Disrupting technologies and their impact in the Mining & Metals sector

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INTRODUCTION

No matter how ironic it may sound, the foremost lesson learned from the crises that have occurred, not just in recent years but throughout economic history since the steam engine was invented at the end of the 18th century, is that crises form an integral part of prosperity. Crisis is the ultimate expression of the "discovery mechanism", which states that destroying old creates new.

We are entering into an era of massive transformation, where a spectacular boom in technology and powerful new markets will drive a shift away from **resource dependence** to a new way of life: **resource efficiency**.

Mobile Internet, Advanced Robotics, Knowledge Automation, Internet of Things (IoT), Cloud Technology, Autonomous Ground Vehicles (AGV) and others are already transforming our industrial processes. And this is not just a new technology wave, it´s the end of the industrial revolution.

Since the early days of industrialization in the mid 1700's, progress has flooded our western society. Five distinct waves of technology, each one initiating with disruptive new technologies and ending with a global economic depression, have influenced or transformed almost every aspect of our industries, societies and citizens daily life.

This is why, now more than ever, mining companies need to understand that technology has been for a long time the biggest and strongest transforming forces of our societies. From the earlier human societies through the modern world, access to technology and its incorporation into industrial and economical processes has separated successful companies from ones who have failed to withstand historical changes.

Technology is the answer - as it has been over all of human history.

THE END OF INDUSTRIAL REVOLUTION AND THE GLOBAL PRODUCTIVITY DILEMMA

It is well known that a direct effect of industrial revolution was that average income and population began to exhibit unprecedented and sustained growth. Probably the best index to understand its deep and massive impact is the evolution over time of the S&P 500 index shown in Figure 1, where the enormous change in economic growth back from early 1800´s all across the 19th and 20th centuries can be seen.

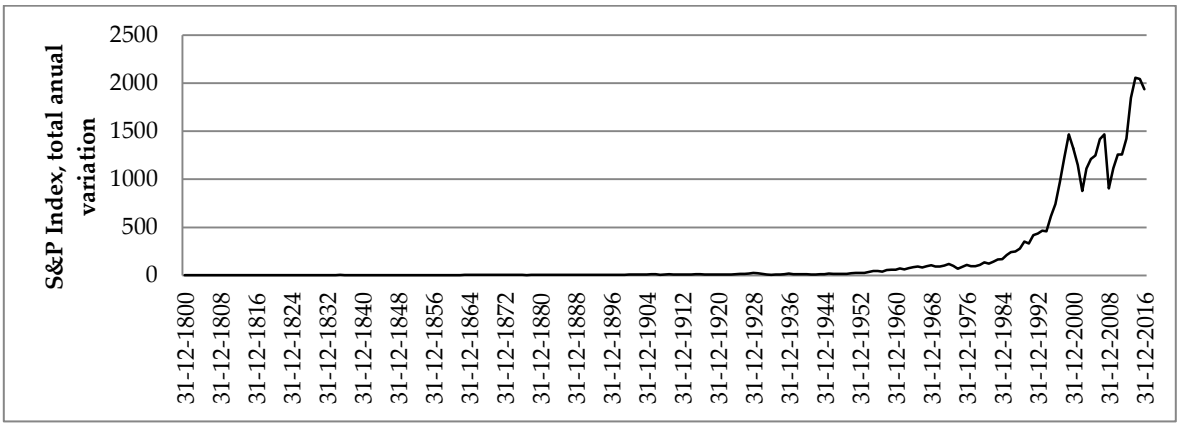

Figure 1 S&P index, total annual volume, World Bank.

Since the industrial revolution, mining has been one of the industries which has beneficiated the most, introducing massive changes to its processes and improving its working conditions, safety and productivity.

Figure 2 Left: Lead mining in the upper Mississippi River region of the U.S., 1865- Barber and Howe. **Right** Robotic Stripping Machine, MIRS 2015, Asarco Copper Refinery, U.S.

The introduction of steam engine, and later on the combustion engine, transformed the entire mining process from being entirely manual to a semi mechanized and later, a fully mechanized, process. This transformation in mining was a revolution originally lead by workers themselves, one of which was Alekséi Stajánov, a Russian coal miner from

Donetsk. - Stajánov introduced a very simple innovative production method by incorporating new mechanical elements. This change enabled the global coal industry to jump from an average of 7.2 tones per shift to 607 tones per shift, and 80 fold increase in production per shift in less than 5 years.

