Our Take

# Transforming India's mining landscape with autonomous technology

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pwc

Rising energy demands and infrastructure expansion are compelling mining companies to boost productivity with a focus on safety. Automation – key to operational excellence – could help achieve this objective. **Yogesh Daruka** and **Ankur Basu** make a strong case for the automation imperative in the domestic mining sector.

The mining industry in India has transitioned from manual to mechanised operations, with technology and automation adoption at different levels of maturity. Regulatory reforms and the opening up of new blocks through auctioning have also caused India's mining industry, known to produce as many as 95 minerals, to gain significant momentum. The aspiration to achieve a USD 5 trillion economy[1] and self-reliance in the energy sector have driven investors to relook at India's mining landscape as a promising avenue that can contribute significantly to the nation's economic and industrial advancement.

With an increase in energy demand and infrastructural growth, pressure is now mounting on mining companies to enhance their production and capacity with a focus on safety and enhanced efficiency. The business model too is evolving to factor in operational cost-effectiveness and benefit stakeholders across the spectrum. This in turn could lead to the empowerment of local communities by enhancing their livelihood options.

PwC's analysis reveals that deployment of the autonomous mining equipment in open-pit mines has grown significantly in the last two decades in both developed and emerging markets. Additionally, the adoption of such technology cuts across the mining of commodities such as iron ore, gold, copper and coal. In 2007, only 18 autonomous haulage system (AHS) trucks were in use. Sixteen years on, 1,234 such autonomous vehicles are in operation around the globe.[2] Indian mines, however, are yet to leverage this technology.

What has kept the mining sector in India from embracing automation wholeheartedly? What are the opportunities that automation presents? This article attempts to answer these questions and offers recommendations to power India's domestic mining enterprise.

1. https://timesofindia.indiatimes.com/business/india-business/india-to-become-5-trillion-economy-early-in-amrit-kaal-finmin/articleshow/105725490.cms?from=mdr
2. PwC analysis

# Autonomous technology in mining

Safe mining operations combined with peak capacity production entails automation. Autonomous mining operations involve two types of technologies – operational technology and information technology. Operational technologies encompassing mining equipment and equipment control systems help achieve automation, while information technology involves communication and transfer of data for analytics and decision-making.

As for the levels of automation, mining operations could be:

| 1. Dependent | 2. Semi-independent | 3. Independent |
|---|---|---|

The first level of autonomy refers to labour-intensive operations that require continuous efforts from the operator. In this level of autonomy, all heavy earth moving machinery (HEMM) is manually operated. The second level of autonomy refers to the conditions in which the system performs a portion of the tasks independently within a defined set of logic while the rest is controlled by the operator. Manual intervention is necessary in the second level, to some extent. The third level of autonomy refers to completely autonomous operations and does not require any manual intervention. In this case, the HEMMs are able to analyse the situation, make decisions, navigate, and perform the desired operation.

After analysing the maturity level of the current mining operations, a guided approach is needed to introduce automation in different aspects of the mining process. Given below is a snippet of the levels of autonomy achieved in various aspects of a mining operation.

## Autonomous drilling

This involves automation of the drilling process, which includes precision drilling without human intervention and capturing the rock mass data while drilling to create a drill face profile.

## Autonomous blasting

The achievable level of autonomy in this process, at present, is semi-independent as the initiating system is handled manually. The loading of explosives into each blast hole can be automated so that the charging operations can be directly controlled by the loading plan created in the system and the charging truck automatically loads the exact amount of explosive as per the plan based on the inputs received while drilling the hole.

## Autonomous loading

This process includes interaction of the bucket of excavator with the rock during which the machine applies multiple forces for excavation and material handling. The loading process is still in semi-independent level of autonomy with some major original equipment manufacturer (OEM) companies promoting the teleoperations for the excavators and loaders.

### Autonomous hauling

This includes transportation of materials through autonomous haul trucks that perform the entire hauling cycle autonomously. Mines in many countries across the globe have achieved complete autonomy in this aspect of mining.

### Autonomous support equipment

This includes automation of support equipment which can be a challenging process. It requires a high level of decision-making capability as auxiliary activities can turn out to be complex and unpredictable due to which logic building becomes a challenge.

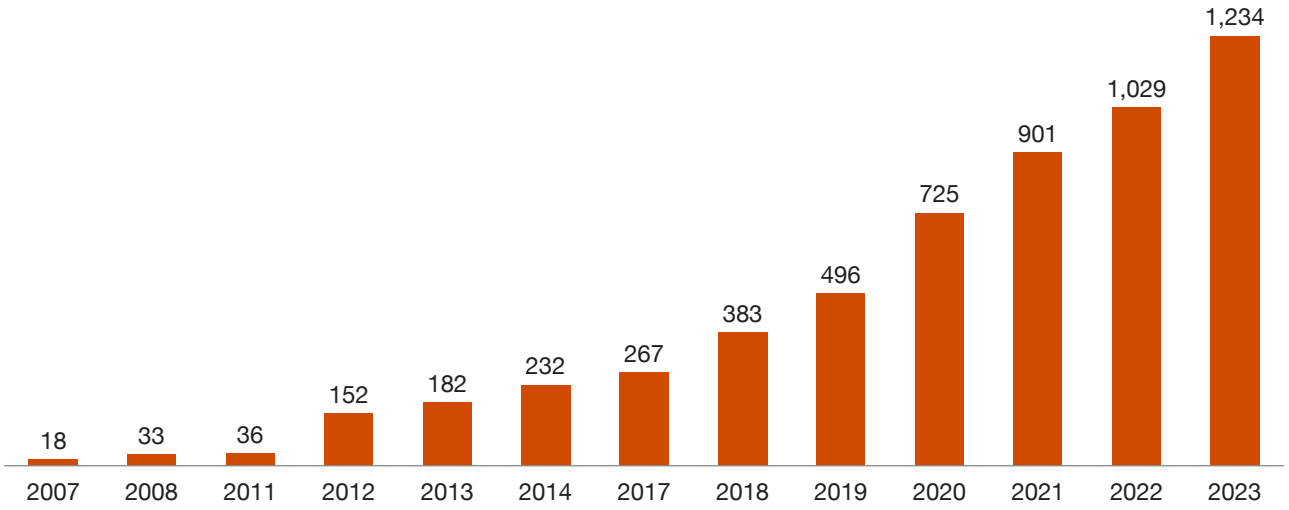
## Global deployment trends in autonomous equipment

The mining sector embarked on its autonomous journey in the nineties as significant research and development (R&D) took place in trial applications. The first successful commercial deployment happened in 2007 in open-pit mine haul trucks.[3] Since then, the technology has evolved significantly to become safer with the deployment of autonomous systems being expanded to both open-pit and underground mines. Moreover, these innovations are not confined to large trucks but include a wide range of equipment such as drills, dozers, load haul dump machines (LHDs) and low-profile dump trucks (LPDTs).

