ISSN 1893-1170 (online edition)
ISSN 1893-1057 (printed edition)
Mineralproduksjon 3 (2013) B21-B40
MINERALPRODUKSJON
www.norskbergforening.no/mineralproduksjon

Note

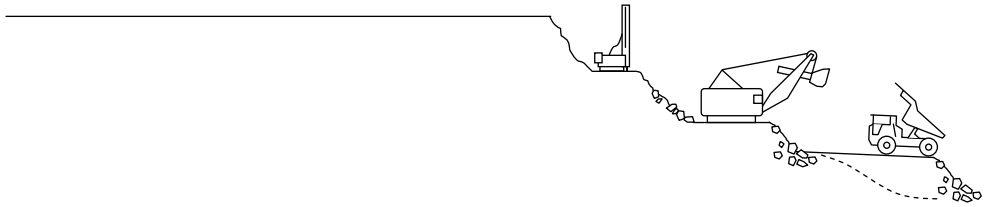
Lean mining

Sunniva Haugen [1,*]

[1] Dept. of Geology and Mineral Resources Engineering, NTNU, Sem Sælandsvei 1, 7491 Trondheim

** Corresponding author: sunniva.haugen@ntnu.no*

The mining industry has its own unique characteristics. How can we make the principles of Lean Production work in this environment?



1. INTRODUCTION

This text discusses how the principles of Lean Manufacturing may be applied in the mining industry. A brief presentation of the 14 principles of the Toyota Production System provides an introduction to Lean Production. For each Lean principle the present situation in the mining industry is described, and ideas for how this Lean principle may be applied in our industry are presented. The text is an abstract from a report written by the author for the Swedish research program Smart Mine of the Future. The analysis draws on the author's experiences from the development and implementation of Boliden's "Process Flow Mine" in 2000-2004, and from the implementation of Boliden's Lean Mining concept, the New Boliden Way, in 2008-2012.

2. LEAN PRODUCTION

Lean Production can be viewed as anything between a set of tools to apply as one sees fit to a fundamental thinking about the way to do business.

In the book "The Lean Toolbox" (Quest Worldwide 2007) a lean organisation or process is identified by the following characteristics:

- Products, one by one or in small batches, are flowing through the process.
- There are minimal work in progress, order stocks, raw material stocks, buffer stocks and finished goods inventories.
- Everything is produced at a pace determined by the customers' needs.
- Employees work in self-managing, flexible teams, producing and supplying their part of a complete product or service.
- The focus is on the company's processes, not its functions.

Lean Production builds upon Toyota Production System, TPS (Liker 2004). TPS has developed within one, stable company since the late 1940's. It came to life in an environment with poor infrastructure and shortage of capital and raw materials for production. The demand for cars was low compared to the American market thus mass-production in the American way did not work. Since then Toyota has developed its production system spreading it to its suppliers and factories in other countries.

The term Lean Production was introduced more than 20 years ago by American researchers (Jones & Womack 1990), who had been studying Japanese manufacturing techniques. Since then the concept of Lean has evolved and expanded into areas outside discrete parts manufacturing like health care and other services.

The mining industry has its own characteristics that may or may not affect the applicability of the principles of Lean production.

3. THE 14 PRINCIPLES OF THE TOYOTA PRODUCTION SYSTEM

In his book The Toyota Way (Liker 2004), Liker describes the Toyota Production System and identifies 14 principles belonging to four groups: Philosophy, Process, People/ Partners and Problem solving. These principles are listed below and will later be discussed in more detail together with their potential application to mining.

Long-term philosophy

1. Base your decisions on a long-term philosophy, even at the expense of short-term financial goals.

The right process will produce the right results

2. Create a continuous process flow to bring problems to the surface.

3. Use pull-systems to avoid over production. Let customer demand set production rate.
4. Level out the workload.
5. Create a culture of stopping to fix problems, to get quality right the first time.
6. Standardised tasks and processes are the foundation for continuous improvement and employee empowerment.
7. Use visual control so no problems are hidden.
8. Use only reliable, thoroughly tested technology that serves your people and processes.

Add value to the organisation by developing your people

9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.
10. Develop exceptional people and teams who follow your company's philosophy.
11. Respect your extended network of partners and suppliers by challenging them and helping them improve.

Continuously solving root problems drives organisational learning

12. Go and see for yourself to thoroughly understand the situation (Genchi Genbutsu).
13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions quickly.
14. Become a learning organisation through relentless reflection (Hansei) and continuous improvement (Kaizen).

