Mine Automation and Data Analytics

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IIT (ISM) Dhanbad

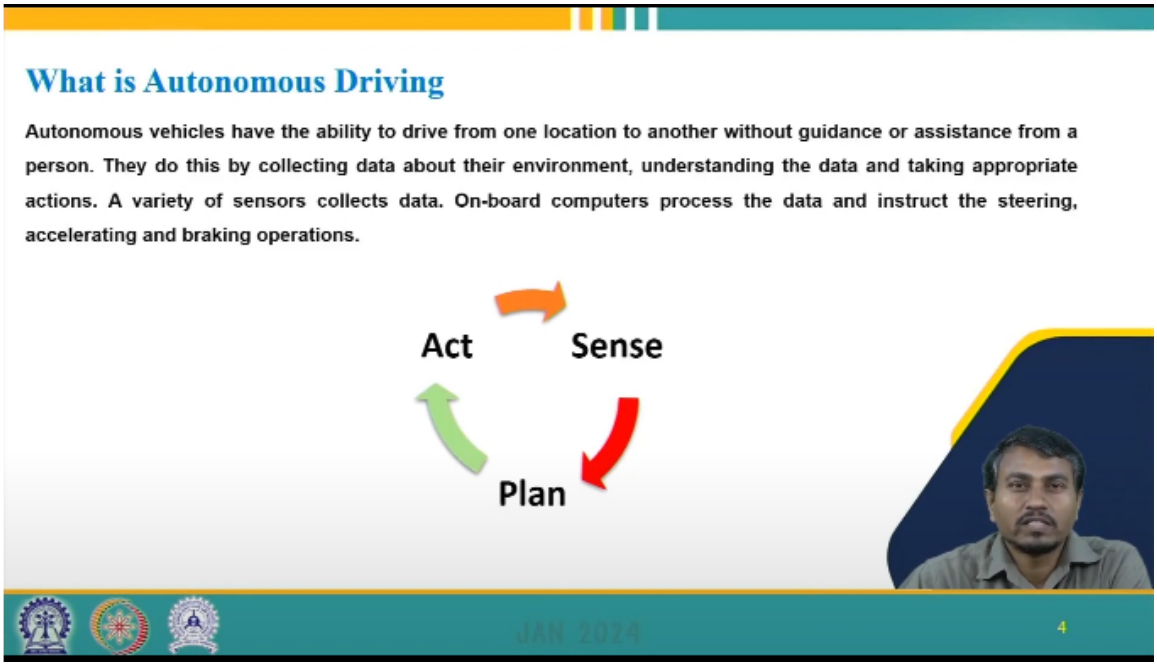
Week-1

Lecture-5

Autonomous Haulage System

Welcome back to my course on automation and data analytics. Today we are going to cover the automated haulage system in mines. So, the first part of the lecture we will cover in this particular lesson is the is the autonomous haulage system. So, in this course, we are going to cover autonomous driving and then, we are going to cover the autonomous haulage system and the different sensors used. We will discuss the benefits of autonomous haul trucks for mining, economic analysis of autonomous haul trucks. We will also show you some of the haul truck manufacturers and automated haul truck manufacturers, and we will also discuss the features of the features of the automated haulage system. We will discuss the haulage system workflows, principles of permission control in the routes, and finally, in today's lesson, we will cover the conversion capabilities of an existing dump truck to the automated haul truck system.

So, what is autonomous driving? Autonomous driving is basically a vehicle that drives from one location to another without any guidance or assistance from a human operator.

