Scientific Article

Mineral Resource Management in Norway

Erik Ludvigsen, Sunniva Haugen, Steinar Ellefmo
Department of Geoscience and Petroleum (IGP), NTNU, Sem Sælands veg 1, N-7491 Trondheim
Corresponding author: erik.ludvigsen@ntnu.no

Synopsis

The article looks back at the evolution of the field of Mineral Resource Management (MRM), with Norwegian conditions as its main perspective. In Mineral Resource Management, company leadership shifts its focus from equipment and personnel to the utilization of the company's main productive asset: the mineral deposit. Key concepts within MRM are: cross-functional integration along the value chain, optimized plans, and a focus on profitability and value creation. Rethinking organization and management has been one of the driving forces behind the development of MRM in Norway and internationally. The rapid technological developments of the late 1970s enabled current working methods. The development of MRM in Norway has also been affected by structural changes in the Norwegian mining industry. The mine engineering course at NTNU has evolved in line with these developments.

Introduction

An article by Haugen (2015) has been revised and expanded with developments from the recent past. It deals with Mineral Resource Management, a concept which, according to Macfarlane (2006) at the University of Witwatersrand was introduced in 1996 in South Africa, where the Anglo American-owned prospecting and mining company Vaal Reefs looked to improve cooperation between geology, mine surveying, resource-reserve estimates and mine planning in one of its mines.
The trend towards Mineral Resource Management in Norway has been parallel to the one in South Africa.

The main underlying forces in Norway:

- Technological advancements
- Structural changes in the Norwegian mining industry
- New organizational and management philosophies

This article describes the underlying conditions, the development of MRM in the mining industry in general, and how cooperation between industry and universities has led to today's educational programs in MRM at NTNU.

Technological advancements

This article attempts to describe how the technology related to mine surveying and mapping, after a gradual development over several thousand years, radically changed as late as the end of the previous century.

Euclidean geometry, named after the Greek mathematician Euclid who lived around 300 BC, along with other topics deals with angles. The knowledge that the angle sum in a triangle is 180 degrees goes back to this era. Protractors must have been in use for measuring angles and distances were indicated with a number of whole and partial units of a standard unit of length. This established the basis for creating maps.

An instrument that can measure angles in both the horizontal and vertical plane, called a theodolite, is described in literature from 1571 (Daumas, 1989). While the technology for measuring angles became increasingly advanced, methods for direct distance measurement did not undergo the same development. Classical mapping methods were based on increasingly more advanced instruments for measuring angles.

Measurement and calculation of the starting points for the mapping was conducted by a specialist called a geodet. The topographer was in charge of the map construction itself. While the geodet calculated coordinates for the starting points, the topographer used a measuring table out in the field to graphically place detail points relative to the starting points. This method of mapping was used virtually unchanged in Norwegian mining from the 1700s right up to the 1960s.

Mapping using photos taken from the ground, terrestrial photogrammetry, was adopted for surveying in Norway at the beginning of the previous century.
A stereo plotter for graphic data transfer from images to maps is among the more advanced instruments for angle measurement used in mapping.

Lantmäteriet in Sweden's Dr. Erik Bergstrand's patent for measuring the speed of light resulted in the launch of the first Geodimeter rangefinder in 1953 (Smith, 1998). This was a turning point that represented a break with thousands of years of evolution. While early mapping methods were guided by opportunities to measure angles, technology based on distance measurement now dominates the field. GNSS, the generic name for the various satellite navigation systems - the American GPS being the best known - is based on distance measurements to satellites. Real Time Kinematic (RTK) is the method most used for surveying. Positions are determined by precise distance measurement. By simultaneously receiving correction data from a reference station of known coordinates, RTK can obtain position accuracy down to the centimeter.

Photogrammetry has again become more relevant, now using pictures taken with an ordinary camera. The stereo plotter has been replaced by a computer with relatively simple computer programs that can match images to models of the photographed object. Mapping using drones, which is now widespread, is a good example of how important consumer electronics have been for industry developments.

