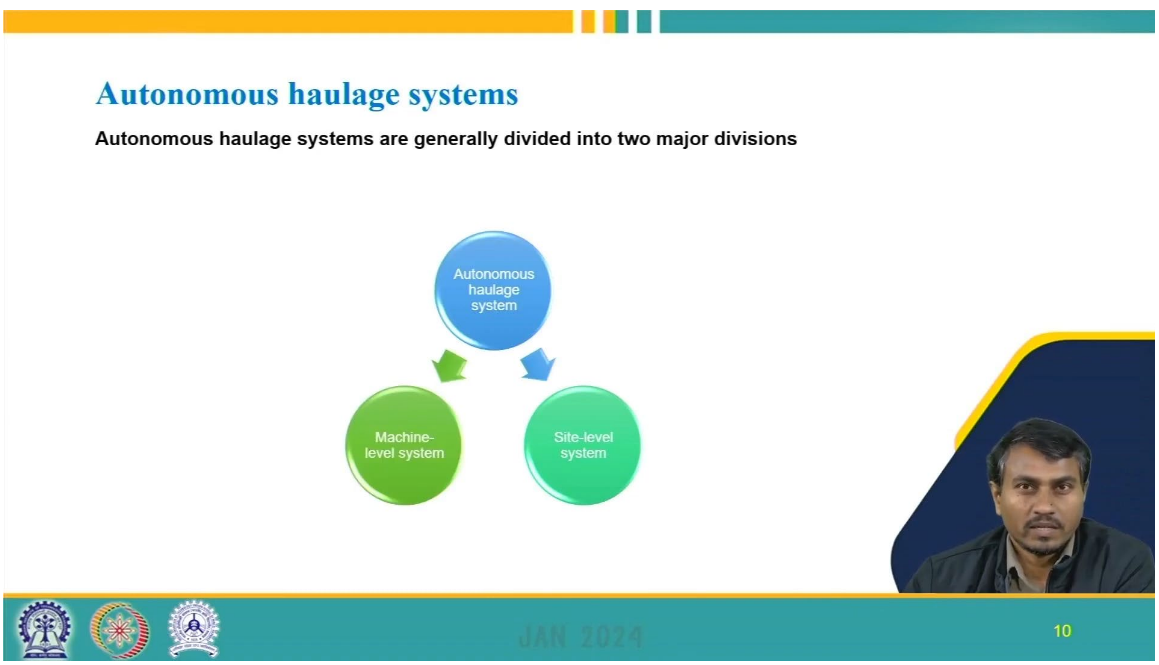
Hauling phase-So the haul trucks transport loaded materials from the loading area to other locations within the testing facility.

Dumping operations-Three distinct dumping areas are provided to replicate the dumping phase of mine site operations. In all mines, there are dumping stages, loading stages, and hauling stages. So, these are basically replicated in the simulation stage.