### AHS deployment has grown four-fold in less than two decades

Our analysis reveals that the adoption of AHS trucks for open-pit mines has grown at a whopping compound annual growth rate (CAGR) rate of 328% between 2007 and 2023.[4]

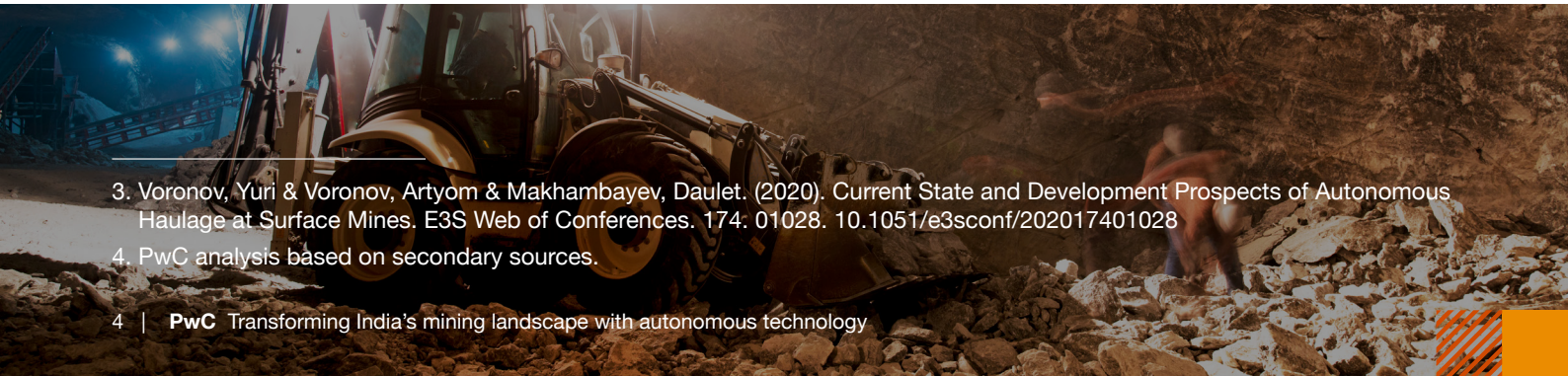
**Figure 1: Cumulative growth of AHS trucks in open-pit mines**




**Source:** PwC analysis

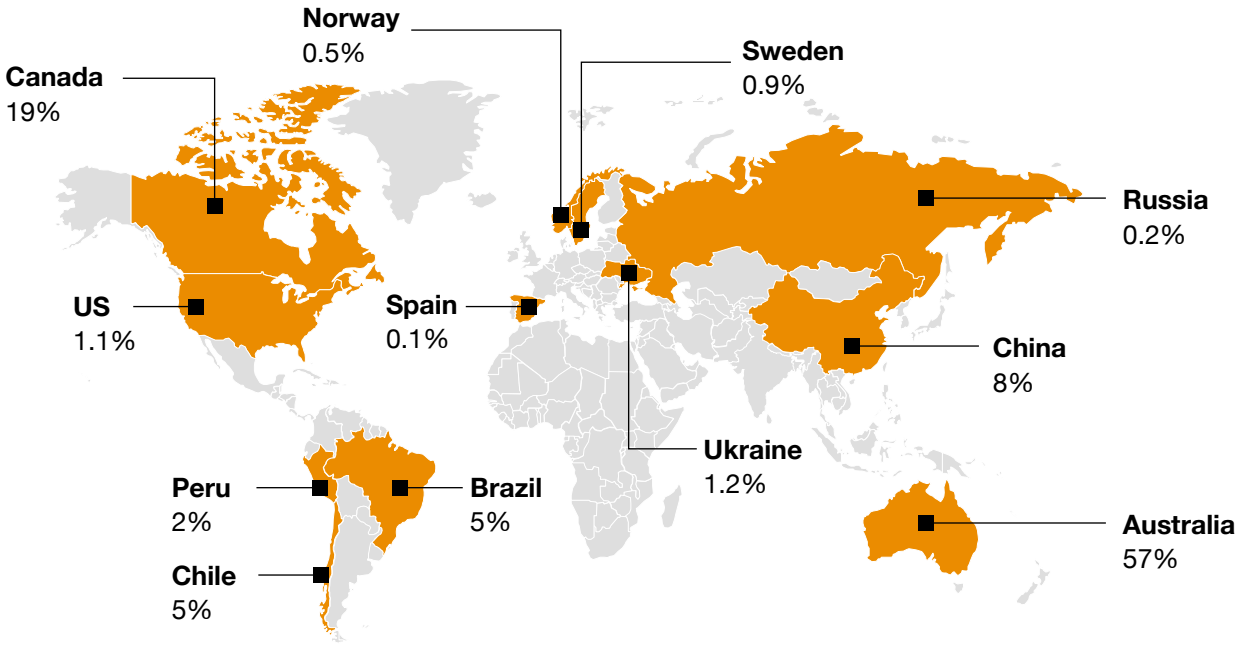
***Note:** Data for some years is not available.

The distribution pattern of autonomous trucks reveals that both developed and developing nations are gradually adopting technology to ensure safety and improve the efficiency and productivity of their operations. While Australia is the frontrunner in deploying the technology, other leading mineral-producing countries are following suit.



