UNIVERSITY OF SOUTHERN QUEENSLAND

FACULTY OF ENGINEERING AND SURVEYING

Review of Failure Mode, Effect and Criticality Analysis (FMECA) on major equipment of the crushing and screening plant at the BORAL Quarry at Ormeau, Queensland.

A DISSERTATION SUBMITTED BY

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In fulfilment of the requirements of

Courses ENG4111 and 4112 Research Project

Towards the degree of

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ABSTRACT

Project Title:

Review of Failure Mode, Effect and Criticality Analysis(FMECA) on major equipment of the crushing and screening plant at the BORAL Quarry at Ormeau, Queensland

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This project was aimed to improve the reliability of the BORAL hard rock crushing and screening plant at Ormeau. A literature review was documented, highlighting the reasons for FMECA and the process involved in carrying the procedure out. A review of BORAL downtime data was conducted, which identified problem machines that were large contributors to downtime. A s study of the plant identified the critical path of the plant and functional diagrams showed dependencies between systems of individual machines. The FMECA required ground rules for a true and consistent evaluation. The FMECA was conducted, criticality values were given to failures and recommendations made to prevent, predict, and fix failures more quickly. The recommendation were expanded apon and developed into an item that can be used by staff to implement the recommendations.

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

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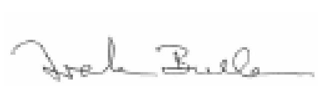

Professor Frank Bullen
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Certification

I certify that the ideas, design and experimental work, results, analysis, and conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated

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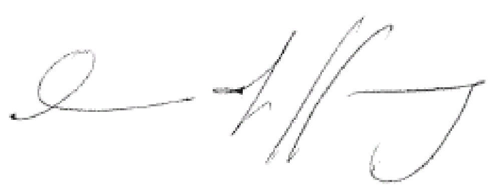

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LIST OF ABBREVIATIONS

CSS	Close Side Setting
QRS	Quarry Reporting System
IEMS	Integrated Environmental Management System
GCCC	Gold Coast City Council
IQA	Institute of Quarries Australia

1. PROJECT STATEMENT, AIMS AND OBJECTIVES

1.1 PROJECT STATEMENT

Conduct a Failure Mode and Effect and Criticality Analysis (FMECA) on major equipment of the crushing and screening plant at the Boral Quarry at Ormeau, Queensland, and develop an appropriate maintenance strategy and any recommendations to improve the plant.

1.2 PROJECT AIM

The aim of this project is to reduce the unplanned downtime as a result of failures to the crushing and screening plant at the Boral Quarry at Ormeau, Queensland. To achieve this aim, a Failure Mode and Effect and Criticality Analysis (FMECA) will be undertaken.

1.3 Specific Project Objectives

The objectives of this project are to:

- Confirm that FMECA is the most appropriate analysis to undertake to ensure the reliability and reduced failure of the crushing and screening plant at the Boral Quarry at Ormeau, Queensland.
- Determine what is required to undertake a FMECA.
- Acquire the needed information.
- Conduct the FMECA
- Develop a maintenance plan that can be used effectively by employees to maintain the plant, with particular attention to the critical path of the plant.
- Provide any recommendations to improve the running of the plant.

The process has the potential to improve the reliability and reduce failure of the crushing and screening plant at numerous Quarry in South East Queensland. Following the assessment of the project, consideration may be given to recommending FMECA be undertaken for all the plants across South East Queensland.

2. LITERATURE REVIEW

2.1 PROJECT METHODOLOGY / JUSTIFICATION AND TIMELINE

The delivery method of this project has been broken into activities and coordinated in the Gantt chart included as appendix 01. The key milestones have been listed below in table 0 with the intention of completing each activity by the date noted.

In this report the application of the FMECA process and Boral Quarry Data will be reviewed to determine the need for the project. It is anticipated that the Quarry data will confirm unplanned downtime due the system failures. The review of reliability and failure analysis will be undertaken to determine if FMECA is the most suitable process to undertake in order to reduce the system failures and therefore increase reliability, the quarry plant performance and overall profit.

1	Submit project statement for review	11/03/09
2	Commence research for project appreciation	12/03/09
4	Complete and submit project appreciation	25/05/09
5	Commence FMECA process on Boral plant	14/08/09
6	Determine recommendations	11/09/09
7	Submit 95% complete dissertation	23/10/09
8	Submit final dissertation	30/10/09

Table 0: Project Milestones

2.2 RISK ASSESSMENT

The University of Southern Queensland, Project Reference Book (2009) notes the importance of risk assessment to engineering projects due to legal and financial implications. A detailed risk assessment and register for the project included as appendix 2. The identified project risks have been assessed against:

- Risk category;
- Risk description and details;
- Likelihood;
- Consequence;

- Risk factor;
- Risk treatment; and
- Responsibility

The risk assessment identified several ‘high’ risk items associated with the project completion. This assessment has ensured that appropriate mitigation strategies have been applied to all risks in order to reduce both the likelihood and consequence.

2.3 BACKGROUND INFORMATION

2.3.1 THE HISTORY AND FUTURE NEED FOR RELIABILITY AND FAILURE ANALYSIS

The year of 2001 will be remembered for the tragedy of the Concorde crash and the destruction of the Twin Towers in New York. ‘Both were engineering feats and landmarks in their own field’ (Camilleri, 2002). The importance of reliability and failure analysis is evident particularly in light of these recent events. In the above scenarios, this type of analysis is used to preserve human life by assessing the safety of the system. However, this form analysis ‘has gained popularity as a best practice to optimise maintenance programmes and design defect free process in the manufacturing/industrial industry.’ (Banerji, & Chakraborty, 2009) It can be applied to categories of systems based on ‘different technologies (electrical, mechanical, hydraulic etc.) and combinations of technologies’ (IEC Standard, 1985).

Failure Modes, Effects and Criticality Analysis (FMECA) as a specific form of Reliability and Failure Analysis, was ‘developed by the US Armed Forces in the late 1940’s, the technique shot to industrial fame when it was used in the Apollo programme to put a man on the moon.’ (Banerji, & Chakraborty, 2009).

2.3.2 PREVIOUS RESEARCH OF RELIABILITY AND FAILURE ANALYSIS

The aim of undertaking such an analysis is to provide the stated function of the system or equipment, with the required reliability and availability at the lowest cost. It requires that maintenance controls are focused on reducing the risk of failure and supported by sound technical and economical justification. As with any philosophy, there are many processes that can lead to the final goal. For reliability engineering the varying processes are listed below:

- Failure Rate Prediction;
- Fault Tree Analysis;
- Event Tree Analysis;
- Reliability Block Diagram Analysis;
- Markov Analysis;
- Petri Net Analysis;
- Stress-Strength Analysis; and
- Failure Mode and Effect (Criticality) Analysis

Previous Studies have been undertaken to determine the most effective reliability and failure analysis for plant and equipment used at Boral Quarry's. A dissertation undertaken by Robbie Cox (2008) at the Queensland University of Technology reviewed the above process and assessed both the benefits and limitations and determined the following:

> *Techniques such as Markov, Petri Net and Stress-Strength analysis involve difficult computational operations that can become unmanageable and impossible without the use of a software tool.*
>
> *Event and fault tree techniques while useful in forming cut sets for future analysis require the production of a new tree for each initiating event or failure mode respectively. Large number of analysis techniques can become problematic when planning and are sometimes difficult to manage.*
>
> *Stress-Strength, Failure Rate Prediction and Markov analysis require in some instances large sources of machine and environmental information to produce meaningful results, therefore the implementation of such techniques is applicable to situations that have historical information and operational technical data.*
> *FMECA, Event Tree analysis, Fault Tree analysis and Reliability Block Diagram analysis are useful in logically representing systems, system failure paths, component and sub-assembly interaction and components and sub-assemblies that are more susceptible to failure and can cause propagated damage.*

The dissertation undertaken by Cox (2008) determined that the most appropriate method of reliability and failure analysis of plant and equipment used at Boral Quarry's was a combination of FMECA, Event tree analysis, Fault tree analysis and reliability block diagrams.

Following the review of the International Electrotechnical Commission (IEC) Standard for Analysis techniques for system reliability – Procedure for failure mode and effects analysis (1985) it has been determined that during the pre-design and design stages FMECA proves to be essential but not sufficient, it should be applied in combination with Event Tree analysis, Fault Tree analysis and Reliability Block Diagram analysis. As the crushing and screening plant at the Boral Quarry at Ormeau, Queensland is a well established plant and is not in the pre design stage it is determined that FMECA (of which function block diagram is a part of) is the most appropriate process to undertake to ensure the reliability of the plant.

2.4 REVIEW OF PROCEDURE FOR FAILURE MODE EFFECTS AND CRITICALITY ANALYSIS

Banerji, & Chakraborty (2009) described the standard components of a FMECA as shown in figure 1.

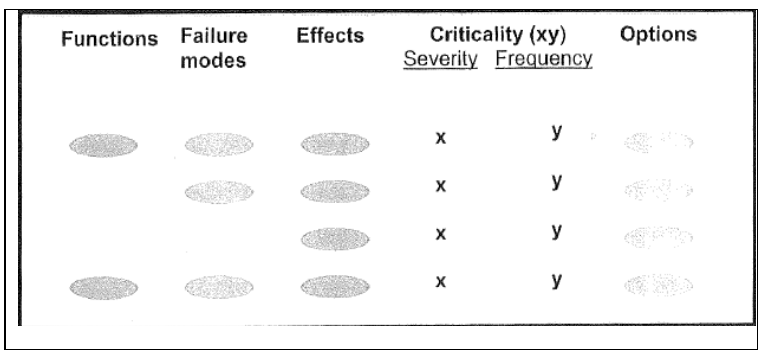


Figure 1: (Banerji, & Chakraborty 2009)

The IEC developed a standard (1985) to document the procedure to carryout Failure Mode Effect Analysis (FMEA) and Failure Mode Effect Criticality Analysis (FMECA). The standard aligns with figure 1, however it provides further detail on each of the components. The steps required to carry out FMEA as per the IEC standard (1985) are listed below.

1. *Definition of the system;*
2. *Development of functional block diagrams;*
3. *Establishment of ground rules;*
4. *Failure Modes, causes and effects;*

5. *Failure detection methods;*
6. *Identification of alternative provisions;*
7. *Report of FMEA process*.

The IEC standard (1985) addresses all the general considerations presented for FMEA which apply to FMECA as one is an extension the following steps are only required when undertaking FMECA (IEC Standard 1985). Note: the reporting of the process is carried out at the end of FMECA.

8. *Determination of event criticality;*

2.5 FMEA PROCESS (AS A PART OF FMECA PROCESS) DESCRIBED

2.5.1 STEP 1 FMEA PROCESS - DEFINITION OF THE SYSTEM AND ITS REQUIREMENTS

The IEC standard (1985) notes that the definition of the system should consists of:

- *A definition of both primary and secondary functions;*
- *Its use;*
- *Expected performance;*
- *System constraints; and*
- *Explicit conditions which constitutes a failure; and*
- *Functional narratives of the system's operation for each mode and its duration.*

The definition of the system should also include information on its functional and environmental requirements. The functional requirements note both acceptable functional performance and the characteristics considered unacceptable performance. The environment (temperature, humidity, radiation, vibration and pressure) where the system will function also needs to be defined.

2.5.2 STEP 2 FMEA PROCESS - DEVELOPMENT OF FUNCTIONAL BLOCK DIAGRAMS

Functional block diagrams are developed to show functional elements of the system, they provide technical understanding, show any series, superfluous relationships and functional failures.

2.5.3 STEP 3 FMEA PROCESS - ESTABLISHMENT OF GROUND RULES

Ground rules are established to determine levels of analysis and rely upon the system results desired. The highest system level is determined as the specified output where as the lowest system level is specified mostly for a newly designed system or one with little reliability history.

2.5.4 STEP 4 FMEA PROCESS - FAILURE MODES, CAUSES AND EFFECTS

Failure modes can be categorised into a set of general failure modes. These being (IEC standard 1985):

- *Premature operation;*
- *Failure to operate at a prescribed time;*
- *Failure to cease operation at a prescribed time; and*
- *Failure during operation*

As any system consists of many components, determining the critical system and ensuring its performance will result in the successful operation of the overall system.

The cause of a failure to a system can be an independent failure of one component. It is imperative that potential failure causes for all components of the system be identified. The IEC standard (1985) notes the cause of a failure mode is determined to:

- *Predict the probability of occurrence;*
- *Uncover secondary effects; and*
- *Devise recommended corrective actions.*

Common causes of failures are listed below. Note: the list is note extensive.

- Structure failure;
- Physical binding or jamming;

- Vibration;
- Fails to open or close, stop or start; and
- Internal or external leakages;

The effect is a direct result of a failure mode. 'Failure mode effects focus on the specific system element in the functional diagram being analysed which is affected by the failure under consideration.' (IEC Standard 1985).

2.5.5 STEP 5 FMEA PROCESS - FAILURE DETECTION METHODS

The failure detection methods need to be described when undertaking the analysis. It is imperative that when a single component of the system is being assessed for failure, if any other component will be affected by initial failure, it should be recorded as this will assist in failure detection of subsequent components.

2.5.6 STEP 6 FMEA PROCESS - IDENTIFICATION OF ALTERNATIVE PROVISIONS

Once the failure mode is detected, the significance of the failure needs to be recorded along with any relevant or proposed design features and other provision that may assist in reducing/eliminating the failure mode. The IEC Standard (1985) notes some of the provisions:

- *Redundant items that allow continued operation if one or more elements fail;*
- *Alternative means of operation;*
- *Monitoring or alarm devices; and*
- *Any other means permitting effective operation or limiting damage.*

2.5.7 STEP 7 FMEA PROCESS - REPORT OF ANALYSIS

The IEC standard (1985) recommends that the report of the FMEA should record

- *Description of the methodology;*
- *The assumptions and ground rules;*
- *Recommendations for designers, maintenance staff, planners and users; and*

- *Failures that result in serious effects.*

2.6 CRITICALITY ANALYSIS

Criticality analysis is undertaken in order 'to quantify the severity of a failure effect and to estimate the probability of occurrence of the relevant failure mode.' (IEC Standard 1985) The process for determining severity and probability are described in items 2.6.1 and 2.6.2 respectively. Once the severity and probability of the failure mode have been determined its total criticality to the system is evaluated, this process is described in item 2.6.3.