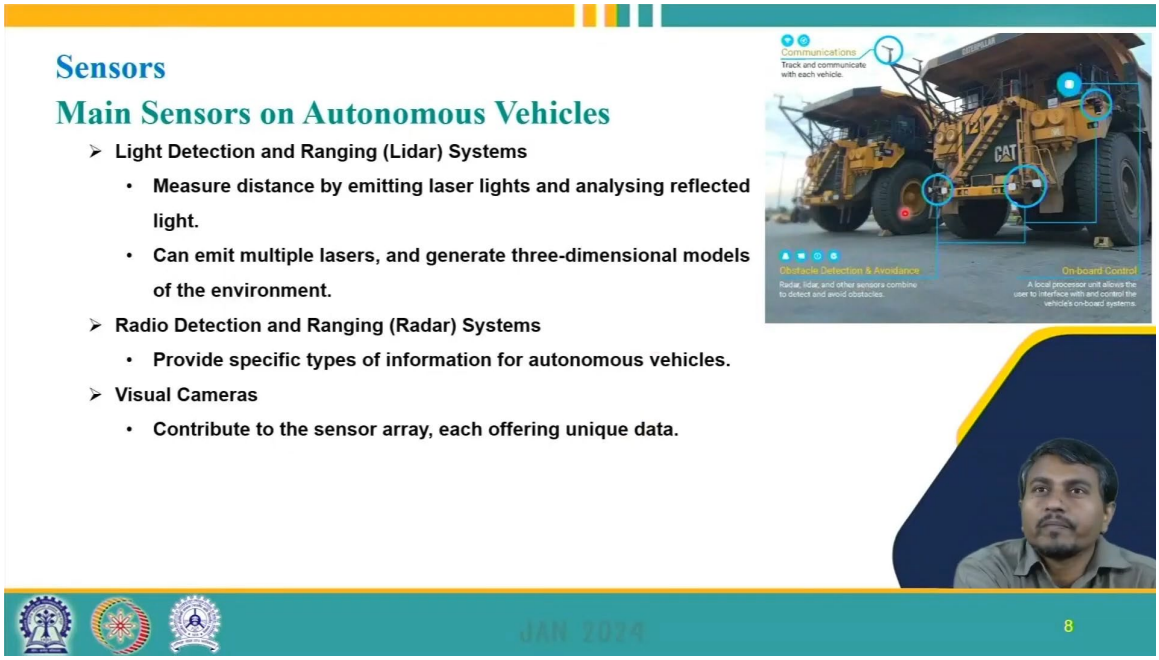


So, it is done by collecting data about the environment, and the onboard system analyzes the data, understands the data, and takes appropriate action. So, there are a variety of censoring systems onboard the autonomous vehicle that basically collect the data from time to time, and the onboard computers process the data and instruct the steering, accelerating, and braking operations.

So, there are basically three actions that work in tandem. So, these actions are acts, senses, and plans. The autonomous driving system works in tandem continuously in continuous coordination of these three actions: action sensing and planning. So let us discuss the autonomous haulage system, so autonomous haulage systems transform conventional haul trucks into unmanned vehicles. Here, there is no human operator in the cabin. So, this technology incorporates wired and wireless networks, virtual infrastructures, servers, and a central control tower with standard desktops and workstations. It has a high-precision global positioning system that ensures one-centimeter accuracy for all mobile vehicles within the autonomous system or autonomous area. This is a typical example of a picture from a mine site autonomous haul truck conveying the materials.

So, it has several safety features, including a lidar and radar system for obstacle detection as well as collision avoidance. So that is a very important feature of collision avoidance, which basically reduces significantly the number of accidents at the mine site with the use of this automated haul truck system. Onboard supervisory logic governs the vehicle, and it's allowing integration with other mine vehicles like light trucks, dozers, and loaders because these machines are also operated by human operators, and there should be some kind of synchronization with these vehicles plying at the mine site or seamless operation of different operations related to mining. Operators monitor the status of the autonomous haulage system and issue vehicle routes following commands. Here, operator means the operator sitting at the central control system. Field operators update vehicle route information based on changes in the mining environment, such as breakdowns or obstacles on the haul routes. So, there are some additional considerations for the automated haulage system. These include autonomous haulage systems, which have a higher risk profile than conventional vehicle operations. These systems rely on wireless technologies for safe production and operational control. Digital transformation within the mining industry has enabled rich connectivity to the operational technology network from enterprise systems, and these existing relevant standards focus on safety, but cyber security is a minor consideration here. So, these standards typically revolve around mitigating risk for personal and functional safety.

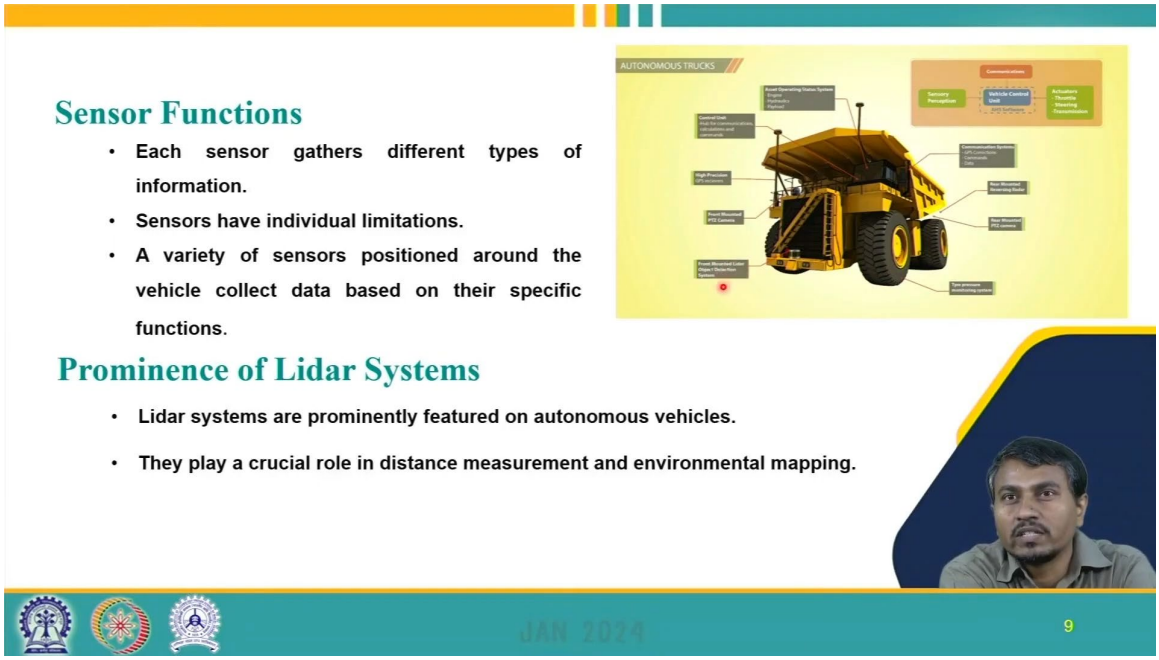
So, the different sensors are on board the systems. So let us look at the sensors installed in the AH system. Main sensors on autonomous vehicles. The first is the light detection