3. Voronov, Yuri & Voronov, Artyom & Makhambayev, Daulet. (2020). Current State and Development Prospects of Autonomous Haulage at Surface Mines. E3S Web of Conferences. 174. 01028. 10.1051/e3sconf/202017401028
4. PwC analysis based on secondary sources.

**Figure 2: Country-wise deployment of AHS trucks**




Total number of AHS trucks in use globally: **1,234**

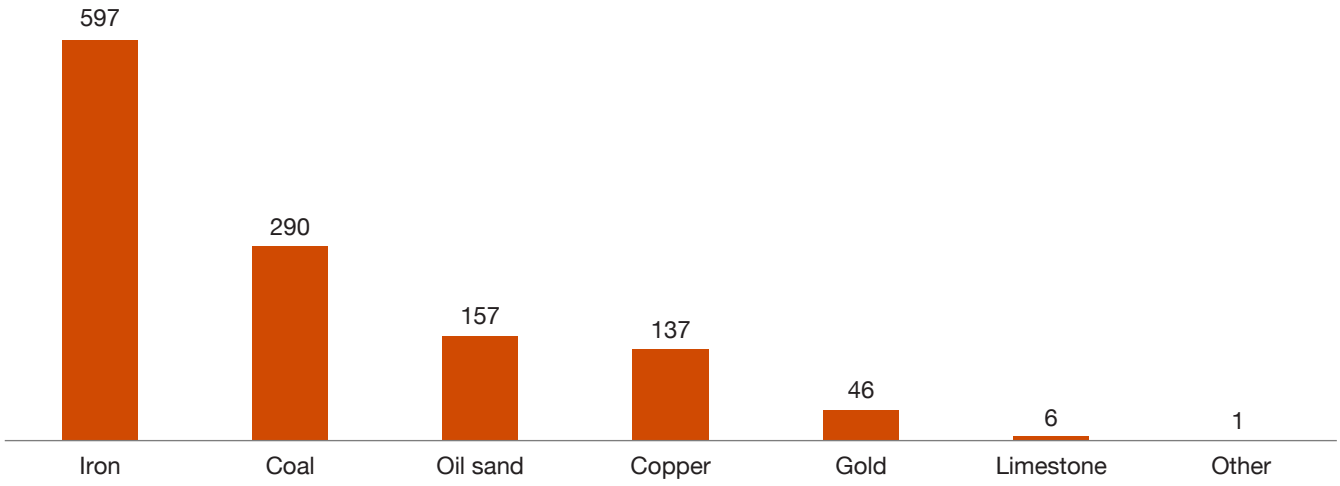
**Source:** PwC analysis

## Automation is being adopted across commodities

While the first autonomous haulage trucks were deployed in iron ore operations, our research shows that over the years, the deployment of the technology has expanded to other commodities.[5] Figure 3 illustrates that the maximum number of AHS trucks are deployed in iron ore mining, but mining operations in coal, oil sand, copper and gold are catching up.

This development also indicates that the challenges related to mining operation methodologies, types of deposit and geometry of mining pits have been successfully mitigated during the planning and trial phases.

**Figure 3: Commodity-wise distribution of AHS trucks**

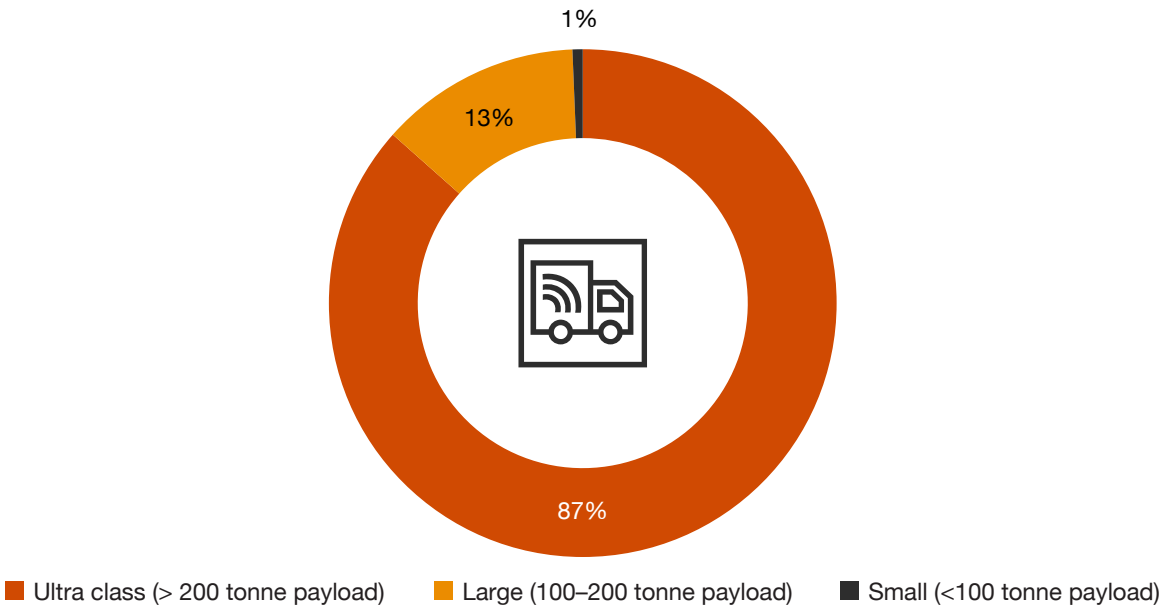



**Source:** PwC analysis

5. PwC analysis based on secondary sources.

Technological advancements are allowing companies to customise technology-driven operations of trucks with lesser payloads whose use can be more cost-effective for new or small mining companies. Our analysis shows that retrofitting of technology is enabling small trucks (less than 100-tonne payload) to increasingly engage in mining. At least 13% of the trucks which are being used in mining today are large (100–200 tonne payload) trucks while ultra class trucks (those with a payload of over 200 tonnes) make up for 87% of the autonomous vehicles in use in mining.[6]

