The Impact of Lean on the Mining industry: A Simulation Evaluation Approach

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Introduction – Mining industry

- Mining important in the African economies due to its contribution to forex earnings and employment creation (IDC, 2013)

- Mining industry profitability has reduced due to rising costs (social and environmental demands) and the downtrend of the mineral prices (Wijaya, Kumar & Kumar, 2009)

- The downtrend of mineral prices which reduces the profitability of mining companies also has a damaging effect on economies dependent on mining (Wills, 2006).
- Due to these challenges, It is imperative that mining organizations increase operational efficiency and reduce production costs so as to survive and remain profitable.
- Companies are increasingly being forced to explore alternative solutions to increase the viability of doing business (Gamme & Aschehoug, 2014).

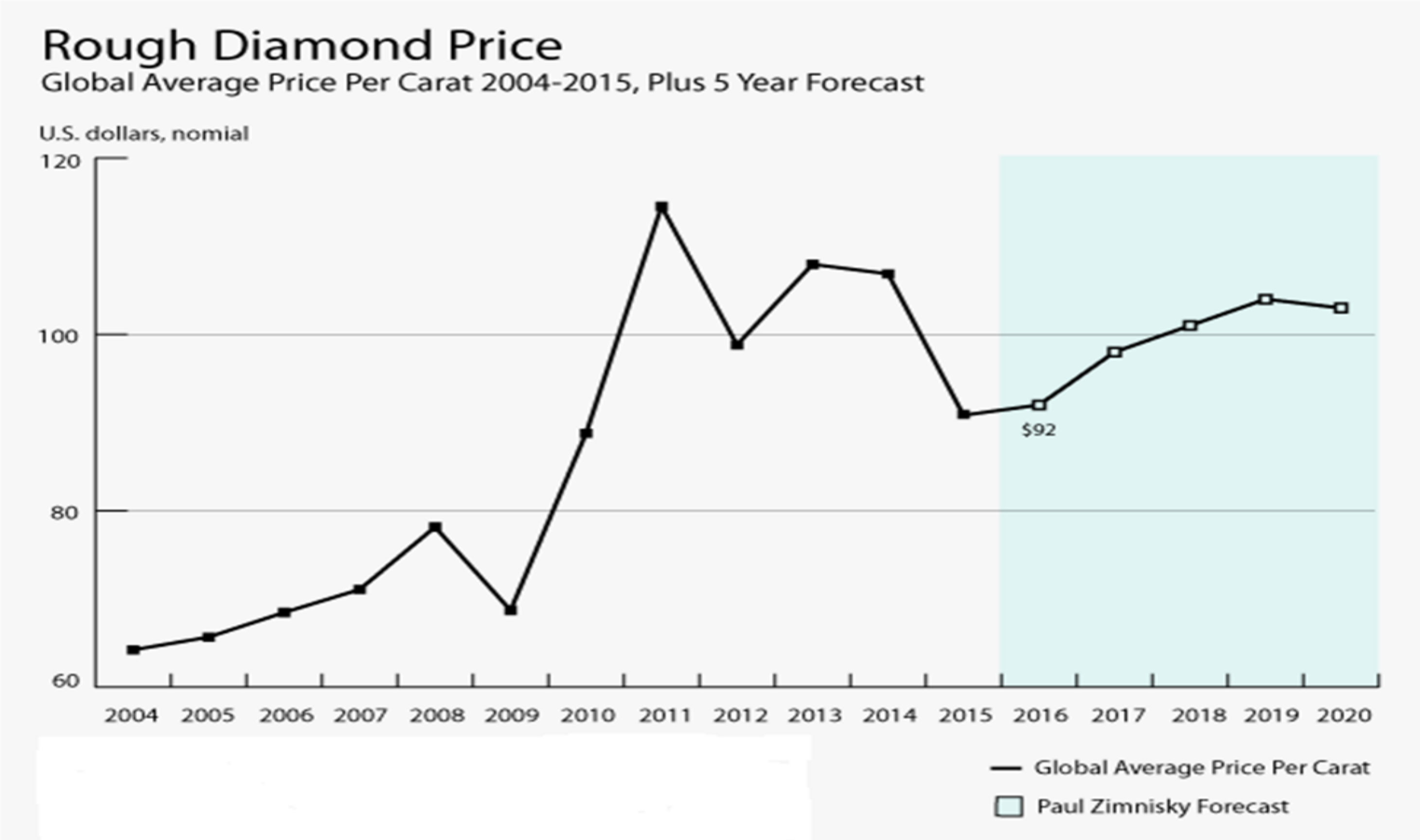
Definition of Mining

Newman et al. (2010) detail the five stages of mining which are prospecting, exploration, development, exploitation, and reclamation. The following table briefly describes the activities involved in each stage.