2.6.1 PROCEDURE FOR CRITICALITY ANALYSIS –SEVERITY ANALYSIS

To determine the criticality of a failure mode, it needs to be assessed in relation to the overall performance of the system requirements, objectives and constraints. The IEC Standard (1985) suggests that severity is classified by the following categories:

- death or injury to operation personnel or to the public;
- damage to external equipment or the equipment itself;
- economic loss due to lack of output or function; and
- failure to complete a task due to inability of equipment to perform its major function.

2.6.2 PROCEDURE FOR CRITICALITY ANALYSIS – PROBABILITY OF A FAILURE MODE

Once the procedure for FMEA is complete, using the data directly from the sources sited, a quantitative assessment, specifically, analytically derived estimates, can be undertaken to determine the probability of occurrence for each postulated failure mode. (IEC FMEA 1985)

Rethinking engineering: risk and reliability analysis, a paper written to promote engineers using analytical tools when undertaken studies of reliability, references a numbering system used to reference probability. Assigning a baseline figure 'targeting probability for normal cases, as what society nowadays seems to accept or consider unavoidable' (Camilleri, 2002) to enable probability to be assessed either below or above the baseline figure.

2.6.3 PROCEDURE FOR CRITICALITY ANALYSIS – CRITICALITY EVALUATION

Criticality Analysis and its evaluation is crucial in determining failure mode priorities and the clear delineation between what is acceptable and what is not acceptable in the performance of any given system. Prioritising failure modes and determining acceptable versus not acceptable is what governs the decision making process and corrective actions. Without appropriate corrective actions the risk and result of a failure mode could be greatly increased.

The IEC standard (1985) has developed a matrix, shown in figure 02, to assist in criticality evaluation. The level of Criticality is recorded from one (1) – four (4) vertically and the probability of failure is recorded horizontally as either very low, low, medium or high. The further result is noted from the origin diagonally, the greater the criticality and the more urgent need for corrective action (IEC Standard 1985).

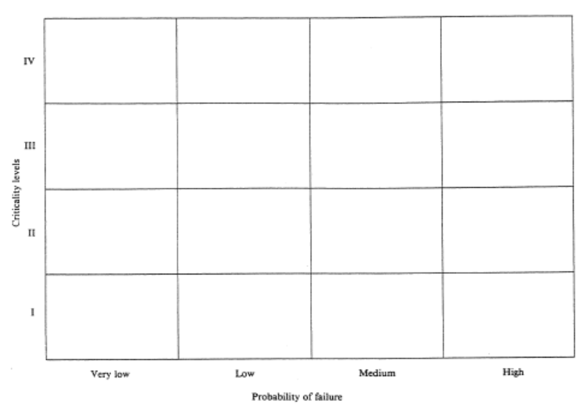


Figure 2: Criticality Evaluation (IEC Standard 1985).

Banerji and Chakraborty (2009) recommend allocating a numerical figure to severity, 'x' and a numerical figure to frequency indicated as 'y'. The criticality of the failure mode can then be assessed as 'xy'. This is indicated in figure 2.

2.7 CHAPTER SUMMARY

Following the review of the literature above on criticality analysis, being severity, probability and the overall evaluation, the criticality of assessment of the crushing and screening plant at the Boral Quarry at Ormeau for this project will be undertaken by:

- Determining the frequency of the failure mode against a numerical figure allocated to ‘target probability for one year for normal cases, as what society nowadays seems to accept or consider unavoidable anyway’ as recommended in the paper Rethinking engineering.
- Similarly, a figure for severity will be assigned to determine a baseline for which all failure modes can be assessed against.
- A third value will also be used in the calculation of the criticality analysis, and that being detection. This value will refer to the detect ability of a failure.
- The overall criticality of the failure mode will be assessed as a multiplication of severity ‘x’ and frequency ‘y’ and detection ‘z’ as recommended in the paper Banerji and Chakraborty (2009), and the authors preference.

3. REVIEW OF BORAL DOWNTIME DATA

The aim of this project is to reduce the failure of the crushing and screening plant at the Boral Quarry at Ormeau. Failure in the plant results in downtime of the system, which is logged in the Quarry reporting system database (QRS). A downtime event is registered whenever the belt weigher is reading less than 50 tonnes per hour on the main conveyor in the system. This information is logged to a data taker, and then is transferred to the QRS. The plant operator must then specify the cause of the downtime in the 'Daily Crushing Data Sheet', see appendix D. The reporting system tracks all plant downtime across Boral South East Queensland Quarries, recording details such as:

- Location
- Duration of the downtime; and
- Asset downtime
- Cause of the downtime (planned versus unplanned)

Planned downtime for crushing and screening plant is necessary to maintain the system. The optimum level of maintenance can be determined as a ratio of operational hours versus maintenance hours. As 'Quarries produce material through a continuous process the failure of one component can often result in the entire production line being halted'. (Cox 2008) Ultimately this will affect production and profit. Therefore, it is unplanned maintenance that will benefit from undertaking an FMECA and developing appropriate maintenance strategies.

The information recorded in the QRS can be analysed to determine common failures, that is, unplanned downtime. The downtime duration and frequency can be used in the FMECA to determine criticality. This log of information will be invaluable when undertaking the FMECA process.

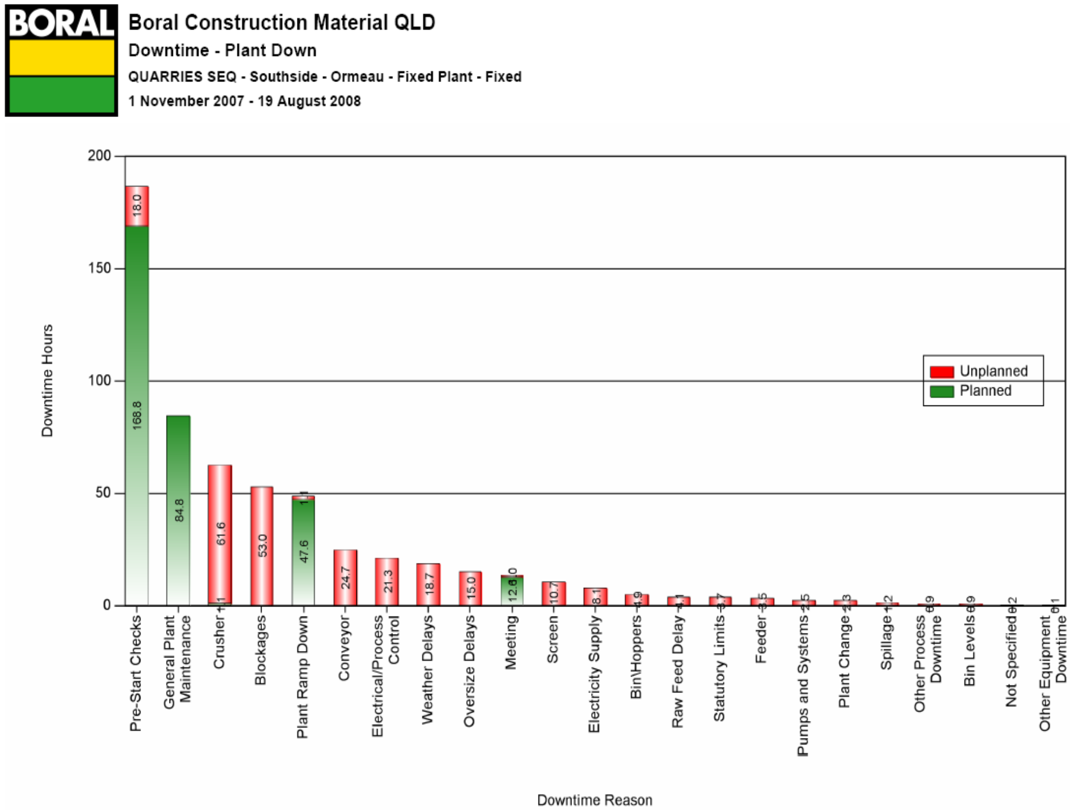


Figure 3: BORAL Machine Downtime Contributors (QRS) 2009

The downtime chart shown, shows planned and unplanned downtime. It also shows the hours that each type of machine contributes to downtime, over the period of examination. It can be said by looking at the figure that the biggest contributors are crushers and screens. This information will be useful when conducting the FMECA in analysing the frequency of failure.

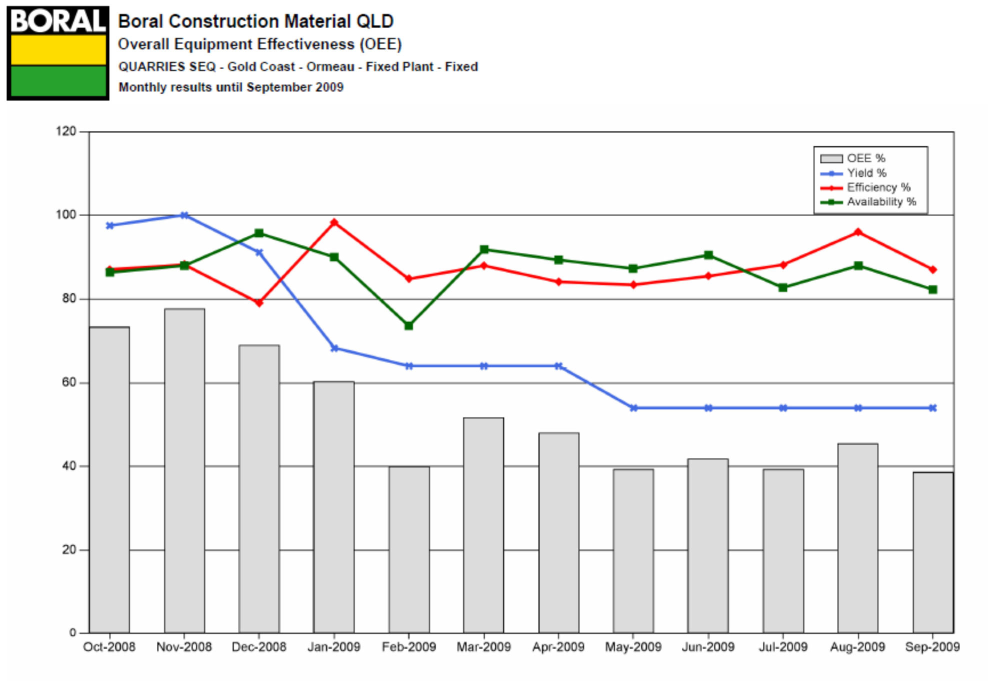
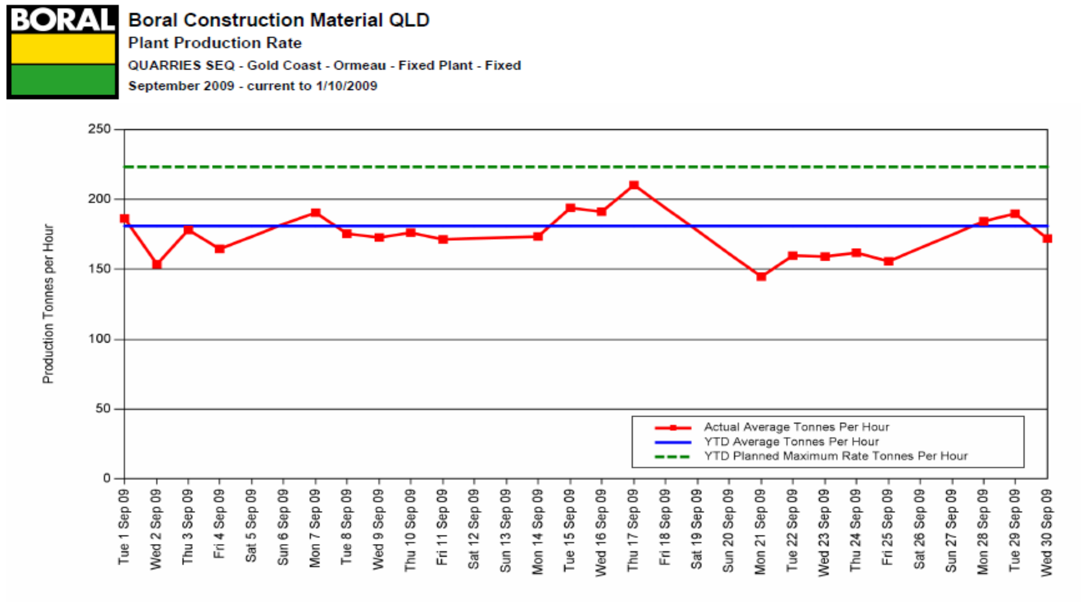


Figure 4: BORAL Downtime Chart (QRS) 2009

The Overall Equipment Effectiveness (OEE), is a measure for quantifying the performance of a plant. It is a calculation involving a plants, yield percentage, efficiency percentage and availability percentage. The figure for analysis from this graph is the availability, which it the percentage downtime of the total available crushing hours. It can be seen that the availability for this analysis period ranges from approximately 70% to 90%.



Summary	This Month - Sep 09		Last Month - Aug 09		YTD - Jul 09 to Sep 09	
	Planned	Actual	Planned	Actual	Planned	Actual
Production (tonnes)	38,720.0	31,700.0	45,920.0	36,500.0	128,890.0	101,750.0
Regimen/ Operating Hours	193.6	182.1	184.0	190.0	577.6	562.5
Production Rate (tonnes / hour)	200.0	174.1	249.6	192.1	223.1	180.9

Figure 5: Production Rate Chart (QRS) 2009

The Production Rate Chart shows the daily average production rate, and also the actual and planned production total for the months of September and August. It can be seen that the actual production total is less than the planned production level. This is due to downtime. As the report shows that the performance of the crushing and screening plant has not meet its target output.

3.1 CHAPTER SUMMARY

In reviewing the BORAL QRS data, it can be seen that an improvement in downtime is needed. An FMECA procedure is planned to reduce the downtime percentage.

From the Downtime chart the downtime contributions are shown, which gives an indication the frequency of machine failure, which will be directly used in the FMECA evaluation.

4. REQUIREMENTS OF THE CRUSHING AND SCREENING PLANT

4.1 SYSTEM PRIMARY FUNCTIONS

The primary function of the Ormeau Crushing and Screening plant is to supply South East Queensland with a high quality screened aggregate to be utilized in concrete and asphalt for construction projects.