and ranging system, or, in abbreviation, the lidar. It measures distance by emitting laser light and analyzing reflected light, and there is the option that it can emit multiple lasers and generate a three-dimensional model of the environment. So here it is an important sensor because in this automated haulage system it needs a good amount of data about the environment. So, the real world is a three-dimensional one, so using this lidar system, the AHS system can generate a 3D model of the nearby environment and its structure so that it can efficiently operate on this particular system and at its route. There is another set of sensors; radio detection and ranging radar system. It basically provides some specific information about autonomous vehicles. Visual cameras help get the object in front of them, and they basically collect the data in a sensor array, each offering unique data.

So, this is basically the autonomous haul truck system, on top of this particular haul truck, there is a communication system that basically tracks and communicates with each vehicle in the nearby vicinity. Here in this front, there are two fronts that are basically installed with radar, a lidar, and other sensors that basically combine and detect the obstacles in front of them. There are onboard control systems. The control system basically has a local processor that allows the user to interface with and control the vehicle control system.

Sensor's function, so each sensor gathers different types of data and information that work in the AHS system. Sensors have individual limitations as well. A variety of sensors placed around the vehicle collect data based on their specific functions. For example, the camera collects the visual data, the lidar collects the distance, and so on and so forth. GPS basically collects data about the position of the vehicle.



Prominence of the lidar system-So lidar systems are prominently featured on autonomous vehicles. They play a crucial role in distance measurement and environmental mapping. As I discussed, it basically helps to get the 3D of the nearby mine environment, and that basically helps the autonomous system to operate well in that particular environment.

So here we have the autonomous haul truck system. So, there is a communication system, and in that communication system, there is a control system that basically senses and basically actuates the throttle, which is throttle speed steering, and the transmission. So here in the front, it is basically installed with the lidar, and that basically collects the data about its front, and it basically works as an obstacle avoidance system. It also fitted with the camera in front as well as on the back. It has the feature of communications on board that communicates with the nearby vehicles. It has an asset status system that basically looks into the hydraulics of this particular machine. It has a sensing system about tire pressure. It has a reverse radar system on the back. It has also included the global positioning system on board this particular haul truck system.