- Table: Mining stages (Newman et al., 2010)

Stage	Activity
Prospecting	Geologists utilize visual analysis and physical measurements of the earth's structure to identify mineral deposits.
Exploration	Geologists deduce the value of the mineral concentration and variability by drilling holes and conducting measurements.
Development	Permission is obtained to own the land and initial preparations are conducted by clearing the top material through sinking of shafts into the earth's surface
Exploitation	Ore is extracted from the ground and it is transported to the surface in Articulated Dump Trucks (ADTs). Afterward, it can be stockpiled, conveyed directly to a processing plant, or dumped.
Reclamation	Restoration of the mined area to its natural state as much as possible.

Introduction – Mineral price trends



Rough diamonds global prices and forecast per carat (Paulzimnisky.com, 2016)

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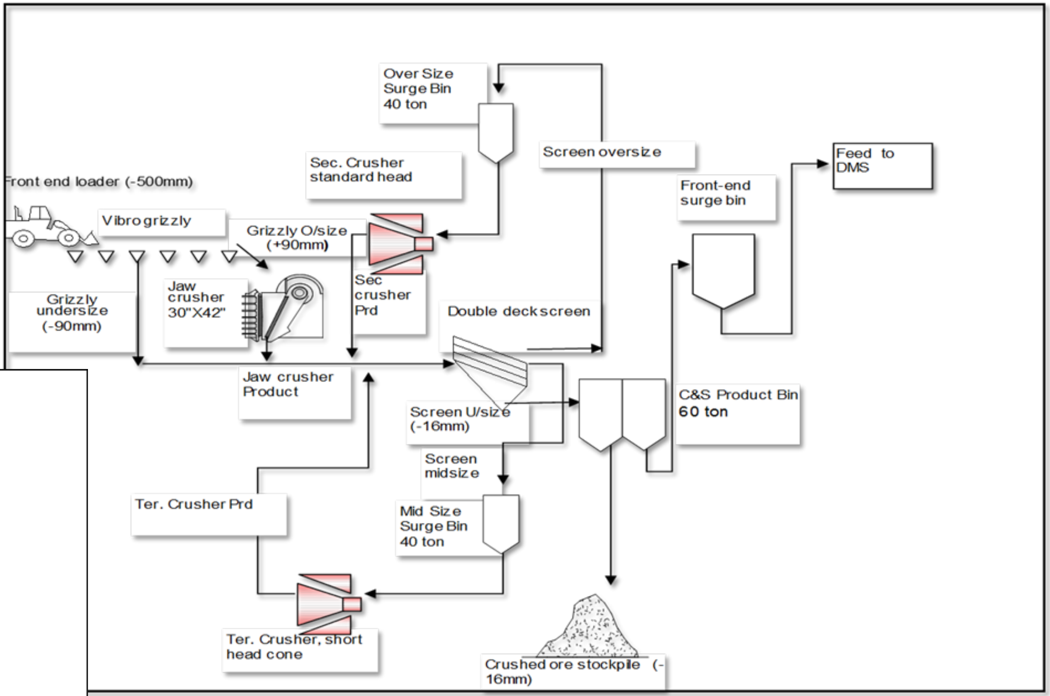
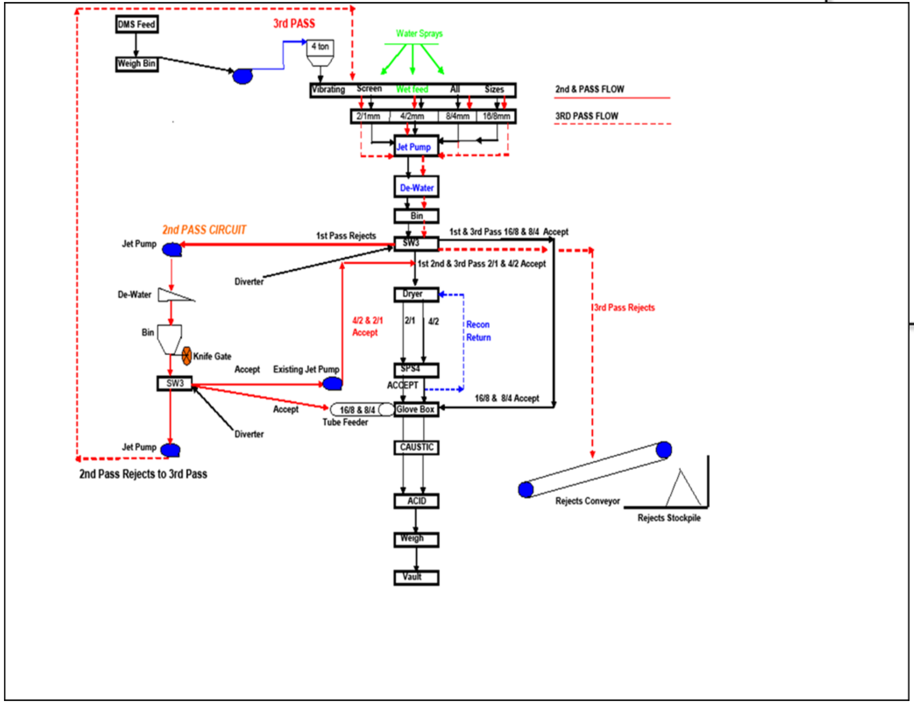
Synopsis of the case study: A diamond production process