4. THE APPLICATION OF THE LEAN PRINCIPLES IN MINING

This chapter describes each of the 14 principles of the Toyota Way in more detail, compares it to the present situation in our mining industry and explores how each principle may be applied in this business.

Principle 1. Base your decisions on long-term philosophy, even at the expense of short-term financial goals.

Lean Production

In stark contrast to capitalistic ideas, making money has not been the major goal of Toyota, but rather to be able to continue what they are doing and repaying their debt to the society the company operates within. This does in no way imply that Toyota does not manage its costs, but cost cutting is not the major driving force. They protect their own employees and have been very reluctant to lay off workers if sales drop temporarily. The message is always: "Do what is right for the company, for our employees, for our customers and the society as a whole". This attitude, or business moral, may well be the foundation for all other Lean principles, and the cornerstone that is missing in most companies that fail in their attempts to copy TPS.

The Mining Industry today

An example of a mission statement in a metal mining company is: "providing metals that make modern society work", and the vision document stresses responsibility for the stakeholders. Faced with a drop in metal prices the first line of action in base metal mines is usually an increase in production combined with a "headcount reduction". In the iron ore market production will be cut.

Lean Mining

Mining is by nature dependent on long planning horizons and strategic investments with long pay-back times. This fits well with Toyotas ideas of making decisions based on long-term goals over short-term financial targets. A fragmented ownership structure on the other hand is a disadvantage, but may be hard for the individual company to do something about.

Principle 2. Create a continuous process flow to bring problems to the surface.

Lean Production

A fast, flexible product flow is the core concept of Lean production, focusing on throughput time instead of traditional economies of scale. By eliminating waste that does not create customer value the time from a customer places an order until payment is received is shortened. The ideal is single-piece flow where the products are in continuous motion at a fixed pace (TAKT) through the production line.

TAKT is the heartbeat of single-piece flow, similar to the Cox or drummer in a rowing boat with several pairs of oars. TAKT should be set at the rate at which the customer buys a product and each production cell should produce at this same rate.

Focus is shifted from optimising the already short value adding time, to looking at the hours lost in non-value adding activities.

Single-piece flow halts production if a problem occurs anywhere in the production process, and forces people to solve the problem immediately. By reducing buffers,

hidden problems and wastes are exposed and people may remove them. The continuous flow inspires many of the other ideas and tools of Lean, like preventive maintenance and built in quality assurance.

The 7+1 non-value adding wastes that should be removed from the production process are:

1. Over-production
2. Waiting (operator or machine)
3. Motion (operator or machine)
4. Conveyance
5. Processing itself
6. Inventory
7. Correction (rework and scrap)
8. Unused creativity in employees

The Mining Industry today

Flow studies conducted at Boliden's cut-and-fill mining operations indicate that a typical mining heading is being worked on less than 25% of the available calendar time. The remaining time is either not scheduled for production, e.g. shift changes, lunch breaks, blasting intervals, or operators and machines are busy working on something else. Of the 25% of the time we work in the heading less than half is spent on activities that truly add value to the product (drill, charge, blast, load and haul). The remaining activities may be termed "necessary waste" and is amongst others needed to create safe and stable working areas.

The processing batch size varies depending on the mining method employed, from 300 tonnes/round in cut-and-fill and room-and-pillar to 50 000 tonnes in a large-scale stope. There may be different batch sizes for different activities; a 50 000 tonne stope may be drilled of as one batch, while it is charged and blasted in batches of 8 000 tonnes and the broken ore is hauled to the ore bin in 15 tonne LHD-scopes or 50 tonne trucks.

Mining operations are exposed to variations in ore grades and rock conditions as well as fairly poor reliability of the production equipment (Mean Time Between Failure < 30 hours). Operation times vary considerably and machine failures and other disturbances contribute to the uncertainty. As a result of the unpredictable nature of the mining operations large buffers stocks, or work in progress, are used to protect the production while the disturbances remain.

Single-front tunnelling is closer to single-piece flow, where each activity in the tunnelling cycle follows each other with minimum delay, and blasting may take place at any time. In these cases the development rate and time to completion of the drift or tunnel is prioritised. Long-walls or continuous miners in coal and soft rock mining are fairly close to a continuous mining process.