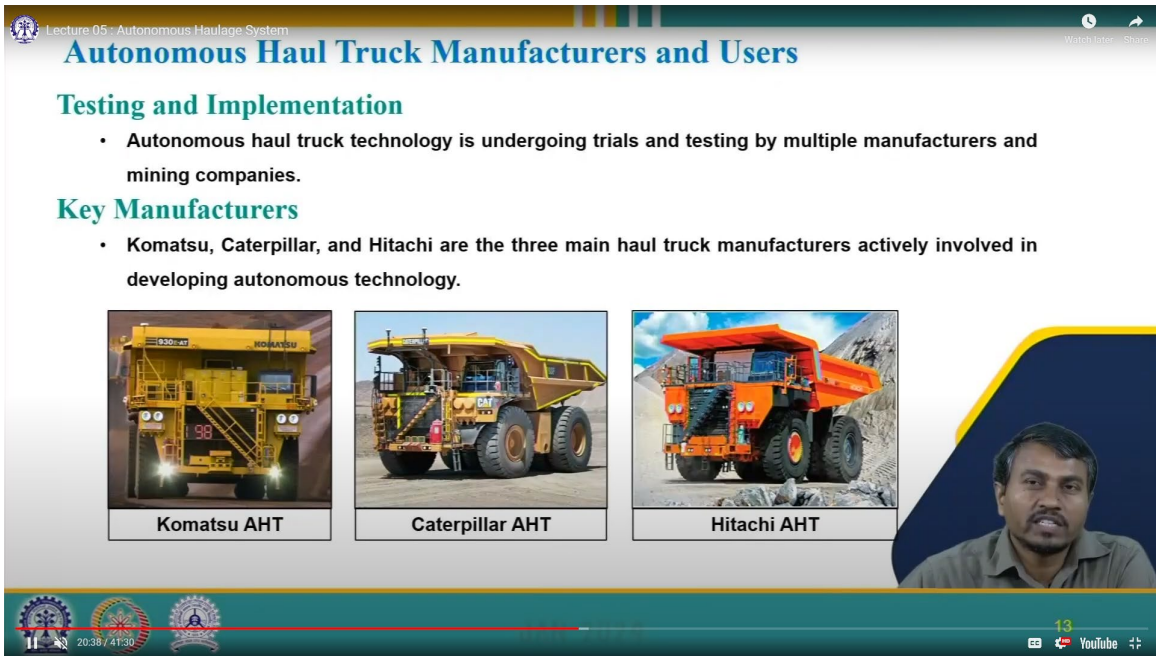
So, what are the benefits of autonomous haul trucks for mining? Mine haul trucks are massive and costly machines that typically operate 24 hours a day, ensuring continuous operations. So that is the major benefit these AHS systems have. So, the advantages of autonomous operation. There are basically many advantages to this autonomous system. First of all, it increases equipment utilization. As I told you, these machines are very costly. So, with increased equipment utilization, it basically helps the mining company gain a lot from this particular system. So, it basically operates without a driver, and this expensive equipment can operate continuously, eliminating idle time during breaks or between shifts, that's a big advantage. So effectively, the operating time of the machines

is increased. Higher efficiency and cost savings, Autonomous trucks achieve equivalent work to manual ones, operating more efficiently with a shorter cycle time. Reduce fuel consumption and improve tire wear. So, these are basically the advantages: reduced fuel consumption because fuel is a costly thing, it basically adds to the running cost, and it also improves tire life. So here are the advantages of the autonomous operation of the haul truck system in mines. So increased safety benefits from this system. Human safety improvement. Having fewer personnel in a hazardous mining environment enhances safety. Job impact, though this system basically eliminates some of the jobs, it also creates new ones with the workers developing their skills in a safer workplace. So, in totality, it basically helps to reduce accidents, improve productivity, make the cycle shorter, and basically reduce idle times, that is a big advantage.

Economic analysis of an autonomous haul truck: Positive economic potential-Implementation of autonomous haul trucks in mines has significant positive economic potential. The reduction in cost is observed in three major areas: improved productivity, reduced labor costs, and lower investment costs. Productivity gains-So there are some case studies that found that actual autonomous haul truck data reveals a 21% increase in haul truck productivity. In another study, it was found that seven autonomous mine haul trucks could replace nine human-operated trucks, showcasing increased utilization. So, in the positive economic potential, we discuss the investment cost, or lower investment cost. So here, with the seven machines, the same work can be performed, or the work that is performed by conventional nine machines. So, there is a big gain from this system. So, the positive economic potential, productivity gains, and efficiency improvement basically make this system a potential system for different candidate mines.

Efficiency improvement-In different studies, it has been found that fuel consumption is improved by 6% and tire wear is enhanced by 7.5% in the overall automated haul truck system. Candidate mines. Large mines in developed countries with higher wages are identified as primary candidates for adopting autonomous haul trucks, primarily for cost savings.

Autonomous haul truck manufacturers and users-There are different stages of testing and implementation of these machines, and different companies are basically working on that. So autonomous haul truck technology is undergoing trials and testing by multiple manufacturers and mining companies before it comes to market. So, the key manufacturers. There are Komatsu, Caterpillar, and Hitachi. So, these three are basically the potential AHS system manufacturers globally, and they are basically developing new features in the AHS systems that are operating in different parts of the world. So, this is the Komatsu AHS system, this is the Caterpillar AHT system, and this is the Hitachi AHT system. Collaborations with mining companies. So, these companies, Komatsu, Caterpillar, and Hitachi, are basically collaborating with prominent mining players like Rio Tinto, BHP, and Fortescue, and there are other companies as well. The collaboration



involves implementing autonomous technology in real mining operating environments. So, with this system being implemented in different mining environments, the capability, efficiency, and enhanced capability of the AHS system and the AHS system are basically improving day by day.

So real-world applications-So the focus is on applying autonomous haul truck technology in practical mining operations to assess its effectiveness and feasibility.