The researcher utilizes one of the leading diamond mining companies in Southern Africa as a basis for the study. Therefore, it is important to understand its operations. The production chain of the mine is therefore summarized below.

- **Mining operations**
- **Crushing and Screening plant**
- **Dense Media Separation (DMS) plant**
- **Recovery Plant**





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Introduction to Lean

- Lean principle has been adapted to by various industries to **eliminate waste** (time, cost and resources)
- The implementation of Lean principle usually starts with mapping current process performance level using **Value Stream Mapping** (VSM) (Das et al. 2014)
- A value stream mapping is a collection of all activities that are required to achieve product flow, beginning with the raw materials and ending with the finished products (Mahmood, 2015)
- The real benefit of Value Stream Mapping is that it enables single point optimization and enables the practitioners **to build a realistic system based on material and information flow across the value chain** (Liker & Meier, 2006)

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Lean in the mining industry

There is not much documentation regarding Lean implementation and optimization in the mining industry. A few companies have initiated a systematic adoption of the Lean principle, and there is also limited evidence that illustrates broad acceptance of Lean production in the mining industry (Castillo et al., 2014). Wijaya et al. (2009) suggest that the mining industry should adopt the Lean principle for two primary reasons:

- The mining industry has declined in profitability due to social and environmental demands of sustainable development. Reducing production costs helps to compensate this effect
- Both automotive and mining industries rely on efficient industrial processes, value stream efficiency, efficiency of their operations and have a strict focus on safety. Lean has managed to improve all those aspects of the automotive industry

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Introduction DES

- **Discrete Event Simulation (DES)** is the process of simulating the behavior of a complex system as an ordered sequence of well-defined events (Anylogic, 2016)
- Simulation has emerged as a complementary tool for the design and improvement of Lean processes (Venkat & Wakeland, 2006)
- Simulations are utilized for the modeling of production processes for a major product category and to validate the current state VSM as well as evaluating alternative scenarios of the future state VSM (Venkat & Wakeland, 2006)
- For purposes of this study, DES is chosen to model the diamond production section of the mine as the mine can be considered a process with a sequence of process steps

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Definitions

Output	Formula
Total cycle time	Mining cycle time + crushing and screening cycle time + DMS plant cycle time + recovery plant cycle time
Mining cycle time	Drilling and blasting time + loading and hauling time
Crushing and screening cycle time	Primary crushing time + secondary crushing time + tertiary crushing
DMS plant cycle time	50 ton per hour DMS time, 90 ton per hour DMS time + 10 ton per hour DMS time
Recovery plant cycle time	Sizing time + x-ray sorting time + hand sorting time + acid cleaning time + caustic fusion time
Crushing and screening plant throughput	WIP/ (crushing and screening cycle time/60)
DMS plant throughput	WIP/ (DMS cycle time/60)

Research Objectives

To evaluate the impact of applying the Lean principle in a mining company using simulation modeling

The study aims to address the following research questions:

- What effect does the Lean principle have on mining operations?
- How can simulation modeling be used as a tool for lean evaluation scenarios?