It is a primary function of the Ormeau plant to operate in a safe manner and allow operator access on and around the plant during both operation and downtime. Safe access to all components of plant is required to ensure the operation and maintenance can be carried without causing any injury to personnel.

The plant at Ormeau is required to have minimal effect of the environment. The crushing and screening process can produce moderate levels of dust, vibration and noise. It is a primary function of the plant to minimize these environmental effects. (N Bellamy 2009, pers. comm., 01 June.)

4.2 SYSTEM SECONDARY FUNCTIONS

A secondary function of the Ormeau Crushing and Screening plant is to operate with a high level of reliability. Due to local council regulations, the plant can operate within the hours 7am to 6pm, Monday to Friday. It is a requirement that the plant operates consistently within these hours and for the entire hours. A reliability measure is monitored using the QRS (Quarry Reporting System) as a reliability percentage and a unscheduled downtime percentage. Reliability is major secondary function of the Ormeau plant. (N Bellamy 2009, pers. comm., 01 June.)

4.3 SYSTEM USES

The Ormeau Crushing and Screening Plant is used to crush raw material of size, 700-1000mm in diameter, and screen to produce: 35mm, 16mm, 14mm, 10mm, 7mm, and 5mm aggregates and course dust and fine dust. This process occurs by passing crushed material through screens with varying aperture holes in them. For example, a 10mm aggregate can be produced by screening material through a 12mm screen and across the top of an 8mm screen.

The Ormeau plant is required to produce a high quality aggregate as this aggregate is a major constituent in products such concrete and asphalt used in public construction projects. Registered technicians test samples of the aggregate to ensure it meets the required specifications, this testing is undertaken to protect the public using the product. A possible reason for an aggregate sample not meeting specifications regarding the crushing and screening plant is contamination, meaning aggregates of different sizes in a specified aggregate size sample. (Hoffman, 2008)

4.4 SYSTEM EXPECTED PERFORMANCE

The Ormeau Crushing and Screening plant was designed to operate with maximum capacity:

- For 11 hours a day, 5 days a week (55 hours of processing);
- Process approximately 180-200 tonnes per hour of raw material;
- Have a minimal effect of the environment;
- Be safe to operate and maintain; and
- Produce a quality screened aggregate;

4.5 EXPLICIT CONDITIONS WHICH CONSTITUTE A FAILURE

There are many explicit conditions that constitute a failure. A failure or downtime event is recorded any time there is less than 50 tonnes per hour on conveyor 1, the main conveyor. A belt weigher is permanently reading the weight on conveyor 1. This information is sent to a data logger. The information from the data logger is downloaded to a computer program which itemizes each time the belt weigher read less than 50 tonnes per hour and is called a downtime event. Each downtime event is assigned a cause. The causes for downtime events are grouped into such groups as: (Daily Crushing Data Sheet, BORAL, 2004)

1. General maintenance
2. Crusher
3. Conveyor
4. Screens
5. Clean up
6. Bin/Hopper
7. Feeders
8. Plant change
9. Electrical/Process control
10. Pumps and systems
11. Metal detector trip (MDT)
12. Electricity supply
13. Other equipment downtime
14. Meetings
15. Meal breaks
16. Early finishes
17. Pre – start checks
18. Shot firing
19. Staff shortage
20. OH&S issue
21. Raw feed delay
22. Blockage
23. Oversized delays
24. Spillage
25. Weather delays
26. Statutory limits
27. Other processing downtime
28. Bin levels
29. Production ramp down
30. Nil surge

The downtime event is classified into one of these groups of explicit conditions

Even though the QRS only registers a downtime event when the belt weight drops below 50 tonnes per hour, this is a 75% loss in production, and would not be efficient to run. Therefore it has been decided that when the production rate drops below 150 tonnes per hour, there is a failure somewhere, and constitutes a failure. (N Bellamy 2009, pers. comm., 01 June.)

4.6 OPERATIONAL USE

The Ormeau Crushing and Screening plant can operate at different production configurations. Depending on the aggregate demand, production configurations must change. The most common configurations include:

1. 16mm minus
2. 14mm minus
3. 10mm minus

A configuration of 16mm minus means 16mm and smaller size aggregates will be produced, while anything larger than 16mm will be returned to the crusher for re-crush and a reduction in size. A production configuration of 16mm minus will have a high production rate and the production rate will decrease as the size of the production configuration decreases.

4.7 DEFINITION OF FUNCTIONAL REQUIREMENTS

The definitions of acceptable performance of the system are the same as the expected performance which include:

- For 11 hours a day, 5 days a week (55 hours of processing);
- Process no less than 180 tonnes per hour of raw material;
- Have a minimal effect of the environment;
- Be safe to operate and maintain; and
- Produce a quality screened aggregate;

The definition of unacceptable performance of the system as include:

- During an eleven hour day of crushing to have an accumulative downtime total of 105.6 minutes would be completely unacceptable. This would calculate to give the planned 84% machine availability given by the monthly Quarry Performance Summary (QRS, 2009).
- 1760.4 tonnes of raw material needs to be processed a day, this is inline with the planned 35207.5 tonnes given by the monthly

Quarry Performance Summary. A total less than 1760 tonnes would be also unacceptable performance, (QRS, 2009).

- Any injury resulting from any system on the Crushing and Screening plant would be unacceptable performance.
- Have an effect on the environment that is greater than allowable.
- Produce aggregates that have contamination of any sort.

4.8 DEFINITION OF ENVIRONMENTAL REQUIRMENTS

The definition of the environment that the crushing plant is expected to operated within would include:

- Temperatures that range from approximately 8 degrees Celsius in the winter to 35 degrees Celsius in the summer.
- An environment that can be high levels of dust concentration
- The system is operated in the open environment, therefore humidity, aging, corrosion, are common.
- A small level of vibration.

4.9 REGULATORY REQUIREMENTS

The Ormeau Quarry site is located in the Gold Coast City Council, the council determines and enforces strict operating hours on the quarry (Holley, 2009). The hours are as follows:

Activity	Monday to Friday	Saturday	Sunday
Extraction	7am – 6pm	Not permitted	Not permitted
Crushing & Screening	7am – 6pm	Not permitted	Not permitted
Blasting	10am – 2pm	Not permitted	Not permitted
Maintenance	7am – 6pm	8am – 12pm	Not permitted
Load and Haul to plant	7am – 6pm	8am – 12pm	Not permitted
Sales and Dispatch	7am – 6pm	8am – 12pm	Not permitted

Table 1: Existing approved hours of operation

Operating hours that pertain to the crushing plant are the: Crushing and Screening hours, Maintenance hours, and the Load and Haul to the plant hours.

The Ormeau quarry site, as all Australian Quarry site are, is regulated by such acts as:

- Mining and Quarrying Safety and Health Regulations 2001.
- Explosives Act.

- IEMS (Boral Integrated Environmental Management System, December 2001), which is issued to the Environmental Protection Agency, EPA, and states how each site is going to meet the requirements of the EPA.

With in the IEMS document the limits for: Water contaminate release, Noise, Blasting, and Air are stated. Again the sections that relate to the Crushing and Screening Plant are Noise and air quality. The limits for noise are as follows (Rigby 2001):

Noise level at a noise sensitive place measured as $L_{Amax,AdjT}$: • 7am-10pm: background noise level plus 5dB(A) and; • 10pm-7am: background noise level plus 3dB(A) **Noise level at a commercial place measured as $L_{Amax,AdjT}$:** • 7am-10pm: background noise level plus 10dB(A) and; • 10pm-7am: background noise level plus 8dB(A)

Table 2: Noise limits for the Ormeau Quarry (IEMS, 2001)

Noise is required to be monitored only after a complaint has been made (IEMS, 2001)

The limits for air quality are as follows:

Ambient particulate matter	120 mg/m^2/day
24 hour average concentration of particulate matter	150ug/m^3/24 hour average

Table 3: Air quality limits for the Ormeau Quarry (IEMS, 2001)

Air quality is required to be constantly monitored (IEMS, 2001). This requirement is fulfilled with the site having 3 air quality monitors permanently placed around the site.

4.10 CHAPTER SUMMARY

The main purpose of the crushing and screening plant is to process raw material, of a size of approximately 700mm – 900mm, into screened usable aggregates and to do it safely and in an environmentally responsible fashion.

The plant must do this between the hours of 7am to 6pm on weekdays only, and be maintained between the hours 7am – 6pm on weekdays and 8am – 12pm on Saturday. During the hours of operation, the plant needs to process at least 35207.5 tonnes in a month. Any time that the plant is processing less than 50 tonnes an hour, a downtime event is registered and classified as 1 of 30 explicit conditions, which is logged to the QRS system.

The plant also needs to abide by environmental regulations, such as air quality levels: 120 mg/m^2/day and 150ug/m^3/24 hour average, and noise limits of: 7am-10pm: background noise level plus 5dB(A) and; 10pm-7am: background noise level plus 3dB(A) in a noise sensitive place and in a commercial place: 7am-10pm: background noise level plus 10dB(A) and;10pm-7am: background noise level plus 8dB(A)

5. CRUSHING AND SCREENING PROCESS AND PLANT DEFINITION

As part of the FMECA process a study needs to be undertaken of the production process. The critical path of the plant must be determined, and any redundancies that may exist that will allow for a machine to failure and not to stop the plant. The outcomes of this study will dictate the 'Effects of a failure' of the FMECA for the machines that will allow production to continue while it has failed.

The crushing and screening plant is spilt up into 2 sections, the primary/secondary section, which processes raw material to an approximate size of 39mm to 45mm and screens off any material that will fit through a 25mm square screen deck, and the tertiary section, which crushes and screens the final products of 16mm, 14mm, 10mm, 7mm, 5mm, course dust and fine dust.

5.1 PRIMARY CRUSHING AND SCREENING SECTION

The primary section produces scalps, course dust and secondary crushed material to a size of approximately 39mm to 45mm.

Blasted quarry face raw material is transported to the tipping bin by dump trucks or front end loaders. It is put in the tipping bin, where it travels through chute 1 by gravity onto screen 1. Screen 1 is controlled by the operator, and is used to regulate the flow of material into the jaw crusher. Screen 1 has a punch plate deck with 90mm diameter holes in it, the material that falls through the top deck of screen 1 travels through the transfer point 2 to conveyor 7. The material that passes over the top of screen 1 goes through chute 2 into the jaw crusher. The jaw crusher crushes the rock to approximately 100mm. The now primary crushed 90 - 100mm material goes through transfer point 1 to conveyor 1A, which has a permanent magnet on it to collect any metallic material. The material now falls into the Jaques cone crusher, where it is reduced in size to 39

– 45mm. The now secondary crushed rock flows through transfer point 3 to conveyor 1 and through transfer point 5 to screen 3. Screen 3 is a 2 deck screen, the top deck has 25mm aperture screens, any material that flows over this deck travels through transfer point 7 to conveyor 10 and to the surge bin. Material that passes through the top deck of screen 3 and across the bottom deck, which has 5mm aperture screens on it, flows through chute 3 to the Barmac. Material that goes through the bottom deck goes to Bin 13 as a final product of course dust. The material that was passed onto conveyor 7, moves through the transfer point 4 to conveyor 8, through transfer point 6 to screen 4. Screen 4 which has a single deck of 25mm aperture, material that passes over the top of the screen deck goes to transfer point 7 to conveyor 10 and to the surge bin also. Material that falls through the top deck of screen 4 moves through chute 5 to bin 16 as a final product called scalps. The bins are empties through bin gates, which are actuated by pneumatic cylinders.

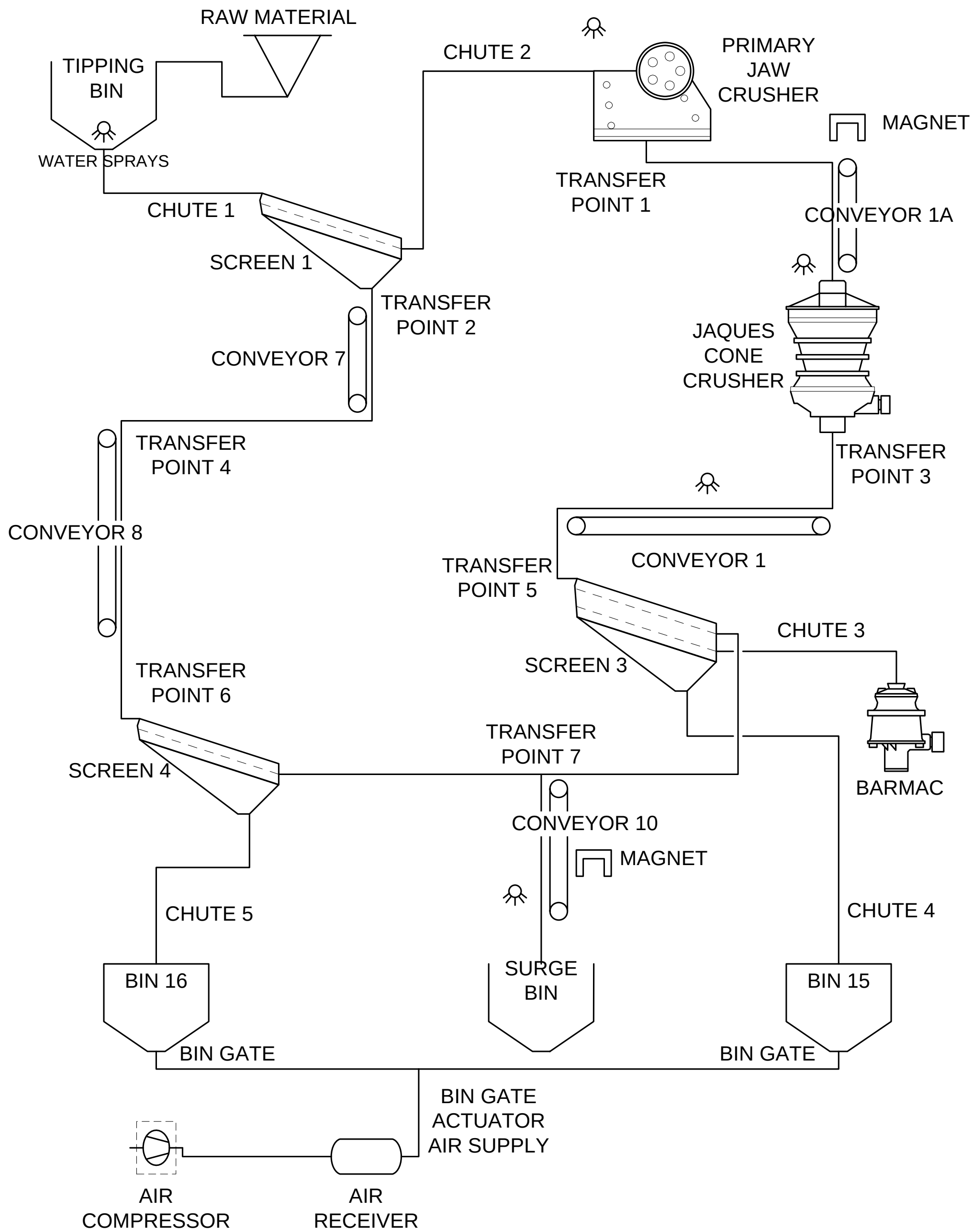


Figure 6: Primary and Secondary Process Diagram

Item	Component Description
Raw material	Face rock transported to the plant
Tipping bin	Machines tip loads of raw material into the tipping bin, where it waits to be feed into the plant.
Chute 1	Delivers material from the tipping bin to screen 1
Chute 2	Delivers material from screen 1 to the jaw crusher
Chute 3	Delivers material from the bottom deck of screen 3 to the Barmac VSI.

