5

The Role of Transport-Related Innovation in the Mining Sector

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5.1 Introduction

Mining and transport are inextricably linked. Raw materials need to get to the destination market, which could be very far away from the mine. As such, different transport modes are necessary to carry these minerals to their destinations. Shipping the mining output is expensive and, in most cases, an unavoidable component of the mining process.

The majority of raw materials that industries use today come from some form of mining, whether it be extracting from far beneath the earth's surface or from open-cut mines on the surface. Early industrializing economies drew on raw materials sourced locally. In some cases, when the location of these commodities was first identified, the most economical solution was often to build downstream factories or processing plants close to the mines and then ship the finished (or semi-finished) product to the final consumer. For example, in the beginning, it was easy and cheap to build power stations near coal mines and build an electricity distribution network than fanned out from the power station. Alternatively, industries sourced their inputs from among raw materials closest to their existing production facilities, which were not always of the highest quality but provided a ready solution.

As industrialization spread geographically and higher-quality resources were discovered remote from the main markets, the importance of transport in the logistics chain of getting raw materials to downstream users increased. This also triggered the need to innovate in the transport sector that led to making mining locations that were more remote and not moveable, more accessible. It can be said, therefore that transport became the enabler for a number of mining products to be used on a much wider scale. The development of the iron ore deposits of Western Australia and of the Amazon region were largely a result of improvements in land-based and shipping transportation. The exploitation of these high-quality resources transformed the world market for iron ore. The same applies to other minerals such as bauxite, copper and manganese.

This chapter discusses the historical importance of innovation in the transport sphere of mining and empirically assesses the recent trends. We show how technological development in the general transport sector has significantly impacted the mining sector from early on to the current days. We focus on the outstanding recent evolution of mining-specific transport innovation to shed light on what is behind this surge. We explore the differences arising both from technological changes (i.e. differences across transport modes) and from globalization (i.e. changes in the geography of stakeholders).

The chapter also looks at the recent evolution of mining-related transport innovation compared to the current trends in total transport innovation. The data shows that mining-related transport innovation (MTI) is not correlated to the overall transport trends (Figure 5.4). There is evidence of mining-specific technologies being follow-on innovations of existing transport ones (Figure 5.9), while the reverse knowledge flow is less pronounced.

Before delving deeper into these areas, the boundaries of the analysis should be clarified. When discussing mining-related transport, the discussion concerns some mining products more than others. The chapter refers mostly to those commodities that require extensive transport resources to be moved, as these are the only ones for which transport will play a key role and therefore MTI can be identified. They are usually moved in bulk and have low unit value. These include coal, iron ore, copper ore and zinc ore. Other materials with high unit value – such as gold, diamonds, rare earth, etc. – are often shipped in small quantities and their transport component will be less important and therefore not captured by our analysis. Oil and gas extraction has also been excluded from the analysis as it is not part of the core analysis in this book and it is often subject to different transport requirements.

Similarly, transport operations can be defined very widely when considering the mining environment. The discussions in this chapter will focus on transport both within the mining area and transport outside, in the form of haulage to destination. While the analysis will look at conveying as a transport means as well as innovations in logistics and above-ground transport innovations at mines, it will exclude hoisting (e.g. lifts) and other aspects that can be primarily considered as being below the ground. Once the raw materials have left the mine, the chapter will review innovations of all transport modes (land, sea and air) that are of direct relevance to the mining industry. It will also look briefly at some of the transport challenges that remain and point to some innovations that may develop in the short and medium term.

A substantial part of the analysis relies on patent data as a proxy for the MTI, which were sourced from the WIPO mining database (Daly et al., 2019) and therefore do not provide results that are disaggregated according to commodity types.

The remainder of the chapter is structured as follows: Section 5.2 describes qualitatively the importance of transport for the mining industry. Section 5.3 focuses on transport innovation in the mining sector. Section 5.4 analyses the recent trends of transport innovation using patent data and explores the direction of knowledge flows between the mining and transport sectors. Finally, future developments and challenges for MTI are discussed in Section 5.5.

5.2 The Importance of Transport for the Mining Industries

5.2.1 Mining Output Is Always on the Move

All mine operations are different. These differences arise from the product that is being extracted, the location of the mine, the destination of the raw material and the time within which it needs to be delivered. As a result, different mining operations require different transport solutions. For example, a coal mine situated close to a coal-fired power station (or rather, a coal-fired power station built near a mine) would need minimal transport and most of the extracted coal could be transported via a conveyor belt directly to the power station.

However, the transport of mining products is usually more complex and requires the use of multiple forms of transport. For example, the overall transport of a mined raw material will involve a conveyor belt or road transport from the mine surface to a storage or processing area within the mining premises, a road leg or, more commonly, a rail leg to a port, and then a sea leg to the destination country and finally a road or rail leg in the destination country to deliver the raw materials to the processing facility. Figure 5.1 stylizes the role of transport in the typical mining supply chain.