Mineral processing is a continuous process where severe problems, like a mechanical failure of the primary mill, usually reveals itself and must be addressed. But many problems result in slightly reduced throughput, recovery or concentrate quality and are not necessarily detected or corrected immediately. The metal concentrate can almost always be sold, at reduced price or to alternative customers. At critical points parallel equipment, like pumps, are installed to protect the process from disturbances and in some cases large tanks swallow some variation in flow.

A prevailing attitude in the mining industry is that loss of production is too costly for us to risk reducing the buffers in order to reveal problems that we may not be able to solve.

Lean Mining

To achieve a more continuous process in cut-and-fill or room-and-pillar mining, the production technology would have to be similar to those applied in coal- or soft rock mining. Using long-walls or continuous miners the heading would supply a continuous flow of ore, and rock-support should be installed right behind the front as it moves forward. Instead of one machine for each unit operation, the new production equipment would be a larger, multifunctional unit or a "train" of smaller units able to work at the heading simultaneously. For large-scale mining methods, the built in buffers of drilled off stopes could be reduced as well as the number of headings to be worked. Management would have to shift focus from utilisation of people and machines to production rate from each heading or stope. But before planned capacities can be increased and the number of stopes or headings in production reduced, the disturbances in operations have to be eliminated.

Principle 3. Use pull-systems to avoid over production. Let customer demand set production rate.

Lean Production

The ideal situation is single-piece flow and zero inventories. If the work stations are too far apart or operation times vary too much, then the solution is a pull system with small buffers. When a customer order triggers assembly of a certain product, parts will be taken from the small buffer at the assembly station. When that buffer level reaches a certain level, a Kanban-card will be sent to the station

that makes the parts and it will start manufacturing a predefined number of these parts. These stations will not work if there is no Kanban-card ordering them to produce more parts. This concept is quite similar to Goldratt's (Goldratt & Goldratt 2003) Drum-Buffer-Rope scheduling rule where the bottleneck resource sets the TAKT. Work at up-stream stations is released a set time before it is needed at the bottleneck, thus creating a buffer stock before the bottleneck in case the upstream resource has a problem. Work is not released before this schedule even though the work stations may be idle. The alternative, traditional push-system is a pre-planned production based on forecasted consumption leading to over-production and even lack of certain parts.

The Mining Industry today

Mine production is planned based on availability of production areas in the mine, a historical achieved capacity from each mining area combined with a desired capacity increase. The daily scheduling and release of work is traditionally left to the individual supervisor's discretion. Boliden has made attempts to improve the scheduling of their underground operations (The Process Flow Mine, and the Lean implementation in Kristineberg). Conflicting priorities that were uncovered in these projects were a belief that expensive machines, or those in the beginning of the mining cycle, should be manned at all times, and that work must be found for them even though other activities in the mining cycle cannot keep up. Due to the large distances in the mine it is assumed that so much time is lost when operators change from one machine to the other that this should be avoided. There are more machines than operators in the production system. What machines that are manned may occasionally be influenced by the competences and preferences of the workers that have reported to work. In cases where the mill is a bottleneck the mine may choose to build up a fairly large inventory of ore in front of the mill to allow for stops, weekends etc.

Lean Mining

Combined with a levelling of the workload as described in the next chapter this principle could present a great opportunity for improving the mining process, either with the help of scheduling software and real-time status reports from the mining equipment, or potentially by simple, manual systems similar to Kanban. Depending of where the constraints in the production process are, TAKT would be determined by the requirements of the mill or by the capacity of a bottleneck resource in the mine. The challenge is likely to be gaining acceptance for the benefits of this scheduling strategy.

Principle 4. Level out the workload.

Lean Production

According to Toyota as long as the production volume (output) varies from day to day, the other tools of Lean Manufacturing cannot be successfully implemented. A slow, steady pace is preferred over high speed followed by stops. Overloading people and machines should be avoided. Variations in workload may be caused by internal problems like breakdown or missing or defect components. Excess people, material and machines are needed to cope with the temporary peaks in workload. When levelling out production, customer orders are collected and dispatched to production at the average customer order pace in such a way that the same number of products and the same product mix is produced every day.

The OPT roadrunner rule (Goldratt & Goldratt, 2003), on the other hand, says: idle when you have no work and work as fast as you can when work is available.