Structural changes in the Norwegian mining industry

By the turn of the millennium there were only three metal mines operating in Norway, compared with 30 at the end of World War II. Today, production of building materials (i.e. aggregate, sand and gravel) and industrial minerals account for the greatest value creation and largest production volumes in the industry (Neeb et al., 2014)

Industrial minerals and building materials are generally priced much lower than metal ores. Lower ore value implies an even greater pressure on costs than in metal mines and manufacturers of industrial minerals and building materials simply cannot afford to carry as large an organization as the traditional mines.

Most aggregates and industrial minerals are taken from quarries or near-surface underground mines with simple geometry. There are major differences in the need for updating the mine map and geometric control of extraction in an open pit compared with a deep underground mine.

Society increasingly demands that the mineral industry and related companies must deal with a large number of stakeholders outside the company - both in the community, in politically elected decision-making bodies, public interest organizations and general public opinion. The road to commencing mineral extraction has been extended. The Minerals Act of 2010 requires an operating license for even the smallest quarry. As a rule, a local development plan must be in place, and in most cases an impact assessment is also required. The planning process has become extensive and laborious. There is a growing need for expertise in this field of the industry, and many businesses are advised to use consultants who are specialists in the planning process, but have limited understanding of mineral production.

At the same time, current laws are more general than in the past and give businesses greater freedom, but also greater responsibility, to choose solutions to ensure that the intentions of the laws and regulations are fulfilled.
Norwegian legislation does not require authorization to perform mine surveying tasks. The mine manager is responsible for ensuring the quality of the maps.

New organizational and management philosophies

In the latter half of the 1980s, many had begun to question the traditional function-based organizational structure, and there was increasing criticism of cumbersome bureaucratic organizations with "watertight bulkheads" hindering communication between departments. The new Japanese ideas on total quality management (TQM) and Just-in-Time proved difficult to implement in Western companies.

Phil S. Ensor (1988) from Goodyear described the issue with this kind of organization as a "silo syndrome": Each department has developed its own culture and internal jargon and there is poor communication across departments. Employees feel greater affinity for their department than for the company as a whole.

In 1985 Michael Porter introduced the concept of the value chain (Porter, 1985). Porter's thinking represented a break with the traditional division of businesses into functional "silos", moving instead toward cross-functional organizations that took responsibility for the product throughout the value chain from raw material to end customer. Porter divided the value chain into primary activities and secondary activities, also called support activities. The value chain concept is closely linked to the concept of value creation.

MRM in the mining industry

As its name indicates, in MRM the focus is moved from the organization and management of equipment and personnel to the utilization of the mineral deposit itself. Macfarlane (2006) sees the mineral deposit as a company's main value creating asset, and notes that the management of this resource is the vital component to corporate success. Macfarlane (2006) writes that the value of the mineral deposit is realized at the point where an essentially assumed resource is converted to a proved reserve, and further into a salable product. Mineral Resource Management could be described as integrated and optimized mine planning. In his definition Macfarlane (2006) emphasized that MRM is not just concerned with describing the deposit, but also developing the optimal plan for extracting the deposit.

Integration is an important concept within MRM: both the integration of plans with varying planning horizons to support the same strategic goals, and cross-functional collaboration along the value chain across disciplines to avoid department-based sub-optimization.

In major mining companies' strategies and plans are rarely developed by one person, but rather through an interaction between specialists serving many different functions: geologists, mining engineers, mineral processing engineers, economists, market analysts and advisors in fields such as legislation, environment etc.

In international mining companies, the need for integration and coordination of large, complex organizations led to the development of the MRM concept. The development of MRM in Norway, however, was driven by the need to distribute the many tasks that had to be solved to the limited human resources in small organizations. This difference has led to the Norwegian mineral industry organizing its MRM tasks in slightly different ways from the big international mining companies.

As previously mentioned, the narrow profit margins in the industrial mineral and building material industries do not allow companies to maintain large organizations on the level of traditional mines. One natural solution is that one person must solve multiple tasks that were previously performed by several different specialists. A smaller quarry may only have one engineer/geologist who in addition to being in charge of the operation also performs planning, geological mapping and mine surveying. Instead of specialists in mine surveying, rock mechanics, geology and mine planning, companies now need a person who can do "a bit of everything" and engages in activities that cross former organizational or professional boundaries.