If we scale this achievement to modern days, it equals an invention capable of increasing the average throughput of a SAG mill from 35,000 tons per day (tpd) up to 2,800,000 tpd.

However, now the big decoupling in productivity is not just affecting mining, but entire countries and global economies. The cause is the same as any large human transformation: Disrupting Technologies are changing the fundamentals of our economy.

This "decoupling" can be understood as the divergence between labor productivity and employment/wages that happened in the United States since the 1980s and has become quite pronounced over the past thirty years in both developing and emerging economies. During the great postwar boom, productivity and wages grew together in the United States. As machine learning advanced at exponential rates, many highly skilled jobs once considered the exclusive domain of humans were increasingly being carried out by computers.

To understand the impact of how much machines (or computers) have replaced humans, think how many extra people and how much extra time would be required to execute the design, engineering, construction, commissioning and ramp-up of a mine site with the complexity of Escondida (BHP Billiton largest site) with NO internet, NO EPCM specialized software such PDMS/PDS and Autocad, NO emails and NO printers or plotters. 20,000, 30,000, 50,000 workers over 20, 25, 30 years?

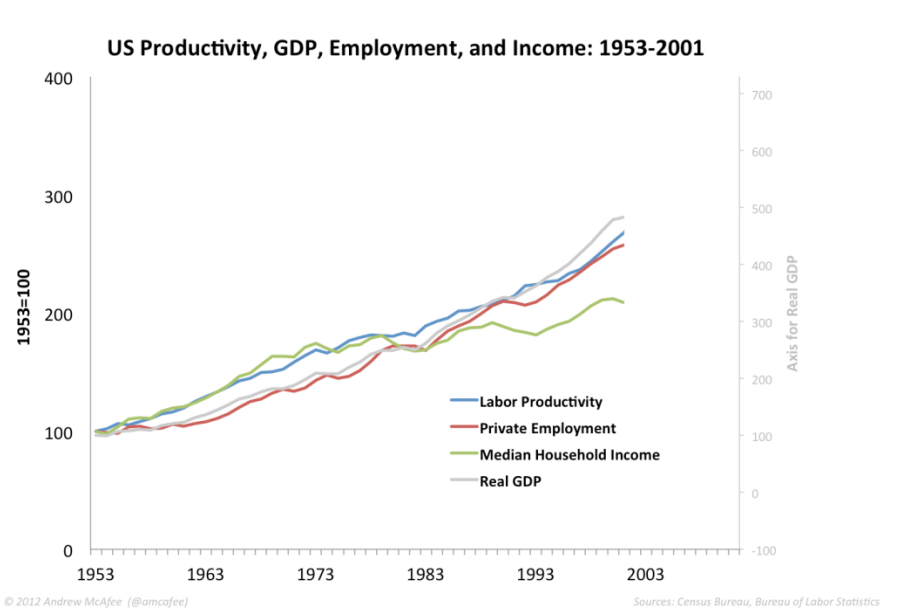

Figure 3 The great Decoupling, June 2015, Harvard Business Review

Moore´s law is probably the best way to understand the speed, impact and penetration of Machine Learning. In practical terms, Moore´s law states that approximately every two years the number of transistors in a microprocessor is doubled. Already by 2004, the semiconductor industry produced more transistors (and at a lower cost) than the total global production of rice grains.

Another example of this is growth is the commercial airline flight between New York and Paris. In 1978, this flight cost 900 dollars and the flight duration was 6 hours. If the same principles of Moore's Law are applied to the commercial aviation industry, this flight today whould cost 1 cent and whould take less than 1 second. Accordingly to Moore´s law, it´s also expected that by 2030 we will see computer processors with the same number of transistors as a human brain has connections.

A NEW ERA: RESOURCE EFFICIENCY

New Disrupting Technologies and social transformation are not new to humankind. In general, history and rhythm of global economy can be described by superposing four cycles: those of Kitchin, Jugar, Kuznets and Kondratiev as shown in the Table 1 below.

