ICT, Mining and the Inversion of Industry 4.0

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Introduction

Theme 3 of the CDO project examines the impact of ICT across industrial sectors of the Canadian economy. In the materials and manufacturing sectors, the impact is characterized as Industry 4.0, associated largely with the rise of new digital infrastructure, robotics and AI applications. The implementation of 4.0 however is radically different in the two sectors.

The future of the digital economy itself absolutely requires mining. Electric cars are a play on cobalt mining. Digitization of the economy is basically electrification, which makes it a play on copper mining. The next ten major copper mines are underground mine designs, for reasons of ore quality. For many people, Waterloo and Sudbury would represent the bookends of the ICT and industrial economies. In Canada, digitization will redraw this economic geography map.

The path of progress however is far from linear. The past decade has witnessed an unprecedented metals price super cycle and at the same time a 28% decline in mining productivity. It has also seen the marginalization and elimination of the classic centres of Canadian metallurgy such as Inco, Noranda, Alcan. Do we think these things are connected? Do they matter?

The industry is at a technology inflection point. Digitization of ore bodies and robotics offers the prospect of everyone working on the surface and having zero emissions mines. At the same time, if the mining industry is to survive in Canada, it has to deal with the productivity challenge.

The Technology Inflection Point in Mining

The mining equivalent of the 3rd wave of the Industrial Revolution arrived in mining in the 1970s and 1980s and used process control, electronics and robotics to automate routine and repetitive tasks (Yeates 2017). In manufacturing, it enabled the creation of huge, highly specialised factories producing a single product with few variants very cheaply. During this wave, factories achieved global scale and were located in regions to access cheap labour. This required the shipping of products to global markets. Supply chains and logistics were the keys to success. While this wave promised high levels of automation, it actually only automated about 20 per cent of the most standardised and repetitive tasks. The promise of cheap labour proved to be temporary, with the inevitable rise in labour costs driven by the very presence of these factories distorting the local market.

This third wave of disruption struggled in mining. Equipment sizes increased and process control were installed in plants, though more often than they not remained in manual mode. But the other advantages that manufacturing leveraged, such as moving to low-cost labour environments and standardised specialist production facilities, were constrained by the ore body. Ore bodies occur where they are found, they are at the scale at which nature created them and they don’t always occur in low-cost labour environments. Each ore body is different and unique. However, mine operators have spent years trying to apply standardised and increasingly large equipment, along with a standard mining process, to highly variable and unique orebodies. Apart from scaling up equipment, very little value was gained in mining from this third wave of disruption. Yeates argues that some of the scale up was to the detriment of the industry, where the scale of the equipment was larger than optimal for the ore body and thus accelerated grade decline through dilution and shortened the useful life of the mine. This has been a poorly understood driver of the reduction in productivity in the industry.

AI, Robotics and the Future of Mining in Canada

It has been proposed that digitalization would enable a breakthrough in improving productivity, safety, and environmental performance for the mining industry (Arnoldi, 2017). In its prediction of the top trends for 2017 for the mining industry, Deloitte rated the digital revolution among the top issues with the potential to transform the industry (Deloitte, 2017). While the mining industry has adopted advanced mine planning and modeling software tools to optimize mine designs and production operations, these tools tend to generate designs that are based on a standard suite of mine designs or limited to use of existing operating equipment and methods (Gosine & Warrian 2018)

For many years, underground miners have been working with tele-operated drilling and loading machines (Cosbey, Mann, Maennling, Toledano, Geipel, & Brauch, 2016). Early advances included tele-operated Load-Haul-Dump (LHD) vehicles that utilized line-ofsight remote operation. The operator stood at a safe distance from the LHD as it was being loaded under unsupported ground. In this application, the operator used a chestmounted console to guide the LHD through the loading process and in backing away from the ore pile. The operator would then get back on the LHD and manually drive the vehicle to its unloading point, unload the vehicle, and return to the loading point where the tele-operated loading process was repeated (Caterpillar, 2017). Marshall et al provided an overview of modern mining practice and a state-of-the-art review of mining robotics for both surface and underground mining operations (Marshall, Bonchis, Nebot, & Scheding, 2016).