The Mining Industry today

In multi-front mining operations with blasting at fixed intervals, one may observe a "wave" of activities moving through the system. Right after blasting there are many headings waiting for loading, later the demand is for scaling, then for shotcreting and so forth. Having certain activities, like shotcrete available only on dayshift introduces the same fluctuations in workload. If ore production is lagging behind plan, ore rounds are taken at the expense of waste rock and certain services and reinstallation of rock support may be postponed until later. In operations with both small scale and large scale mining methods, production in the small scale areas is slowed down if there is good availability of large scale stopes, thus creating large fluctuations in workload. Cut-and-fill operations are known to suddenly have too many headings waiting for back-fill and thus unavailable for production. Weekend shifts may be spent "preparing" for next week's production.

Lean Mining

Decide on the required production level week by week, ideally but not necessarily linked to the capacity of the constraining resource – the bottleneck. Distribute the different mining methods over time. Decide on a reasonable capacity in each mining area to determine the number of headings needed to be worked on. Maintain spare headings not to be worked unless in emergency. From the planned number of rounds required each week, calculate how many rounds must be mined each shift. Knowing the standard mining cycle, calculate how many activities of each type must be performed each shift and use this to plan and control operations shift by shift. Include mine services and periodic rock support in this plan. The goal would be to make every shift the same. This is likely to result in that we do not man all types of equipment throughout a full shift, but that the operators change jobs during a shift.

Principle 5. Create a culture of stopping to fix problems, to get quality right the first time.

Lean Production

This is another fundamental concept of the Toyota production system. When buffer stocks are small, getting things right from the start becomes extremely important. Quality problems must be detected when they arise, and the problem corrected before it is transferred down the line. If needed, part of the production process is stopped. The idea is that problems that occur today will reoccur tomorrow if it is not fixed. Poka-yoke or mistake proofing is a built in mechanism in the production that prevents human errors from occurring, e.g. computer forms that cannot be submitted unless all fields are filled in, diesel nozzles at petrol stations that will not fit in a car that runs on petrol, spare parts that can only be fitted in one position and to the machine where it belongs. The capability to detect quality problems and shut down may be built into the machine and is then called autonomation. Each employee is given authority to stop the production if they detect a defect. By pressing a button, a signal (Andon) lights up indicating where the problem is and the team leader can assist the worker in solving the problem. The production process is separated into several Andon-areas with small buffers between and if one station shuts down the other stations may continue producing for 7-10 minutes before the whole line shuts down. When a quality problem is detected the root-cause is sought using 5 Why?

The Mining Industry today

Product quality is not a major concern to most base metal producers, but internal quality problems result in re-work or affect the future production system negatively (uneven ramps, unstable pillars). In mills the price received for the concentrate is affected. As in traditional western mass production the mining industry strives to keep production rolling at all costs. Rather than eliminating the root cause of problems we accept it as an unfortunate but unavoidable nuisance. Workers are expected to deal with problems themselves not "complaining" about it or requesting assistance from supervisors. A driller suspecting that the line and grade of a drift was wrong asked his supervisor if he should continue following the potentially wrong grade or a surveyor could come down to assist him. He was instructed to drill without solving the problem so that the blast would not be delayed by one shift. Bringing problems to the surface has an almost negative ring to it. It is seen as complaining or blaming people for mistakes. We prefer taking about and learning from our successes rather than our problems. Another aspect of this is that people may believe that the mining process is so unpredictable that solving yesterday's problems has no impact on tomorrow's situation, when a completely new set of problems will occur.

Lean Mining

The responsible team of workers or supervisors should exercise short interval control where problems are registered shift by shift and analysed the following morning. The cause of the problem should be identified and mitigating actions decided and followed up. More complex problems may be forwarded to a problem solving project team (6 sigma).

Principle 6. Standardised tasks and processes are the foundation for continuous improvement and employee empowerment.

Lean Production

In TPS standardisation is more than effective and repetitive tasks at the factory floor. Even construction and product development processes are standardised. For the factory floor a standard consists of three parts: takt time, or pace, by which the work should be completed, the sequence of activities and the size of local buffer.

In order to improve a process it must first be standardised and stabilised so that the causes of a problem may be investigated or the effects of an improvement observed. When a problem is detected the first question is: Was the work performed according to the standard? If the problem persists the standard has to be changed.

The Mining Industry today

During the last 10-20 years the mining industry has removed itself from detailed, written standards or instructions. It was felt that standards prevent initiative and improvement. By training operators properly, they would themselves be able to select the proper cause of action in each individual situation. This change may be motivated by the prevailing perception that conditions in mining vary considerably and prevents us from designing one best way of doing things. When interviewing and observing miners charging explosives it was first of all discovered that none followed the procedure that had been taught to them during training. They all felt that experience had shown them that it needed to be "improved". The difference between two operators charging similar rounds was much greater than the difference between rounds in different conditions charged by the same operator.