For this analysis, the Kondratiev cycle is particularly relevant. It identifies economic cycles of approximately 50-60 years lead by technological transitions affecting global production and consumption. The cycle is divided in to three phases: expansion, stagnation and recession. The cycle is explained by the fact that infrastructure demand such aschannels,

railways, freeways, submarine data cables, satellite connections etc., tend to saturate at some point, which then leads to economic stagnation. However, this stagnation doesn't necessarily mean that these markets are yet completely mature. Sometimes, a phenomenon called "Destructive Creation" is important. For example, iron was displaced by the steel technology and the steel industry workforce was displaced by machines, to be later once again employed due to the economic growth in other industries. The stagnation period is normally characterized by lack of good investing options, low interests rates and a diminution of credit levels, which normally lead to financial speculation and high debt levels, followed by a collapse and a financial crisis.

Cycle Name	Economic Impact	Duration
Kitchin cycle	Inventory Cycle	3–5
Juglar cycle	Fixed assets investment cycle	7–11
Kuznets cycle	Infrastructure cycle	15–25
Kondratiev cycle	Technological base cycle	45–60

Table 1 Economic cycles and their impact in our economy

In recent years, several crises that have occurred in rapid succession, including the Global Financial Crisis . The recent financial and debt crisis may be a presage of a 6th Kondratieff cycle. Five Kondratieff characteristics that point to a new Kondratieff cycle would seem to be fulfilled already:

1. Potential for further exploitation of an old basic innovation is exhausted (cycle of around 40 to 60 years).
2. High level of excess financial capital (versus physical capital).
3. Period of severe recession (period of radical change).
4. Social/institutional transformations.
5. New technologies are overcoming macroeconomic bottlenecks.

Labor was the foremost economic bottleneck factor in all economic cycles over the last 200 years, whereas the ever increasing shortage of commodities and energy resources could well be the key factors affecting the global economy in the 21st century. As such, the next long cycle of prosperity will likely be characterized by two drivers: no longer just enhanced labor productivity, but also, and above all, increased resources and energy productivity.

This new sixth, "green" Kondratieff cycle, will be characterized by global structural change in the economy from parasitic to symbiotic economic growth and/or a sustainable "green" path of growth. This is because under the new conditions imposed by globalization, demographic development, climate change, scarce resources and greater awareness of, and responsibility towards, the environment on the part of consumers, growth will probably be generated from a new mix of economics and ecology.

The dovetailing of the 5th Kondratieff cycle with the 6th Kondratieff cycle, i. e. the connection of information technology with "assets" is likely to continue increasing. This new 21st century technology infrastructure and economic growth will probably be based on five technology pillars which are underway already:

1. Mobile Internet (Yes, your smartphone)
2. Automation of Knowledge (have you heard about Google?)
3. Internet of Things (iWatch, Apple TV, GE and the Industrial Internet)
4. Cloud Technology (Google Drive, yes, Google again)
5. Advanced Robotics (DaVinci surgical robot, MIRS, Komatsu)