**Figure 4: Distribution across the size of trucks**




**Source:** PwC analysis

## Automation in other mining machinery is also on the upswing

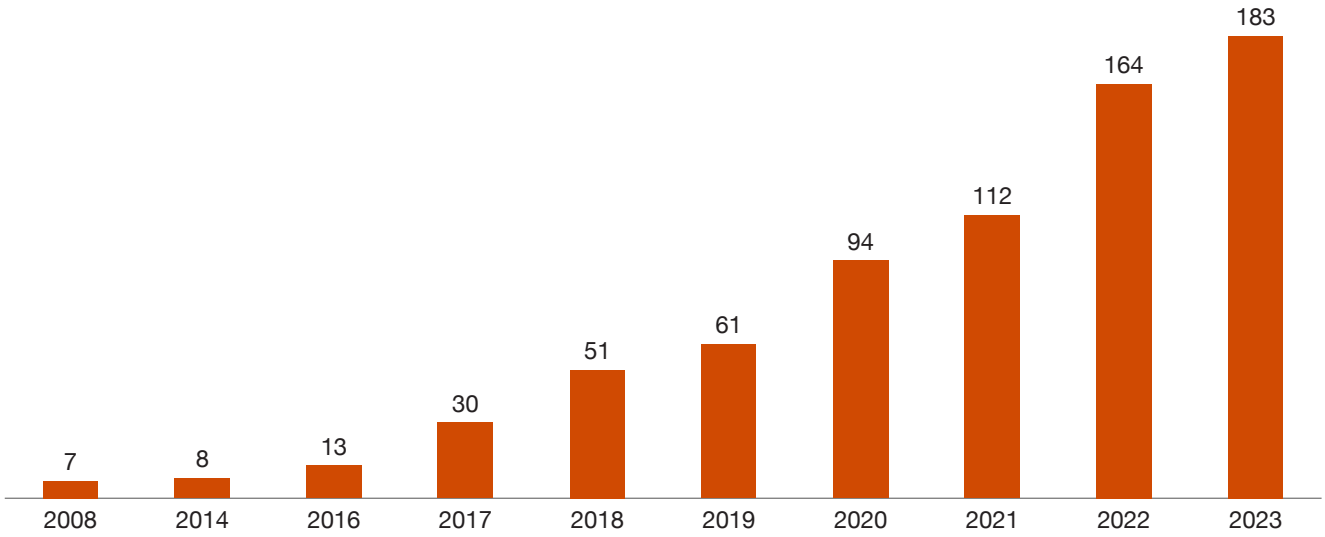
While the deployment of autonomous trucks has grown significantly, drilling equipment has also seen considerable growth and adoption across the globe. Though the automation level for drilling can vary based on the on-site requirements, it can be broadly categorised into four types:

- remote control
- tele remote
- semi-autonomous, and
- autonomous.

Our analysis shows that the deployment of automated drills (considering varying levels of automation) in open-pit mines has grown at a CAGR of 74% since 2008.[7]

6. PwC analysis based on secondary sources.
7. Ibid

**Figure 5: Cumulative growth of automated drills in open-pit mines**




**Source:** PwC analysis

***Note:** Data for some years is not available.

Oceania is the frontrunner in deployment of automated drills followed by South America as seen in figure 6. Figure 7 illustrates that the use of automated drills is also being expanded to various commodities.

**Figure 6: Distribution of drills across global regions**

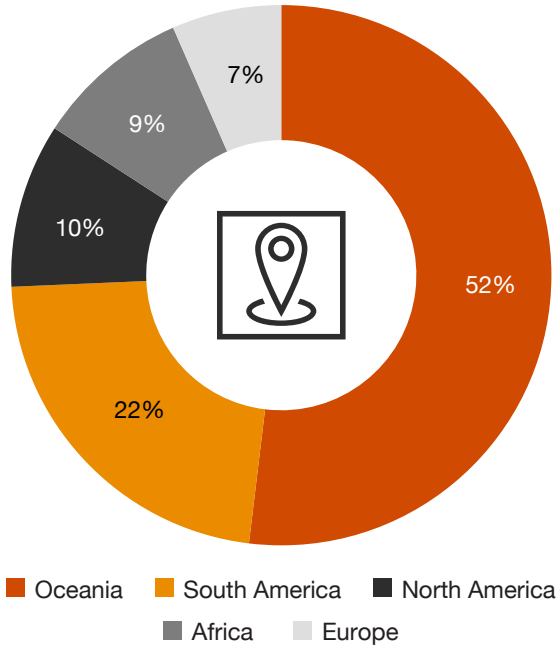
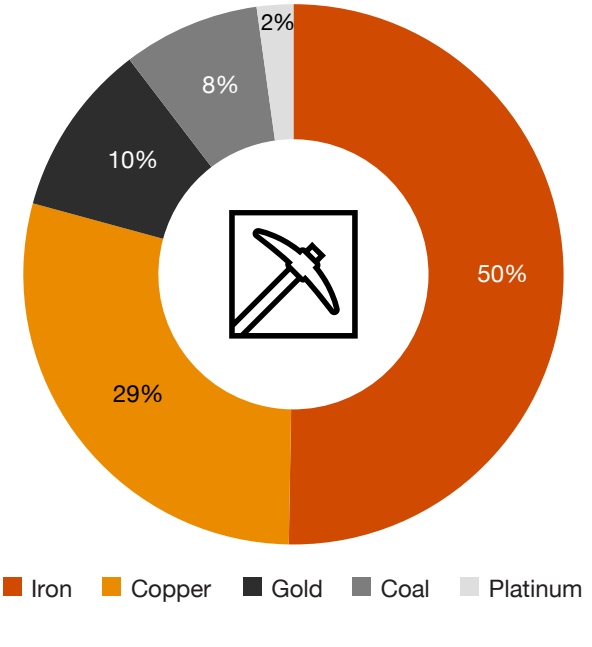