Work orders containing planned start and finish times have been met with resistance. It has been claimed that variations in operation time makes time standards irrelevant and that expected durations may force people to end an operation before it is complete with negative impact on safety or quality.

Lean Mining

Standardised operations are an important foundation for any structured improvement of the operations and should be developed in close cooperation with the people performing the operation. An important new task for the supervisor will be to follow up that the standards are used and revised. Standard operation times or takt should be introduced to allow people to know if this has been a good shift or not. Long operation times would then trigger an investigation and possibly solution of that problem.

Principle 7. Use visual control so no problems are hidden.

Lean Production

Visual control is more than using 5S to create a clean and tidy work environment. A visual communication device at the workplace allows you to see at a glance how the work should be performed and if there are deviations from the standard. It allows the worker to see how well they are doing. It may show where certain objects belong, how many of these objects should be there, what the standardised working procedure looks like, how much work in progress there is etc.

The Mining Industry today

There is limited short interval control in mining, hardly any standards and thus little visual information of this kind to display. Performance indicators tend to be weekly or monthly financial or productivity figures with limited relevance to the operator. Safety instructions may be found. In some areas 5S is being introduced. As noted previously the idea of highlighting your own problems is not appealing to most people in our organisations, and it is often more interesting to monitor and discuss other people's performance.

Lean Mining

Due to the decentralised, solitary nature of underground mining visual information boards at central locations may be difficult to implement. An interesting option is to make this kind of information available on screens in the mobile production equipment. But first one must agree on what key performance indicators (KPI's) and other visual information to use making sure it is relevant to the person looking at it.

Principle 8. Use only reliable, thoroughly tested technology that serves your people and processes.

Lean Production

Toyota has been known to lag behind its competitors in acquiring new technology. Even so, they are an example of how to utilise value adding technology that

supports processes and people. In many cases simple, manual systems are preferred over advanced technology. When introducing new technology several people from different parts of the organisation are allowed to test and evaluate it. Before new technology is introduced the consequences to the existing processes are analysed. The value adding activities performed by the operators are studied first, looking for possibilities to eliminate waste and level out the workload. Then a pilot is initiated to improve the process in question using existing equipment, technology and people. When all possible improvements are made the new technology is evaluated once more to see if it may lead to further improvements.

The Mining Industry today

The mining industry is technology intensive and recent improvements in productivity, cost and safety are to a large extent thanks to introduction of new technology. Mechanisation of mining, introduction of autogenous grinding and larger scale production equipment are some examples. One will find views that the introduction of new technologies, like underground wireless LAN, to the operations eventually will reveal beneficial use for this new technology that are not evident up front.

Lean Mining

When considering pushing new, unproven technology into the operation one should at least learn from Toyota the way to evaluate and introduce it; redesigning the process it is supporting at the same time, involving all participants in the process and planning for the change in roles and responsibilities. Personally I would rather advocate introducing technological solutions as a response to problems and constraints experienced by the people in the existing production processes.

Principle 9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.

Lean Production

Stability is a core concept in the Toyota Production system, so also on management level. Toyota has been able to develop its own production philosophy since the end of the Second World War, while many other companies have embraced one management philosophy after the other as they come in and out of fashion. Toyota has recruited their leader within their own ranks, never bought successful CEO's from other companies. Their leaders are required to live, understand and teach the Toyota Way and have a detailed understanding of the situation at the work floor. Toyota leaders stay long enough to make a personal imprint on the company culture. Liker (2004) presents in his book The Toyota Way four types of leaders

with varying degrees of top-down and bottom-up approach as well as varying levels of understanding of the actual work performed. The least effective leader in this model is he or she who manages from the top down and has only general knowledge of business management. The leader who encourages bottom-up initiatives but lack detailed knowledge of the work is called the group facilitator. This type of leader can motivate the team to move in the same direction, but cannot teach or lead the work itself or even judge the efforts of the people in the organisation. The third type is the top-down boss with expert knowledge of the work, but who lacks understanding of people. This leads to micro management where the whole process may collapse if this leader fails to pull a tread. Toyota managers on the other hand both have a detailed understanding of the work itself and the ability to develop, teach and lead their people. They are respected for their knowledge in technical matters and seen as exemplary leaders.