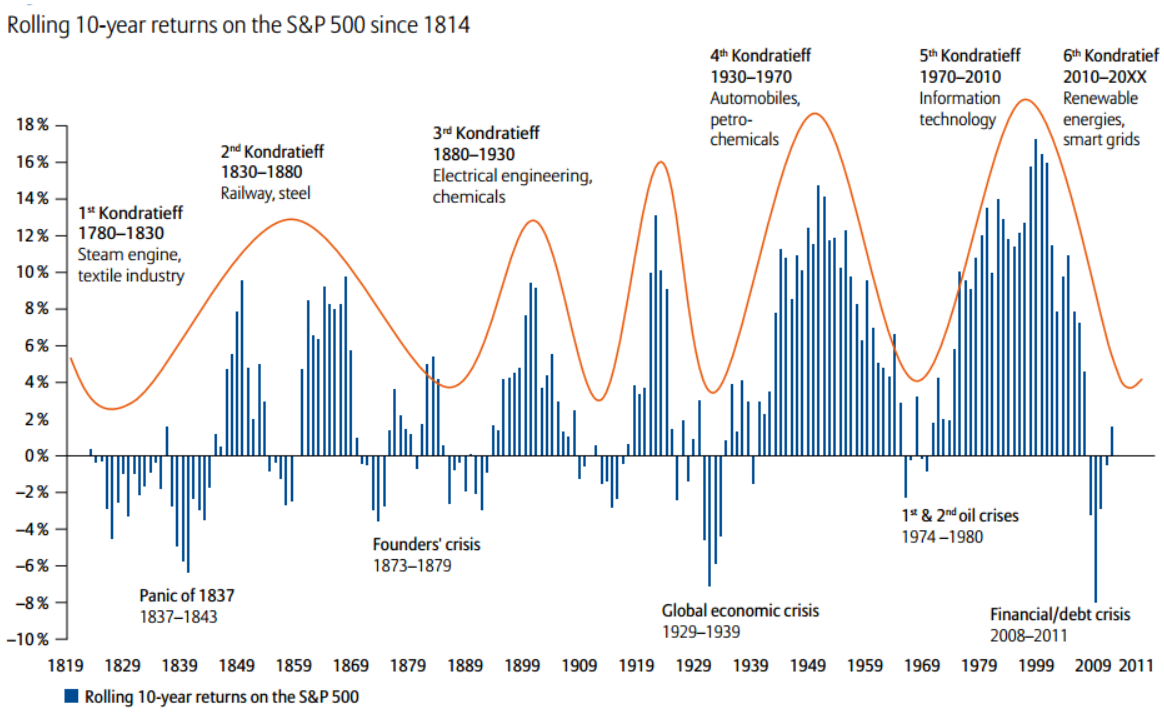

Figure 4 Allianz Global Investors Capital Market Analysis; The Sixth Wave, James Bradfield Moody and Bianca Nogrady

These technologies have the power of "creative destruction", and will likely gain further strength in the years to come. Overall, the rise of new markets will likely cause numerous conventional sectors of industry to fall.

A more specific facet of this shift, which explains the recent demerger of BHP Billiton into South32, and the announcement of Anglo American to get rid of 60% of its assets, has been beautifully explained by Andrew Mackenzie, BHP Billiton Chief Executive Officer, on its annual 2015 report: "*Across the globe, communities are experiencing transformational change – economically, socially, technologically and environmentally. As these accelerate and interconnect, they create opportunities for innovation and improvement. Emerging economies require construction materials like steel as their populations expand and new cities and heavy industry develop. As economies grow and people become wealthier, a consumer economy emerges and* ***steel intensity slows*** *while demand increases for materials that are used* ***in consumer goods****, such as copper. Increased income leads to a demand for agricultural commodities, including potash*"- BHP Billiton Annual Report 2015 (www.bhpbilliton.com)

MINING & TECHNOLOGY: THE POWER OF CREATIVE DESTRUCTION

But let´s not lose focus and get trapped into the "standard" definition of words. "Resource efficiency" applies not just to natural resources such oil, gas, water and metals, but also to all other aspects of "resources", including the most important of them all: human resources.

During the next two decades, we will see in mining how "Automation of Work" takes place in tasks that were meant to be for humans today:

- Self-driving cars for staff and supplies transport
- Drone surveillance and surveying services
- Unmanned ground mine vehicles such drillers, shovels and off road trucks
- Real-time interconnected mine smart models management system thought IoT
- Cloud Expert systems which can be accessed by vendors to monitor and improve their equipment efficiency and productivity
- Advanced robots performing hazardous tasks such Mill relines while enabling mining operations to achieve their ultimate goal: Continuous mining.

Most likely, in the near future, "thinking" will lead the job descriptions in mining and will substitute "doing" as a job specific task of many positions in our industry. Mobile Internet, Automation of Knowledge, Internet of Things, and Cloud Technology together will drive mining operational efficiencies to levels never dreamed before, while Advanced Robotics

will gradually replace manual tasks such transport, driving and heavy equipment maintenance.