**Figure 7: Distribution of drills across commodities**

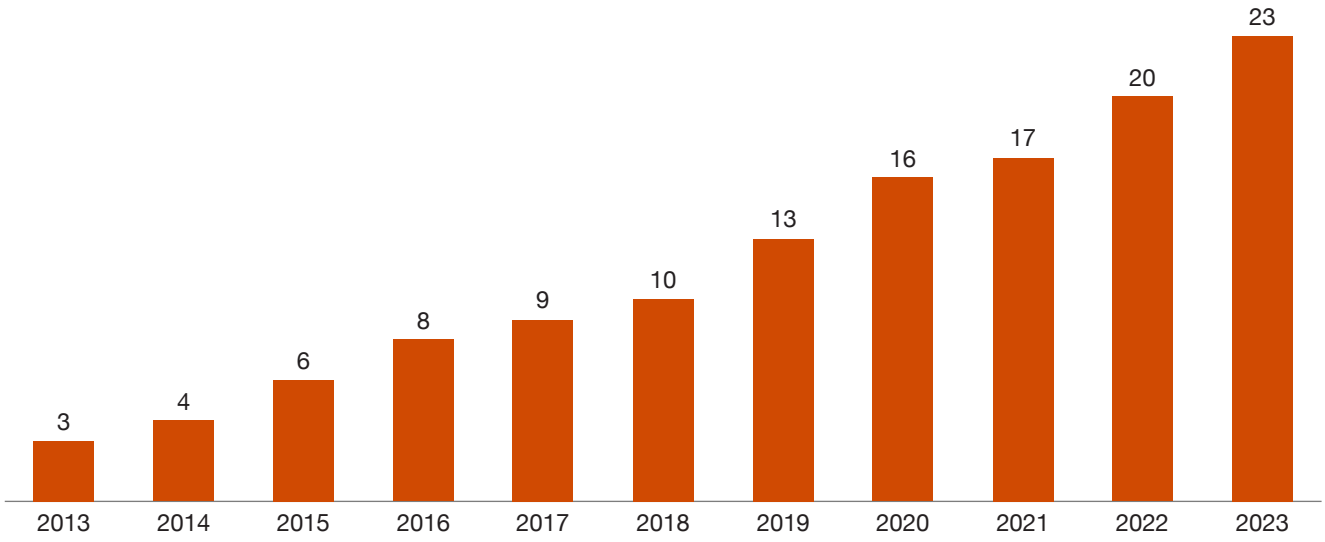



**Source:** PwC analysis

While efforts are underway by OEMs to advance remote operations of primary mining equipment such as loaders, automation of mining equipment which is not directly involved in extraction of materials such as crushers, drills and haul trucks has provided flexibility in mining methods. For instance, dozer-assisted methods are increasingly being used in open-pit mining. Our analysis found that globally, at least 23 mines have semi-autonomous or autonomous dozers in operation.[8]

8. PwC analysis based on secondary research.

**Figure 8: Growth of automated/semi-automated dozer sites over the years**



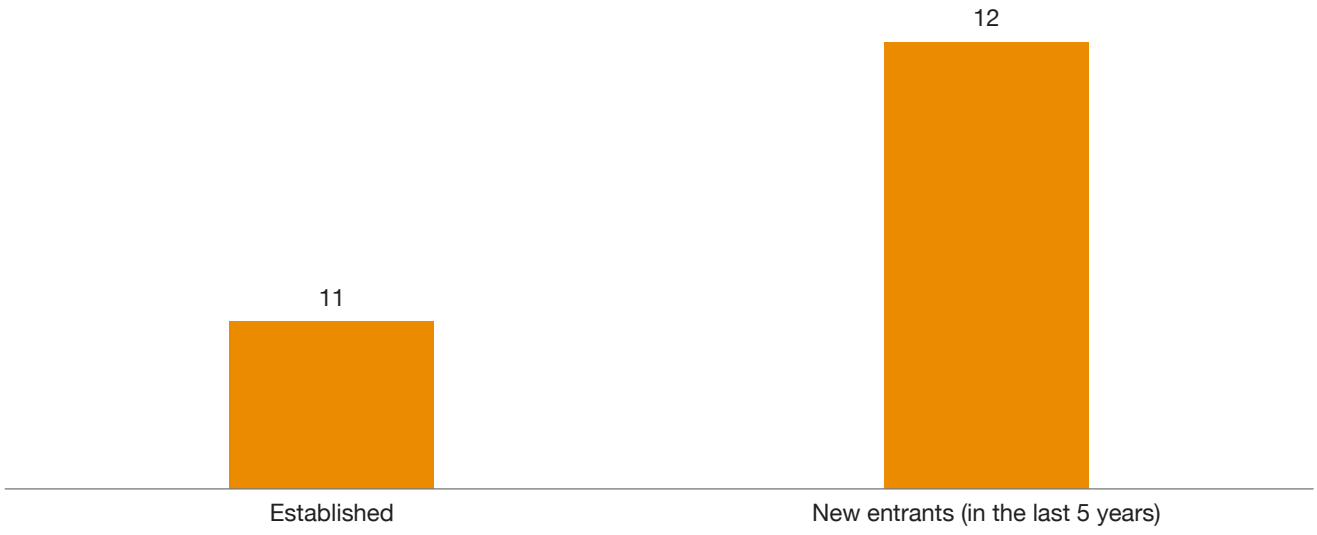

**Source:** PwC analysis

While open-pit mining operations have been quick to adopt autonomous technology, underground mining operations are also making the transition to ensure worker safety and to overcome difficult geotechnical conditions. Though tele-remote operations are common in underground coal and metal mining, a few mining sites now have full autonomous control of equipment from the surface command centre.

## New tech players are entering the market and innovating for smaller vehicles

Much of the R&D and trials that took place two decades ago included large or ultra class mining trucks and, for a long time, deployment was limited to these categories of vehicles. Increased automation adoption has benefited technology solution providers, opening up opportunities for new players to enter the market. Our analysis shows that the number of new technology providers has increased significantly over the last couple of years. These players are developing technological solutions that are not tied to a specific OEM which is critical for wider adoption in mining as companies use different classes of equipment from various manufacturers. While major OEMs have provided solutions which come with their equipment, new solution providers are offering retrofitted solutions embedded in different types of equipment.