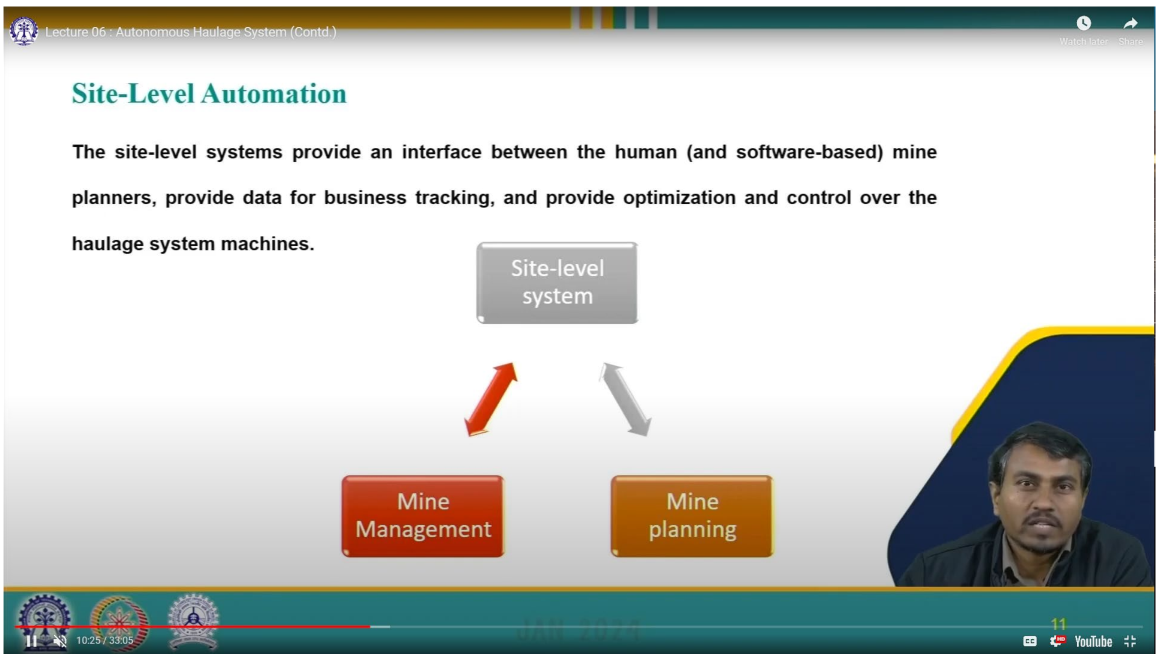
Comprehensive testing environment-The configured layout facilitates thorough and accurate testing of the entire sequence of mine site operations. So, these models are basically doing the same thing as what is done at the site with the simulation, so the development time of these modules is reduced. So, this setup enables the assessment of the performance and efficiency of the systems involved in loading, hauling, and dumping processes. So let us see these three pictures. So, the first picture shows a dump truck being positioned at a loading location specified by the excavator. Then the second picture



shows the permission-control-managing vehicles converging at an intersection. So, at these intersections, there are specific permission controls for different vehicles operating at this particular mine site. Third is showing the dump carrying the earthen materials in the mines.



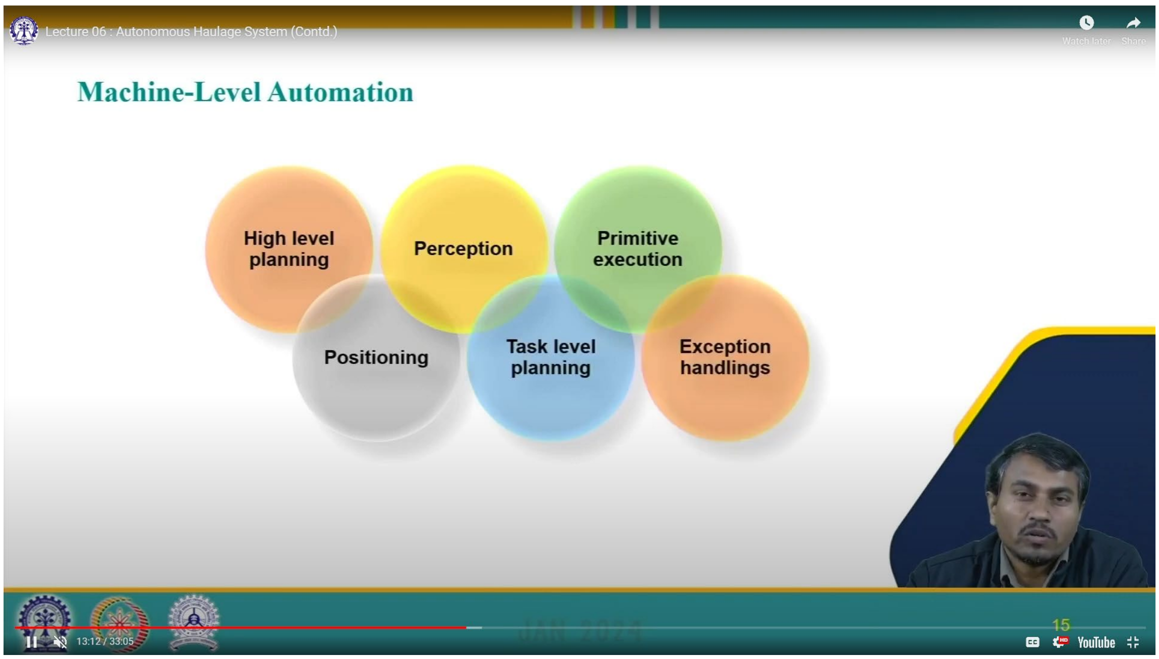
Autonomous haulage system-Autonomous haulage systems are generally divided into two major divisions. One is the site-level system; the second is the machine-level system. So let us focus on site-level automation. The site-level system provides an interface between human and software-based mine planners, provides data for business tracking, and provides optimization and control over the haulage system machines. The site-level system consists of mine planning and mine management. So, both are interconnected, and in the synchronous operation of these things, the synchronous execution of mine planning by the mine management basically comprises site-level automation and site-level systems.