AHS haul truck features-So in an autonomous haul truck system, there are high-precision global navigation satellite positioning systems, advanced sensing systems, and several levels of control systems that basically enable remote control of this machine from a central room in an unmanned haul truck. Autonomous operations. An autonomous haul truck operates autonomously using high-performance wireless networks, including LTE. Autonomy allows for centralized control with a single operator managing the entire fleet, that's a big advantage.

Interconnected system-The interconnected system facilitates safe interaction between the automated haul trucks and manually operated equipment such as loaders, dozers, graders, and light vehicles, as well as human-operated vehicles plying on the mines. So these interconnected systems allow the seamless operation of all these machines in a synchronous way without any collisions or breakdowns.

Optimizing mining operations-So the integration of autonomous haul trucks and manual equipment is designed to optimize overall mining operations, enhancing efficiency, safety, and coordination within the mine environment, and effectively allowing the mining company to enhance its productivity.

So let us discuss a few questions.

Question number 1

How do autonomous vehicles navigate between locations? Human guidance, Sensor data analysis, steering wheel control, Acceleration commands.

The right answer is sensor data analysis.

Question number 2.

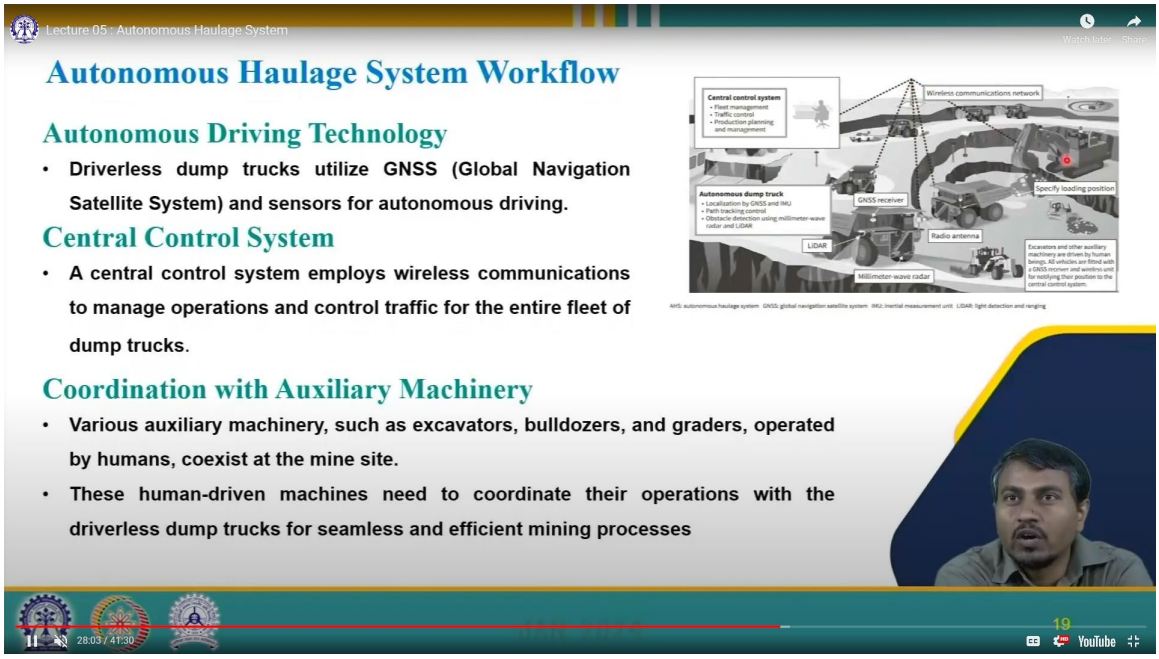
What types of networks do automated haul trucks use for autonomous operations? GPS, HP GNSS, wireless network including LTE, radar networks.

The right answer is wireless networks, including LTE.

Question number 3.

What is the main goal of integrating autonomous haul trucks and manual equipment into mining operations? Increasing manual labor, reducing efficiency, optimizing overall mining operations, and isolating autonomous systems.

The right answer is optimizing overall mining operations.



Now let us discuss the workflow of the workflow of the autonomous haulage system. Autonomous driving technology-So the driverless dump trucks utilize GNSS, the Global navigation Satellite System, and sensors for autonomous driving.

