LEAN METHOD TO IDENTIFY IMPROVEMENTS FOR OPERATION CONTROL AT QUARRY SITES

*D. Rylander[1,2] and J. Axelsson[1]

[1]School of Innovation, Design and Engineering
Mälardalen University
Västerås, Sweden
*(*Corresponding author: david.rylander@mdh.se)*

[2]Volvo Construction Equipment
Eskilstuna, Sweden

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ABSTRACT

The operation of Quarry and Aggregate sites are similar to factory production, since it contains sequential production processes, tasks and activities to produce the output product. Compared to the plant though, the quarry processes are generally not synchronized and controlled towards the overall throughput of the site in real time. Some quarries control parts of the production but do generally not utilize real-time technologies for the whole site and all its activities. This fact indicates a general improvement potential in increased productivity at quarry sites, but also unsolved challenges for the same reason. The main contribution of this paper is the presentation of a Lean based method for how to describe the processes to identify control improvement potential within a site. The aim of the identified improvements is to increase overall site productivity by optimizing site, fleet and machine utilization towards the overall throughput, and minimizing operational expenses and inventories. Further the paper exemplifies the method's usability with field studies at operational quarry plants successfully identifying and quantifying potential wastes and improvements. In addition the identified productivity improvements based on increased control and automation indicate challenges and needs in wireless communication and sensing technologies.

KEYWORDS

IT Applications, Quarry Operation, Lean, Wireless Communication, Automation, Construction

INTRODUCTION

Quarry operation is an important part of the construction business. Quarries produce and supply the material such as different types of aggregates, gravels and asphalt to all sorts of mass, road and building constructions globally. Quarries exist all over the world and the production and consumption is mainly "local". In Europe 2010 the industry concluded over 24 000 quarries and pits and the crushed stone production was more than 1.9 billion tons aggregates per year (UEPG, 2012). In US 2011 the annual production of crushed stones was 1.15 billion tons, at an estimated value of over $11 billion (USGS, 2012).

A quarry contains a set of over-all main processes which are the same at all quarries even though the machines used depend on the availability, production capacity needed at the specific site and the aimed substance. Due to the characteristics of work in these processes there should be an optimization potential in real-time control of the overall process in optimizing each task towards the overall production throughput using manufacturing production optimization principles such as Lean.

Lean production is a manufacturing improvement philosophy and technique developed by Toyota (Liker, 2003). Lean can be described as a method and approach for continuous improvements of a production process. Lean is used to increase quality, just in time and decrease production costs. A typical project approach to Lean is to analyze improvements in a specific process to achieve a certain output metric. Lean defines a set of principles, tools and methods. The ones that are of special interest for this report are identifying wastes in the production process through value stream mappings (VSM) and time studies. Those are mainly based on studying the actual real process on site, instead of studying the ideal, wanted or planned process.

The purpose and contribution of this paper is to evaluate and demonstrate the usability of Lean principles for identifying potential improvements of productivity in operation at a quarry site. The method utilized is waste identification based on VSM and time studies. Initial studies have been carried out at five quarry sites on two continents analyzing different setups at 10 occasions on different days. The improvement potentials identified assume wireless control over the production to be able to optimize resources towards throughput.

RELATED WORK

Within recent research on quarry real-time operation optimization, attention has mainly been on how to optimize and control isolated production activities during operation. These discrete process and machine optimizations have either focused on the mobile machines such as excavators, wheel loaders, articulated haulers and trucks or the geographically static machines such as crushers and sorting and screening processes. Mobile machines used for mass transportation and movements have been shown to have a potential in fuel savings while controlling speed and gear shifting due to topology (Fu & Bortolinb, 2012). The size reduction processes such as blasting and crushing as well as sorting and screening have shown to be possible to improve in terms of machine wear and production quality as well as energy consumption and machine utilization**.** The research has highlighted the importance of adapting the crusher to time dependencies and its variables such as material size as well as feeding pace (Bearman & Briggs, 1998; Pekka, Matti, Antti, & Keijo, 2012).