**Figure 9: Players in the autonomous technology market**




**Source:** PwC analysis

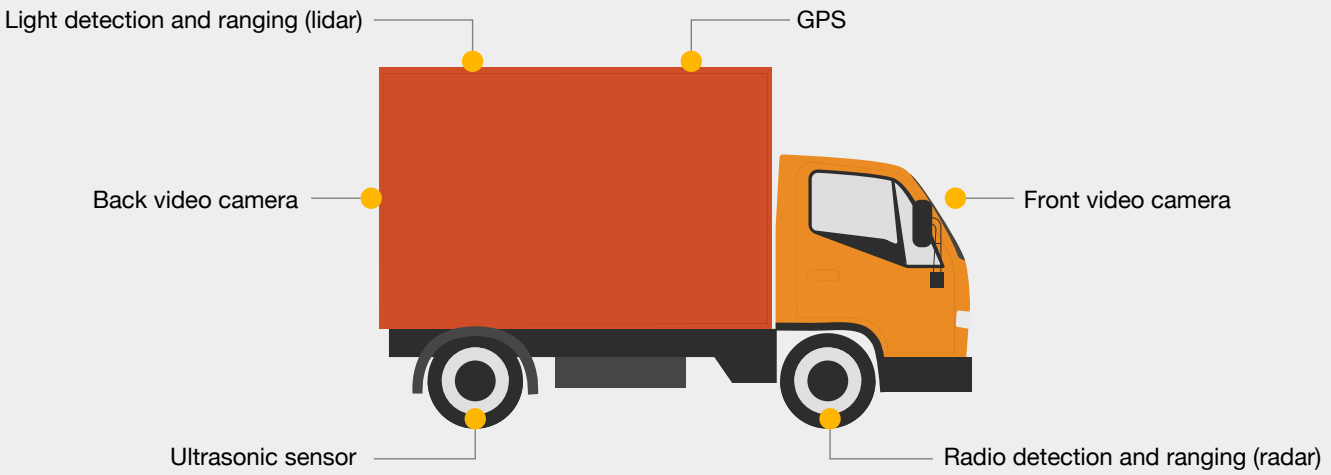
# Advancements in autonomous technology

Over the past few years, autonomous technology has gone through significant developments and advancements with the advent of Industry 4.0. The Fourth Industrial Revolution is expediting the R&D of autonomous vehicles by providing cutting edge technologies like image processing, deep learning, decision support systems and making the technology safer and cheaper. For example, lack of access to satellite-based global positioning data in underground environments led to challenges for the mining sector in terms of miners' safety, materials tracking and autonomous-truck deployment. Now an underground tunnel positioning system based on light detection and ranging (lidar) and underground positioning system (uGPS) can pinpoint the exact location of miners, drillers, surveyors and autonomous truck or robotic drills.[9]

While the technology used in mining has advanced and new concepts are continuously evolving, the fundamental elements sit across four underpinning technologies:

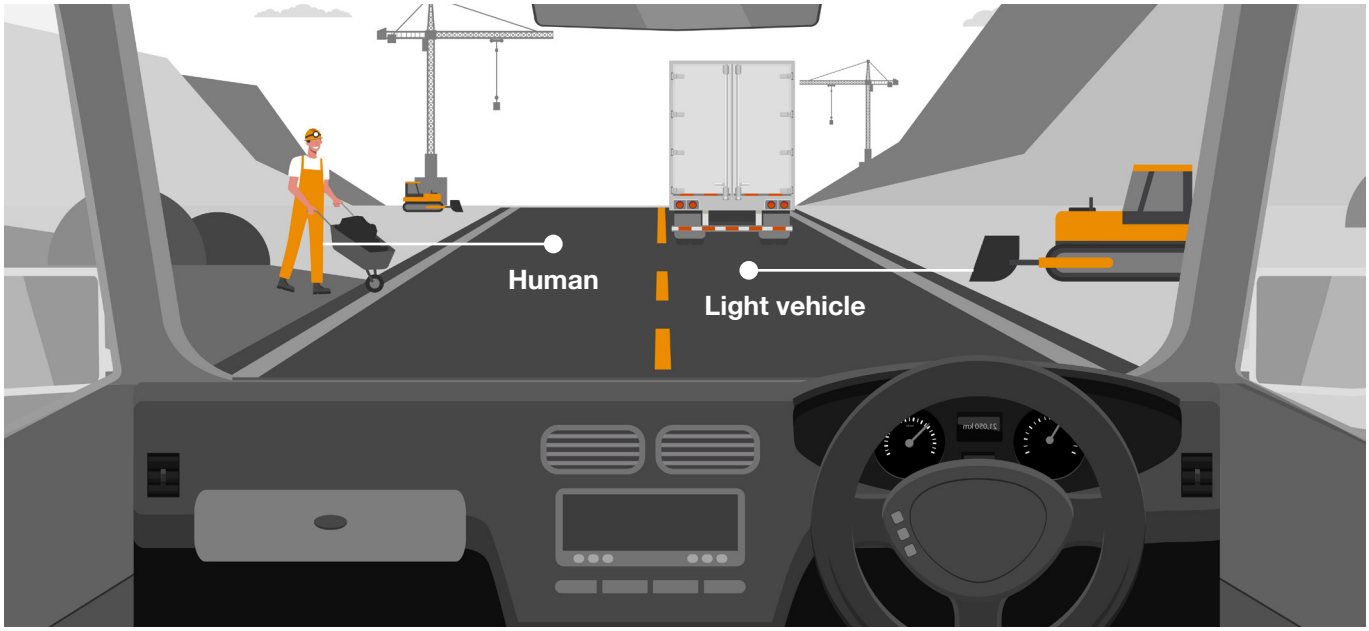
- **Communication technology:** The current AHS mines rely entirely on wireless communication, which employs standard 802.11 Wi-Fi technology operating in the unlicensed spectrum. The flexibility offered by these technologies made Wi-Fi attractive for AHS solutions. Autonomous trucks, in particular, require continuous and seamless connectivity to the network. A wireless mesh network is not used for autonomous fleet management, but it can sometimes be used in an underground mining environment in areas which lack any sort of network connectivity.
- **Sensing and imaging technology:** The main sensors found on autonomous vehicles include lidar systems, radio detection and ranging (radar) systems and visual cameras. Each sensor provides different types of information. Lidar systems are the most prominently featured sensors on autonomous vehicles and measure distance by emitting laser lights toward a point and analysing the reflected light. When combined with rapidly rotating mirrors they can create 3D models of their environment.
- **System process:** The system process is the brain of the truck and relays the information from the vehicle, servers and command centre. The powerful CPU computing power installed on each equipment helps in taking decisions in real-time.
- **Navigation technology:** GPS tracks the location of a vehicle by receiving signals from orbiting satellites. GPS can enable an autonomous vehicle to choose the shortest route from one location to another. However, there are limitations to GPS as the accuracy of GPS tracking in determining a vehicle's position can vary by meters even under ideal conditions. Inertial navigation systems (INS) – which include on-board sensors – reduce the vehicle positioning error when the GPS signal is lost. The sensors, such as accelerometers and gyroscopes, continuously calculate and update the location of the vehicle without external information.