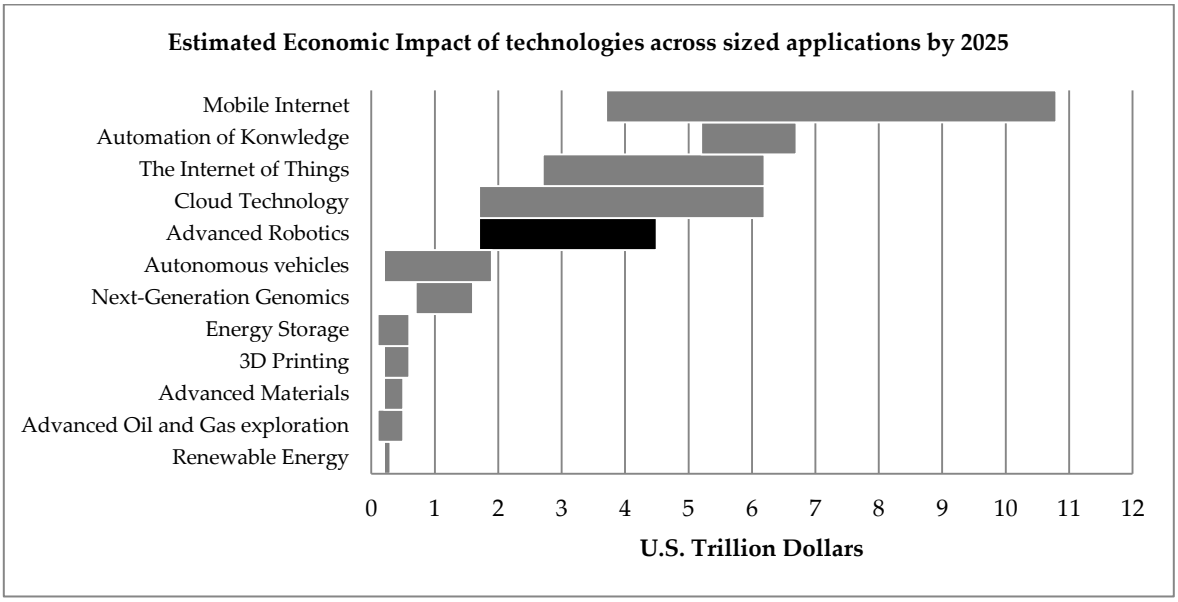

Figure 5 Minimum and Maximum Estimated Economic Impact of technologies across sized applications by 2025, McKinsey Global Institute

From all these new technologies, Advanced Robotics is expected to deliver a business volume between 1,7 to 4,5 trillion dollars within the next 10 years, as shown in Figure 6. Some of this volume has already been captured by the mining sector in countries such Chile and Australia in the form of unmanned haulage trucks.

This "Robotization" effort has been already started by the introduction of several models of UGV´s or autonomous mine trucks lead by Komatsu, Caterpillar and ASI among others. Rio Tinto, Fortescue Minerals, BHP Billiton, Codelco and all other major mine operators have launched in the last 5 years massive programs to achieve full automation of their haulage systems as well as the use of Unmanned Aerial Vehicles (UAV) to replace many other manual tasks at their sites.

Mining Industry Robotic Solutions (MIRS), a Chilean-German Robotic Company, along with BHP Billiton and Codelco have introduced advanced robotics to improve process efficiency and improve process quality and stability. Successful solutions have been applied to mill maintenance, electrowining plant operations, stripping machines, cathodes and anodes manipulation stations, and other sub-processes in smelters, SX-EW plants, and concentrators.

Figure 6 MIRS - Starter Sheet Stripping Robot, Amarillo Refinery, Asarco Group U.S. 2015

MIRS has been developing and working hand-in-hand with the copper giants Codelco, Anglo American, BHP Billiton and other mining companies to close the gap between standard robotics and mining operations. As a result of 10 years of collaboration, MIRS now provides a wide range of robotic solutions that can enable the future challenges of mining.

Figure 7 MIRS Robotic Sampler for concentrate - Assembly and Factory Acceptance Test for one of their customers at Codelco Mining Corporation

ADVANCED AUTOMATION IN MINING

For other industries, such as the automotive industry, advanced automation and robotics have been a reality for decades. For the mining industry and other natural resources industries, automation, and robotics in particular, have been a challenging step forward. However, during the last few years, important reductions in the costs of robotic systems, along with new developments in control systems and ancillary sensing systems, have allowed mining companies to incorporate robots for more and more tasks, thereby reducing operational costs, improving process safety by reducing the number of hours exposed to hazardous environments, and improving processes quality and stability. All of these are key aspects of long term sustainable mining.