The Mining Industry today

The situation obviously varies from company to company within the industry, but a change of top management is often accompanied by a change in philosophy. Many companies recruit lower level managers with technical background from within their own ranks and supervisors spring from the operator level. Even so we sometimes feel the need to get some new blood or a fresh pair of eyes from the outside. Top management may not have stayed on long enough to develop a common production philosophy for our leaders to grow into. New leaders are to some extent expected to put their personal mark on their operation and visionary leaders with striking personalities are preferred over "administrators".

Lean Mining

To be able to grow leaders who live the philosophy and teach it, we first need a philosophy and a culture to live in and to teach. Achieving this will require continuity in top management. At the very least we need a stable direction from the board of directors and a clear anticipation on our new managers to live by and develop the concept of Lean Mining.

Principle 10. Develop exceptional people and teams who follow your company's philosophy.

Lean Production

Toyota teams consist of 4 to 8 people and a team leader who acts as support and coordinator for the team. The team leader performs no manual work as long as no one is absent from the team. A first line supervisor has three to four teams reporting to him. Both the team leader and the first line supervisor play important roles in problem solving and continuous improvement. In traditional factories

white collar workers or specialised technicians are responsible for problem solving, quality assurance, maintenance and productivity. In Toyota the team plays the key role. The remaining organisation is there to support the team. A similar observation was made at smelter in southern Norway, where experts from the previous R&D department had been distributed to support the different teams.

Team members do manual, standardised work and are responsible for problem solving and continuous improvement. The team leader has tasks that traditionally belong to white collar managers even though they are not managers and have no formal authority over the other team member. His or her primary task is to make sure the production flows smoothly and the quality is correct. The team leader will step in if the Andon system signals a problem. He or she will also monitor the process and try to foresee and prevent problems, like shortage of material. And the team leader will fill in at the line when regular team members are absent. First line supervisors perform many functions traditionally belonging to HR-, construction- or quality departments. They participate in process improvements and introduction of new products and processes. And they give short lectures to the workers. They may even participate in the actual work.

The Mining Industry today

Multifunctional teams with some responsibility for maintenance do exist in the mining industry. Operators are multi skilled, sometimes to the extent that you cannot trace who performed a certain task at any given time. They may rotate to get variation and reduce stress, and in some cases the operator will not know in advance what activities he will be performing before he gets his assignment at the beginning of the shift.

In development and tunnelling small teams with a supporting team leader may be found. Previously mines were split into production levels with small, 3-4 man teams with dedicated production equipment. This team was responsible for all production activities on that level.

In a small Norwegian mine the teams consisted of multi skilled workers who operated the production equipment when it was running. If a machine broke down the operator and one of the other team members with expert maintenance skills would repair the broken down unit and then go back to operation.

In general the span of control is much larger in the mining industry than at Toyota, each first line supervisor having at least 10-20 people reporting to him and no team leaders. There are usually 3 to 5 different crews required to fill all shifts of the week and each supervisor is responsible for one crew that covers the whole mining cycle from drilling to haulage.

Lean Mining

It might be beneficial to have someone responsible for the improvement of sub-processes of the mining cycle like drill and blast, load and haul and rock support. Integrated teams of for instance drillers and drill rig maintenance is an option, as is a crew responsible for loading, haulage, road construction and maintenance and equipment maintenance. The same would be the case for rock support with the addition of a rock mechanical technician. The mill could be divided into comminution (grinding) and separation (flotation, gravimetry etc.).

At a Norwegian smelter each team member had defined primary, secondary and sometimes tertiary roles. This may be a good solution to maintain variation in the work, but get more stability and accountability.

Finding a set-up that will cater for small, focused parts of the mining cycle and that works when people work different shift, is a challenge.

Principle 11. Respect your extended network of partners and suppliers by challenging them and helping them improve.

Lean Production

Toyota is regarded as the most demanding customer by their suppliers, but even the best. Toyota maintains high standards and expects their suppliers to do the same. They are even prepared to help their partners achieve this standard. They train their suppliers' employees and audit their production systems in order to improve them.

The Mining Industry today

Mining is a "primary" industry with no suppliers of raw material or components. There are several manufacturers of equipment for mines and mills in Scandinavia, and there has traditionally been a close co-operation between the Scandinavian equipment manufacturers and the Scandinavian mining companies in development of new technology. The Scandinavian mining companies are valuable partners in development of mining equipment since we utilise technologically advanced equipment. There is at least one example from a Boliden mine where a major contractor was included in a 5S initiative with good results. In another case a construction contractor has moved into mining after working for a mining company.