**Figure 10: Technology used in autonomous trucks**




9. Technology roadmap for coal sector

**Figure 11: Image-based object detection by AHS trucks**




**Source:** Autonomous and remote operation technologies in Australian mining, Cluster research report No. 2.5

# Benefits of automation in mining

Mines worldwide are integrating automation into their operations to enhance safety, improve productivity, reduce cost and adopt sustainable practices. The degree of gains, however, vary according to the maturity level of the deployment and adoption, and across different countries and geographic regions. The advantages of automation for the mining sector are as follows:

- **Enhanced on-site safety**

  Deploying autonomous equipment in mining operations reduces the need for human presence on the ground, thus protecting workers from potentially hazardous situations. Meanwhile, in its technology roadmap for the coal sector, the Ministry of Coal has also noted that technology in mining operations can lead to safer working conditions via improved underground communication, more sophisticated mineral and metal transportation, and emergency response measures.[10] While autonomous equipment offers increased safety, there are some challenges which need to be addressed. For instance, machine-to-machine collisions can occur, which have significant cost implications in terms of equipment damage recovery. This has prompted OEMs and technology providers to focus on developing robust solutions with more accuracy and reliability.

- **Improved productivity**

  Autonomous technology has become a viable solution in situations where human efficiency is compromised due to harsh operating conditions and fatigue. Automation has made it possible to use machines more efficiently by improving how they are handled and ensuring that they operate at a uniform speed. This has a direct impact on production as there's higher productivity, increased tire tonne-kilometre per hour (TKPH), higher equipment availability and reduced unplanned maintenance. Embracing automation can lead to:

  – an increase of 15% to 20% in output

  – a decrease of 10% to 15% in fuel consumption

  – decrease in tire wear by 5% to 15%

  – an increase in truck up-time by 10% to 20%

  – decrease in maintenance by 8%.[11]

10. Ibid

11. Australasian Mine Safety Journal, Autonomous mining trucks: Are there any limitations?

- **Reduced costs**

  Use of autonomous equipment can directly impact operating and maintenance costs through reduced fuel consumption, increased tire life and productivity, and reduced unplanned maintenance. For example, a global mining corporation using autonomous haul trucks reported 13% reduction in fuel use.[12] While reduction in operator cost adds a significant percentage to the cost savings of a company in a developed country, the same is not true for developing nations where wages are generally low. Moreover, the CapEx cost for the equipment can be prohibitive. Innovative, new retrofitting technologies compatible with different classes of equipment are playing a key role in making the technology accessible in developing countries. Automation can reduce:

  – maintenance cost by 17%

  – operating cost by 30%.[13]

- **Meeting expectations on sustainability**

  Through most of human history, mining technology has been centred on maximising yields while minimising associated costs. However, striking a balance between economic growth and environmental sustainability has remained a challenge. In order to mitigate the adverse ecological impact while continuing to foster growth, it is important to adopt responsible and innovative approaches. Reduced fuel consumption by autonomous equipment directly reduces carbon emissions and makes it a sustainable option. However, with the introduction of alternate fuel options such as hydrogen fuel cell and liquified natural gas (LNG), carbon emissions can be further reduced, strengthening the sector's environment, social and governance (ESG) compliances.

12. Ibid.

13. Gölbaşı, Onur & Dagdelen, Kadri. (2017). Equipment Replacement Analysis of Manual Trucks with Autonomous Truck Technology in Open Pit Mines

# Our take

## The imperative of autonomous mining in India

OEMs can play a key role in encouraging automation by providing technology that is aligned with the operating models in Indian mining. While much of the technology already exists, its adoption is limited in India owing to the lack of infrastructure, shortage of skilled workforce and cost economics. Another major hurdle is that the technology is sometimes unfit for use in the equipment class deployed in operations. These barriers can be overcome with a deeper and collective understanding of the needs of the Indian mining sector, which also highlights the need for technology customisation requirements. Mining companies have started taking conscious steps in terms of factoring in customisation requirements by making pilot deployments or shifting to specific equipment based on their requirements. Some of the major developments in this space are:

- **Development of a technology roadmap for the coal sector:** The Ministry of Coal, in consultation with various stakeholders, has drafted a roadmap for technology deployment and possible new technological interventions in future. The roadmap outlines proposed autonomous trucks and drills deployment as a futuristic initiative in a phased manner.[14]
- **Introduction of tele-remote mining equipment in underground operations:** To make its operations safe and efficient, an Indian integrated mining and resources producer and pioneer in adopting advanced technologies has tied up with a technology partner to deploy autonomous solutions on two underground loaders in one of its mines. The machines will be controlled by tele-remote operations from underground automation centres.[15]
- **Roll out of tele-remote surface drilling:** Indian mines have started adopting automated surface drill rigs that provide high-quality drilling. In such a setup, the operator operates the equipment in line-of-sight mode from the remote operator station. This keeps the operator away from potentially hazardous situations.