Another area of research is design and planning of a site as well as information management within it. This area handles the initial setup and design of capacity in the different processes, tasks and machines. Typical application for this area of research is the modeling of initial configuration of the site where the overall production can be designed towards the site layout, placement of fixed machines and its capacity as well as configuration of mobile machines capacity, size, type and amount (Uhlin, 2012) to calculate total cost of ownership (TCO). In addition simulations (Fu, 2012) which demonstrate its usability in designing the sites configuration of machines towards mass capacity between the different processes have been presented. The area also handles the overall task allocation towards individual machines. In addition there are models demonstrating cost savings in utilizing site production planning systems based on differentiated cost production including labor and fuel towards expected market demand (Leung & Wu, 2004).

Within the construction area, a research field called Lean Construction has been established. Within this field Lean principles has been analyzed and evaluated for the utilization in the construction domain (Howell, 1999). Even though Lean Construction has the potential of improving productivity in all types of construction, the research has mainly been on operation management and the construction segments of fixed installations and the normal final product e.g., structures, buildings and roads referred to as site-position assembly (Salem, Solomon, Genaidy, & Minkarah, 2006). Not very much research can be found utilizing Lean construction on the quarry and aggregate site for operation control.

Using the current state of the art approach, the site can be configured with machines' capacity and performance as well as designed in layout and placement for optimally calculated throughput. But research does not handle the operational deviations from the initial setup in real-time. When production rate of the crusher is decreased, the capacity of the other machines is usually static. While several machines can be used for loading and transports these are not synchronized towards each other or the throughput of the site. While throughput is the rate at which the system generates income through sales, operational expenses is how much the production costs and inventory is the cost for buffers that are needed within the production. Therefore there is a lack of research in modeling the full site and optimizing the productivity in real-time. This paper presents a way of modeling the site using Lean VSM as a tool to identify the wastes that may be improved using real-time control by analyzing the sites current state.

Since a quarry is very similar to a manufacturing production plant with well-defined processes and activities and a main sequential flow of material, manufacturing techniques and production control principles should be useful also in this field of operation. Lean is a well-known method for optimizing organizations and processes within manufacturing. But the utilization of Lean principles within quarry operation optimization has been very limited and there is a lack of research to control the full quarry site and each quarry process in real-time to optimize throughput and minimize wastes. Since Lean includes principles for how to understand the site's current whole value chain and compare productivity and throughput of each task, Lean methods may be a good approach towards identifying improvement potential in optimizing quarry operation in real-time.

ANALYSIS

A quarry business can be described defining six main processes (Volvo, 2012): Site establishment, Exploitation, Processing, Distribution, Maintenance and Reclamation. Of these activities, the main processes in operation are then Exploitation, Processing and Distribution. Maintenance is done mainly to keep these processes in efficient operation over time. Site establishment can be considered as the phase to prepare the site and business and the Reclamation is done to reinstate the area in a proper way when it has been fully utilized. The steps of Exploitation and Processing consider initial phases of stone handling such as blasting/digging and material transport to crushers. Since the transport is done by machines there is an important step in the process to drive the machines back to loading area, even though the machines then are empty.

A quarry site normally has different setups and the whole process is based on that raw material is created (blasting and oversized stone handling). Normally the blasting cannot be done in parallel in time with the other activities due to safety risks, therefore this activity can be excluded from the analysis since it cannot be synchronized in real-time. The main processes that are considered within this work are those that are performed in sequence and/or parallel in time so that they can be synchronized and optimized towards each other. Those activities are then transporting to crusher, crushing, sorting and delivering to customers. Those activities are also those that represent main part of the work time at a quarry site.