Lean Mining

This principle may primarily be of interest to mining companies that use contractors in mining or maintenance. In order to teach others, the mining company must have reached some level of maturity in their lean efforts.

Principle 12. Go and see for yourself to thoroughly understand the situation.

Lean Production

Toyota encourages creative thinking, but it must be based on an understanding of all aspects of the actual situation. You cannot understand a problem unless you have observed it and investigated it at the place where it occurs. Nothing must be taken for granted, and one cannot rely only on reports from others. This is called Genchi Genbutsu or Gemba in Toyota. The Toyota Way requires all managers and all employees to understand production processes and standardised work and be able to judge and analyse what is happening. They must also be able to find the root cause to the problems they detect and to communicate their findings to others.

The Mining Industry today

As expected this varies greatly depending on the company in question. In some operations there is a perceived conflict between granting authority and trust to employees and "looking over their shoulder" at the actual work being performed. In surprisingly many cases supervisors and managers have limited knowledge of how the work is performed or what problems occur in their operation. Managers in the Scandinavian mining industry are often engineers and will strive to make decisions based on data. In some cases data are hard to measure, but in other cases a lot of data are collected without being used.

Lean Mining

Supervisors and managers need a much more detailed understanding of their operations. Some may be acquired by introducing appropriate KPI´s and short interval control. Some may be acquired by spending more time not "visiting" the work areas, but actually studying and analysing what they see and engaging the operators. Fact based decisions are still desired, particularly in our industry where large variations and long cycle times may cause "snap-shot" observations to be not representative. An important learning from Lean is to question all old truths and verify all information. First line supervisors or team leaders should be included when operators are being trained on new equipment and methods. Otherwise they cannot be expected to participate in management and improvement of the new process.

Principle 13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions quickly.

Lean Production

At Toyota a lot of time and effort is put into the choice of solution and planning for a change. Their decision-making process may seem tedious and slow to people that

are new to it, but it results in a faster and more successful implementation. The decision making process consists of five steps:

1. Determine what really happens, using amongst others "go see for yourself".
2. Explore the root cause of the problem, asking "Why?" five times.
3. Consider all alternative solutions and motivate in detail the proposed solution.
4. Build consensus within the team, including workers and external partners.
5. Effective means of visual communication is used to assist in these steps. This is usually one single A3-paper base on Deming's PDCA-circle (Plan-Do-Check-Act).

The A3 report is used instead of long technical reports and is communicated throughout the decision making process. It has a standardised layout containing a business case, description of the present situation, the desired future state, actions with implementation plans, follow up of results. In additional to a very structured approach to problem solving, the project meetings are well prepared, disciplined and short.

The Mining Industry today

Most companies experience from time to time that improvement projects take too long to implement or are terminated before the desired results are achieved. Long implementation times allow resistance to build up, key participants in the implementation to be replaced and priorities to change. There is often a sense of urgency; of a need to be seen to act quickly that leads us to start implementation without the necessary preparations. In many change projects the main focus is on designing a good technical solution and too little effort is put into redesign of the organisational process associated with it. The degree to which mining companies evaluate many alternative solutions may vary, but it is at least supposed to be part of the conceptual studies when new deposits are developed or new production facilities built. Stakeholders are usually kept informed of decisions that may affect them, but consensus is not required.

Lean Mining

This is probably the area where the changes have been most visible in Boliden's Lean implementation. Disciplined, well prepared meetings have been greeted with enthusiasm. The involvement of all stakeholders in the design of new solutions, instead of only informing them of the new solutions, has also proven to be beneficial. A successful implementation of a fairly good but accepted, solution may

be better than failing to implement the "perfect" solution. A tight schedule and close follow up of implementation has allowed implementation of the new solutions in much shorter time than what historically has been achieved.

Principle 14. Become a learning organisation through relentless reflection and continuous improvement.

Lean Production

The core of a learning organisation is the combination of innovation and creativity with standardisation of work. When one worker discovers a better way of working, this new method must be standardised, taught to the rest of the workers and used until an even better method is discovered.

A stable, standardised process is a prerequisite to continuous improvement. A learning organisation must have limited turnover of personnel, slow promotion in the organisational hierarchy and selective recruiting of new employees. To learn is to be able to build on previous experiences, not having to start all over again with new people in every new project.