Mine planning-Significant human introduction is essential for setting goals in mine planning. Goals include prioritizing production volume and considering significant cost factors such as fuel usage and the risk of machine damage. Another aspect involved prioritizing long-term production needs versus long-term mine efficiency. The challenges in mine planning lie in accurately translating both explicit and implicit goals into the automated mine management system.

Mine management-A substantial amount of experience exists in the field of mine management systems. Despite this, the evolving landscape demands a new generation of mine management systems. The emerging need is driven by the requirements of autonomous systems within mining operations. The upcoming generation of these systems will necessitate more intricate mine models. Additionally, a host of new features will be essential to effectively managing autonomous equipment in mines.

Machine-level automation-Machine-level automation requires the ability to understand what tasks need to be accomplished, high-level planning, and determining location, that is, positioning. Perceive the environment based on the location and perception. Based on the environment and position, plan future tasks to achieve the desired goals.



Execute the planned primitives, handle primitive execution, and handle exceptions. Machine-level automation comprises high-level planning, perception, primitive execution, positioning, task-level planning, and exception handling. So, all these building blocks need to work in tandem so machine-level automation can be successfully implemented in the overall automation strategy of an automated haulage system. So, synchronization of all these operations is the aim of an automated haulage system so that it can function well, perform well, and basically hire up the utilization of machines during the mining process. High-level planning. Interpreting directions from the mine management system is a key aspect of high-level planning. The autonomous truck must select appropriate behaviors based on the provided directions. When directed to a load area, the truck needs to comprehend the path it should take. Validation of the chosen path is crucial to ensuring accuracy and safety in execution. The autonomous truck must confirm that it possesses the necessary behavior and capabilities to carry out the plan effectively.

Positioning-Positioning involves determining the machine's pose, which includes its location and orientation. In the case of autonomous machines, having an accurate and reliable pose is crucial. While absolute accuracy is not always the top priority, accurately registering the machine's pose to the mine model is a necessary requirement. The process of positioning involves considering multiple types of positioning methods to meet the desired accuracy and reliability. For above-ground applications, the most common real-time kinematic, kinetic global navigation satellite system RTK GNSS are A.) RTK GNSS plus machine sensors such as odometers; B.) RTK GNSS plus machine sensor plus inertial measurement unit; C.) RTK GNSS plus machine sensor plus inertial measurement unit plus perception-based positioning; and D.) RTK GNSS plus machine sensor plus inertial plus pseudo lights, ground-based satellites or reference satellites.