Using Lean Values Stream Mapping to Identify Wastes

Value stream mapping (VSM) is a Lean method to analyze the flow of material and information through the production process. It is based on creating a current state value map that can be further analyzed to improve the production process. To create a VSM, the different process steps and information flows within the production are identified and analyzed. To be able to analyze the value stream, each step and activity needs to be measured with respect to cycle times, setup time, value adding times, lead times and delays. The value stream is then assessed by identifying wastes and improving the current state by defining a future improved state value flow. Within Lean, wastes are identified by actions and tasks that consume resources but do not add value to the product. The principle originally described seven different wastes (Womack & Jones, 2003) :

- Overproduction (producing more than is needed)
- Waiting (idling processes, waiting for work)
- Transportation (carrying material longer distances than required)
- Processing (the process has more steps than is really required)
- Inventory (long lead times, too much stocks and buffers between steps)
- Movements (unnecessary movements, changing of tools and/or patterns)
- Defects (unnecessary amount of rework of actions and/or products)

Activities and processes in a VSM can be divided into: value adding activities and non-value adding activities. The non-value adding activities can be divided into non-value adding but necessary, and non-value adding and not necessary activities. The non-necessary activities should be removed and the necessary ones should be further minimized. To further define the metrics required for the VSM analysis, time studies are used. Time studies have a long history within manufacturing improvements. The method divides each task into different elements and measures those by timing each task iteratively. This approach results in a best result, accumulated value and variance in measurements. Those values can be used to calculate total cycle times, delays, work moment and task timings for each process step. The variance can be used to analyze the improvement potential with real-time control since it describes the stochastic deviations within a site operation.

Since a quarry always has the same over all purpose of producing aggregates, a general value stream can be defined with the main activities. Within this work, the main VSM is shown in Figure 1 and it has been successfully used for all sites analyzed. It can be seen as a starting point from which adaption can be made depending on the layout or the actual sites configuration.

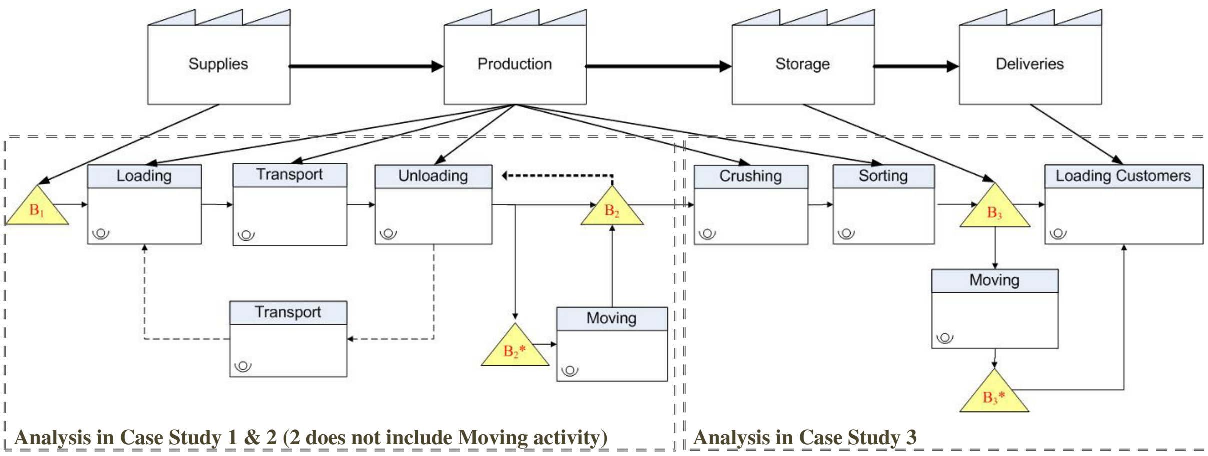

Figure 1 - Figure showing the developed general VSM activities for a quarry site

Buffers in
Figure 1 are described as:

- B_1 = Supply of blasted stones
- B_2= Main buffer at the crusher (crusher shovel/bucket)
- B_2*= Spare Buffer located on side of crusher, requires extra machine to move mass to B2
- B_3= Main sorted mass inventory from crusher and sorting process
- B_3*= Extra buffer/inventory when B3 is full

Lean Value Stream Metrics

Within quarries the configuration of machines for the different tasks and activities varies. The variation is mainly depending on the availability of machines but also of the required capacity and site design. The utilization of a machine can be described as the machine uptime. Uptime is defined as the amount of time that is used to obtain the purpose of the task, i.e. uptime = working time / (working time + non-working time). Non-working time can be different wastes such as waiting for assignments, or idling.