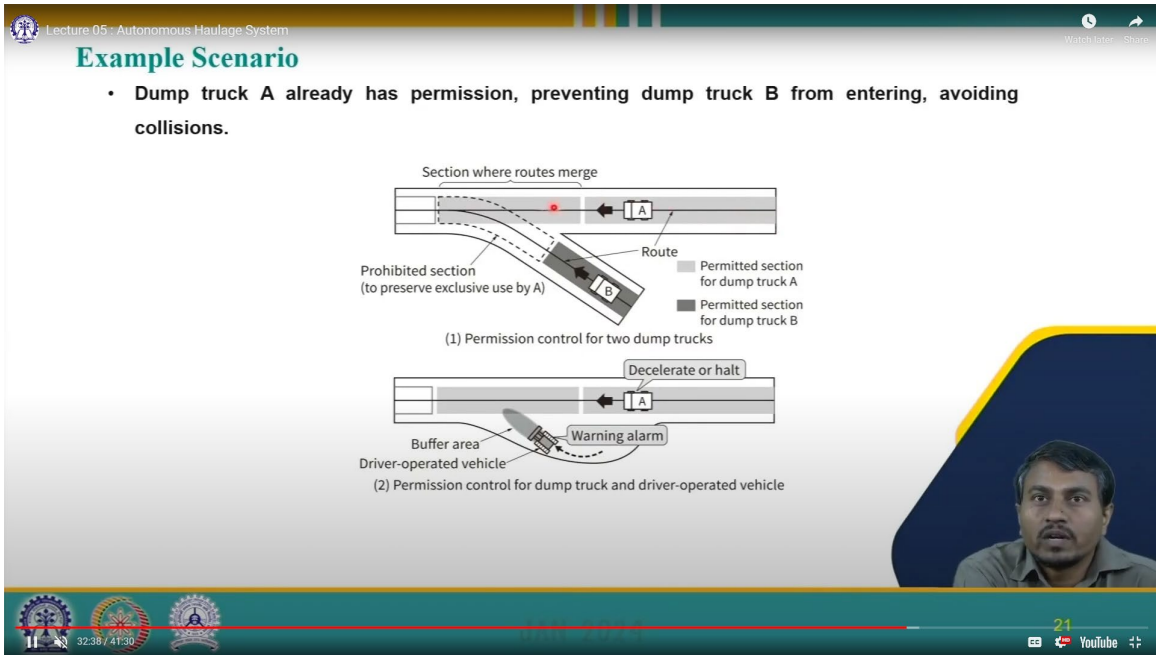
Central control system-A central control system employs wireless communication to manage operations and control traffic for the entire fleet of dump trucks. So it is situated at a convenient location in the mines, and from that location, it controls the entire fleet operation.

Coordination with auxiliary machinery-That is the most important part because there are several machines that are operated by human operators, so there is a necessity of good coordination with these machines so that all the mining operations can be done seamlessly with good coordination and with a shorter cycle time. So various auxiliary machinery, such as excavators, bulldozers, and graders operated by humans, coexisted at the mine site, and their coordination was crucial to making these AHT systems successful. So these human-driven machines need to coordinate their operations with driverless dump trucks for seamless and efficient mining processes.

So this is the mine, virtual mines. So, these mines are fitted with a wireless communication network. So, these wireless communication networks enable us to connect all these machines that are operating at the mine site. So, all these machines, whether human-operated machines or driverless haul trucks, have a communication receiver that basically communicates with each other and with this tower through this receiver. Also, each machine is equipped with or fitted with a GNSS system so that the central control tower can have data about its location in real time. So, the central control system manages the entire fleet by the operator sitting at the central control system. It also looks after traffic management, and it also basically works according to the production planning, which is basically executed efficiently by this central control system. So, the autonomous haul truck, having the GNSS receiver network, lidar sensor, millimeter-level radar sensors, and radio antenna, enables it to maintain continuous connectivity with the central control systems and operates without any driver. These mines can work efficiently, if all these machines operated with and without drivers are working in tandem in synchronous mode with no possibility of collision, then these AHT systems will be successful and also, from time to time, whenever necessary, the central control system will intervene and give a command to the machine to specifically execute the specific task.

Principle of permission control. So, this is a very important feature in the AHT because there is a possibility of collision and traffic congestion. So, vehicles are prevented from interfering with each other by controlling their movements and ensuring exclusive use of their permitted sections. So, from that, permission control mechanisms come into picture. So, the permission control divides the route into sections, allowing only one dump truck at a time to drive on each section. So thereby, it basically ensures that there is no possibility of any collision. Dump trucks can drive through their current permitted section without continuous communication with the central control system. So continuous data exchange is not required when a particular dump truck is given a particular route or

section. Request and grant system-So this particular protocol will be active when there is a junction and those junctions basically interfere with each other, so when approaching the end of a section, the truck sends a request to the central control system for permission to enter the next section. So, there are possibilities that two roads are basically crossing each other. In that particular scenario, there is a necessity to request and grant a control system to avoid the collision. So, if permission is granted, the truck continues its route; otherwise, access is denied, preventing potential collisions. So let us see one example of how this is basically executed in the field.