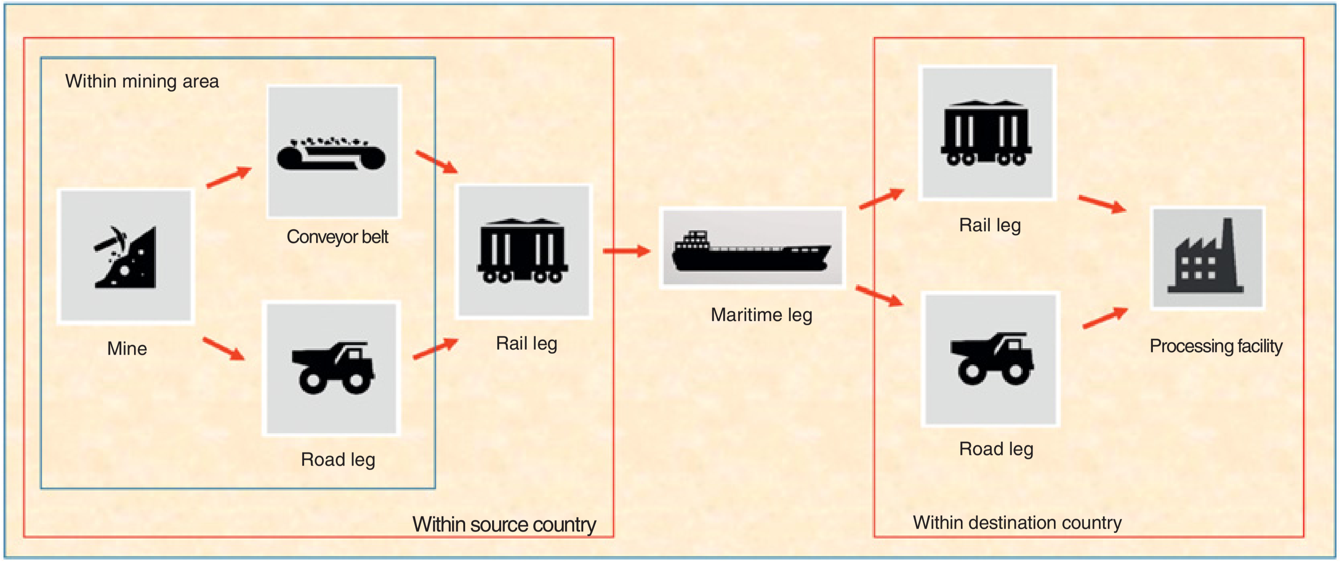

Figure 5.1 Transport in the international mining supply chain
Source: Authors' elaboration, iStock.

This movement of raw materials has a time as well as monetary cost with a typical journey from an Australian mine to China needing more than two weeks just for the sea leg,[1] while the monetary cost can be a significant share of the final delivered cost as discussed later in the chapter.

Given these multiple legs, there are opportunities to increase efficiency all along this transport chain and this is where innovation plays a key role. It could either reduce the amount of time it takes to deliver the raw materials to the customer, or the cost of doing so, or affect both of those by delivering more raw materials in a single shipment. These actions contribute to making existing sites more efficient but also make sites that were previously not economically viable, worth considering for mining operations.

5.2.2 Mining Products Are Traveling Increasingly Longer Distances

More countries are involved in the exchange of mining products today than ever. Many of these have explored their whole geography to find the most profitable mining sites. As a result, mining output is transported increasingly long distances, both within and across countries. For instance, the global production of coal – the most produced and traded mineral in volume – now has increased its geography both in its domestic and export-oriented component (The Carbon Brief, 2016).

In addition to this growing trend in production, the average distance traveled by the raw material from mine to processing facility has also increased. The global production of coal, once limited to a handful of industrialized regions producing and using it, is now produced and used by countries all around the world with different levels of industrialization (see Figure 5.2). In 2014, the largest exporter in volume was Indonesia and in value was Australia, while the largest importer was China (The Carbon Brief, 2016). This is not only the case of coal. In 2015, the largest exporter of iron ore, with over 50 percent of international exports, was Australia and the largest importer was China, absorbing 66 percent of worldwide exports.[2]

5.2.3 The Cost of Transport Operations Remain a Key Driver for Decision-Making

Given the highly competitive nature of mining operations across the world and the different modes that are used, it is difficult to pinpoint

[1] www.ports.com
[2] www.worldstopexports.com, data extracted on April 10, 2019.

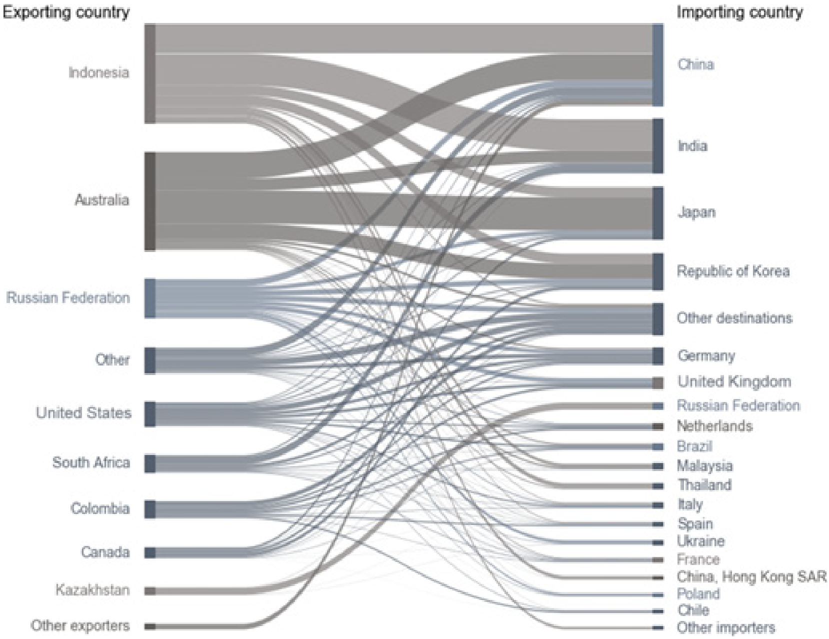

Figure 5.2 Coal and lignite imports and exports 2014
Source: UN Comtrade data, based on The Carbon Brief (2016) methodology.

the contribution that transport makes to the overall final price of the delivered raw material. Setting up infrastructure – be it rail, road or port – and buying rolling stock, vehicles and vessels impose enormous sunk-costs on firms and governments that are only worth making with a continuous and long-term revenue stream.

The cost of transporting mineral output from mine to plant is a significant component of the overall final cost. Data shows that the share of transport costs has fluctuated significantly over time. Morrow (1922) documented that the transport share in the cost of coal in the USA increased from about 22 percent in 1914 to over 50 percent in 1922. More recently, the US Energy Information Administration (EIA, 2016) estimated it to be around 36 percent and 39 percent in 2008 and 2014, respectively (see Figure 5.3). These averages hide the fact that transport cost differ substantially depending on the main transport mode utilized. The EIA (2017) estimates that the transport cost of moving coal can be 9 to 13 percent on inland waterways, about 15 percent on road, and between 41 and

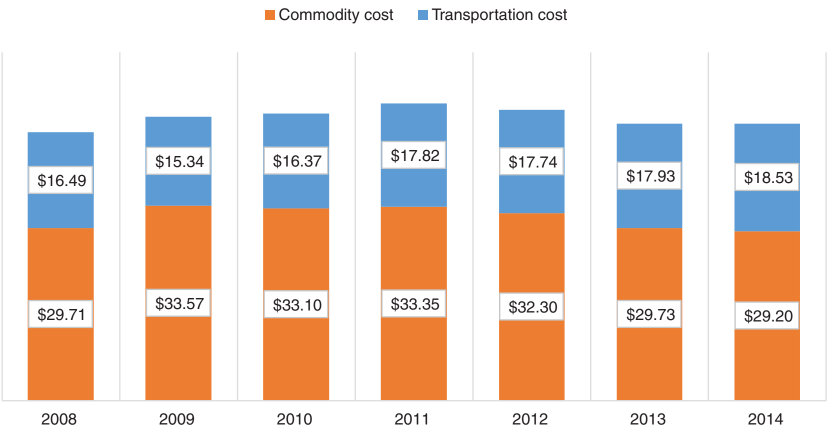

Figure 5.3 Average commodity and transportation costs for US coal (2008–14)
Source: EIA (2016).