In late 1990s and early 2000s, Canadian industry and academia were leaders in R&D related to tele-operated mining with the support of PRECARN, an industry consortium designed to translate advanced research in robotics and intelligent systems into practical use (The Scientist, 1987). In 1998, Canadian nickel mining company Inco articulated a vision for automated mining whereby “from any location in the world, a tele-operator can instruct intelligent, automated mining equipment to execute their missions. If the equipment encounters an unexpected situation beyond its ability to manage, it will ask for help. The tele-operator will respond immediately to requests for help from a wide range of intelligent, automated mining equipment” (Inco, 1998). With the support of PRECARN, Inco along with technology providers and academic partners pursued a series of technology development projects to automate various types of mining vehicles and operations in order to improve productivity (Werniuk, 2001). In 2007, Orica Ltd., in collaboration with the Commonwealth Scientific and Industrial Research

Organisation (CSIRO) from Australia and C-CORE from Canada, demonstrated tele-operation of an explosive emulsion loader (C-CORE, 2007). Due to the technology limitations of the time, these projects generally focused on single-point, rather than system-wide, solutions. Today's technology can support more radical innovation, targeting the entire value chain and providing the greatest prospect for transformation in productivity.

PRECARN was also instrumental in supporting industry university collaboration related to human-machine interaction for heavy equipment, leading to the spin-off of Motion Metrics International from the University of British Columbia in 2000 (ICICS, 2010). Today, Motion Metrics International continues to develop machine vision and sensor systems directed toward improving "safety, efficiency, and productivity in mining" (MMI, 2017).

During this period, there were also research chairs at Canadian universities focused on mining automation, including the NSERC/Noranda Chair in Mining Automation at Ecole Polytechnique de Montreal and a Canada Research Chair (CRC) in Robotics and Mine Automation at Laurentian University. Penguin ASI, a technology company based near Sudbury, Ontario and developing automation technologies, is a spin-off from the work of the CRC at Laurentian (Mining Global, 2014).

Other recent advances have been demonstrated for underground mine operations, including locating miners on the surface, or away from the mine site, and out of danger, with advanced human-machine interface tools for remote supervision and control of multiple highly-automated mining robots having auto-pilot and navigation capability. The current state-of-the-art involves automation of discrete phases of the mining cycle rather full automation of the mine site (Watkins, 2017).

In September 2016, Barrick and Cisco announced an ambitious partnership to integrate digital technology across all of its mine operations at Cortez, Nevada (Barrick, 2016). Mining and construction equipment manufacturer Altas Copco offers tele-operated and autonomous vehicles, with the primary drivers for automation being safety, productivity, qualified labor, and production costs (Atlas Copco, 2015). Sandvik, another manufacturer of automated LHDs, reported a 30% improvement in haulage productivity through use of their systems (Sandvik, 2017). There have been reports of considerable advances in the development and application of autonomous trucks for surface mining applications at BHP Billiton and Rio Tinto mines, and at Suncor oil sands operations (Simonite, 2016) (Gershgom, 2016) (Topf, 2016).

In the future, many direct production jobs in mining could be carried out from operation centres distant from production sites. Such operations could be safer because of reduced exposure of workers to dangerous and inhospitable environments, with increased productivity, lower environmental impact, reduced energy requirements, and lower capital and operating costs. For example, while locating equipment operators at a distance from production sites may decrease productivity by removing some of the cues (i.e., visual, audible, tactile and olfactory) they have at the rock face, there are efficiency gains from significantly decreased transit times to the production sites.

Overall, disruptive technologies, such as the internet of things (IoT), big data and analytics, automated vehicle technology, robotics, advanced imaging and sensing systems, wearable computing, and other intelligent systems technology, could become commonplace within the mining industry. Their widespread application would facilitate greater connectivity and autonomy of assets, with increased amounts of data collected and processed in real-time to aid in planning, optimization, and execution of operations. These technologies could help manage and coordinate various manually-operated, remotely-controlled, semi-automated, and automated vehicles and machinery working simultaneously at a production site.