Chute 4	Delivers material that falls through the bottom deck of screen 3 to bin 13
Chute 5	Delivers material that falls through the top deck of screen 4 to bin 16
Transfer point 1	Transfers primary crusher rock from the output of the jaw crusher to conveyor 1A
Transfer point 2	Transfers material that falls through the top deck, of screen 1 to conveyor 7(Approximately 90mm minus),
Transfer point 3	Transfers secondary crushed material from the output of the Jaques Cone Crusher to conveyor 1
Transfer point 4	Transfers material from conveyor 7 to conveyor 8
Transfer point 5	Transfers material from conveyor 1 to the input of screen 3
Transfer point 6	Transfers material from conveyor 8 to the input of screen 4
Transfer point 7	Transfers material that is screened across the top deck of screen 3 and 4 (Approximately 40mm – 25mm) to conveyor 10
Conveyor 1A	Handles material from transfer point 1 to the Jaques cone crusher
Conveyor 1	Handles material from transfer point 3 to transfer point 5
Conveyor 7	Handles material from transfer point 2 to transfer point 4
Conveyor 8	Handles material from transfer point 4 to transfer point 6
Conveyor 10	Handles material from transfer point 7 to the surge bin
Jaques Cone Crusher	Crushes primary crushed material of size 100-90mm into secondary crushed material of size 45-39mm.
Jaw crusher	Crushes 750mm to 90mm raw, quarry face material
Barmac VSI	Vertical Shaft Impactor (VSI), shapes material of size 25-5mm
Screen 1	Single deck screen, the deck is an impact plate with 90mm holes in it.
Screen 3	Double deck screen: top deck uses 25mm square, wire, screens; bottom deck has 5mm square screens.
Screen 4	Single deck screen, the deck uses 25mm square, wire screens.
Magnet	Permanent magnet placed over the top of the conveyor to remove material contamination
Surge bin	30 tonne surge bin, provides lag time between the primary and tertiary. The surge bin feeds the tertiary section 45-25mm material.
Bin 16	Bin 16 is feed 25mm minus material from screen 4, called Scalps

Bin 15	Bin 15 is feed 5mm minus material from screen 3, called course dust.
Air system	The air system consists of a: air compressor, air receiver, air lines, pneumatic actuators and electronically controlled directional control valves operated by a wireless activation system.

Table 4: Primary and Secondary System definition

5.2 TERTIARY CRUSHING AND SCREENING SECTION

The tertiary crushing section produces 16mm, 14mm, 10mm, 7mm, 5mm, course dust and fine dust.

Material, of size 45-25mm, is gravity feed through transfer point 8 on the material handling conveyor 11 which feeds directly into the Omnicone crusher. Conveyor 11 is variable speed.

The Omnicone crusher, the tertiary crusher, has a hydraulically adjusted CSS, which is maintained at approximately 16mm. Material that passes through the Omnicone passes through transfer point 10, as 25-2mm material, which delivers material to conveyor 3. It travels along conveyor 3 to transfer point 11. Transfer point 11 contains a fixed gate which delivers material to chute 8 and screen 5 at an approximate percentage mix of 45/55%. 55% of material that travels on conveyor 3 is feed into screen 5. Screen 5 is a double deck screen. The top deck is a 20mm screen, material that flows over the screen, travels into chute 7, through transfer point 15 and back to the surge bin for re-crush. Material that falls through the top deck but over the bottom screen, which is a 3mm screen, travels through chute 8 into screen 6, and material that falls through the bottom deck travels through chute 9 to Bin 4 as the fine dust final product. Screen 6, which is a double deck screen, the top deck being 16mm screen and being feed from screen 5. Material that flows over the top screen, travels through chute 10 and transfer point 15 onto conveyor 6 and back to the surge bin for re crush. Material that falls through the top deck and across the bottom deck, which is a 13mm screen, falls into bin 1,2 and 3 as a 16mm final product. Material that falls through the bottom deck travels through transfer point 12 onto conveyor 4, through transfer point 13 and into screen 7. Screen 7 in a double deck screen, the top deck being an 8mm screen, material that flows across the top of the screen travels through chute 11 into bin 5 and 6 as a 10mm final product. Material that falls through the top deck and flows across the bottom deck, which is 3mm screen, travels through chute 12 into bin 7 as a 5mm final product. Material that falls through the bottom deck falls through chute 13, into bin 8 as a course dust final product.

The tertiary crushed material that is diverted through the fixed gate from conveyor, travels through chute 6, into transfer point 13 and onto conveyor 5. The material travels though transfer point 14 and into screen 8. Screen 8 is a triple deck screen, material that flows across the top of the screen is returned to the surge bin for re crush though: chute 14, transfer point 15, conveyor 6 and chute 22. Material that falls through the top deck, but across the middle deck, travels through chute 15 to bin 9 as a 14mm final product. Material that fell though the middle deck, but across the bottom deck travels through chute 16 to screen 9. Material that fell through the bottom deck moves through chute 21 to bin 10 as fine dust final product. Screen 9 is also a triple deck screen. Material that travels across the top screen moves through chute 17 to bin 13 as a 10mm final product. Material that fell through the top deck and moves across the middle deck is transported through chute 18 to bin 12 as a 7mm final product. Material that fell through the middle deck but moves across the bottom deck, travels through chute 19 to bin 11 as a 5mm final product. Material that falls through the bottom deck, travels through chute 20 to bin 10 as a fine dust final product. Material travelling back to the surge bin for re crush can be diverted into the Barmac through the adjustable gate. The adjustment of the gate which varies the amount of material going into the Barmac, depends on the operating current draw.

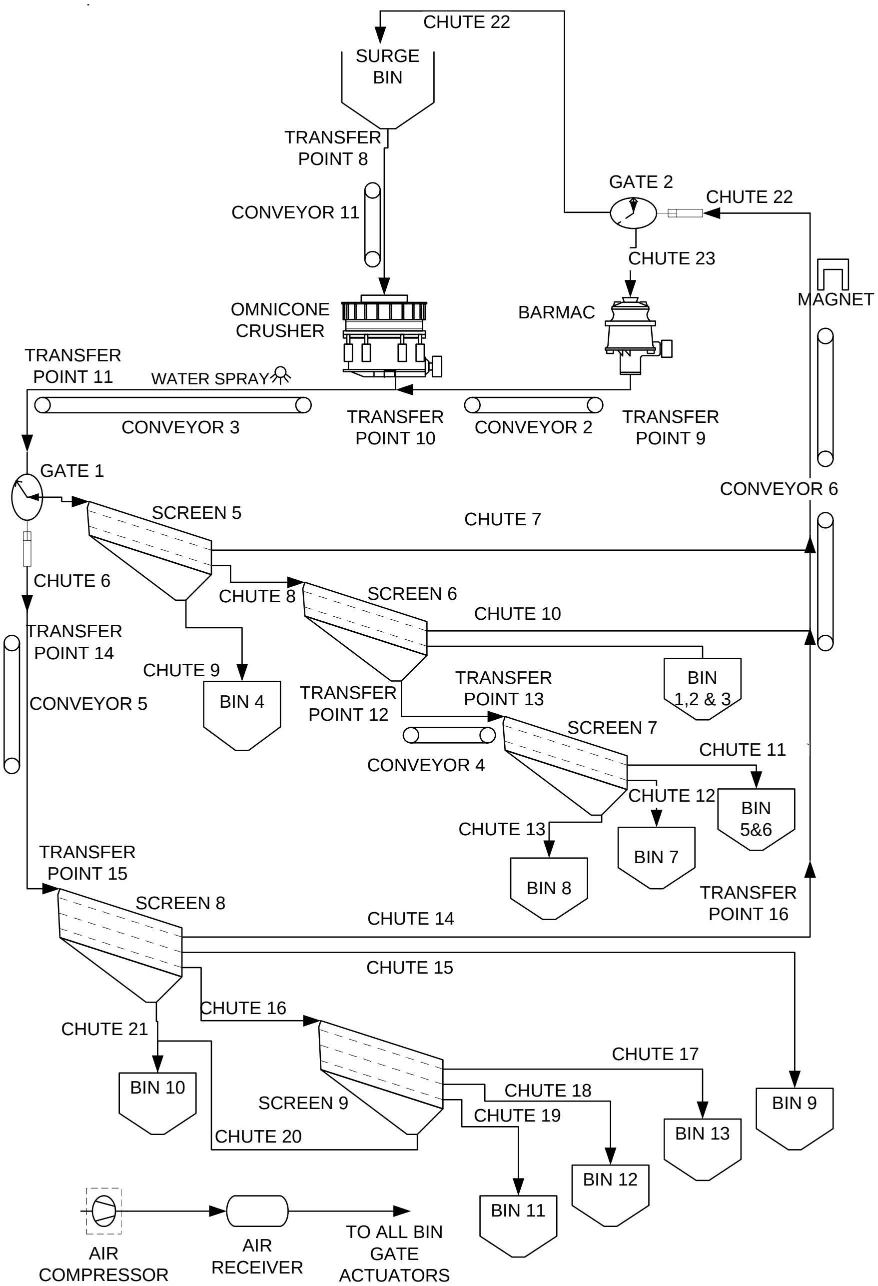


Figure7: Tertiary Process Diagram

Item	Component Description
Raw material	Face rock transported to the plant
Chute 6	Delivers material from the tipping bin to screen 1
Chute 7	Delivers material from screen 1 to the jaw crusher
Chute 8	Delivers material from the bottom deck of screen 3 to the Barmac VSI.

Chute 9	Delivers material that falls through the bottom deck of screen 3 to bin 13
Chute 10	Delivers material that falls through the top deck of screen 4 to bin 16
Chute 11	Delivers material from screen 7 to bin 5 and 6
Chute 12	Delivers material from screen 7 to bin 7
Chute 13	Delivers material from screen 7 to bin 8
Chute 14	Delivers material from screen 6 to transfer point 15
Chute 15	Delivers material from screen 9 to bin 9
Chute 16	Delivers material from screen 8 to screen 9
Chute 17	Delivers material from screen 9 to bin 13
Chute 18	Delivers material from screen 9 to bin 12
Chute 19	Delivers material from screen 9 to bin 11
Chute 20	Delivers material from screen 9 to bin 10
Chute 21	Delivers material from screen 8 to bin 10
Chute 22	Delivers material from conveyor 6 to the surge bin.
Chute 23	Delivers diverted material from conveyor 6 to the Barmac.
Transfer point 8	Transfers material from the surge bin to conveyor 11
Transfer point 9	Transfers material from the output of the Barmac to conveyor 2
Transfer point 10	Transfers material from conveyor 2 to conveyor 3 and also material from the output of the Omnicone crusher to conveyor 3.
Transfer point 11	Transfers material from conveyor 3 to fixed gate 1
Transfer point 12	Transfers material that falls through the bottom deck of screen 6 to conveyor 4
Transfer point 13	Transfers material from conveyor 4 to screen 7
Transfer point 14	Transfers material from chute 6 to conveyor 5
Transfer point 15	Transfers material from conveyor 5 to screen 8
Transfer point 16	Transfers material from chute 14, chute 10 and chute 7 to conveyor 6.
Conveyor 2	Handles material from transfer point 9 to the Jaques cone crusher
Conveyor 3	Handles material from transfer point 10 to transfer point 11
Conveyor 4	Handles material from transfer point 12 to transfer point 13
Conveyor 5	Handles material from transfer point 13 to transfer point 14
Conveyor 6	Handles material from transfer point 15 to the surge bin
Conveyor 11	Handles material from transfer point 8 to transfer to the Omnicone crusher
Omnicone Crusher	Crushes secondary crushed material of size 30-45mm into tertiary crushed material of size 18-

	25mm.
Barmac VSI	Vertical Shaft Impactor (VSI), shapes material of size 25-5mm
Screen 5	Double deck screen, the top deck 20mm screen, and the bottom deck is a 3mm screen
Screen 6	Double deck screen: top deck uses an 18mm screen; bottom deck has 12mm square screens.
Screen 7	Double deck screen: top deck uses an 8mm square, wire, screen; bottom deck has 3mm square screens.
Screen 8	Triple deck screen: top deck uses an 16mm screen; intermediate deck uses a 12mm screen; bottom deck has 3mm square screens.
Screen 9	Triple deck screen: top deck uses an 8mm screen; the intermediate deck uses a 5mm screen; bottom deck has 3mm square screens
Screen 4	Single deck screen, the deck uses 25mm square, wire screens.
Magnet	Permanent magnet placed over the top of the conveyor to remove material contamination
Surge bin	30 tonne surge bin, provides lag time between the primary and tertiary. The surge bin feeds the tertiary section 45-25mm material.
Bin 1,2 and 3	Bin 1, 2 and 3 holds 16mm final product from screen 6
Bin 4	Bin 4 holds fine dust final product material from screen 5.
Bin 5 and 6	Bin 5 and 6 holds 10mm final product material from screen 7.
Bin 7	Bin 7 holds 5mm final product from screen 7
Bin 8	Bin 8 holds fine dust final product from screen 7.
Bin 9	Bin 9 holds 14mm final product from screen 8
Bin 10	Bin 10 holds fine dust from screen 8 and 9
Bin 11	Bin 11 holds 5mm final product from screen 9
Bin 12	Bin 12 holds 7mm final product from screen 9
Bin 13	Bin 13 holds 10mm final product from screen 9
Gate 1	Fixed gate, divides tertiary crushed material between screen 5 and screen 8.
Gate 2	Adjustable gate, allows oversized material to bypass the Barmac or travel back to the surge bin for re crush.
Air system	The air system consists of a: air compressor, air receiver, air lines, pneumatic actuators and electronically controlled directional control valves operated by a wireless activation system.