So, this is basically the machine having all these facilities to get an accurate position. Here is the inertial measurement unit, here is the GPS antenna, here is the GPS receiver, here is the control system, and here is the hydraulic valve model. So, these are basically fitted onto this machine and everything working in tandem so that machine can perform well in the exact mine environment that is replicated and model for this particular machine for its higher performance. For below-ground applications, the most common types of positioning systems are radio frequency-based distance measurement, perception-based positioning machines plus machine sensors, perception-based positioning plus machine sensors plus inertial measurement units, and perception-based systems used in factories for over two decades and in mining for nearly 10 years. The RTK GNSS-based system has offered centimeter-level accuracy in construction for decades. RTK GNSS needs augmentation due to poor coverage, especially near poles and areas with blockage. So, there is a significant development in this particular aspect: global government support is increasing and promising improved GNSS coverage with more satellite deployment. Inertial sensors plus odometers are a well-proven short-duration technology for GNSS augmentation. Other options include pseudo lights and RF ranging for ground-based positioning, but they are costly to install and maintain. So, this is a typical example of pseudo-lights in addition to the GNSS system, which basically helps for better precision in the positioning of that particular machine that is plying on the ground on the mine site.

Perception: An autonomous machine needs a thorough understanding of its surroundings for object detection and occasional positioning assistance. The perception system relies on information from the mine model and positioning system for accurate object location reporting. The common forms of perception sensors include radar, laser, vision, and sonar. So, these sensors contribute to the machine's ability to interpret and navigate its environment effectively. A seamless integration of perception data with the mine model and positioning system enhances overall autonomous machine performance. Perception sensors, radar, millimeter wave radar, and the and the recent development of our object detection capabilities. Radar strengths include long-range detection and the ability to penetrate dust and fog. However, radar has a lower resolution compared to laser-based systems. Object detection size is influenced by the radar cross section and determined by the object projected area returning the signal. So, this is a typical example of a radar system fitted in many machines of the AHS system.

Let us discuss a few questions

Question 01

What is the purpose of the wireless communication unit in a hybrid simulator? broadcasting traffic updates, transmitting commands to dump tracks, controlling virtual reality simulations, and monitoring pedestrian traffic.

The right answer is transmitting commands to dump tracks.

Question 02

What does the perception system of an autonomous machine rely on for accurate object location reporting? Global weather reports, satellite imagery, mine model and positioning system, and historical data of mine area.

The right answer is mine model and positioning system.

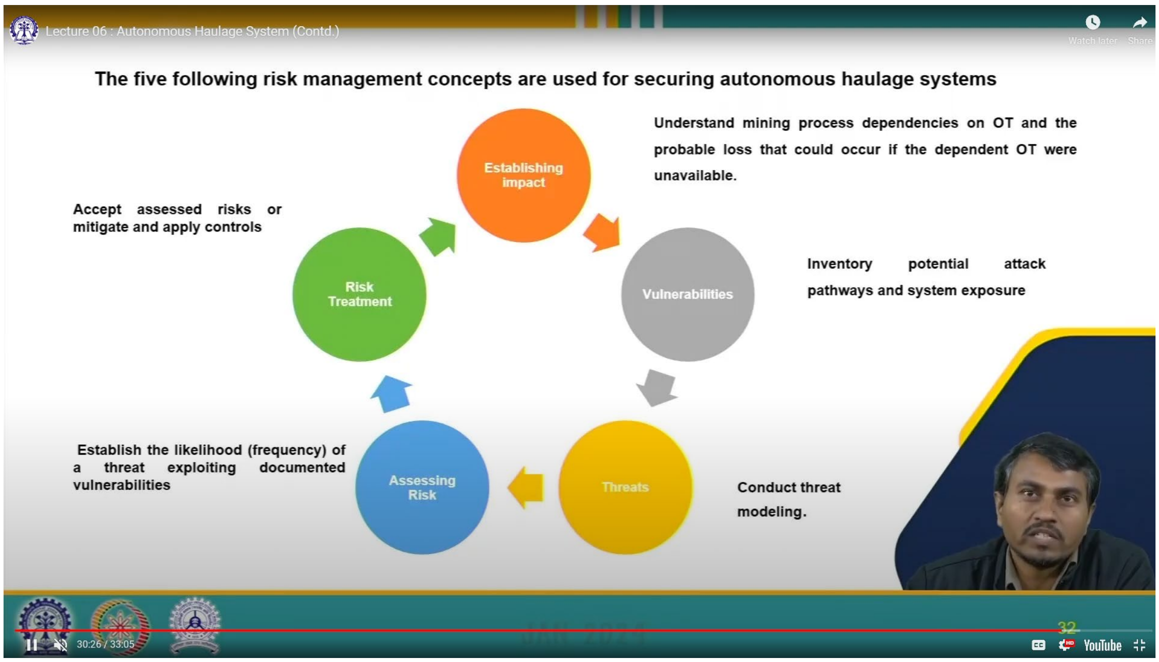
Laser sensors-Laser systems offer the best resolution but can be affected by the presence of dust and fog. Newer lasers address this limitation through multiple reflections from each point or time, getting returns to mitigate interference from small diffuse particles such as dust, fog, rain, and snow. The method's effectiveness diminishes as particle density increases. So, in a very dusty environment, this laser sensing system will not be functional. Retro reflectors like tail lights or reflective tapes can be added to targets to significantly improve their visibility to lasers. So, this is a typical picture of a laser sensing system that is installed on the autonomous haulage system in the front as well as in the back to get the data and picture about the mine environment.