47 percent on rail.[3] In addition to the mode of transport, the distance that the shipment of coal travels is also a significant driver of the transport cost – and hence the final price – as well the grade of the coal. A higher-grade coal (e.g. anthracite or bituminous) will bear higher transport costs but permit longer journeys than will a lower grade coal (e.g. subbituminous or lignite).

As the averages in Figure 5.3 are for relatively short distances within the USA, it is important to note that this is not necessarily representative of mining transportation – including coal – around the world. This is particularly true as they exclude a sea leg (e.g. from Australia or Brazil to China) which is a significant cost segment and proportionate to the distance traveled. Sea legs can increase the cost of transportation to over 50 percent (UB POST, 2011). For instance, transportation to Port Hedland accounts for around 20 percent of total operating costs of Western Australian producers of iron ore, and 12.7 percent of the total transport costs are incurred in the maritime leg to reach the Port of Qingdao.[4]

There is a surge in the transport cost component even in the presence of MTI activity aimed at making the transport of mining products more efficient. This is probably due to the increasing distance traveled by mining products. Indeed, the price-over-distance ratio shows that there is still room for efficiency gains through MTI. For example, the shipping

[3] EIA statistical data from "Form EIA-923, "Power Plant Operations Report."
[4] Assuming iron ore (62 percent Fe), delivered cost of $55/wmt and freight costs of $7/wmt.

Table 5.1 *Average distance and Capesize vessel shipping price to Port of Qingdao, China*

Selected ports	Distance (1000 nm)	Price ($/wmt)	Price–distance ratio
Port Tubarão	13.53	17.25	1.27
Port Saldanha	9.74	13.00	1.33
Port Hedland	4.06	7.50	1.84

Source: S&P Global Platts (2017) and www.ports.com.

costs from Port Saldanha (South Africa) or Port Tubarão (Brazil) are significantly higher, reflecting their longer distances (see Table 5.1). However, they are not linearly proportional to distance, indicating that there are efficiency gains in place as a result of the sunk costs being distributed over a longer distance. This is quite important because innovation developments in seaborne transport – such as the recent Valemax vessels – have been a huge factor shaping the global trade in minerals, significantly reducing the cost per nautical mile. This innovation is also essential to absorb the very volatile nature of maritime freight rates (S&P Global Platts, 2017).

To sum up, based on anecdotal evidence there is an increasing trend in the distance traveled by mining products. As a consequence, transport costs have become an increasing component of overall costs. These give mining companies strong incentives to reduce these costs and transport innovation is one important instrument to serve this purpose. The majority of the innovation in mining transport is aimed at reducing transport costs by optimizing various aspects of the transport segment within the mining value chain, namely infrastructure, rail, vehicles, containers, conveying, hauling, shipping, control and automation.

5.3 Transport Innovation in the Mining Sector

5.3.1 What Motivates Transport Innovation in Mining?

The main reasons for transport innovation in the mining sector are efficiency (through cost reduction, increased operation or distance reduction) and safety (through risk reduction and improved work conditions).

Efficiency (through cost reduction) remains the main driver of innovation in transport. It involves any action, investment or new process that can reduce production costs and increase the competitiveness of mines. The drive to increase efficiency targets direct costs such as cheaper inputs into the transportation process (e.g. lower fuel costs) as well as indirect costs (e.g. reducing energy consumption of vehicles or optimizing routing). The latter is the field where innovation can have the largest impact. Other examples of this type of innovation relate to the use of longer and heavier trains with which larger quantities can be moved around from the mines to the clients reducing the marginal cost of transporting the raw materials. Smart maintenance regimes (e.g. predictive instead of preventive maintenance[5]) have led to a reduction in the downtime of the network and lower maintenance costs.

Closely related to efficiency is the ability to increase output through increasing **operational times**. Any innovation that allows for 24/7 operation, in all seasons and weather, increases the effectiveness of a mine. The introduction of partial or full automation (e.g. through the use of radars) has ensured that road vehicles can work in all seasons and all weather with no need to stop for operator rest breaks.

Innovation has a direct impact on reducing **distance** (actual or perceived) to the customer. For example, new building techniques for viaducts allow them to withstand higher loads and thus reduce the direct distance between two locations; alternatively, the introduction of improved signaling intended to increase the speed of transport, or a protective coating applied to the top of loads prior to departure to reduce loss during transit.

Safety and **working conditions** are fundamental considerations in the operations of a mine to make the mining process more socially and environmentally sustainable. As such, those actions that reduce the risk of accidents and remove factors such as driver fatigue within the mining area – including through the introduction of automation and sensors/radars – are highly valued by mining companies. Innovation aims at removing staff 'from the coal face' and out of danger, as well as removing them from direct contact with extracted material. Improving the working conditions of miners could increase the attractiveness of jobs in the sector by reducing the high-risk level of these positions.

[5] Preventive maintenance is when maintenance is carried out according to a specific schedule identified at the time of installation. Predictive maintenance is when maintenance is carried out based on the actual condition of the infrastructure and, therefore, the actual wear and tear of the infrastructure.

Safety and working conditions go beyond the mining site as civil society is increasingly demanding sustainability standards of mining companies operating in their area. The key requirement is to reduce the **environmental impact** of mining operations. Innovation has therefore focused on reducing the carbon footprint of transport operations for mining, for example, through reducing fuel consumption. It can also help to ensure that mining operations reduce the impact that they have on surrounding communities.[6]

All these drivers of innovation are closely linked and a number of synergies and positive externalities may arise from certain actions. For example, innovation in one area aimed at reducing costs, say through more fuel-efficient vehicles, has spill-over effects into other areas such as environmental impact and working conditions. Furthermore, many mines are closed systems, meaning that they have minimal or no interaction with public traffic (road or rail). This means that innovation is less likely to be impacted by restrictive certification requirements or public requirements set out in the national highway code.