Table 5: Tertiary System definition

5.3 CHAPTER SUMMARY

The production process has been defined and after researching the plant, it is clear that all machines are on the critical path of the production process. There are no redundancies available. When evaluating the 'Effect of failure' in the FMECA process, as the effect of some failures will cause the plant to stop, the effect is the opposite to the aim of reducing unscheduled downtime, and therefore will be evaluated quite high.

6. MACHINE DEFINITION

From the process diagrams shown in Chapter 5, it can be seen that the following machines make up the crushing and screening plant at Ormeau.

- 1 Pegson jaw crusher, 1100mm x 850mm, as the primary crusher
- 1 900mm Jaques gyratory cone crusher in a secondary configuration
- 1 Nordberg Omnicone gyratory crusher, tertiary configuration
- 1 Barmac Rotopactor Vertical Shaft Impact crusher (VSI) as the quaternary crusher
- 8 Malco 2.4m x 1.2m vibrating screens
- 11 material handling conveyors of different sizes
- Material handling transfer points
- Material handling chutes.
- 16 aggregate storage bins
- Surge bin
- Aggregate bin level sensors.
- Aggregate bin gate opening system
- Aggregate bin truck
- Dust suppression system
- Comp Air hydraulic rock breaker.
- 1 Atlas Copco air compressor.

All of the above machines make up the crushing and screening plant and all lie on the critical path of the production process, meaning that if one of the above machines fails, then all production is lost.

As a step in the FMECA process, it is necessary to define how each machine operates and the systems that are involved in allowing the function to occur.

6.1 PEGSON JAW CRUSHER

The Pegson 1100mm x 850mm jaw crusher is the primary crusher in the process of the Ormeau Crushing and Screening plant. It is referred to as the primary crusher because of its position in the system; it is the first crush in the process. Raw material ranging in size from 90mm to 700mm in diameter is feed into the crusher. The crusher size classification of 1100mm x 850mm is the rectangular feed opening at the top of the crusher.

Raw material which has been screened over a punch plate with 90mm holes in it, meaning anything that will not fit through a hole of a 90mm diameter, is feed into the jaw crusher. The jaw reduces this material by placing it in compression between a fixed jaw face and a moving jaw face also referred to as the swing jaw face. The fixed jaw, which uses a wear liner, is aligned with the swing jaw in a V configuration with the swing jaw which also uses a wear liner. The fixed jaw face is the stationary breaking surface, while the swing jaw exerts the breaking force to the rock. It does this by forcing it against the fixed jaw face. The distance between the fixed jaw face and the moving jaw face at its closest is called the Close Side Setting (CSS); this is relative to the size of rock being outputted, as a rock will remain in the crushing V section until it is small enough to pass through onto the discharge conveyor.

The swing jaw gets its movement profile from the eccentricity of the eccentric shaft. This particular jaw has a 37mm eccentricity. The top of the swing jaw face is connected to the eccentric shaft, through the pitman frame, while the bottom of the swing jaw is held by the toggle plate assembly and the toggle rod assembly which are both hinged to allow movement in the vertical direction and also horizontal direction. The jaw crusher motion is a continuous cycle.

The toggle plate assembly allows the bottom of the pitman to move up and down with the motion of the eccentric shaft as well as provide a protection to the jaw. The toggle plate has a specified strength in compression, if something is feed into the jaw crusher that has compression strength higher than that of the toggle plate, and is bigger than the CSS, then it will bend and allow the foreign object through the jaw opening without causing major damage to the jaw crusher. Details can be viewed at <http://www.aggdesigns.com/Jaw-Crusher-info.htm>

The tension rod assembly includes a rod and spring. It serves the purpose of a tensioning the lower end of the swing jaw to the toggle seats, which are the areas where the toggle plate sits.

Drive to the Jaw crusher is provided through multiple drive V belts driven by an 110KW electric motor. Rotational energy is supplied into the crusher by large flywheels mounted on both sides of the eccentric shaft. The flywheels are not mounted eccentrically; they are mounted on machined centred surfaces.

Lubrication is required daily for the jaw crusher eccentric shaft bearings, this daily greasing is undertaken by the operator at approximately mid day, as through experience it has been found that greasing has been more effective if greased when the bearings are at operating temperature and running at operating speed. (N Bellamy 2009, pers. comm., 01 June.)

The feed material is abrasive and so throughout the life of fixed jaw wear liner and the swing jaw wear liner the CSS is adjusted to maintain a constant output size of rock. This is done by adding shims, into the required position which is behind the toggle block and against the structural frame. This moves the bottom of the swing jaw toward the fixed jaw. Wear liners because of the nip points being at the bottom of the crusher, most of the wear occurs there and so the jaw wear liners can be rotated to give the operator maximum life from the wear liners.

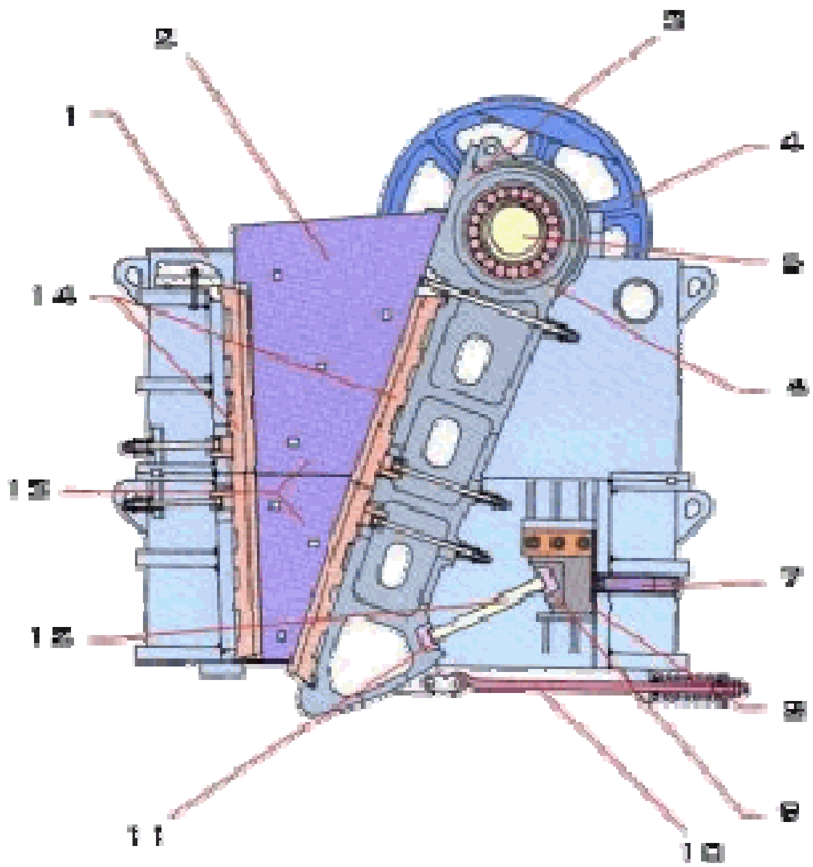


Figure 8: Jaw Crusher Cross sectional Assemblies

<http://www.aggdesigns.com/Jaw-Crusher-info.htm>

No.	Component or Sub System Description
1	Jaw crusher frame
2	Jaw crushing chamber
3	Swing jaw and main bearing housing
4	Jaw crusher flywheel
5	Jaw crusher eccentric shaft
6	Jaw crusher bearings
7	N/A
8	Jaw crusher shim
9	Jaw crusher toggle block
10	Jaw crusher tension rod with spring
11	Jaw crusher toggle seat
12	Jaw crusher toggle plate
13	Jaw crusher cheek plates

Table 6: Jaw Crusher Parts Sheet, reference Figure 8

CRUSHER PROTECTION SYSTEM

There is no protection system for the jaw crusher. It is started on demand and shut down on demand.

6.2 900MM JAQUES GYRATORY CONE CRUSHER

The Jaques Cone crusher at the Ormeau Crushing and Screening plant crushes primary crushed material from the jaw crusher, of feed size of approximately 100mm to 50mm, through the use of an eccentric rotation. The rotation occurs only at the bottom of the main shaft. An 110KW electric motor creates the drive to the eccentric assembly through multiple drive V belts. The eccentric assembly turns at a constant speed, causing the lower end of the main shaft to gyrate. The main shaft is pivoted at the top of the main shaft by the spider bearing. The process is continuous.

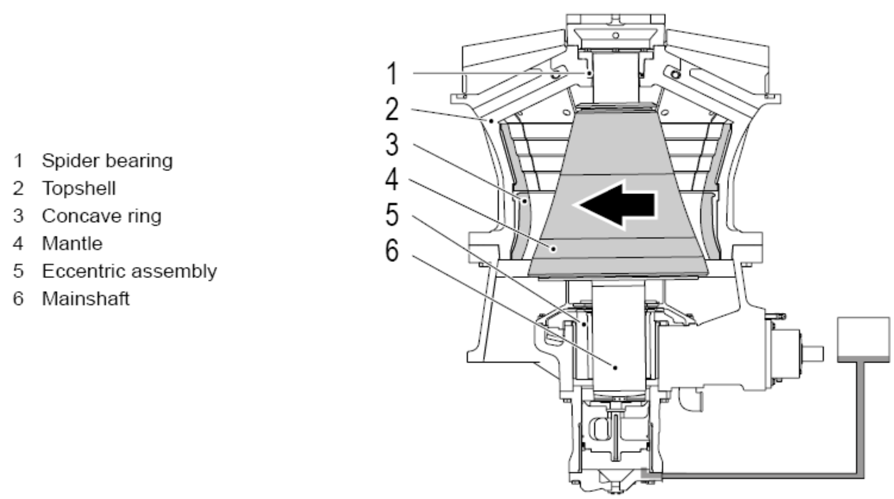


Figure 9: Gyratory Cone Crusher Cross section (Sandvik 2007)

After material has passed through the jaw crusher it is feed into the Jaques gyratory cone crusher, which in the system is called a secondary crusher. Crushing occurs when pressure is applied to material which falls in between the eccentrically rotating main shaft wear liner called the mantle against the fixed wear liners called the concave ring and concaves. Due to the eccentric rotation there is a close side between the mantle wear liner and the concave wear liner, and also an open side. Therefore feed material falls into the crushing chamber and is crushed at the nip points, close side, as the mantle eccentrically rotates around the concave. Some material may fall through the cycle without being crushed on the open side. Material that has passed through the crusher on the open side will be crushed on other cycles. After material, which is now called secondary crushed, falls onto a discharge conveyor and travels to the next stage of the process. (Cox 2008)

The close side distance of the crushing chamber is called the Close Side Setting (CSS). The CSS is the distance from the mantle to the concave at the point where nipping occurs. The larger the CSS, the larger the output rock will be. The CSS can be adjusted and is accomplished by raising or lowering the main shaft assembly. By raising the main shaft assembly, the CSS would decrease. The open side measurement, on the opposite side of the mantle is called the open side setting (OSS). The OSS is equal to the eccentricity plus the CSS. The adjustment is achieved mechanically. The top of the main shaft assembly is threaded, and so by way of turning the suspension nut the height of the main shaft assembly and subsequently the CSS is adjusted.

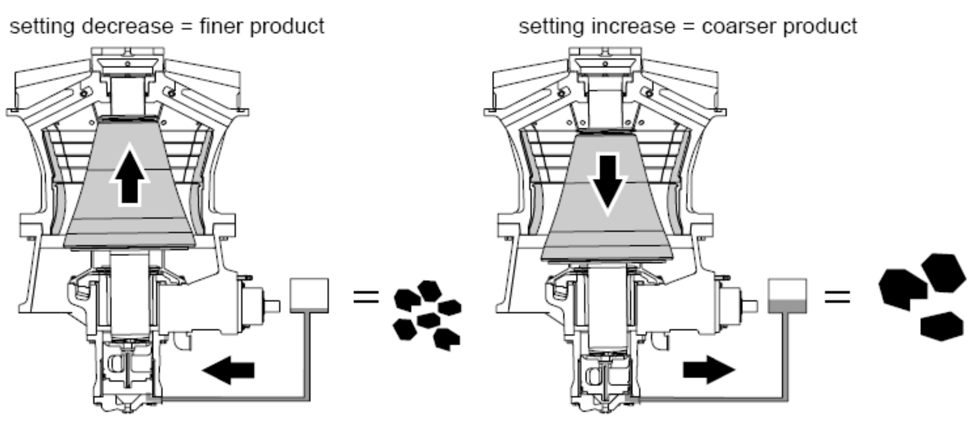


Figure 10: CSS reference output rock size (Sandvik 2007)

As a secondary crusher, it uses a superior mantle and concave, this refers to the shape of these two components. The shape allows for a larger input size of material, while still outputting a well reduced size of rock. This is referred to as the Percentage Reduction. Therefore the percentage reduction of the 900mm Jaques Gyratory Cone Crusher is higher than the tertiary crushing configuration. (N Bellamy 2009, pers. comm., 01 June.)