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Case Study

- Since the Lean management principle was adopted from the automotive industry, it is imperative to look at the **differences** between the mining and the automotive industries so as to know how to apply Lean relevantly to the mining sector. Dunstan et al. (2006) detail a comparison of the two industries in the following manner:

- **Table: Comparison between the mining and automotive industries (Dunstan et al., 2006)**

Mining Industry	Automotive industry
Physically constraining environment	Ambient environment
Inherently variability	Stable work environment
Geographically spread-out teams	Compact plants
Inherent variability in raw material supply	Consistent supply of raw materials
Remote locations	Located in large centers

- The study utilizes one of the diamond mining companies in Southern Africa

- The areas of focus are mining, crushing and screening plant, dense media separation plant
- and recovery section.

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Research Methodology

Sample data collection → VSM Construction → Simulation model configuration → Variance analysis → Lean simulation optimization

Discrete Event Simulation (DES)

The idea of DES method is that the modeler considers the modeled system as a process, i.e. performing a sequence of operations across entities (Anylogic, 2016). The typical output expected from a discrete event model is:

- Utilization of resources
- Residence time of the entities in the system
- Waiting times
- WIP Queue lengths
- Process throughput
- Bottlenecks

For purposes of this study, Discrete Event Simulation is chosen to model the diamond production section of the mine as it is a process with a sequence of process steps.

Seven Original Wastes	Role of DES
1. Transportation: movement of products that are not needed for processing	Modeling the process flow and measuring transportation times
2. Inventory: unprocessed Work in process and finished product.	Modeling inventory queues
3. Motion: people or equipment moving or walking more than is required to perform the processing	Modeling the interconnection between resources (people and equipment) and the process
4. Waiting (Delay): waiting for the next production step	Modeling queues that evolve as a result of variability in interconnected processes
5. Overproduction: production ahead of demand	Modeling the link between variabilities in demand and production
6. Over-processing: resulting from poor equipment or product design creating activity	Modeling the process flow and measuring utilization of resources and processes
7. Defects: the effort applied in the inspection and fixing of defects	Modeling of variability in defect occurrence, identification and its impact on the flow of processes

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Setting up the simulation

Simulation setup using Anylogic

- States include, Normal operations, Minimum and maximum

Initial tests to determine most significant

- Secondary trials to determine optimum

Trial	Iteration
1	Current state
2	Top two significant variables at minimum
3	Top three significant variables at minimum
4	Top four significant variables at minimum
5	Top five significant variables at minimum

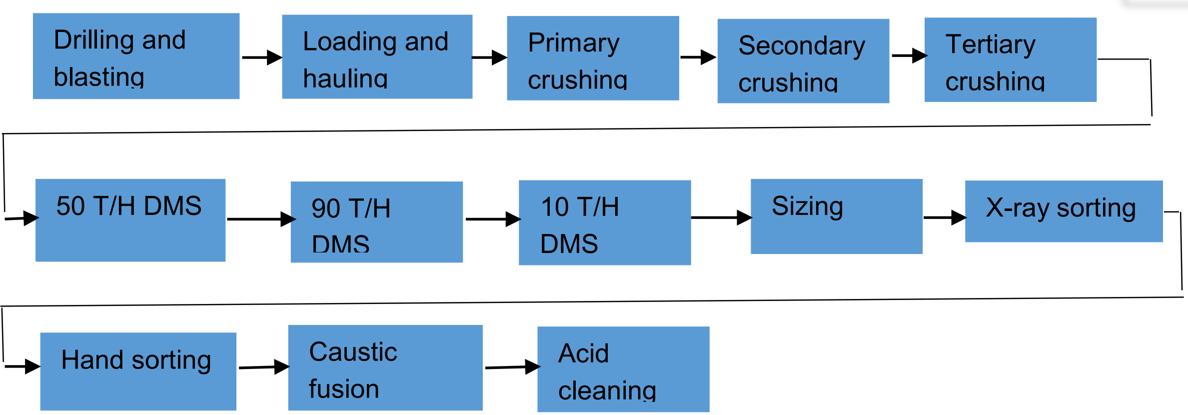

Figure 1: Process steps in the simulation model

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Synopsis of the outputs for the simulation model for the current study

- The study identifies key performance indicators for the case diamond mine production set up. These key performance indicators are chosen to be the simulation outputs so as to observe how they are affected by Lean optimization of cycle times. These are; sectional cycle (process) times, which comprise of total cycle time, mining cycle time, crushing and screening plant cycle time, DMS plant cycle time, recovery plant cycle time, Lead time and plant throughputs which comprise of crushing and screening plant throughput and DMS plant throughput.