14. Technology roadmap for coal sector
15. Autonomous solutions in India

# Key drivers for autonomous mining operations in India

The successful implementation and deployment of autonomous operations in the Indian mining sector demands a comprehensive approach. Some of the key drivers that can collectively pave the way for more proactive autonomous mining practices in India include:

- amendments in the regulatory landscape and introduction of more supportive regulatory frameworks
- collaboration among OEMs
- adherence to safe and sustainable mining practices
- economies of scale
- change in work culture.

## Amendments in the regulatory landscape and introduction of more supportive regulatory frameworks

Regulations will need to be amended to encourage the use of technology which can boost efficiency while reducing the environmental impact. Mining and its ancillary activities such as mineral beneficiation and its storage and transportation are highly regulated and impacted by commodity prices, market forces and technological advancements. Regulations, therefore, play a key role in ensuring safe and sustainable mining practices. When it comes to integration of autonomous technology, regulatory frameworks can be pivotal in shaping the sectoral landscape as well. For instance, opening up the sector to new entrants can foster healthy competition, resulting in more innovation and collaboration.

## Collaboration among OEMs

It can be challenging for mining operators to use automated equipment from multiple OEMs. Therefore, OEMs need to encourage interoperability among autonomous systems so that they can be seamlessly integrated across equipment. Retrofitting of mining equipment from multiple suppliers requires a functional safety framework system and advanced practices. Therefore, technology providers, OEMs and mine owners should collaborate and redefine the mining industry by adopting new technologies and developing an advanced and robust ecosystem. Moreover, academia-industry partnerships should be encouraged for R&D to further expedite the introduction of autonomous mining fleet in the Indian mining landscape.

## Adherence to safe and sustainable mining practices

Safety and sustainability are among the most touted benefits of autonomous mining operations. Workers are often exposed to harsh conditions and significant risk in both open-pit and underground operations. Companies that opt for autonomous equipment can reduce the risk exposure of their workforce. Moreover, shifting towards automation aligns with the sustainability efforts of mining companies that are increasingly trying to decarbonise mining operations by reducing emissions.

## Economies of scale

Companies can leverage autonomous systems for continuous and efficient mining processes to gain a competitive advantage over their counterparts. Autonomous equipment can operate round the clock, resulting in increased productivity and more efficient mineral extraction. This can lead to higher yields and reduced operating costs per tonne of material extracted. While automation may add to substantial CapEx costs, mining operations can cover these with improved yields.

### Change in work culture

Implementation of new technology is often met with resistance from the workforce, mainly due to the fear of job loss. In this regard, upskilling the workforce to perform more value-added services can overcome this challenge. Moreover, it is important to bring about a shift in employee mindset. Organisations can drive this transformation through effective change management.

Apart from the sectoral drivers, there are some technical factors that can promote the adoption of autonomous technology. These are as follows:

- **Network infrastructure**

  Automation in mines requires a robust IT infrastructure for high-speed, low-latency continuous network connectivity. Existing terrestrial network mechanisms such as 4G, VoLTE, Wi-Fi have low reliability. Maturity and adoption of 5G technology can help overcome this challenge.

- **The Internet of things (IoT) device availability**

  IoT systems can enable more efficient day-to-day operations by monitoring operations in real time or enabling early detection of possible dangers. India relies heavily on the import of IoT devices, such as sensors, which can pose challenges to the continuous uptime of the equipment in case of sensor and device unavailability. Therefore, a thrust on indigenous development can help OEMs and technology providers to find the right platform to manufacture such devices, which will also boost the economic growth of the mining sector.

- **Mine planning**

  Mine planning – which involves the development of a detailed plan for extraction activities – will need a more structured approach to ensure that the predefined path for trucks is well-planned. Implementing digital solutions in planning activities can enhance efficiency and sustainability. For instance, developing 3D models of mines can facilitate the simulation of contingency scenarios.

## Looking ahead

Increased focus on decarbonisation and digitalisation of the mining sector will bring sustainable mining practices to the forefront. This will encourage mining companies to reduce their ecological footprint for long-term economic viability. Although embracing automation will propel sustainability efforts, widespread technology adoption would require a rejig of the regulatory landscape, restructuring of the operating business model, financial support, technological investments and overcoming workforce shortage.

In India, the prevalent mining business model involves the deployment of HEMM, machinery and equipment at the mine site for waste, overburden and mineral removal. With autonomous fleet deployment, this business model would need to be amended. Simultaneously, statutory authorities across mining and technology will need to extend adequate support to ease the adoption of the advanced mining technology. Identifying alternative ways of workforce engagement and establishing upskilling programmes would also be required to support the deployment of autonomous technology.

# How PwC can help

PwC's dedicated Mining and Metals practice has worked with over 50 global mining companies. The team has developed a comprehensive roadmap for technological adoption that can assist mining companies which are embarking on their automation journey. The areas in which PwC can empower mining companies to undergo a digital transformation are highlighted below.

**1. Assessing readiness for autonomous mining operations**

- Assessment of readiness of the existing mining operation for deployment of autonomous equipment
- Assessment of infrastructure requirements for deployment of autonomous mining activities
- Risk assessments and risk mitigation plans for transitioning to autonomous operations
- Benchmarking with global best practices and mapping the identified gaps

**2. Developing a strategic roadmap**

- Designing a strategic roadmap for transitioning to autonomous mining operations
- Bringing in the right technology solution provider
- Designing a comprehensive total cost of ownership (TCO) model and evaluating the tangible benefits
- Designing a suitable business model for deployment of autonomous mining operations
- Designing appropriate operating and service models

**3. Rendering implementation support**

- Selection of OEM vendors through competitive bidding and assistance in contract management
- Assistance in programme management, monitoring and governance during the implementation
- Preparation of training modules, working guidelines of relevant stakeholders
- Preparation of standard operating procedures (SOPs) for modified and revamped business processes

**4. Assistance in developing institutional framework and capability development**

- Skill-gap mapping and designing a skill upgradation programme
- Supporting the organisation's change management initiatives
- Setting up an autonomous mining operations centre of excellence
- Supporting the creation of code of practice

# About PwC

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