This particular crusher at Ormeau has been modified from the Original Manufacturers specifications. The crusher is lubricated through one simple system. Oil is transferred from the reservoir by the oil pump. The pump is driven by a speed reducing gearbox which is connected to a 5KW electric motor, instead of being driven directly from the main shaft. Oil then enters a filter, and then through an oil cooler. Oil then enters the crusher through the pinion housing. Oil flows through the pinion housing to the crown wheel and through the eccentric assembly. Oil is then gravity feed through a port in the bottom of the pinion housing back to the reservoir. (Jacques 1957)

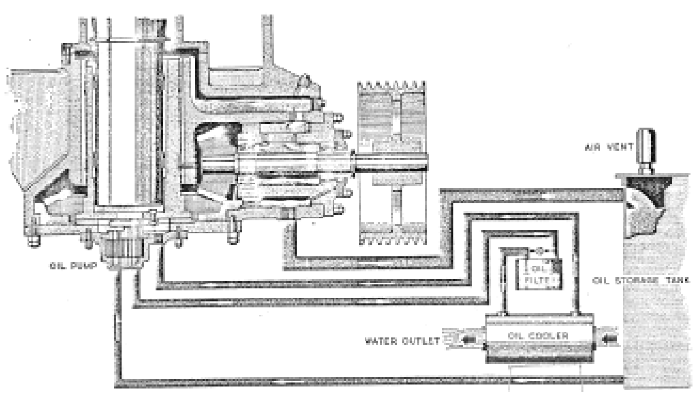


Figure 11: Jaques Cone Crusher oil System (Jacques 1957)

Figure 11 shows the oil flow diagram with the oil flow directions included. Figure11 also shows an oil pump driven from the main shaft, which is in reality modified from the configuration to have an independent electric motor driving the oil pump.

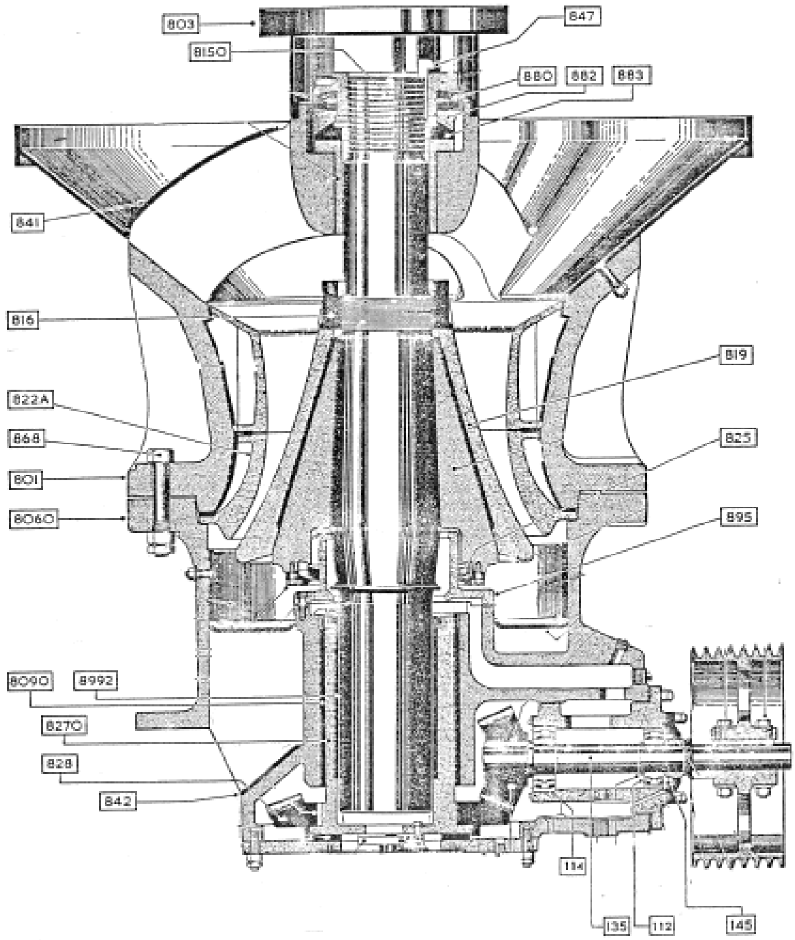


Figure 12: Jaques Cone Crusher Cross Section (Jacqes 1957)

No.	Component or Sub System Description
112&114	Counter shaft(Pinion Shaft) bearings
135	Counter shaft
145	Countershaft oil seal
801	Top shell assembly
803	Spider cap
816	Head nut
819	Mantle wear liner
822	Concave wear liner
825	Dust seal ring
828	Crown wheel gear
841	Spider arm shield
847	Suspension nut assembly
868	Shell mounting bolts
880	Suspension nut assembly
882	Suspension nut assembly
883	Suspension nut assembly
895	Dust seal bonnet
8060	Bottom shell
8090	Eccentric assembly
8150	Main shaft
8270	Eccentric assembly
8992	Eccentric assembly

Table 7: Jaques Cone Crusher Parts List, reference Figure 12

CRUSHER PROTECTION SYSTEM

The crusher is fitted with protection systems. The crusher motor is electrically interlocked, therefore the crusher drive motor will not start until the oil pump has been started and the low oil flow sensor is not reading low oil flow. The low oil flow sensor is located on the return side of the lube system, and so oil circulates the entire system and is returned back to the tank, before the low oil flow sensor does not read. This means that the crusher has sufficient lubrication and can be started. The interlock now allows for the crusher motor to be started. This interlock also works when operating the crusher; if the low oil flow sensor reads low oil flow the crusher motor will stop, as there is a problem. (B Fitzpatrick 2009, pers. comm., 02 June.)

6.3 NORDBERG OMNICONE GYRATORY CONE CRUSHER

The Nordberg Omnicone gyratory cone crusher is the tertiary crusher in the crushing sequence. It crushes secondary crushed and retained material from a 25mm screen of approximate size 45mm – 25mm through the use of an eccentric rotation. The rotation occurs only at the bottom of the main shaft. A 150KW electric motor creates the drive to the eccentric assembly through multiple drive V belts. The Omnicone is different; however still a gyratory crusher, to the Jaques gyratory cone crusher. The Omnicone main shaft assembly is not supported at the top its shaft. The main shaft is driven and supported through the eccentric assembly. The eccentric assembly turns at a constant speed, causing the entire main shaft to gyrate. The process is continuous. (Nordberg 1987)

Gyratory cone crusher principles apply to the Omnicone; see 900mm Jaques gyratory cone crusher

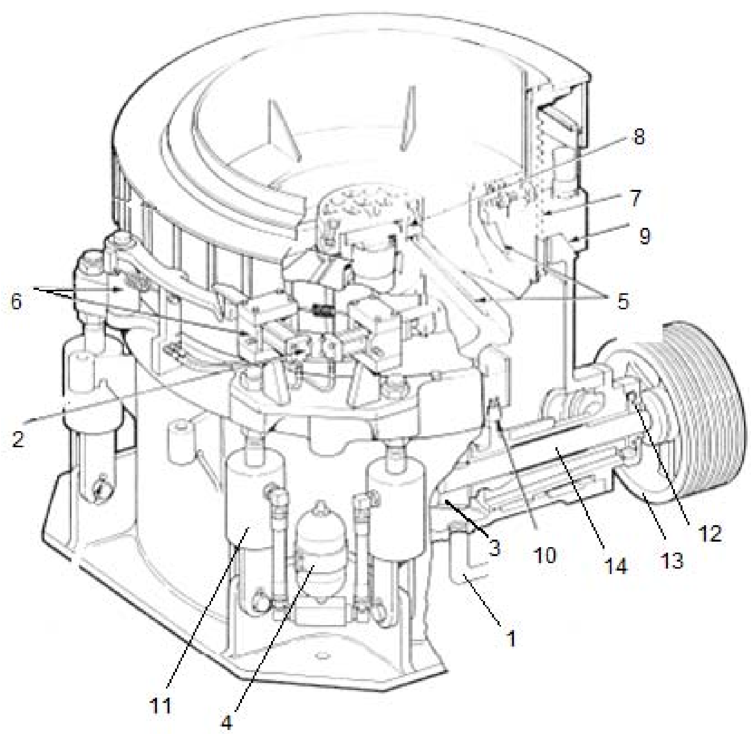


Figure 13: Omnicone Gyratory Cone Crusher Cross Section (Nordberg 1987)

No.	Component or Sub System Description
1	Oil return line
2	Adjustment cylinders
3	Pinion and crown wheel gears
4	Tramp cylinder accumulators
5	Mantle and concave wear liners
6	Concave adjustment locking mechanism
7	Adjustment thread
8	Head nut cover
9	Top shell locking surface
10	Dust seal
11	Tramp cylinders
12	Pinion seal
13	Multi V belt pulley
14	Pinion shaft

Table 8: Omnicone Gyratory Cone Crusher parts sheet, reference figure 13

As a tertiary crusher, the Omnicone uses a tertiary mantle and concave which uses a more blunt profile mantle and concave than a secondary crusher mantle and concave wear liner shape profile. The tertiary mantle and concave shape limits the input size of material. As a tertiary crusher it also operates with a CSS of approximately 15 – 18mm. Due to the tighter CSS and the tertiary profile the material thro put, that amount of processed material is lower than the secondary crusher. (N Bellamy 2009, pers. comm., 01 June.)

The Omnicone has 2 oil systems; a lube system and an adjustment system. The lube system is identical to the Jaques system, oil is transferred from the reservoir by the oil pump. The pump is driven by a speed reducer gearbox which is connected to a 5KW electric motor. Oil then enters a filter, and then through an oil cooler. The oil is forced air cooled, by way of a electric motor driven fan. Oil then enters the crusher through the pinion housing. Oil flows through the pinion housing to the crown wheel and through the eccentric assembly. Oil is then gravity feed through a port in the bottom of the pinion housing and back to the reservoir. (Nordberg 1987)

The adjustment system consists of 2 sub systems. A sub system is called the tramp system. The tramp system holds the clamping ring to the main frame by the use of 4 hydraulic cylinders; they are placed on 90 degree spacing around the crusher body. Oil pressure is maintained in the cylinders to ensure that that top shell of the crushers is held tightly against the mainframe. The tramp release assembly incorporate an accumulator. There is an accumulator for each hold down cylinder; the accumulator is used as a protection. If a metal object is feed into the crusher oil pressure from the hold down cylinders will flow into the accumulators and release the tramp, this will allow the top shell of the crusher to rise and allow the metal object through the crusher without causing major damage. (Nordberg 1987)

The second sub system is for the use of CSS adjustment. As the crusher mantle and concave wear liners wear it must be adjusted to maintain the desired output size rock. To adjust the Omnicone CSS, the tramp system releases the pressure from the hold down cylinders, and by using the directional control valves; oil is directed to the adjusting cylinders. The adjusting cylinders contact the adjusting ring, and lock into the edges. The cylinder continues to extend, pushing the adjusting ring. The adjusting ring is threaded on the inside and as the adjusting ring turns, so does the concave height with the thread. After the adjustment has occurred, the hold down cylinders regain pressure and clamp the clamping ring to the main frame. (Nordberg 1987)

The tramping and adjustment oil system draw oil from the same reservoir, through an electric driven oil pump.

CRUSHER PROTECTION SYSTEMS

The crusher is fitted with a similar protection system as the Jaques crusher. The crusher motor is electrically interlocked, therefore the crusher drive motor will not start until the oil pump has been started and the low oil flow sensor is not reading low oil flow. The low oil flow sensor is located on the return side of the lube system, and so oil circulates the entire system and is returned back to the tank, before the low oil flow sensor does not read. This means that the crusher has sufficient lubrication and can be started. The interlock now allows for the crusher motor to be started. This interlock also works when operating the crusher; if the low oil flow sensor reads low oil flow the crusher motor will stop, as there is a problem. (B Fitzpatrick 2009, pers. comm., 02 June.)

The Omnicone also has a temperature switch incorporated into its protection system. The temperature switch specifications show that the electric motor can not start until the oil is within the range 16 – 70 degrees Celsius. The temperature switch is also used to switch the electric motor ON and OFF for the cooling fan, it switched the fan ON at 40 degrees Celsius. (B Fitzpatrick 2009, pers. comm., 02 June.)

6.4 BARMAC ROTOPACTOR (VSI)

The Barmac Rotopactor Vertical Shaft Impactor (VSI) consists of a feed tube, rotor, crushing chamber, a bearing cartridge and a discharge chute. The rotor is driven through multi drive V belts from a 200KW electric motor. The rotor is spinning at approximately 1040rpm. The Barmac is called a rock ‘Shaper’ and not a rock crusher because the 2 main reduction methods used by the Barmac are attrition by glancing blows with other rocks and abrasion as the rocks interact. Therefore the concept of the Barmac VSI is rock on rock shaping. (Allis Tidco 1988)

The Ormeau Barmac is set up to have two inputs, one from screen 3, of size 25 – 5mm through chute 3, and the other from oversized material returning to the surge bin for re crush, which is diverted into chute 23 by the adjustable gate 2. Therefore, an input material summary is 25 – 5 mm. Once through the Barmac material travels through transfer point 9 to conveyor 2.