5.3.2 How Relevant Has Transport Innovation Been for Mining?

Historically, the importance and impact of transport-related innovations on the mining industry has fluctuated significantly. Figure 5.4 sets out the historical evolution of mining-related transport patents as a share of all mining patents. It shows that the share has ranged from as low as 2 percent to as high as 7 percent. Three periods emerge from this historical analysis.

The first 15 years of the twentieth century show a period of boom. This is likely a delayed result of the *Industrial Revolution*, when steam engines were introduced to the transport industries to improve navigation and develop the railways.[7] It was not until the beginning of the twentieth century and the technological revolution, that widespread adoption of these pre-existing technological systems – like railways, but also road-going vehicles – started. As a benchmark, the overall share of transport innovation also experienced a boom in the first two decades of the twentieth century. However, until

[6] For a discussion on mining environmental innovation, see Chapter 6.

[7] For example, steam engine technology was first introduced as pumps to remove water from flooded mines. Jerónimo de Ayanz obtained an invention privilege from the Spanish Crown in 1606 and Thomas Savery obtained a patent (No 356) in London in 1698. This is, therefore, an example of a technology first developed in the mining sector and then applied in other sectors as well.

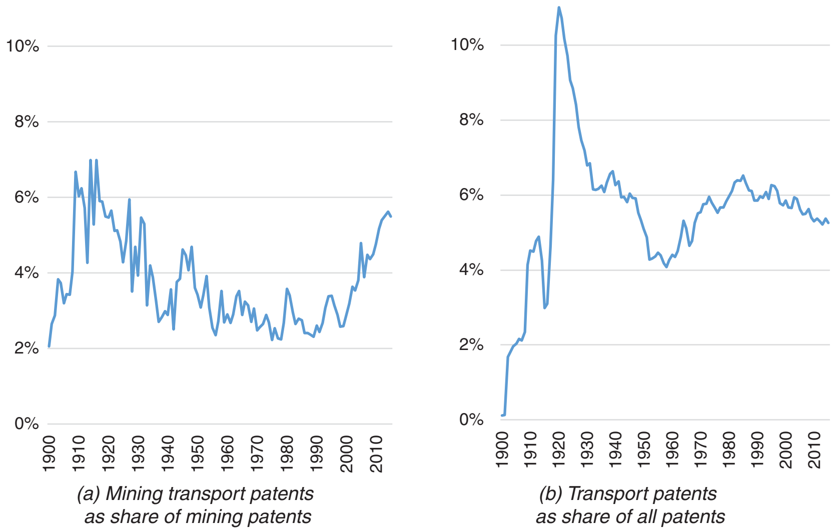

Figure 5.4 Historical change in transport-related innovation (1900–2015)
Source: WIPO mining database.

1918, it seems that MTI was proportionally more important for mining than transport innovation was for all innovations.

Despite this very innovative initial period, the share of transport-related patents compared to the rest of mining-related innovation shrunk in the following decades. This downward trend continued until the mid 1970s. As shown in Chapter 1, this trend looks to be the inverse of other mining categories such as blasting, exploration or environmental technologies whose share in the overall mining innovation pool grew steadily over this period. Related to this, metallurgy innovation using mining products did not change significantly during this period, while the processing category saw a decline similar to the transport category. Refining innovation reached a peak of almost 80 percent of total mining innovation at the beginning of the 1970s, after which it started declining steadily until the lowest point at around 10 percent in 2015.[8]

This decline of transport-related innovation in mining seems to follow the pattern of all transport innovations, which also observed a major plunge from 1920 to the late 1950s. This decline is particularly true for railways-related innovation, which has a similar trend to MTI. Part of

[8] For an in-depth analysis of the evolution of all mining categories over time, see Chapter 1.

this decline can be attributed to World War II reconstructions, which aimed at infrastructure expansion and not necessarily innovation. Indeed, MTI did not see the slight recovery that transport innovation saw from 1960 to 1985. Moreover, transport innovation has constantly been a smaller share of all mining technologies than transport innovation is for all technologies together. It seems that the mining sector has underutilized transport innovations compared to other sectors in the economy during this period. This is probably related to the small contribution of railways and shipping-related innovation observed in that period as opposed to the share of automobile-related innovation that had a relatively higher impact outside the mining sector.

Nevertheless, MTI follows a completely different trend compared to overall transport innovation and railway innovation starting from the beginning of the 1990s. While the latter two remained pretty stable as a share of all innovations in the period 1990–2015, mining transport-related innovation increased sharply as a share of all mining innovation. Almost all other mining categories lost importance in the last two decades. Their shares were absorbed by both the transport and the automation categories. Moreover, by 2014, almost a century after 1918, transport-related innovation was again proportionally higher in mining than for the average industry.

There are two potential and complementary explanations to such resurgence in mining transport patents. First, transport technologies might be benefiting from a technological push in line with the new wave of information and communication technologies (ICTs) observed in this period. Indeed, as the steam engine did in the past, ICTs are considered general-purpose technologies (GPTs) with the potential to open several avenues for further transport innovation among other industries. GPTs have had difficulties developing fully in decentralized economies (Bresnahan and Trajtenberg, 1995). However, because of the close-system characteristics of transport in the mining sector, it is possible that transport innovations related to ICTs are explored there first.

The second explanation is related to the extraordinary demand conditions in this period, which arguably led to a technological pull for transport innovation. As discussed in Section 5.2, in this period, not only was there increased globalization (e.g. increase of internationally traded goods) but also a major geographical shift of production, most notably to Asia and particularly to China. Both had a direct impact on the need for increased transport innovation. In the mining sector, this has been translated into extraordinary high price cycles and into an increase in demand for bulk minerals to feed the industrialization of Asian economies (see Chapters 1 and 7). As a result, higher prices made more remote mining sites profitable; and since China became the main destination for the output of numerous mining sites, it made the average distance to market higher in a very short period of time. Transport innovation related to mining was suddenly crucial.