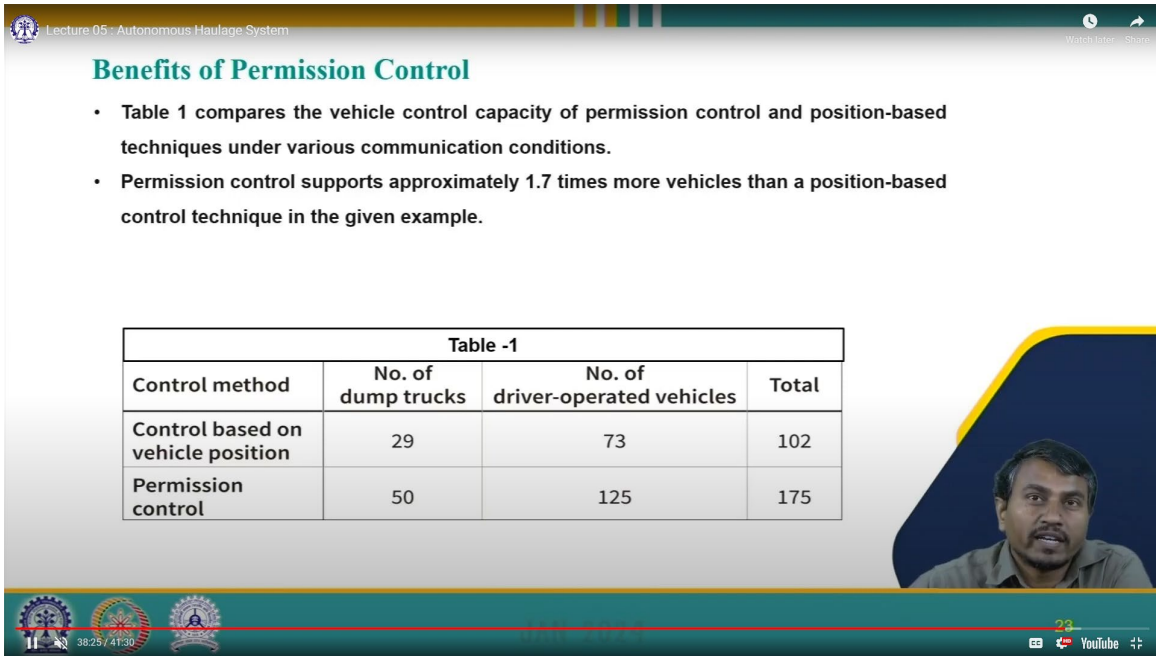


So, in the first part of this figure, this particular shaded route is given to the dump truck A. So, for the movement of dump truck A in this particular route, so dump truck A does not require any special permission to move in this particular route, but when this particular route comes into close proximity with another permitted route for dump truck B, this black shaded portion interferes with these particular two routes. So maybe the control tower will give permission to dump truck A to move through so the dump truck A will move without any de-acceleration or any halt is required for the dump truck A, or here the dump truck B will not be given permission to enter into this particular route. So the movement of vehicle A, which is dump truck A, is not interfered with, so it moves seamlessly, and there is no possibility of any collision between these two dump trucks. There is another picture, so this particular route is dedicated and given permission control for the dump truck A, and there is some possibility that human-operated vehicles flying in different parts of the mines suddenly come into closer proximity with the permitted route of the dump truck A, and there is some buffer area as well, so there is a system that the human-operated vehicle will basically activate the warning alert, and it will communicate with the central control system for giving access to this particular route,