The rock is continuously feed into the feed tube of the Barmac, which directs material into the centre of the high speed spinning rotor, which throws the material out, at a speed of 50-85m/s, as a continuous rock stream into the stone lined crushing chamber. The material size reduction comes from the airborne rock on rock interaction and the rock on rock interaction as the rotor accelerated material hits the material build up on the sides of the crushing chamber. The material build in the rotor and the crushing chamber are vital components to the Barmac. The rotor and crushing chamber are lined with wear plates but rely on material build up to protect the system from wear from the high speed material interaction. Material once shaped is deposited through the discharge chutes and onto the conveyor belt. (Allis Tidco 1988)

The rotor is at the centre of the VSI. It is mounted on a bearing cartridge which consists of 2 radial bearings and a trust bearing, with 2 grease seals. The bearing cartridge must be greased daily to the manufactures specifications of 15 grams of grease a day. (Allis Tidco 1988)

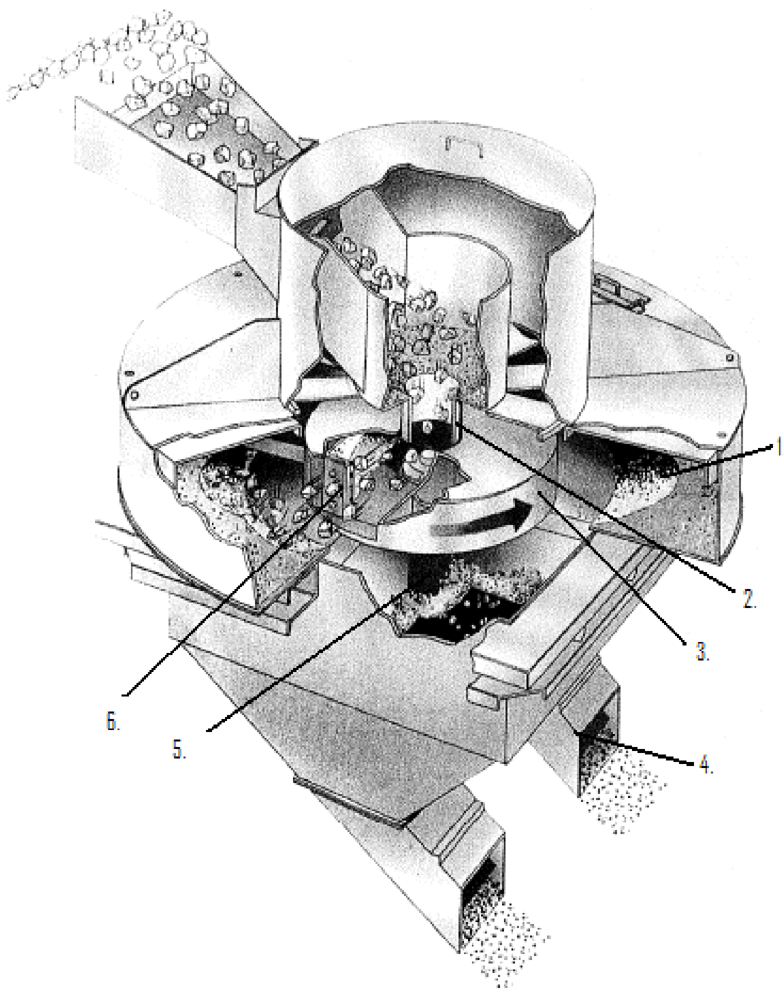


Figure 14: Barmac VSI Cross Section (Allis Tidco 1988)

No.	Component or Sub System Description
1	Crushing chamber
2	Feed Tube
3	Rotor
4	Discharge chute
5	Bearing cartridge
6	Rotor wear plates.

Table 9: Barmac VSI Parts Sheet, see Figure 14

BARMAC PROTECTION SYSTEMS

There are no protection systems for the Barmac systems, it is started and stopped at the demand of the operator

6.5 MALCO VIBRATING SCREENS

The Ormeau plant uses 8 Malco vibrating screens. Vibrating screens are driven by 7.5KW electric motors running at 1040rpm, the speed is reduced through pulley ratios; the drive is transferred to the screen through dual drive V belts. The V belts turn the main shaft of the screen, attached to the shaft is an offset counterweigh. As the screen shaft turns the counterweigh causes a cyclic weight imbalance, and the screen moves in an orbital motion. The orbital motion together with the screen declination angle gives the material 'throw' and causes the material to flow down the screen. The motion is accommodated by the springs which are located on all 4 corners of the screen body. The vertical motion allows for the vital concept of 'Separation' which either causes material to be retained on a screen deck or screened though the screen deck (Malco 1986). The process is continuous except for screen 1, which is turned on and off by the operator to control the amount of material going into the primary jaw crusher.

Screen 1 instead of using a direct drive from the drive V belts uses a fluid coupling. The fluid coupling allows for a soft start and also as a load dampener. Since screen 1 is stop started approximately 30 times in an hour with material on the screen, to not overload the motor, it needs to be soft started and also an amount of drive slippage between the motor and the screen.

The fluid coupling is oil filled. Once the electric motor is started the impeller begins to turn. Oil is thrown outward strikes the vanes of the turbine causing the turbine to rotate. Therefore power is transferred through the fluid between the input and output. The turbine is connected directly to the driver v belt pulleys. The fluid coupling is not to be confused with a torque converter. The difference being the angle of the turbine vanes.

Figure 15: Fluid Coupling Cross Section (Bennett & Norman 2006)

Figure 16: Vibrating Screen General Assembly (Malco 1986)

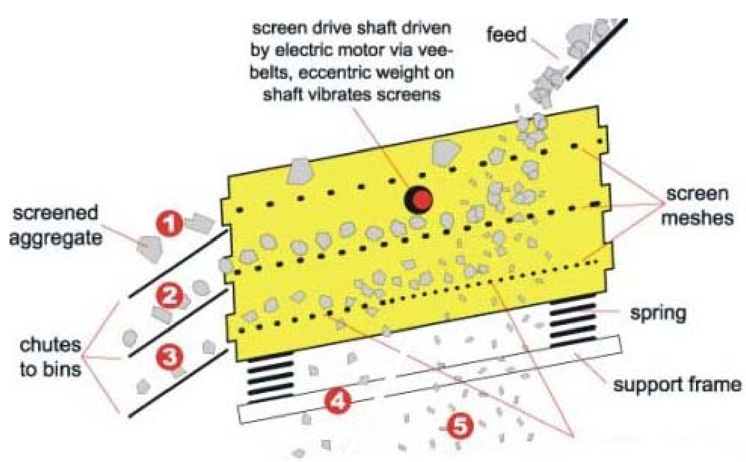


Figure 17: Vibrating Screen Operational. (Malco 1986)

From figure 11 is can be seen how the vibrating screen operates. Material, which consists of a mixture of sizes, is feed into the screen. The mixture of size feed material is vital, as oversized material is needed to hold undersized and near size material close to the screen cloth so that it can be separated and pass through the screen matt. Screening efficiency is affected by many things like: deck motion, speed and throw, frequency of vibration, screen area, retention time, etc. A vibrating screen is generally not 100% efficient in separating materials. (N Bellamy 2009, pers. comm., 01 June.)

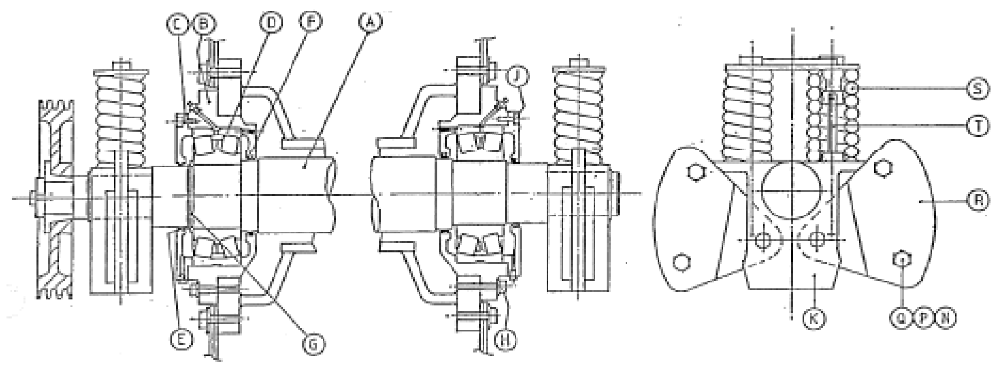


Figure 18: Vibrating Screen Cross Section (Malco 1986)

No.	Component or Sub System Description
A	Shaft
B-J	Bearing assembly, which consists of the bearings, bearing retainers, and fasteners
K	Counterweight hub
M-Q	Fasteners
R	Counter weight segment
S	Counterweight spring
T	Connector bar – N/A

Table 10: Vibrating Screen Parts, reference Figure 18

VIBRATING SCREENS PROTECTION SYSTEMS

There are no protection systems for the vibrating screens that will switch the electric motor off in the event of a failure, but each of the screens are connected to a sequence interlock switch. The sequence interlock switch will not let a component start if the screen or conveyor further down the production process is not running first. The advantage of this is that a component that is not running will not be filled with material. Once the component gets filled with material, it must be removed by hand. (B Fitzpatrick 2009, pers. comm., 02 June.)

6.6 MATERIAL HANDLING CONVEYORS

Material handling conveyors are used throughout the plant. They are of different sizes, inclines, declines, handle different amounts and sizes of material, and run at different speeds. The conveyor systems used in the Ormeau plant utilize the same components.

The conveyor belts used in the Ormeau plant are large rubber bands stretched between 2 pulleys, one called the head drum which is where the conveyor discharges is, and the other being the tail drum, which is where the loading occurs. They travel at a consistent speed. The belt is supported between the head and tail drums by the use of trough rollers. The trough rollers are a system of 3 rollers, 1 in the middle of the belt which is flat and the side 2 which are set up an angle of 30 degrees. This angle is used to increase the capacity of the belt. The bottom of the conveyor belt, or the return side, is supported with return rollers which are flat. Drive to the conveyor is provided at the head of the conveyor through an electric motor coupled through the use of v belts to a speed reduction gear box. The size of the electric motor and the ratio of the gearbox vary depending on weight carried and the operating angle of the conveyor. (Swinderman, Goldbeck, Marti 2002)

Tension is provided to the conveyor belt through mechanical means. Threaded rods attached to the tail drum, which when adjusted apply tension to the belt. This system is also used to align the belt, and allow it to run straight between the trough rollers.

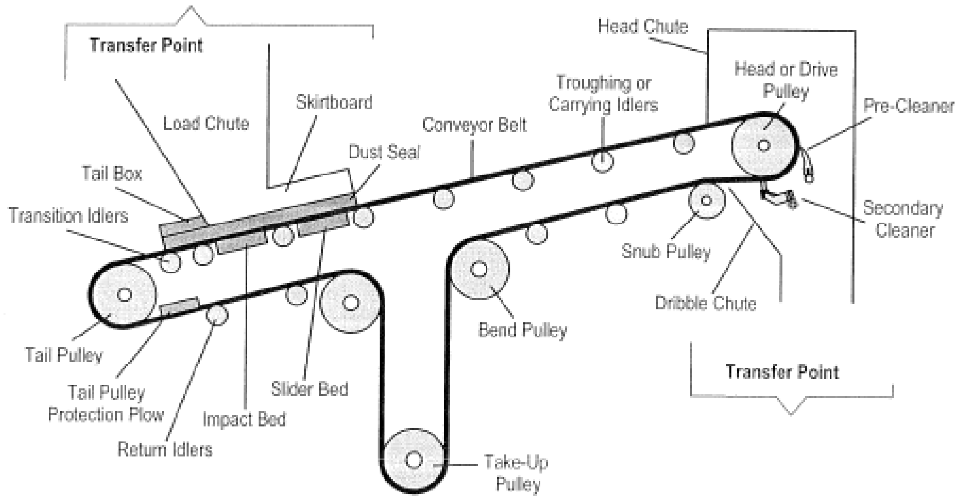


Figure 19: Conveyor General Arrangement (Swinderman, Goldbeck, Marti 2002)

Ancillary components are used to clean the belt like: belt scrappers, and tail pulley plow scrappers. Belt scrappers, scrap the outside of the belt and are positioned so that the scrapings go with the flow of material. Pulley plow scrappers are located at the tail drum, on the inside of the belt, with a function to scrap material from the belt and direct it off the edges of the belt so that it does not run in between the tail pulley and the belt and potentially cause damage.

MATERIAL HANDLING CONVEYOR PROTECTION SYSTEMS

Like vibrating screens there are no protection systems for the conveyors that will switch the electric motor off in the event of a failure, but each of the conveyors are connected to a sequence interlock switch. **Refer:** Vibrating screens protection systems for details of the sequence interlock.

6.7 MATERIAL HANDLING TRANSFER POINTS

Material handling transfer points transfer material off of material handling conveyor belts and onto another conveyor belt. They consist of a delivery chute which directs material off the preceding conveyor and onto the next conveyor belt. Transfer points also seal the delivery chute to the loading zone of the next conveyor belt through the use of rubber dust seals which are adjustable and must make good contact with the conveyor belt to ensure that the material stays on the belt. Refer to figure 18 to observe the load chute, skirt board and dust seal configurations. (Swinderman, Goldbeck, Marti 2002)

Transfer points are lined with sacrificial wear liners made of high grade steel, and must be replaced when the wear plate is becoming thin enough that they do not do their intended job.

Transfer points are also prone to blockages due to material build up.

MATERIAL HANDLING TRANSFER POINT PROTECTION SYSTEMS

There are no protection systems for material handling transfer points. In the event of a blockage, it is up to the operator to visually see the overflowing material.

6.8 MATERIAL HANDLING CHUTES

Material handling chute direct material into components like aggregate storage bins, the surge bin, the Barmac. Chutes do not deliver material onto conveyors, but can direct material away from conveyors and screens. Chutes are lined with sacrificial wear liners. (Swinderman, Goldbeck, Marti 2002)

MATERIAL HANDLING CHUTE PROTECTION SYSTEMS

There are no protection systems for material handling chutes. In the event of a blockage, it is up to the operator to visually see the overflowing material.

6.9 AGGREGATE STORAGE BINS

The Ormeau plant has 16 storage bins. The bins are delivered final product aggregates and hold them until the material is emptied by the bin truck operator. The storage bins are lined with a sacrificial wear liners made of high grade steel. The bins also use a bin gate, which is a 2 gate system, geared together and rotate on bearings.

AGGREGATE STORAGE BIN PROTECTION SYSTEMS

The protection system for the aggregate storage bins to protect against material overflow is the bin level switch system.

6.10 SURGE BIN

The surge bin temporarily holds secondary crusher material. The surge bin feeds conveyor 11 through transfer point 8 which travels directly to the Omnicone for tertiary crushing. The surge bin is lined with a sacrificial wear liner made of high grade steel.

SURGE BIN PROTECTION SYSTEMS

There are no protection systems for the surge bin.

6.11 TIPPING BIN

The tipping bin is the transfer point between the load and haul and the crushing plant. It is a live tipping bin, meaning that it has a steep floor that gravity feeds material into the plant. It is lined with sacrificial wear liners.

TIPPING BIN PROTECTION SYSTEMS

There are no protection systems for the tipping bin.

6.12 AGGREGATE BIN LEVEL SENSOR

Each aggregate bin has a bin level sensor. The sensor is called a ‘Tilt Switch’, which as the material level inside the bin rises, it eventually raises enough to build up under the level sensor which tilts the switch and connect the circuit. The circuit is connect to an indicator light, which lets the bin truck operator know that the bin is full and needs to be emptied. (B Fitzpatrick 2009, pers. comm., 02 June.)

AGGREGATE BIN LEVEL SENSOR PROTECTION SYSTEM

There is no protection system for the aggregate bin level system.