The culture of cooperation between the contracting parties in Norwegian industry, and small differences in status between people at different levels in the organizational hierarchy, combined with a high level of education, has given us a flexible workforce. This flexibility allows the Norwegian mineral industry to realize the potential in technological developments, by moving some tasks that were previously on an administrative level down to the operational level of their organizations.

Geodet-topographer situations

As an analogy to past surveying work where the geodet was the knowledgeable facilitator and the topographer carried out extensive field work, we look for similar situations and opportunities in the mine surveying of today.
We have a similar situation in current satellite-based mapping. The geodet is involved with satellites and base stations, while the topographer is the user of the

receiver equipment. By coding measurements while in the field, we have once again returned to maps being "drawn" in the field.

Underground mapping with a total station can be performed by one surveyor, as opposed to earlier methods that required a helper to hold the prism. One person was thus freed for other tasks - in some cases the mine surveyors themselves. The mine surveyor could take the role of geodet, while the helper became the topographer.

Data should be captured where they occur by the person present in the moment. This is often the machine operator. In tunneling the driller often positions and orientates the rig based starting points established by the mine surveyor. The rig can be instrumented so that the position of all boreholes are registered after a blast, which in turn provides the foundation for generating a map.

New software for photogrammetry opens new opportunities for mapping, including the mapping of tunnels. Using the light source of the rig for photographing the previously blasted part of the tunnel is an opportunity for capturing survey data.

We asked the question, if photographs covering the last part of a tunnel are taken just before drilling starts, and a georeferenced model is created from these pictures, is it possible to extend that model with new sets of pictures taken before the next blasts? If so, how many sets of pictures can be joined before a new set of pictures have to be georeferenced?

Figure 1. Mapping tunnels by taking pictures just before drilling starts.

Preliminary tests performed by Wycisk (2016) gave promising results. In this case, the topographer is the driller who spends 5-10 minutes to take the necessary pictures, while the geodet is responsible for control points and modeling based on the images.

In quarries satellite-based systems are used for positioning - the position of the boreholes gives the foundation for generating a map in this case as well.

During the drilling process the rigs performance parameters can be logged. Measurement while drilling (MWD) data such as the penetration rate, percussion pressure and rotation, can be used to examine rock properties. We see a potential for MWD data associated with tasks such as developing sampling strategies, classification of rock properties, improving fragmentation and production planning.

Research-based education

An important industrial partner in the early development of the MRM concept was the sulphide ore mine Grong Gruber who chose to develop its own modular IT system (GROSYS) instead of using one of the integrated systems with proprietary file formats that were common at that time (Ludvigsen, 1990). GROSYS provided a foundation which later opened for extensive research in cooperation with industrial mineral companies.

A group of doctoral students who researched the different parts of the value chain in mineral production was established. The thesis topic illustrates the group's focus on integration along the supply chain: Karlsen (1995) carried out geological and geophysical studies of a talc deposit. Osland (1998) modeled variations and estimated quality factors in an olivine deposit. Haugen (1999) studied the operational planning and management of industrial mineral production, and Watne (2001) studied how quality variations in a limestone deposit affected product quality and how variations in the deposit could best be managed. Based on the same concept, Ellefmo analyzed (2005) the value chain in an underground iron ore mine from deposit to finished product.

A long-time partnership with Visnes Kalk- og Marmorbrudd AS has provided great insight into the work that must be done in terms of securing the extraction permit, developing operational plans, extending the local development plan, relating to local government and neighbors, and the strategy behind the development of new products and markets, an insight that has been vital to our understanding of MRM.

It is one thing to integrate all the MRM functions into a computer system, but quite another to integrate all these skills and knowledge in the mind of a single person. Our courses in mining engineering and MRM are adapted to the needs of the modern Norwegian mineral industry, and will prepare students for the tasks they will face out in the industry.

The specialization within the master's degree program, Mineral Production and Technical Resource Geology, stresses that the study is integrated along the value chain. Students study both geology, mining, rock mechanics, mineral dressing, environment, health and safety. Two cross-functional MRM subjects are taught, incorporating material from Mine Surveying, Mine Geology, Mine Evaluation, Mine Design and Mine Planning. The focus is on 3D modeling of a deposit's geometry and qualimetry (quality variations) and designing open pit and underground works. The course also discusses the planning process relating to getting the required permissions.

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