Toyota solves problems using a process with 7 steps:

1. Initial problem selection and description
2. Determining what the problem really looks like
3. Localising the "point of cause" – the source of the problem
4. Finding the root cause (5 Why)
5. Eliminating the root cause
6. Evaluating the result
7. Standardising the new work method

Hansei is a Japanese concept that is quite alien to most people in the west. Liker (2004) has translated it to "relentless reflection". Even though the team plays an important role at Toyota, the individual responsibility is very evident. Part of the concept is to be truly sorry when you make a mistake and strive to never repeat it. There is a profound difference between the "American" culture where we pat ourselves on the back celebrating work well done and the Japanese culture which focuses on problems and weaknesses and that what can be done to improve the situation. This is also seen when a project or other work is presented to the manager who will always point out some weakness or flaw. No matter how good the project or presentation is, the belief is that it can always be improved, and that it is a duty to do so.

The Mining Industry today

Based firmly in the western business sphere, the Scandinavian mining professionals share the preference for success stories over "fault finding" criticism of our work. However, project team members and members of the organisation in general all have different personalities, and the kind of people that contributes by picking proposed solutions to pieces in order to improve them is also found. Boliden's Lean Mining implementation projects showed that challenging performance and focusing on problem solving initially can be perceived negatively by some, both by those who have made the mistake or experience the problem and by the managers that are supposed to challenge them. Not all mining companies embraced Total Quality Management (TQM) in the eighties, and the well-known tools of the trade (5 Why, Pareto charts, Ishikawa diagrams) are not so well known. Attempts have been made to establish so called "improvement teams" to increase the awareness and motivation in the organisation. These teams have been allowed to select topics they like to work with, without proper linkage to observed problems in operations or to company goals. The main problem has been that these groups have focused on suggesting improvements to someone else's work, not their own. In Sweden, an agreement exists between the mining industry and the unions stating that workers are to receive a personal, financial reward for improvement suggestions that they submit and that are approved. In addition to making workers reluctant to share their ideas, this practise emphasises that continuous improvement is not part of the blue collar workers regular responsibilities. White collar workers are not rewarded for improvements, as this is considered part of their work.

Lean Mining

This concept is part of the short-interval control that was implemented in the lean pilot in Boliden's Kristineberg mine. A number of operational measures have been chosen to monitor the performance of operations every shift and every day. One of these measures is disturbances (or internal quality problems). The results are reviewed every day, and targets that are not met initiates root- cause analysis and mitigating actions by the responsible supervisor/manager. For prevailing or complex problems a group is assembled to analyse and solve the problem. Ideally the operators should be involved in this work, but we are still struggling to find a practical set-up (when, where, who) for this. Operations in the mine will stop when the operators attend meetings, while this would be more easily arranged in the mill. The shift schedule with 3-5 crews and at least one crew off every week makes it challenging to gather everyone at the same time. Automated or semi-automated processes in the mine will facilitate this type of work, and it is perhaps not necessary for everyone to be at the same meeting to gain consensus for a new way of working?

5. OBSTACLES TO THE IMPLEMENTATION OF LEAN IN MINING

A continuous production flow and the reduction of buffers expose hidden problems and waste, thus motivating improvement. But before buffers are eliminated one must make sure that we are capable to handle the problems that will surface. If not the only outcome would be a higher stress level in the organisation.

A stable, predictable and repetitive production process is a prerequisite for the Lean principles or tools to work properly. Looking at our mining industry, the production process in the mill is more or less continuous, but not all that stable. The mining operations are discrete with large buffers, or work in progress, and rock related disturbances and machine failures make operations very unstable.

The unlimited marked demand and strive for labour productivity improvements make base metal mining companies reluctant to remove operators from the mining operations to participate in improvement activities. The around-the clock operation with many different crews, the large distances between work faces and rotation of operators on different operations precludes continuous improvement efforts involving the "shop floor".

And last but not least, Lean contributes to reduced production costs by providing flexibility and speed, not only by eliminating waste to reduce the number of workers or machines needed. If this effect is not considered desirable to the mining company due to the market demand and a perceived low value of the capital tied up in work in progress, Lean mining may not be the way to go.

REFERENCES

Goldratt, E., & Goldratt, A., 2003: Insights into Operations. Goldratt's marketing group.

Jones, & Womack., 1990: The Machine that Changed the World. Rawson.

Liker, J. K., 2004: The Toyota Way. Liber .

Quest Worldwide., 2007: The Lean Toolbox. Quest Worldwide Consulting.