When a machine works in cycles, the cycle time (C/T) can be measured, normally in minutes. The cycle time is the time the task takes to perform for one machine, i.e., the time interval between start and finish of an operation task. In addition to Cycle time a task can have a setup time (S/T). The setup time is the time to prepare for the activity i.e., the time from an assignment has been communicated until the execution has started. Setup time can be the time for a machine to move to the position where the activity need has emerged. Set-up time can also include waiting time at the start of the activity if that is required. Another interesting measure is the mass capacity, often measured as ton/h. The mass capacity is the mass processed in the activity at a specific time interval. This measure can be used to calculate productivity of the site, but the productivity can never be more than the mass capacity of the weakest process activity. The final measure utilized in the VSM is the Lead time. The Lead time is the time required from initiation to finalization of a process. It includes both Cycle times and Setup times for the defined process. Other data to measure can be the distance of transports and bucket capacity of the machines. The distance can be used to calculate average velocities when the activity cycle time has been defined. The bucket capacity can be used to calculate mass capacity when the Lead time has been defined.

Quarry Value Stream Method

The method developed is based on video recording of field data from operation in a limited time interval. The method uses the video capture to conduct time studies of the different activities the machines perform and then calculate values on desired measures. The first step of the method is to identify the process activities and main tasks that are performed in the site, referred to as Site Visualization in Figure 2. The second step is to capture this area during the desired capture period. During the study, two cameras were used, synchronized in time to get an overview of all activities in the production and of the machines, since it is important that the loading and unloading is captured during the same cycles in time to obtain correct values.

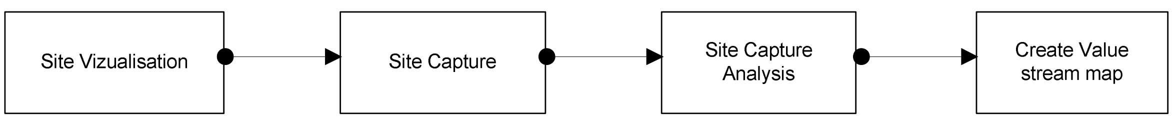

Figure 2 - Developed method process steps

Based on the videos the activities can be measured. The approach used was to time the different activities in each cycle. The total duration of the measured activities are accumulated towards an average value used in the VSM. The VSM can then be used to analyze different improvements and to create a potential future state map. Such an improved future VSM can be used to analyze the improvement potential and to calculate return on investment of possible measures to obtain this future state.

CASE STUDIES

To verify the developed method, several case studies were conducted. Since the overall processes at the reference sites have a critical bottleneck (the crusher) that everything produced at the site passes, the processes before and after the bottleneck can be studied in isolation. This is due to that the machines at the site are not simultaneously active before and after the crusher. Since the activities before and after the crusher are not affecting each other's productivity they are only dependent of the production rate of the crusher. Within the scope of this paper only the production process is analyzed using the method. The case studies presented only have one loading area and one unloading area as well as one crusher, as depicted in Figure 1. Other sites can have several crushers both in sequence and in parallel, it can also have several simultaneous loading areas, and the method can be generalized to handle this.

Quarry Site Case Study 1 – Feeding Crusher

The first case study followed the process in Figure 1 during 1.5 h productive time, containing 11 cycles of loading, transport and unloading as well as 35 cycles of moving at B2. The value adding activity is Crushing. Non-Value adding activities but required for the production are: Loading, Transport and Unloading. The Non-Value adding activities that is not required is: Moving.