While the benefits of emerging digital technologies may be realized by the mining industry, this would require companies to embrace Industry 4.0, a choice that “could be the most important strategic decision that companies make” (Yeates, 2017). Currently, fewer than 10% of mining companies are thought to have developed a digital strategy

The Decline of Canadian Metallurgy

The 20th century saw the emergence of the modern mining industry in Canada and the growth of major metallurgical capacities at their associated industrial sites such as Inco Sudbury, Noranda, Alcan etc. The subsequence elimination of these capabilities is a major contributor to the decline of mining innovation and productivity in the Canadian industry.

It was an industrial landscape where technical and laboratory capacities had become part of the standard architecture of the modern corporation, built originally on the model of the late 19th century German industrial corporation. This was the key development that drove expansion of modern mass production and its productivity frontier.

In the day, the major metallurgy centres provided the underlying physical and technological substructure for Industrial Canada, its manufacturing, transportation and infrastructure base of our modern mass production and mass consumption society. To understand the contribution of metallurgy, it is important to document the pathways and networks of transmission of metallurgical knowledge and technology in its diffusion across the economy. Much of it was led by great personalities of Canadian metallurgy, reflected in its Hall of Fame recognition.

That was then and this is now. The great centres of metallurgy associated with Canada's leading mining and materials: Inco, Noranda, Alcan, Cominco and Stelco were all marginalized and ultimately abandoned from the mid 1990s to the late 2000s.

They were the victims of corporate and financial changes: movement of investment to developing countries, shareholder value ideology, the decline of the classical corporate R&D laboratory in the industrial landscape, etc. It happened all over. Examples include the decline of the legendary laboratories at ATT, IBM, Dupont, General Motors and US Steel.

The forms and norms of the modern industrial corporation underwent a fundamental shift. While the corporate centres and labs went away, the need for and existence of modern metallurgy were still vital to the modern economy and its progress. New networks and agents emerged. Many individuals migrated from private industry to universities and government labs. There were expanded roles for engineering consulting companies like Hatch. Public research infrastructure and universities came to play a proportionally larger role. And, at mining sites, their regional economies like Sudbury, saw the emergence of a mining engineering and technology supply companies growing to a combined size that equaled or exceeded the size of the production work forces of the heyday of the industry. These service clusters took over much of the innovation role that the classic corporate centres had played (Hall 2017).

Emerging Digital Technologies in Mine Operations

Limitations on Mining Innovation

Mining has a long history and reputation of being a very conservative culture in terms of investing in new technologies. Changes do happen in terms of the extraction and production model for the industry such as the mover to ‘bulk mining’ led by Inco in the late 1980s and early 90s, but then that model gets locked in for the next 30 years. It is indeed that bulk mining model paradigm that is now under pressure for many reasons including new digital technologies, problems of heat and energy consumption as the next generation of operations enter the 3-5 thousand meter depth levels.

Cyclicality

A practical problem for miners is the volatility of metal markets. When prices are high, they are too busy to innovate. And, when prices are low, they don’t have the money to invest. There is never a “good” time.

Mine Designs

Another important variable is that mine designs are exceptionally complex and once decided, almost totally exclude anything but incremental change. It is much more complicated to implement a disruptive technology in a mine than it is in an auto factory. These are all the challenges of change in legacy industries.

Digital technologies

When mine operators look at new technologies, they are concerned about productivity improvements but atleast 50% of their attention is directed to half reduction of risks. Mining is an inherently risky business and much attention in the application of technologies is about risk reduction through changes in processes and procedure. There is a linkage between the two in that much cost of mining is about risk mitigation.

Digital Examples

A mine will have millions of bore holes drilled. Drilling costs include core logging, face inspections and plan assays. All of these re to deal with greater uncertainty.

Prospective digital technology solutions include automated surveying, rock recognition, optimized blasts, automated face inspection, automated haul trucks, real time assay and automated surveying. All of these are to reduce uncertainty.