5.4 What Explains the MTI Surge?

5.4.1 How Has Globalization Changed the Geography of Transport Innovation?

The geographical shift of supply and demand for certain minerals has arguably affected the technological landscape in the sector. The United Kingdom and Germany have historically been among the top innovation stakeholders of this sector, while other economies have overtaken them in more recent years. Particularly, since 1990s, the United States, the Russian Federation, Japan, China and the Republic of Korea have been the most active countries in transport innovation (Figure 5.5).

Among these new stakeholders, China is the most significant. There has been an exponential growth of Chinese mining-transport-related patents over the last 10 years, both in absolute and relative terms. This has coincided with the shift of demand for many raw materials to China. A similar trend has been documented for all Chinese mining patents (see Chapter 2). It is worth noting that China has been increasing consistently in all technological domains during the past decades (Hu and Jefferson., 2009). However, the Chinese performance in mining transport technologies is particularly astonishing. In 1990, China was responsible for less than 1 percent of all patents whilst accounting for almost 40 percent of transport-related mining patents. By 2015, China represented 53 percent of all mining patents and more than 80 percent of the MTI ones (WIPO, 2018).

5.4.2 What Are the Technological Changes across Modes of Transport?

Transport innovations related to mining cover all transport modes and all aspects of the transport chain mentioned previously. This section explores the surge of transport-related innovation according to the contribution of the main transport chain segments. These include the traditional transport modes – such as road, rail, maritime, and conveyors – and innovations applied horizontally across all these modes. Among the latter, the review focuses on containers, which could travel

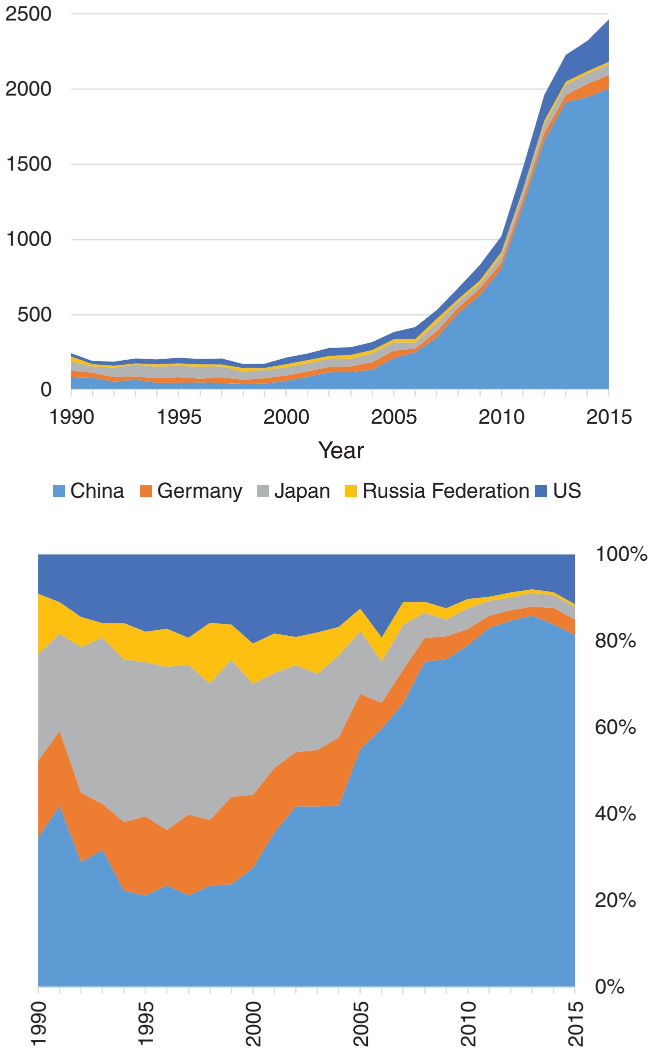

Figure 5.5 Country of origin of mining transport patents (1990–2015)
Source: WIPO mining database.

either by road, rail or sea, and control, which includes logistics and automation technologies.[9] Figure 5.6 summarizes the evolution of MTI showing the number of patent families applied in each mode of the defined categories.

[9] See annex for more details on the mining transport categories and subcategories.

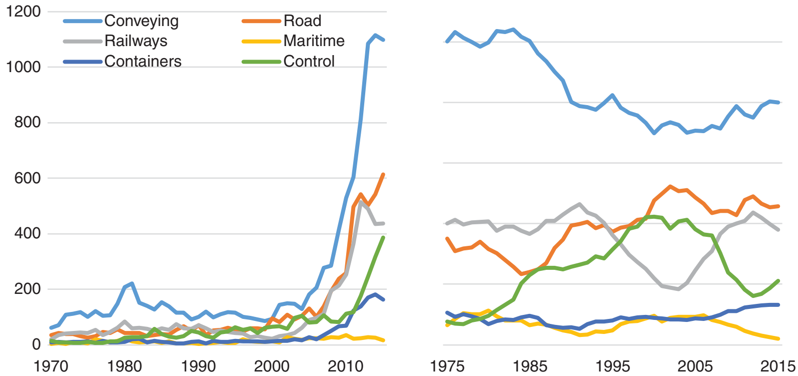

Figure 5.6 Mining transport patents by mode of transport (1970–2015)
Notes: Shares on the right are smoothed using a 5-year moving average.
Source: WIPO mining database.

A significant amount of transport innovation within the mining sector involves fixed equipment – such as conveyor belts – moving mining output within the mine site. New developments in the ***conveying technologies*** field have led to longer conveyors being installed, with lower energy consumption, higher capacity and lower running costs thanks to more durable components.

Technologies related to transporting mining output through ***conveying*** represent the largest volume of patents in the data. These have also seen the highest increase in volume during the last four decades. A cursory look at the patent pool shows that many of these patents are for detailed components of conveying systems rather than systems as a whole. This partially explains the large number of patents, but also indicates that there is considerable incremental innovation happening within this technological field.

In relative terms, innovation in this mode of transport has lost ground with respect to other categories over the period analysed, potentially pointing to an approaching technology frontier. However, the share of conveying technologies has been growing again since the 2000s as part of the mining transport surge. China's technological focus on improving this transportation tool largely explains this reverse of trend.

Recent years have seen substantial innovations in ***road transport*** within and outside the mining sector. Currently, road technologies are the second transport mode in patent volume, overtaking railways technologies. Road technologies relating to vehicles and hauling (i.e. the trucks) explained most of this growth, while road infrastructure technologies has still grown but not as fast. Two thirds of recent road technology advancements relate to vehicles and hauling. For example, in the 1960s, the largest trucks in operation carried around 30 tonnes; today there are trucks carrying 450 tonnes.