Task-level planning-Task-level planning involves creating a sequence of tasks or behaviors to achieve a goal and is typically rule- or constraint-based. The nature of task planning depends on factors such as goal type, the number of constraints, environmental variability, and automated system flexibility. Machine-level planning often includes tasks related to object avoidance. Object avoidance is a common and essential aspect of machine-level planning within automated systems. Primitive execution-Using planned primitives is a fundamental machine operation. Examples of these operations include drilling, trimming, loading, grading, stability control, dumping, and ripping. These operations typically involve continuous closed-loop control. They closely resemble human skills in machine operations. Exception handling-There are some capabilities of this kind of automation system. So, handling exception is the ability of an autonomous machine to recognize that it does not have the means or required primitive ability to handle the existing situation, and thus it resorts to fail-safe behavior, usually stopping and asking for help, or that is a fallback system.

Challenges in autonomous haulage systems in the mining industry-Autonomous haulage systems function as cyber-physical systems and heavily rely on wireless communications incorporating systems or object avoidance detection global positioning systems like GNSS and artificial intelligence. So, the autonomous haul truck needs constant wireless connectivity, and that is vital for tracking in challenging terrain during autonomous haulage system operation in mines. The reliance on wireless technology introduces challenges, including frequency interference, concern about channel utilization for efficient communication, and the risk of signal jamming impacting the reliability of communication links. The integration of operational technology and information technology in AHS increases vulnerability to cyber security issues. The combination of AHS with wireless technology and OT-IT integration presents operational and cyber security challenges requiring careful consideration during implementation and maintenance.