As an example of successful robotic solutions, consider the hourly cost of performing manual tasks in mining, such as concentrate sampling of trucks, to the cost of performing the same task with a robot. In addition to considering direct costs of performing the task, economic value is also created through indirect costs related to the quality of the process. From the graph below, it is clear that economically, it can no longer be justified to use people for taskes that can be performed by robots.

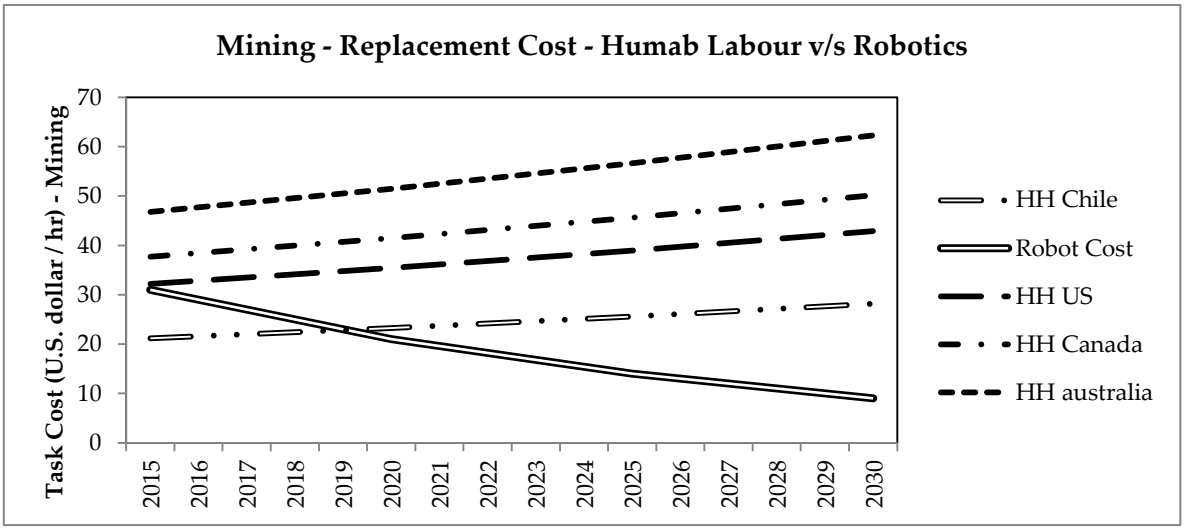

Figure 8 Mining replacement cost – Human labor vs robotic solutions, sources: BCG, Cochilco & MIRS internal analysis

The barrier then is no longer budgetary, but technical: can the robot perform the task a miner does? As per MIRS recent developments, and in line with the Boston Consulting Group and other market research organizations, it is just a matter of time for most manual tasks to be technologically feasible to be replaced. Today, simple activities such as sampling can be delivered at lower costs, higher performance, and most importantly,

improved quality, when compared to a human operator. The replacement of human labor with robots in other more complex tasks, such as idler change-outs in overland conveyors (with the conveyor operating), mills and primary crusher robotic relines, conveyor belt change-outs, truck tire replacement, refueling and general truck servicing are just around the corner. These applications will be an integral part the transformation of mining operations.

CONCLUSIONS

The discovery mechanism, or crisis as creative destruction process, is considered by many a source of opportunities. It is during crisis when leaders can make a difference to their organizations and stakeholders, because the problem is not the crisis itself, but rather in knowing what to do during the crisis.

It is now, when the fundamentals of modern economy are shifting from resource dependency to resource efficiency, when mining companies have the golden opportunity to transform its processes and become a more sophisticated activity.

As in the early 1900's when Mining was the leading industry in mechanization and was responsible for improving the standard of living for millions of workers, today mining is required to transform its operational structure, and move away from mechanization and submerge itself completely in automation.

While mobile internet, internet of things, automation of knowledge and cloud technology are expected to dramatically increase mining assets productivity, advanced robotics are expected to replace human labor for low level tasks.

Autonomous Mine Vehicles at Rio Tinto and Codelco and the application of MIRS Robotic systems in BHP Billiton and Anglo American mine sites are examples of the necessary transformation from human operation to advanced robotic that mining operators are undergoing in order to remain economically viable.

The rise of robotics has become a reality, and with it, there are tremendous opportunities for the mining industry.

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