Quite a lot of transportation by trucks takes place within the mining area, whether to crushers or to processing plants (e.g. concentrators) before products are moved away from the mine. Part of the exponential growth relates to the fact that transportation by truck within mining sites is a closed system, as mentioned previously. However, some of this growth may now have reached the limits imposed by the “real world” outside of closed systems. For instance, truck size may have reached a technical barrier linked to the maximum size of their tires. Tires cannot be transported to a mine as spares if they cannot fit on or under existing public road structures (e.g. tunnels or bridges) outside the mines. Where these technological developments are not limited by the requirements of public infrastructure they have also been applied outside the mining area. For example, real-time information on the status of truck tires can be provided to operators to allow them to change tire pressures according to their load, reducing wear and increasing durability. Furthermore, there are trials underway in relation to platooning technologies, where a semi-autonomous road convoy has a lead truck driving (for the moment with a driver, but potentially in future also autonomously) and several vehicles following it autonomously through the use of radars.

Among the top patent-filing economies, China and Japan are more specialized in vehicle technologies, China is also more specialized in hauling technologies and the Republic of Korea, Japan and the Russian Federation are more specialized in road infrastructure.

Outside the mine area though, it is not economical to transport raw materials by road, unless the distance to destination is small (less than 80–100 km) because of capacity restrictions but also due to fuel and maintenance costs related to the vehicles. Therefore, the transport of mined raw materials often involves at least one rail leg to deliver the extracted material to the customer. While railways have a significant element of sunk costs in the building of the infrastructure and the buying of rolling stock, the subsequent maintenance costs are manageable and as such make the use of railways more economically viable.

The evolution of ***railway technologies*** resembles, in volume and trend, that of road developments. The 1980s and 1990s saw railway technologies decline in share, but they made a sizeable contribution to the recent MTI boom in the early 2000s although this has dropped off more recently. China has been the largest contributor to these technologies in the recent boom, while Japan has focused on rail infrastructure in relative terms.

The railways have also seen their fair share of innovations that have benefited the mining sector. On the infrastructure side, new asset-management techniques have been introduced seeking to optimize the maintenance schedule to limit the amount of time that the line needs to remain closed for maintenance. This has been accompanied by extensive data gathering that has allowed infrastructure managers to move from preventative maintenance regimes to predictive regimes based on the actual condition of the tracks. Modular systems have also been developed to allow railways to be built and dismantled more easily if a mine needs to be operated for a shorter period of time than is usually expected for a full mining operation.

Similar to road vehicles, rail locomotives and wagons have improved their efficiency to increase the throughput for the sector. Many mining railways essentially exist in a closed system where mining traffic is the only traffic that runs on the network, which allows for more efficient techniques to be introduced. For example, a freight train traveling on the European rail network often cannot be longer than 750 m because of the requirements in relation to signaling and power, while some of the mining trains in Africa, South America and Australia are over 3 km long with the longest on record being over 7 km long.[10] To be able to haul this weight, locomotives have needed to become more powerful as well as more reliable and over the years innovation has focused on these areas. On the infrastructure side, an important factor for the railways is also the speed at which the trains are loaded and unloaded. Over the years, significant improvements have been made in this area to increase the efficiency of this process exemplified by the move from volumetric train loading systems, through gravimetric and continuous loading systems to the more modern fully automated train loading systems. These newer systems have led to improvements in loading speed, but have, more importantly, made loading more reliable and consistent in terms of train load.

Maritime technologies in the mining sector exhibit a similar trend to other transport modes, but they represent a volume at least 10 times smaller than for rail or road technologies. Among the top mining-

[10] See *Railway Gazette*, August 1, 2001, and Laing O'Rourke Website (retrieved 2011), Wikipedia.

transport patent-filing economies, the United States is the more specialized in maritime technologies.

The limited number of patents is likely related to automation and innovation within ports being the more significant innovation in the maritime sector when it comes to mining industries. Vessels have seen fewer innovations as, in terms of size, they are often constrained by key shipping lanes and canals such as the Panama Canal.

Nonetheless, capacity has increased significantly over time primarily with the introduction of Capesize vessels aimed specifically at carrying bulk cargo. These vessels average around 175,000 deadweight tonnage (DWT), with the largest in operation being about 400,000 DWT.[11] This increase in size has been accompanied by an increase in the number of ports that can accept these vessels, although, given their size, the number of ports where these vessels can call is still small. In addition, vessels have become more fuel efficient and have been able to haul raw materials using better practices through improved sealing of load-carrying compartments.

In terms of horizontal technologies applied across all these transport modes, ***container technologies*** is the largest in patent terms. Historically, the number of patents related to containers has been very low, but more recently it grew much faster reaching more than 180 patent families in a single year. Today these technologies outrank the maritime ones. Across the years, improvements to containers have allowed the transport of mining products over longer distances and in all weather conditions. Modern containers isolate the mining load, reducing loss during transfer. Among the top filing economies, the United States, the Russian Federation and China are specialized in container technologies.

Over the past four decades, modern ***control technologies*** – including logistics and automation – have been deployed in the MTI sector. In recent years, new logistics practices have optimized the movement of raw materials building on common, general innovations such as just-in-time deliveries. In addition, significant innovations in the command and control sphere have occurred, with new techniques, such as the possibility of predictive maintenance and better asset management for transport infrastructure, as well as more efficient management of the movement of vehicles, also through the introduction of automation.