Emerging Digital Technologies in Mine Operations

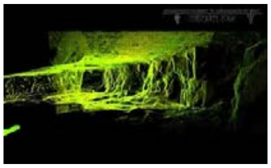
Mining operations have been employing robotics for things like load-haul-dump machines for 30 years. The operator, for safety reasons, stands about 100 feet back from the rock face and runs the machine from a joystick console, using electrical-mechanical robotic controls.

Digitization changes this operating environment substantially.

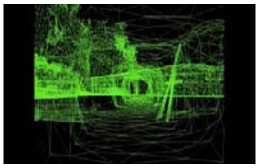
Underground Drones

WIFI technologies are next to useless in underground operations. There are multiple applications of drone and sensor technologies now in the marketplace. They fly around mine tunnels like bats.

The underlying technology is the same Lidar technologies used in autonomous vehicles, that originated with crop and land scanning from airplanes. However, the digital output is not the navigation guidance for a can driving down he road but to produce the dimensional images of the rock face.



The next step in application of digital technology underground is positioning of the equipment. The vehicle positioning is critical to the optimization of robotic drilling. Large mines could have 100 kms of mostly dark, tunnels. Mining companies regularly misplace equipment underground because some one has left it in a remote, unspecified place in a tunnel. WIFI doesn’t work, so what other technologies are available for precision location of large objects in the dark? The US Navy and submarines! The generic locational locational technology from the Navy has been retrofitted with mine design algorithms.



The technical engineering robotics for mine operations are taken from the most advanced auto industrial robotics at Nissan but robots in a car plant are in a fixed environment. Underground mines are a constantly changing, it is a dynamic environment.

Precision positioning of the equipment the allows the drill machine to be optimized against the drilling plan of the mine design in that specific location. A new, digitized form of precision drilling. To fully implement this has required the replacement of the current electro-mechanical control systems of the operators console. What they have been replaced by is gaming software from the Montreal gaming cluster.

The moment the operator moves the joystick, instead of issuing an electro-mechanical command, it triggers a gaming software module like Ubisoft which has had inserted a set of optimization algorithms for the location of the bore holes.

The Inversion of Industry 4.0

Modern extractive industries tend to be dominated by huge global firms. The last Commodities Boom escalated mergers and acquisitions among already highly concentrated companies. Many of these deals were over-leveraged and based on unrealistic expectations for commodity markets. Individual units and properties from these ventures are now being dismantled and sold off. From the bottom up, it is also the case that disruptive technologies are driven by smaller and less traditional firms.

The mental model for mining executives seeking to reverse the productivity challenge is to use the new digital infrastructures to lift the roof off the mine and run operations like an Industry 4.0 automotive factory. There are serious problems with this model. The production function in manufacturing 4.0 is to take standardized inputs and convert them into complex and heterogeneous outputs. In mining, Industry 4.0 is inverted – you take complex and heterogeneous inputs (the ore body) and convert them into standardized outputs.

The research seeks to identify trends and opportunities for new technology-intense SME firms to emerge as leaders in the extractive industries of the future.

The mining industry currently has three different ICT technology trajectories. Within the operating companies, there is relatively little innovation taking place internally, they are mostly dependent on equipment vendors and other supply chain providers. What technological dynamism there is, is led by precious metal producers. However things like gold mining are part of the financial economy, not the industrial economy. There is little to no metallurgy in precious metals mining so the linkages between mining, materials science and advanced manufacturing is not made. And, the decline of Canadian metallurgy continues and an important gap in realizing the full potential of new technologies in advanced manufacturing will remain.

Mining equipment providers, like car manufacturers, remain captive to their existing product design platforms. There is no great advance to be made by just web enabling existing electro-mechanical robotics equipment from the bulk mining platform of the 1980s. The next generation of deep mining, with precision drilling linked to digitization of ore bodies will require different kinds of mining technologies. Regional supply chain clusters, as in Sudbury, are experimenting with these developments but they are mostly SMEs with constrained technical and financial resources.

The most advanced ICT technologies are being developed and applied in the exploration and development segment of the mining industry, where Canada through things like PDAC is a global leader. However, beyond the exploration stage, there is relatively little downstream impact with mine operations and manufacturing.

Linking the digital technologies in mining to the broader economic linkages of advanced manufacturing remains a challenging gap.