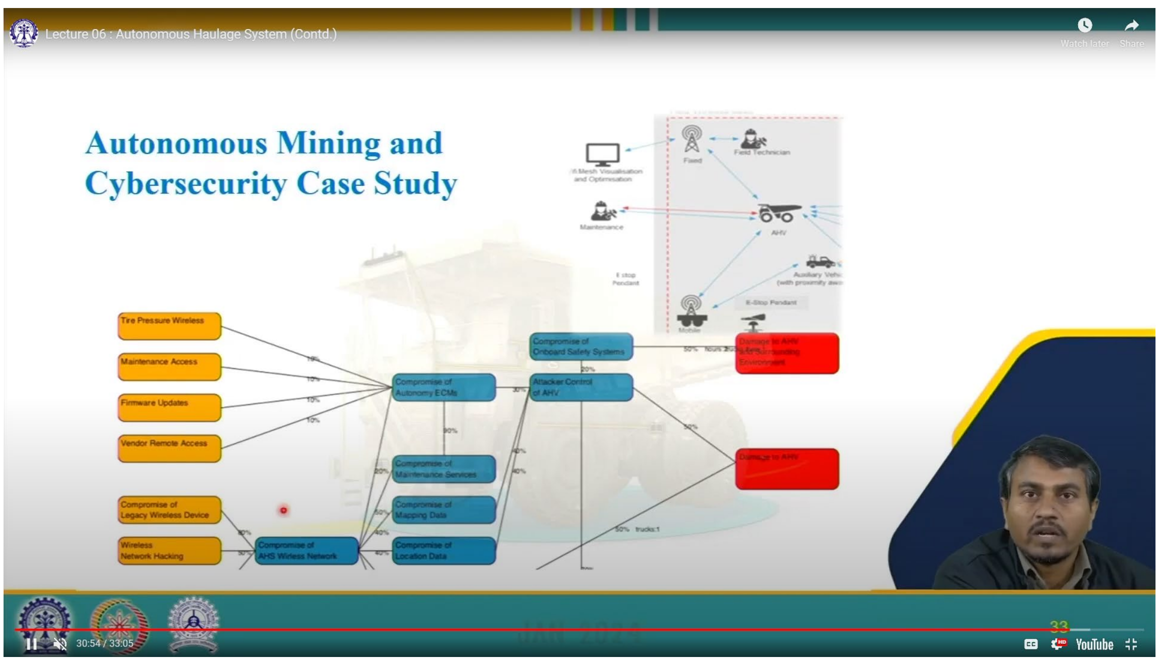
GPS positioning in an autonomous haulage system: understanding and mitigating realistic threats-Securing GPS positions is of the utmost importance in an autonomous haulage system. Classifying GPS attacks into two categories: spoofing and jamming, with a focus on their realistic nature. Spoofing is the act of intentionally misleading the correct location by creating a false signal. On the other hand, jamming uses sophisticated techniques such as nulling to eliminate GPS signals by transmitting encrypted negative signals, enabling covert attacks. The insufficient safeguarding of GPS data presents a significant safety risk that could result in severe collisions with other automated haulage system settings.

Automated haulage system-Risk management practices: Securing autonomous haulage systems comes down to understanding autonomous haulage systems comes down to understanding the risk relationship between operational assets used in the mining process and the autonomous system on which the processes are dependent. These dependencies can pose potential safety, production, and regulatory compliance impacts and risks. Understanding good risk management practices, including security requirements, is crucial to securing an autonomous haulage system effectively.



The five following risk management concepts are used for securing an autonomous haulage system. First, establishing impact means understanding the mining process dependencies on OT and the probable loss that could occur if the dependent OT were unavailable. Vulnerabilities-inventory potential attack pathway, and system exposure. Third, the threat-conducting threat modeling that will help to assess how the system is compatible under these threats. Understanding risk will establish the likelihood or frequency of a threat exploiting documented vulnerabilities. Then the last is the risk treatment, which accepts, assesses, mitigates, and applies control. These five things are interrelated, and that basically comprises the management concept of securing the autonomous haulage system.

Autonomous mining and cybersecurity case study-Here, we are basically trying to showcase the vulnerability related to this autonomous system and its compromising possibilities. So, these are basically the tire pressure or less; these are the maintenance access, farmer access, vendor remote access, and compromise of the legacy wireless devices and wireless network handling. So, these are the areas where there is a possibility that wireless data can be compromised and that may damage the autonomous haulage system. So, the interrelationship with different data and different tools is shown so that a robust secure cybersecurity model can be built up for this kind of automated haulage system and that can be implemented in the mindset, and different mindsets basically take into consideration these risk factors and the possibilities of threats and attacks, and that is basically already incorporated into the newer version of the autonomous haulage systems.



So, these are the references. So let us conclude in a few sentences what we have covered in this lesson. So, we have explored the integration of hybrid simulators for streamlined development and testing of autonomous haulage systems, emphasizing efficiency in the developmental phase. We have discussed the configuration of a comprehensive test site tailored for AHS, recognizing the importance of a realistic testing environment to validate system functionality. We have examined the different levels of systems within the autonomous haulage system, providing insight into the hierarchical structure and functionalities of various tires. We have addressed the challenges inherent in the implementation of autonomous haulage systems in the mining industry, acknowledging and analyzing obstacles to their seamless integration. Thank you. We will meet you again in the next lecture.