It is clear that automation is a significant focus of innovation in more recent years and will be going forward (see Figure 5.7). Patent data shows

[11] http://maritime-connector.com/wiki/capesize/

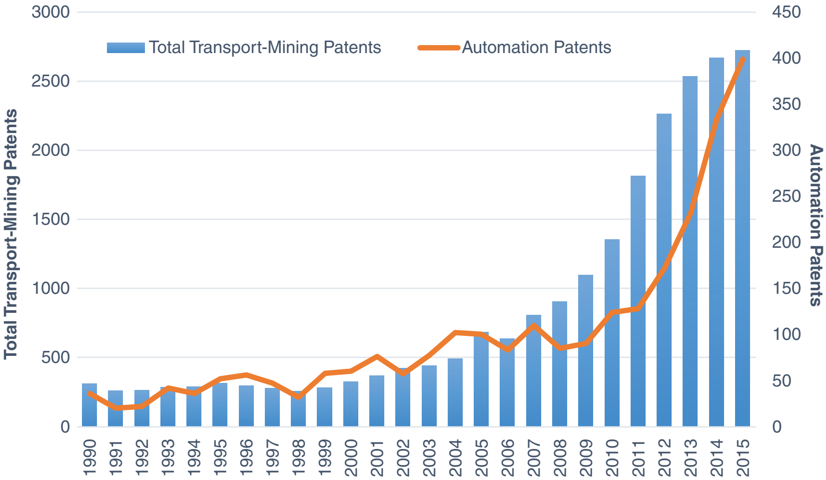

Figure 5.7 Transport patents in automation
Source: WIPO mining database.

that since the early 1990s, automation follows more or less the same increasing patterns of other transport-related patents. When focusing on more recent years, this pace has an even sharper increase. In 2015, up to 15 percent of transport patents filed globally had an element of automation. The breakdown of automation data by country indicates that the USA and Japan are the leading countries in this area. Germany and the Republic of Korea follow them by a significant margin (Figure 5.8).

Automation finds multiple applications across the different modes of transport in mining. On roads, trucks are also becoming more automated with numerous sensors and radars to optimize their movement and speed within the mining area, thus reducing congestion, diesel use and tire wear, while at the same time increasing the safety of those working on and around these vehicles. Finally, more recently, partially and fully autonomous vehicles within the mining area have been introduced. Railway transport could also benefit from automation. For example, technology can remotely operate locomotives spread along an entire train within a train consist or ensure that weight and power are distributed equally and effectively. One mining company in Australia is currently trialing an autonomous train to bring iron ore from the mine to the port for export. The trials have taken a long time mainly to ensure the service was safe as well as efficient and the service is now operational.

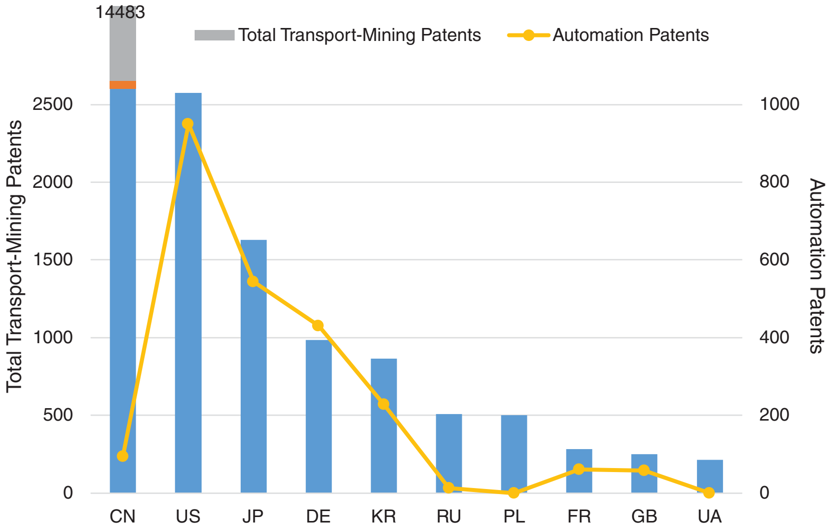

Figure 5.8 Transport automation innovation per country
Source: WIPO mining database.

5.4.3 Does Knowledge Flow In and Out of the Mining Transport Sector?

Diffusion of knowledge across industries varies and depends on its intrinsic characteristics in terms of breadth of applicability in other technological fields (Appleyard, 1996). In order to understand the role of innovation in transport and its contribution to mining innovation as a whole, it is also important to look at where MTI has come from. In the pool of 21,155 mining transport patents, more than one third have cited another patent of any technological field. For each cited patent, an analysis has been carried out on whether they are part of mining technologies or not[12] and looking also at what technology field they belong to.[13]

The aim of this analysis is to identify whether the mining transport subsector is a recipient of knowledge spillovers from other sectors – such as transport in general – or whether it produces knowledge that is then used in sectors outside mining. The pool of citations is divided into those referring to either the mining or non-mining technological fields. Figure 5.9 shows that 84 percent of the citations refer to non-mining sources, whereas only 16 percent of these refer to a mining technology.

[12] See Chapter 2 for more details on measuring mining technologies using patent data.
[13] For a discussion on measuring spillovers using patent citations and their limitations, see Trajtenberg (1990), Jaffe et al. (1993) and Michel and Bettels (2001).

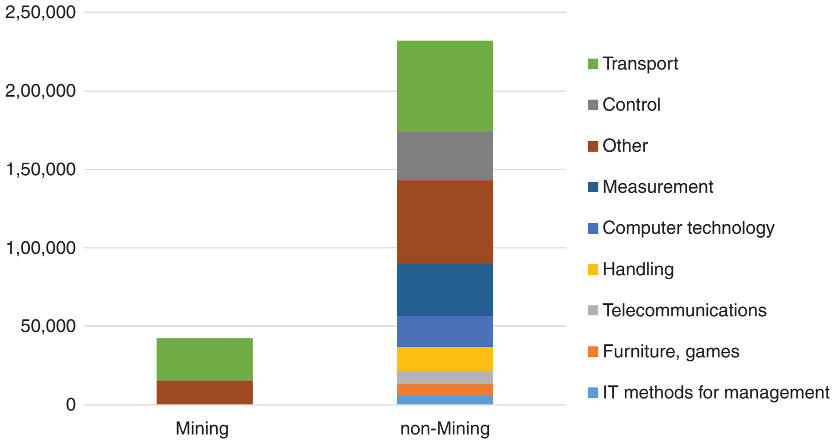

Figure 5.9 Where does MTI source technology?
Note: Patent citations from mining transport technologies by mining/non-mining and technological fields of cited patents. Fractional counting used when multiples technological fields.
Source: WIPO mining database.

Interestingly, transport is the top technological field among the patent citations from both mining and non-mining technologies. Indeed, citations to transport technologies not related to mining are an evenlarger group than those related to mining transport. Within non-mining technologies, ICTs citations as a whole – including control, computer technology, telecommunications and IT methods – are comparable in size to the transport citations. This suggests a strong knowledge flow from pure transport technology and ICTs to mining transport applications. Of those citations to other MTI (Figure 5.9, left column in grey), 74 percent refer to control technologies. This is interesting because it contrasts with the share of control in all mining transport patents, which was around 20 percent at its peak. Moreover, this reinforces the importance of ICTs as a source for mining transport technologies.