The Moving activity is, based on this analysis, a waste that should immediately be removed. In this case the Moving activity is required due to the scheduling of the personnel resources and required breaks, since the transport activity requires personnel to be included during operation and the crushing does not. Since B2 capacity is less than the needed break time for the personnel for the feeding (loading, transport and unloading) activities, the stockpiling in B2* and Moving activity during breaks is required to obtain 100% crusher uptime.

The loading, transport and unloading activities are done by the same machines, in this case 3 mining trucks. Therefore the activities can be considered as one process with its own cycle time. The Moving activity was conducted during the break of the transport machines (mining trucks) and was performed by a wheel loader. In Table 1 the aggregated values from the observations are presented.

Table 1 - Measured aggregated values from Case Study

	Activity	Activity Cycle Time	Activity % of Lead time	Setup Time	Uptime
Mining Trucks	Loading	2:52	33.1%	1:06	72.3%
	Transport	4:16	49.4%	0:29	89.8%
	Unloading	0:22	4.3%	0:00	100%
	Waste/cycle	1:08	13.2%		
	Lead time	8:38	100%		
Wheel Loader	Moving	1:06	100%	0:08	88.9%

The following wastes were identified for this process during the study:

- Waiting at loading: At the loading there was continuously waiting by queuing. This time is included in the setup time for this activity as well as in the overall wastes.
- Meetings: During transport the machines occasionally met at places where only one machine could fit. This caused stops and waiting for the transport going towards the loading since the machine going towards the unloading was given priority.
- Waiting at moving: at the moving activity the crusher became full and the wheel loader needed to wait to be able to empty the bucket.
- Moving: the moving activity is a waste in itself and each cycle of the wheel loader does not have the same capacity as the trucks. Anyhow the activity erased most of the waiting at the crusher since the buffer size of B2* has more or less unlimited capacity. But the activity does not increase throughput, instead it adds inventory and increases operating costs.

Quarry Site Case Study 2 – Feeding Crusher

The second case study observed the process seen in Figure 1, but excluding the moving activity since the site did not have a second buffer for the crusher. The observed current state VSM during 1 hour productive time, containing 13 cycles of loading, transport and unloading. The loading part is now done using one wheel loader and one excavator, which increased the capacity at this activity. The transport and unloading is done using three mining trucks. The value-adding and non-value adding activities are the same as in the previous case study, but in this case there is no non-value adding activity that is not required.

Table 2 - Measured aggregated values from Case Study 2

	Activity	Activity Cycle Time	Activity % of Lead time	Setup Time	Uptime
Mining Trucks	Loading	5:34	39.5%	0	100%
	Transport	3:22	23.9%	0	100%
	Unloading	0:30	36.6%	4:40	9.75%
	Waste/cycle	4:40	33.1%		
	Lead time	14:07	100%	4:40	66.9

Table 2 shows the measured values from the case study. In this setup the waste identified occurred at the crusher. There were almost continuously two out of three trucks waiting for the crusher bucket to be empty enough to unload. The capacity of the crusher was significantly less than the capacity of transporting and loading, resulting in a 33% waiting/setup time of the overall lead-time.

Quarry Site Case Study 3 – Sorting

In the third case study, the storage and delivering in Figure 1 activities were measured during 91 minutes. The reference site used two wheel loaders for these tasks. The area of work cover a distance measured to 850 m. In the study, Wheel loader 1 had the main mission of stock piling and moving material from buffer B3 to B3* in Figure 1. Since the stock piling need was unlimited, the uptime was 100% during the task and since no other main activities were conducted there was no interest of analyzing that machines activities further. Wheel loader 2 had the main activities to load customers and an articulated hauler for transports to the site asphalt production area. Since these activities were not cyclic, instead the activities had a more stochastic behavior based on current customer needs. Due to this the data presented in Table 3 are total work time per activity instead of per cycle as in previous studies.