Cycle (Process) times

- Cycle time is total time to move a unit of work from the start to the end of a physical process. When referring specifically to plant operation, it is the time required to complete an entire operation on one part from entering the machine to the exit of the machine (Agrahari et al., 2015). The cycle time outputs for the case study are; total cycle time, mining cycle time, crushing and screening plant cycle time, DMS plant cycle time and recovery plant cycle time. For study purposes, the researcher observes a batch of ore (one ton).

Lead time

- According to Bharath & Prakash (2014), Lead time is the time spent between the original customer order and the final delivery of the product to the customer.

Plant throughput

- There is a need to improve plant throughput to meet production targets (Alden et al., 2006). According to Emerson Process Management (2003), The study investigates how Lean simulation optimization affects plant throughput outputs. The plant throughputs under investigation in the diamond mine case study are; crushing and screening plant throughput and DMS plant throughput.

Drilling and blasting

	Target	Current state
Drilling and blasting cycle time	606.7 minutes	666.7 minutes

Loading and Hauling

	Target	Current state
Loading and hauling Cycle Time	18 minutes	25 minutes

Crushing and Screening Plant

	Target	Current state
Primary crusher throughput	220 tons per hour	160 tons per hour
Primary crusher cycle time	0.273 minutes	0.375 minutes
Secondary crusher throughput	245 tons per hour	185 tons per hour
Secondary crusher cycle time	0.245 minutes	0.324 minutes
Tertiary crusher throughput	190 tons per hour	170 tons per hour
Tertiary crusher cycle time	0.316 minutes	0.353 minutes

Dense Media Separation (DMS) plant

	Target	Current
90 T/H module throughput	55 tons per hour	50 tons per hour
90 T/H module cycle time	1.09 minutes	1.20 minutes
50 T/H module throughput	56 tons per hour	55 tons per hour
50 T/H module cycle time	1.07 minutes	1.09 minutes
10 T/H module throughput	12 tons per hour	10 tons per hour
10 T/H module cycle time	5 minutes	6 minutes
Total DMS cycle time	7.18 minutes	8.27 Minutes

Recovery plant data

	Target Cycle times	Current Cycle times
Sizing	10 minutes	60 minutes
x-ray sorting (first, second and third passes)	220.5 minutes	220.5 minutes
Caustic fusion	30 minutes	30 minutes
Acid cleaning	210 minutes	210 minutes
Hand sorting	720 minutes	780 minutes

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Results Setup – Variance analysis table

	Drilling & blasting	Loading & hauling	Primary crushing	Secondary crushing	Tertiary crushing	50tph DMS	90tph DMS	10tph DMS	sizing	Hand sorting
Normal lead time	2144	2144	2144	2144	2144	2144	2144	2144	2144	2144
Minimum lead time (50%)	2114	2140	2143	2144	2144	2144	2144	2143	2119	2114
Variance (50%)	30	4	1	0	0	0	0	1	25	30
Minimum lead time (100%)	2084	2137	2143	2143	2144	2136	2134	2143	2094	2084
Variance (100%)	60	7	1	1	0	8	10	1	50	60