As well as understanding where MTI might come from, it is also important to highlight which other sectors use mining transport technologies as prior knowledge. The analysis therefore looked at which sectors are likely to make use of the technologies created in the mining transport subsector through the use of the citations received by mining transport patents.

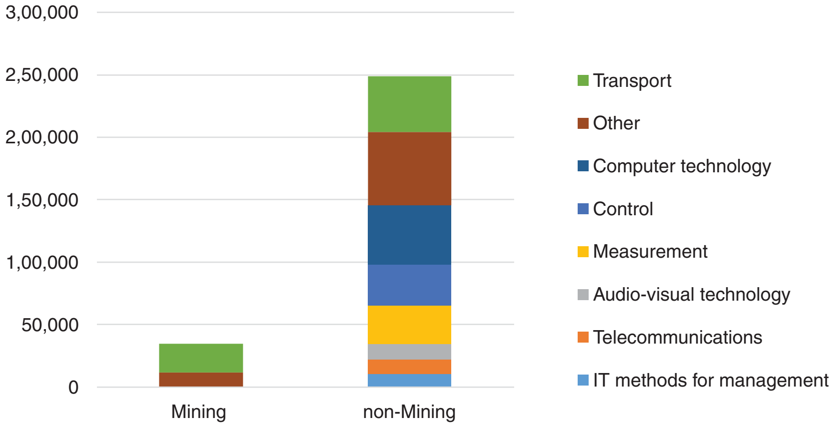

Figure 5.10 Which sectors make use of mining transport technologies?
Notes: Patent citations to mining transport technologies by mining/non-mining and technological fields of citing patents. Fractional counting used when multiples technological fields.
Source: WIPO mining database.

In the pool of 21,155 mining transport patents, almost half have received a citation from another patent. The majority of citations to mining transport technologies are from non-mining patents (88 percent). From the 12 percent that remain within the scope of mining technologies, the greater part is mining transport technologies citing mining transport patents (Figure 5.10, left column). This suggests that very little follow-on innovation spills over from mining transport to other mining technologies.

Within the non-mining citations (Figure 5.10, right column), ICTs as a whole are the bulk of citations toward mining transport technologies. In particular, citations from patents related to computer technology alone are larger than those from transport patents. Still, transport patents – not related to mining – remain one of the main categories citing mining transport patents. Both ICTs and non-mining transport gather a much larger volume of citations than mining transport ones.

These findings support the idea that transport within the mining sector might be a testbed for transport and other technologies from outside to be deployed and concept-proofed. How much this exercise benefits societies at large and mining economies in particular is a question that escapes the scope of the current research.

5.5 Future Developments and Challenges in Transport Innovation in Mining

Current technological developments both inside and, as discussed in the previous section, outside the sector can have a significant impact on MTIs and the operation of the entire mining supply chain. Patents can give us a hint on where future innovation lies and where there are still problems that need to be solved, such as empty running, that is, when a truck, train or vessel delivers the mined materials to its destination and returns empty, which essentially means that the variable cost of transport is twice as high as it could or should be. This is an issue that has affected, especially, freight transport, from early on and an innovation that minimizes this would make a significant change in relation to transport costs. The same also applies to continual improvements aimed at reducing heavy energy use.

Innovation in transport within the mining sphere has been fundamental to the growth of the sector and to increasing efficiency and safety and is also now starting to assist in reducing the environmental footprint of mining. MTI affected all possible modes of transport of mined materials within and outside the mine, namely road, rail, ships and conveyors.

The analysis has documented how important transport technologies were for mining innovation at the beginning of last century, how it declined for more than 70 years, and how it became remarkably relevant again in the last two decades. The chapter has explored the reasons behind this surge in several dimensions. For example, China has become a major player in this field, even beyond the outstanding performance that Chinese overall patenting has had. This is partially explained by the role China has played as both producer and user of mining output and the transport needs its geography and size demands. It is clear that conveying technologies made a strong contribution in the recent surge, especially given their volume. Railways and road technologies also contributed in different moments to this surge. A special mention is due to control technologies – particularly automation-related ones – which seem to be not only part of the surge but also the engine of the most recent and future developments in this sector. Interestingly, this is a domain where the impressive Chinese innovation trend has not yet had an impact.

Transport innovation – in principle more general purpose technology – seems to find an easy application in the mining sector, probably following some customization to serve mining-specific needs. On the other hand, it seems that knowledge created inside the mining transport sector then spurs ICT technologies. This result is probably driven by the recent increase in automation and digitalization, which are becoming important components of all sectors including the mining-transport one.

This could give us a hint on where future innovations are likely to go. Except for the early and more general innovations, most MTIs have been small and incremental on previous initiatives. These incremental innovations contributed extensively to increasing efficiency in transport, moving more commodities and by making the movement of bulk commodities faster, safer and more reliable.

However, there are still significant transport problems to be solved. The largest of these remains the problem of empty running mentioned previously. The continual progress of battery and alternative propulsion technology is also likely to have a positive effect on the transport of mining products, in particular in seeking to address the problem of high energy use of the mining sector, both inside the mine and outside as a partial substitute for diesel on road and rail and potentially on seagoing vessels. The growth in drone transport may also have an impact with larger, more powerful drones being used in exploring potential mining sites as well as moving equipment to those sites. Drones can also be used to inspect road and rail infrastructure from a distance, cutting down maintenance needs and reducing infrastructure unavailability.

What is clear is that innovation is often unpredictable. What has previously been considered an impenetrable frontier for technological development (e.g. automation) can be overcome from one day to the next with a milestone invention that then snowballs into further innovations that increase operational efficiency, bring down costs and increase safety.

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Annex

For the purpose of the analysis, the chapter distinguished MTIs in the following categories and subcategories:

- Road
- Railways
- Containers
- Conveying
- Maritime
- Control

These were applied to the WIPO Mining Database based on the International Patent Classification (IPC) or Cooperative Patent Classification (CPC) in the patent documents. For a detailed description of the subcategories, please refer to Daly et al. 2019.