Table 3 - Measured aggregated values from Case Study 3

	Activity	Activity Time	Activity % of Lead time	Setup Time	Uptime
Wheel Loader	Loading	70:37	77%	7:11	90%
	Transport	13:23	15%	0:00	100%
	Waste	7:11	8%	0:00	

During the capture, the main waste activities identified were to wait for customers and that the wheel loader drove to the wrong gravel pit to load customer which caused unnecessary driving and time wasted. A third waste observed was the lack in utilization of machines, since when one wheel loader was assigned to one activity, it did not perform other activities even if it was at nearly the same geographical area. Due to this the other wheel loader needed to transport itself unnecessarily long distances to perform the activities. The presented table does not include the waste of unnecessary transports since it was not determined further how this change in work would affect the overall throughput of the site.

DISCUSSION

The method developed, described and demonstrated within this paper, utilizing time studies as a source of measures to create a VSM of the site productivity proved to be very useful. The quarries often have a high position surrounding the sites where a camera can be placed to collect the raw data. The analysis of the data using time studies generates the needed data to identify and calculate waste in the process and utilization of the machines. The analysis identifies the bottle necks in the process based on the configuration used at the time of the study and capture. The accuracy of the study is based on assumptions (e.g. bucket weight capacity and fullness) and the accuracy of, e.g., identifying when a vehicle has stopped or not which is a subjective assessment that may vary some seconds depending on the reviewer. Anyhow the method should not be used in such an accurate way that this would be a problem. Instead it should be used to identify potential of improvements and assess overall productivity of a site where measurement faults in 1-10 seconds have very little effect on the total average times of the study and result of the analysis. A challenge noted during the captures of data was that at a specific site, the configuration may differ significantly at different occasions and days. The usage of different machine types and amount for different tasks were different between the observations. Therefore, the potential improvement applications would need to be very flexible, to handle the different dynamic behaviours and configurations at the sites.

During this study the main improvement potential was found in the areas of transports and buffer/inventory handling as well as in the customer delivery/loading activity. Assessing the identified wastes of overproduction, waiting, Processing and inventory/buffers and unnecessary movements such as stop and go in the case studies, show a potential in improvements and further optimization utilizing production control techniques. Since the machines are mobile this would require wireless communication and sensor technologies to identify and communicate the required data. The machines need to know, e.g., its tasks, its position, destination, path, meeting areas and related information about other machines at the site to control and optimize its speed and movements

CONCLUSIONS

The method developed, described and demonstrated within this report is to utilize Lean principles of waste identification based on VSMs, obtained by time studies. It has proven to be a good way of identifying improvement potential for control technologies at quarry sites. The method is a single window analysis and does not statistically present the real measures for the sites productivity. Based on well-known production theories, the potential improvement applications for quarry operation should be based on knowledge of the overall production system and each activity can be synchronized towards each other, the throughput and the identified bottle neck.

Future Work

- The method developed was not verified in quarry processes containing asphalt production. A validation and possible adaptation will be a complementary future activity. The method is also likely to be applicable in other segments, such as road construction and mining.
- Since quarries have many limitations and constraints on technologies such as, dusty environments, lack in power supplies, remote locations, dynamic topology as well as electromagnetic interference from the

machines contribute to a challenging environment to deploy wireless control solutions towards. Future work will further develop and evaluate solutions for this purpose.

- The availability of data and information as well as lack in standardized systems and interfaces within this domain makes a general system solution challenging to deploy. A broader analysis of the current state, praxis and available standards and solutions utilized in other domains with similar needs will be an interesting future activity.

ACKNOWLEDGMENTS

This research is supported by the Knowledge Foundation (KKS) through ITS-EASY, an Industrial Research School in Embedded Software and Systems, affiliated with Mälardalen University, Sweden.

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