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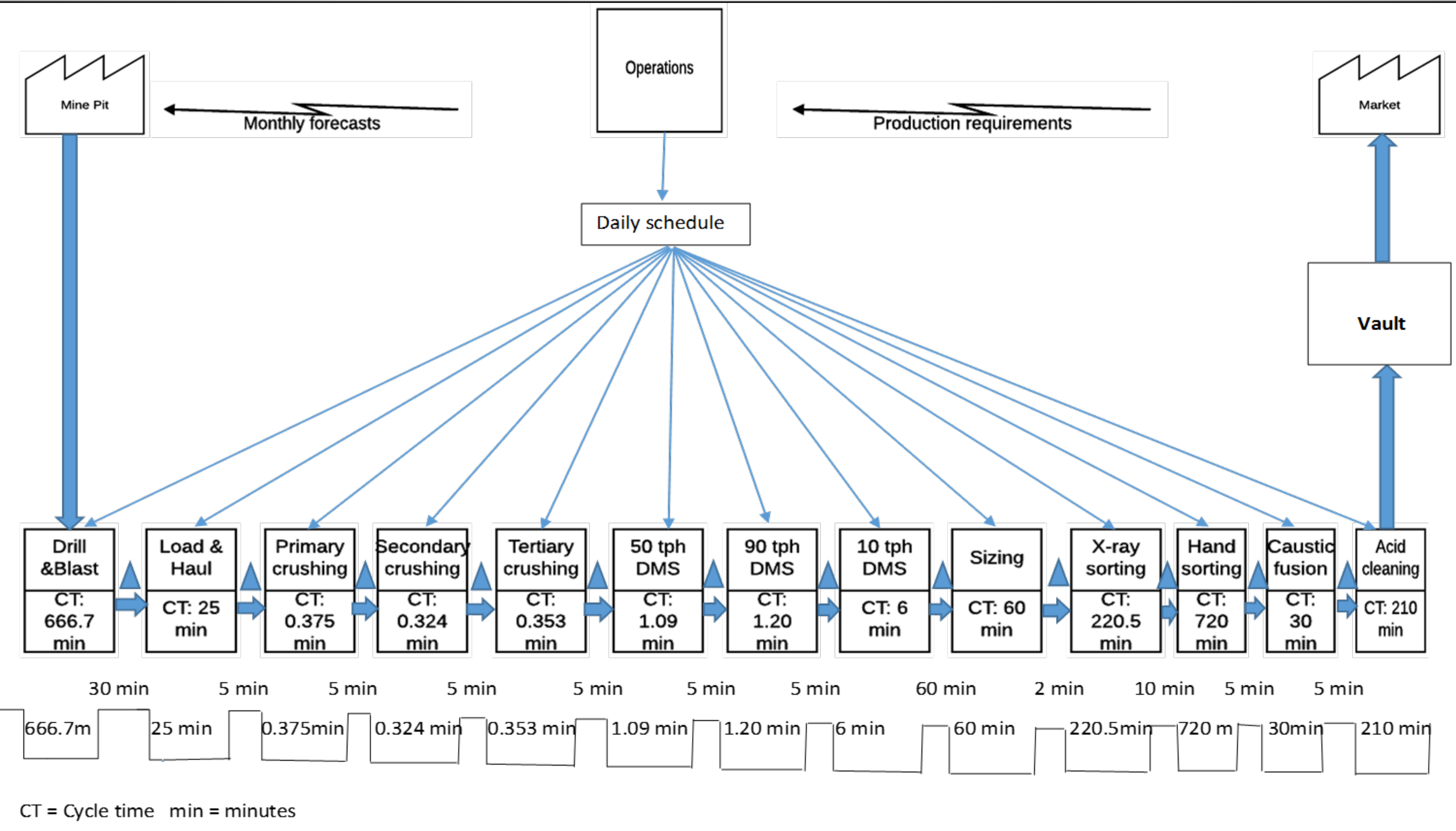
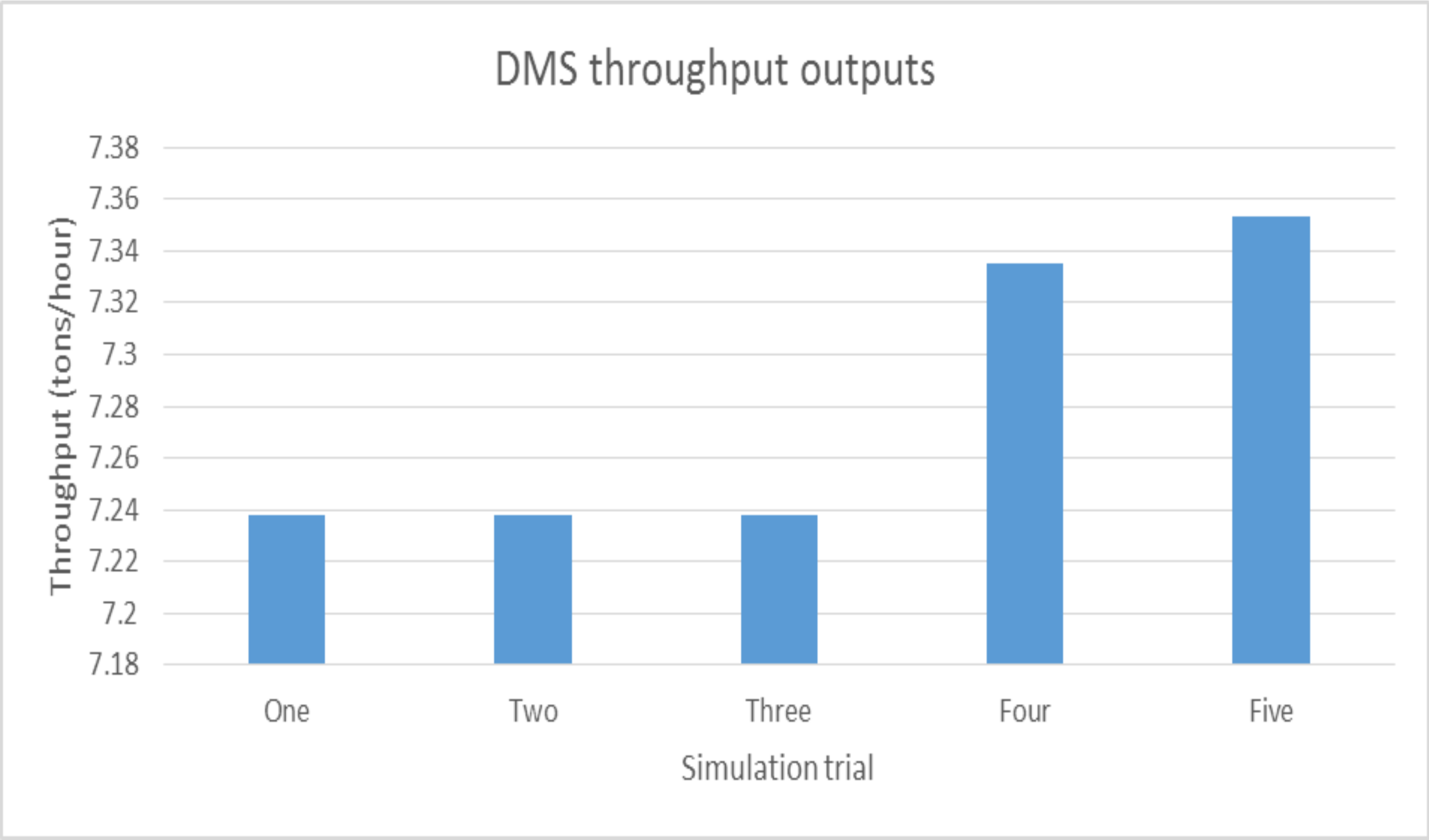
Results