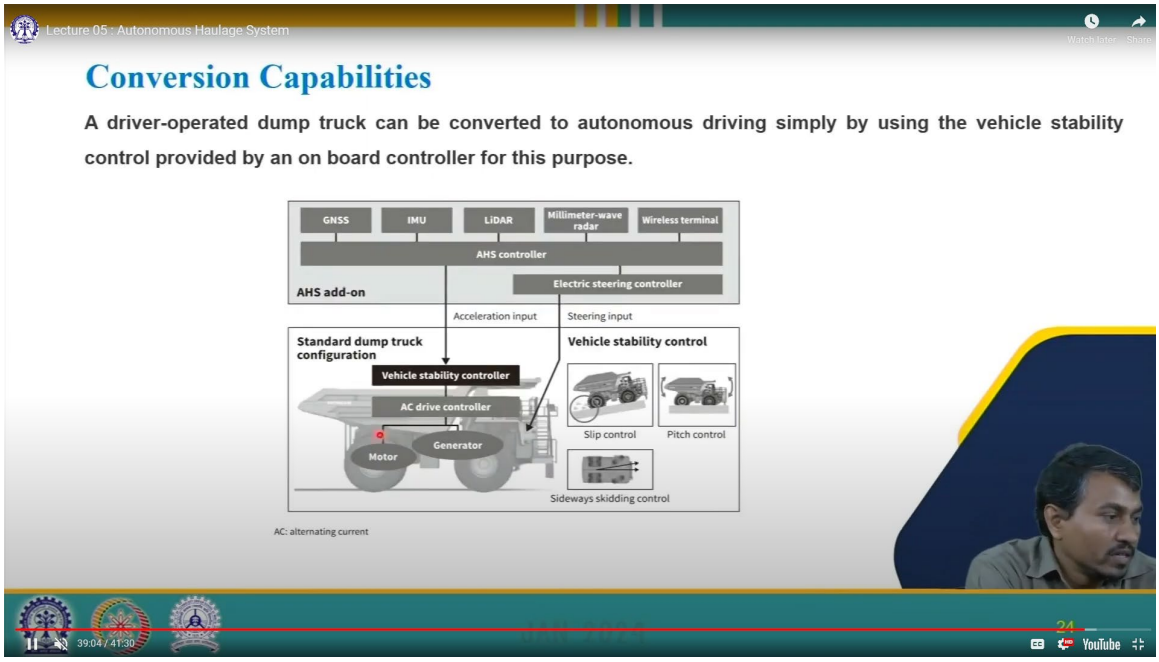
which is already given to dump truck A. So based on the data and based on the understanding of this particular mining environment and based on the particular necessity of the mining headquarters, as well as the planners and the engineering management, this particular vehicle may be given permission to enter this particular area, and at that particular point in time, the dump truck A will be given the command to de-accelerate or halt so that an effective collision is avoided. So, in these two scenarios, where two dump trucks are operating, there is dedicated permission control and two routes are given up to two kinds of dump trucks, and there is no possibility of any collision, but when they come into close proximity, there is a case of being given access to a particular dump truck, whereas access is denied to other dump trucks. In a human-operated vehicle, access is given to the human-operated vehicles, and the dump trucks are halted. So effectively using this permission control mechanism, we are basically getting higher efficiency and ensuring no collision between the vehicles in the mines.

Management is exclusively for autonomous vehicles, so this management by permitted sections is tailored for autonomous vehicles and not employed for vehicles operated by drivers. So, driver-operated vehicles are guided to avoid sections allocated to autonomous dump trucks.

Warning and control measures: driver-operated vehicles are equipped with terminals displaying sections allocated to autonomous dump trucks. In situations where the buffer area of a driver-operated vehicle overlaps with a section assigned to an autonomous dump truck, warnings are displayed, and the central control system may issue instructions to slow or stop the dump truck, ensuring safety and preventing collisions.



Benefits of Permission Control-So this table one compares the vehicle control capacity of permission control and position-based techniques under various communication conditions. So here, this particular system controls vehicles based on their positions from time to time; it gives the locations and etc.; it operates a total of 102 machines, whereas the permission control system operates efficiently with 175 machines in the mines with 50 dump trucks and 125 driver-operated vehicles. So, the permission control technique supports approximately 1.7 times more vehicles than a position-based control technique in the given example. So, the efficiency of permission control lies in its reduced demand for frequent position information updates, enhancing overall system scalability.



Conversion capabilities: a driver-operated dump truck can also be converted to an autonomous driving system simply by using vehicle stability control provided by an onboard controller for this purpose. So here is basically the vehicle with a driver-operated system. Now it is fitted with a GNSS system, an IMU system, a lidar millimeter wave radar, and a wireless terminal that basically comprises an AHS controller system that basically helps with the acceleration inputs to the vehicle stability controller and to the AC drive controller, generator, and motors. There is an electrical steering controller on the system that basically gives the steering input for the vehicle stability control, slip control, pitch control, and sideways skidding control. So, this kind of system is portable; it can be implemented in the field, and there are many case studies that have converted existing machines to autonomous systems by incorporating all of these onboard sensing systems and control systems on the machines.

So these are the references. So let us conclude what we have covered in this lesson. We have explored the multifaceted impact of automated haul trucks, covering advanced

sensors, economic considerations, and distinctive features. We have emphasized the strategic significance of these vehicles beyond mere technological innovation, particularly in terms of safety, economic benefit, and efficiency in mining operations. We have discussed the seamless workflow of an autonomous haulage system, highlighting the integration of various components and the necessity for synergy. We have also discussed the role of permission control, stressing the importance of a robust governance framework for managing access and ensuring security. Thank you. So, we'll meet you again in the next part of this particular lesson on Part B of the autonomous haul truck system. Goodbye.