Operations
Mine Pit
Monthly forecasts
Production requirements
Market
Daily schedule
Vault
Drill &Blast
CT: 666.7 min
Load & Haul
CT: 25 min
Primary crushing
CT: 0.375 min
Secondary crushing
CT: 0.324 min
Tertiary crushing
CT: 0.353 min
50 tph DMS
CT: 1.09 min
90 tph DMS
CT: 1.20 min
10 tph DMS
CT: 6 min
Sizing
CT: 60 min
X-ray sorting
CT: 220.5 min
Hand sorting
CT: 720 min
Caustic fusion
CT: 30 min
Acid cleaning
CT: 210 min
30 min
5 min
5 min
5 min
5 min
5 min
5 min
60 min
2 min
10 min
5 min
5 min
666.7m
25 min
0.375min
0.324 min
0.353 min
1.09 min
1.20 min
6 min
60 min
220.5min
720 m
30min
210 min
CT = Cycle time min = minutes

Results



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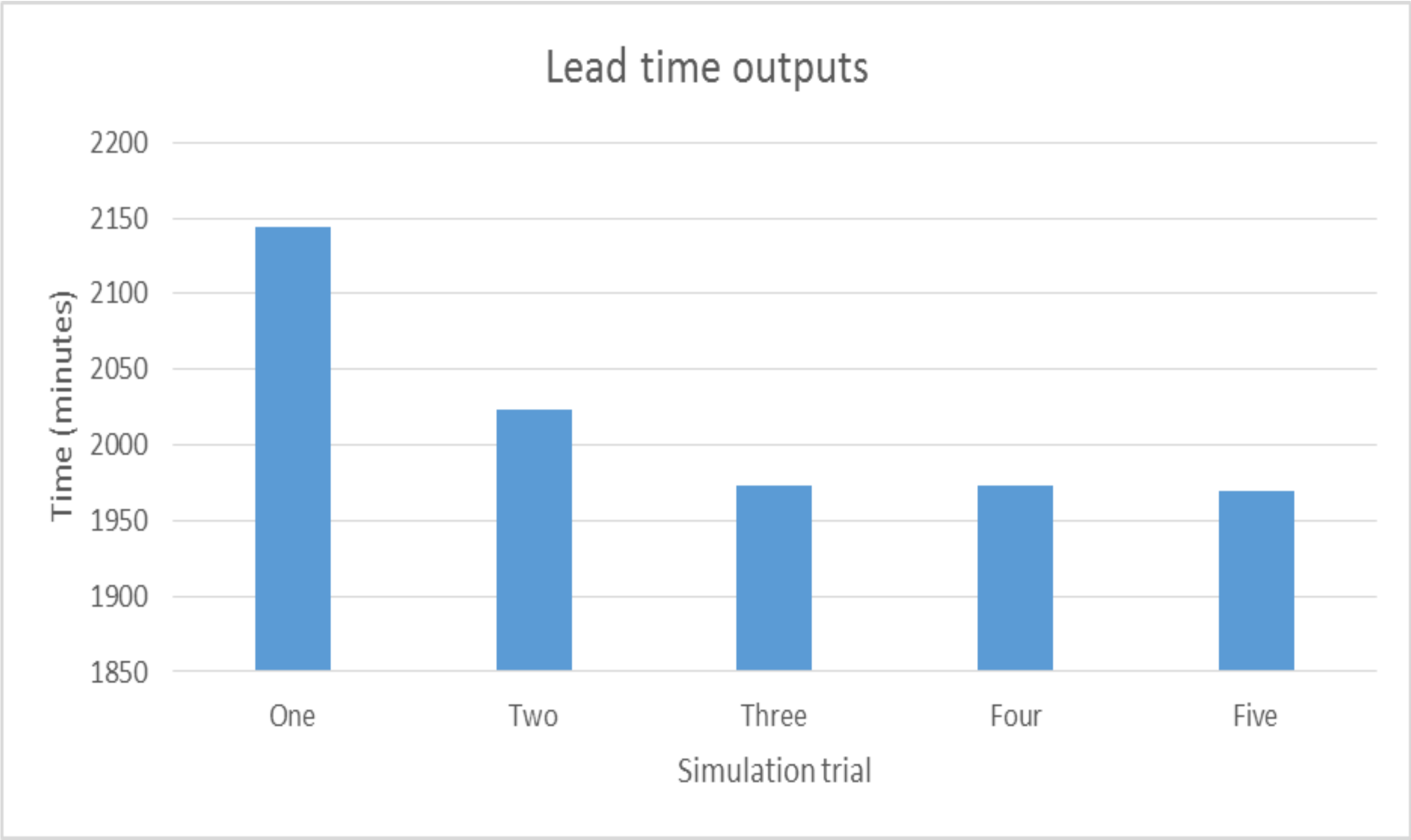
Results



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Key Findings

When Lean is correctly implemented to reduce cycle times, lead time is reduced the plant throughput increases

Simulation modeling complements Lean tools such as Value Stream Mapping in providing a Lean evaluation framework.

The experiment proved that simulation modeling is a useful tool in testing the impact of applying Lean before the actual implementation.

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Recommendations

Adaptation of (FINITE) Lean in the mining industry to improve process efficiency, reduce lead times and improve plant throughputs

Simulation modeling as a complimentary tool for Lean evaluation in mining companies

The simulation modeling technique to test how key performance indicators will be impacted by lean optimization before actual implementation

For future study purposes, a more holistic and integrated study is suggested, expanding the scope to production, maintenance, logistics and management of the whole mining process.

Lean simulation optimization of all these elements is suggested to improve the organization's efficiency.

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THANK YOU

QUESTIONS

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