6.13 AGGRGATE STORAGE BIN GATE OPENING SYSTEM

The aggregate storage bins must be emptied constantly as they fill up. The capacity of the bins are 28 tonnes each. The bin gate opening system is a wireless system that operates the directional control valves for each separate bin, which then opens the bin gate actuator. The advantage of the wireless system is that the bin truck operator does not need to stop and vacate the truck to open bin gates. When a particular bin is full the bin truck operator places the bin truck body under the bin gate, they then select the bin that they wish to empty on the transmitter mounted in the truck, they send the signal to open the bin to the receiver and the receiver operates the directional control valve which sends air to the selected pneumatic cylinder, which opens the gate. (B Fitzpatrick 2009, pers. comm., 02 June.)

AGGREGATE BIN GATE OPENING SYSTEM PROTECTION SYSTEM

There is no protection system for the bin gate system.

6.14 THE AGGREGATE BIN TRUCK

The aggregate bin truck empties the aggregate bins. The bin trucks continuously empty the aggregate bins. The bin trucks are 12 tonne body trucks and are only serviceable by trained personnel. Due to the plant capacity, one bin truck is needed to service all bins.

BIN TRUCK PROTECTION SYSTEM

The bin truck has protection systems in the way of engine management systems, but are unserviceable by BORAL staff.

6.15 DUST SUPPRESION SYSTEM

The dust suppression system uses a water pump to draw water from a storage dam through a filter to a storage tank located at the crushing plant. Another water pump draws water from the storage tank though a filter, and delivers the water to a manifold located at the plant control room. The manifold is operated by the plant operator, who can turn water on to different parts of the plant as needed to keep the airborne dust contaminates to a minimum

DUST SUPPRESSION PROTECTION SYSTEM

There is no protection system for the dust suppression system

6.16 COMP AIR ROCK BREAKER

The Comp air rock breaker is a hydraulic impactor. It is used to dislodge or break large rocks that fall awkwardly into the jaw and jam, or are simply too big to go through. The rock breaker is boom mounted and is situated beside the jaw crusher. When the Jaw becomes blocked, the plant operator will operate the rock breaker and free the Jaw input.

The rock breaker uses a simple hydraulic circuit; an open centre system, with the hydraulic pump connected to an electric motor, the oil flows through a filter to the directional control valves, and back through an oil cooler and to tank. The direction control valves are lever actuated. The system is not running constantly, it is only turned on when needed.

COMP AIR ROCK BREAKER PROTECTION SYSTEM

There is no protection system for the rock breaker.

6.17 ATLAS COPCO AIR COMPRESSOR

The air compressor supplies the plant with air. The system has 3 air receivers, 2 remote mounted on the plant to service the bin gate actuators for faster operation. The air compressor is a complete unit and is unserviceable by untrained personnel.

6.18 AS/NZ 3000 AND AS3007

Under the Australian standard, AS/NZ 3000 AND AS3007, electrical systems used throughout the plant, are only serviceable by trained, qualified electricians and this is definitely the case at the Ormeau site. (IQA 2009)

Also under AS/NZ 3000 and AS3007, all electrical components must be fitted with current overload switches, which must be matched to each system separately, and the trip time for the overload must be no greater than 30ms. The main function of both of these devices is the safety factor, but it also acts as a protection system. Other objectives of AS/NZ3000 is the prevention of electric shock, prevention of excess temperatures, and the prevention of explosions. Other objectives set by AS3007 is the guarding principles. The Electrician that is contracted to work on the Ormeau plant is fully aware of all standards, and has shown this in a tender evaluation process to win the job. (IQA 2009)

6.19 CHAPTER SUMMARY

In previous chapters the critical path of the plant was determined, and found it to be all machines used in the crushing and screening process. This chapter outlined the parts involved and the how each machine operates. It identified any protection systems currently in use.

7. DEVELOPMENT OF FUNCTIONAL DIAGRAMS

Functional diagrams were developed to show the functional breakdown of elements in the system and sub systems, they provide technical understanding; show any series, superfluous relationships.

Once the assembly, or system interactions are known, it will be possible to understand which components may fail, and stop the overall machine which will stop the plant, as it was discovered in production process study, or which components may fail and still allow the machine to continue operation. This information is important to the FMECA process, as it will directly relate to the 'Effect of a failure'.

7.1 FUNCTIONAL DIAGRAMS

To assist in the analysis of the crushing and screening plant, functional diagrams were constructed. All machines that were considered in chapter 9 will be analysed.

The functional diagrams will be used to show the interactions of the systems and sub systems together with the various sub assemblies. To make sure that the functional diagrams remain concise, sub-assemblies have been used. The sub assemblies have been detailed in the tables to show which components are included in the assemblies.

Within each system and sub system, different interactions occur. Within the functional diagrams these interaction will be modeled. The different interactions will be categorized into: structural support, wear protection, lubricant supply, and power transmission (Mechanical/electrical/hydraulic). This interaction will be shown in the legend below.

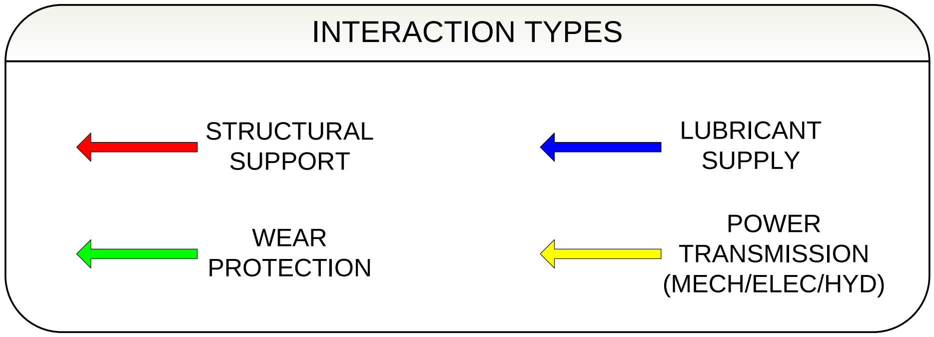


Figure 20: Interaction types used in functional diagrams (By Author)

The top down approach will be utilised for the construction of the functional diagrams. The top down approach has the systems that are directly responsible for fulfilling the primary function of the machine at the top of the functional diagram. From the top of the functional diagram the systems and their interactions are detailed down the diagram. To ensure that the functional diagram dependencies are understood correctly the following example interaction is shown below. (Cox 2008)

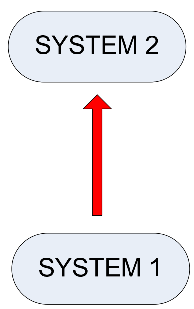


Figure 21: Example System Dependency

From figure 20 it can be seen that system 2 depends on system 1 for structural support and that system 2 is more responsible for fulfilling the machines primary function as it is at the top of the diagram.

7.1.1 PEGSON JAW CRUSHER

The primary function of the Jaw crusher is to reduce the size of the feed material to a size that can be feed into the secondary crusher

<http://www.aggdesigns.com/Jaw-Crusher-info.htm>. At the top of the functional diagram is the fixed jaw wear liner and the swing jaw wear liner. The fixed jaw relies on the structural backing frame to give a solid crushing surface, and the fixed jaw wear liner is held in place by bolts. The swing jaw wear liner is attached to the structural frame, and held in place by bolts, which is driven by the eccentric shaft. The eccentric shaft gives the motion to create nip points for crushing to occur. The lower end of the swing jaw relies on the toggle system for its movement, rigidity and adjustment. Continuous drive motion is provided through the electric motor, V belts, and momentum is conserved by the large flywheels which are mounted on either side of the parallel shaft. See figure 8.

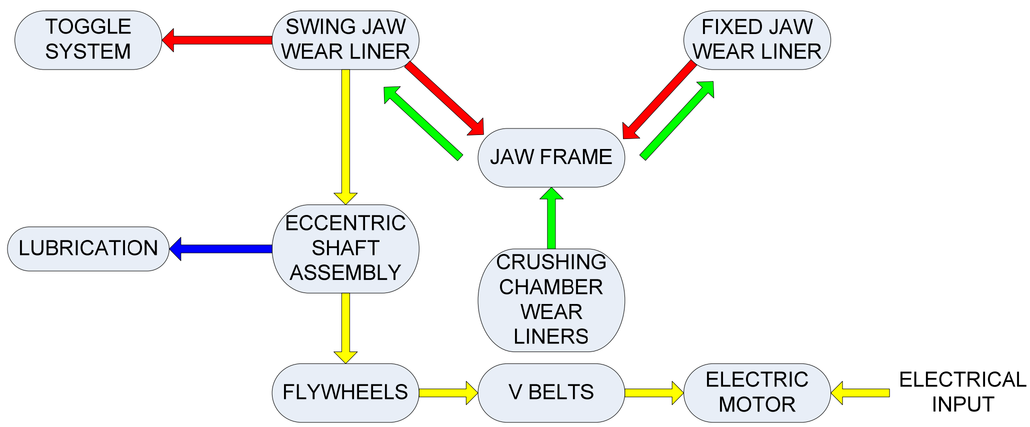


Figure 22: Flow diagram for Jaw Crusher (By author)

Component or Sub System Description
Swing jaw liner
Fixed jaw liner
Jaw frame which includes: Fixed jaw pad, swing jaw pad, structural frame, and wear liner mounting bolts.
Crushing chamber wear liners, also called cheek plates and mounting bolts
Toggle assembly, which consists of :Jaw crusher toggle block, tension rod with spring, toggle plate and toggle seats
Eccentric shaft assembly which includes: eccentric shaft, shaft bearings, eccentric bushing.
Flywheels which includes: pulley and flywheel and mounting bolts.
V belts: 6 belt system
Electric motor: 110KW

Table 11: Jaw Crusher Sub Assembly Details, reference Figure 22

MACHINE SUMMARY

The jaw crusher uses the fixed and swing jaw wear liners to perform its primary function of reducing the input size of rock. Continuous movement is provided to the swing jaw wear liner through the eccentric shaft, which is driven by V belts and an electric motor.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, the parts sheet, and the operation of the Jaw Crusher, that all components all vital to the running of the entire machine, and further more the plant. The system can finish a shift with slight defects for example: 1 V belt broken, slight wear liner mounting problems, or slight framing cracks, with constant monitoring and full repairs to take place in a planned manner.

7.1.2 900MM JAQUES GYRATORY CONE CRUSHER

The primary function of a cone crusher is to reduce the size of the feed material to a desired range of output sizes through compression of the material (Jacques 1957). This function is performed by the mantle and concave wear liners which are shown at the top of the functional diagram. The mantle is connected to the main shaft, which creates nip points through the eccentric assembly which is driven by the input shaft (Pinion shaft). The pinion shaft cartridge is driven by the electric motor through multi drive V belts.

The concave is supported structurally by the top shell which is mounted on the bottom shell. The main shaft is also supported structurally by the top shell and the suspension nut assembly, which can be adjusted to give the desired CSS.

Lubrication is supplied to the pinion and eccentric assembly through an electric driven oil pump. The heat exchanger is also in series with the lube oil and requires a flow of water which is gained by an electric motor driven water pump.

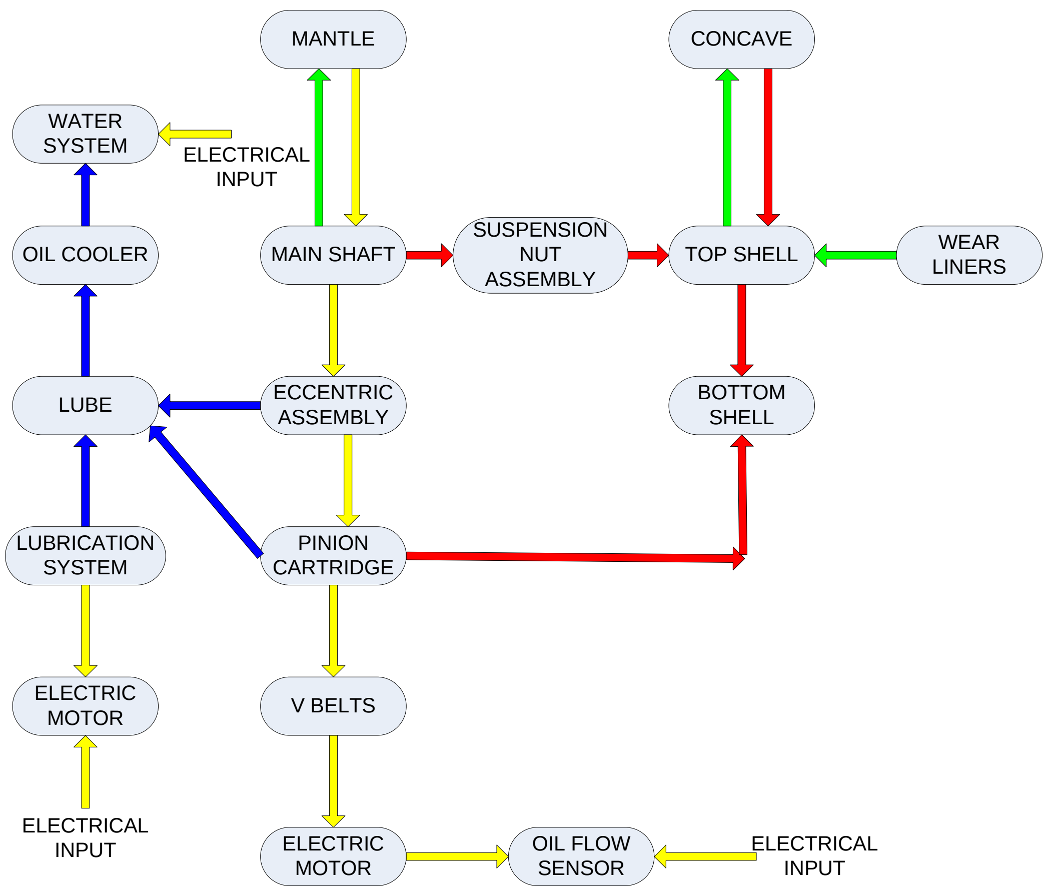


Figure 23: Flow diagram for Jaques Gyratory Cone Crusher.

Component or Sub System Description
Mantle - wear liner
Concave - Wear liner
Main shaft
Eccentric assembly which includes: eccentric bushing, eccentric casing, crown wheel gear (gear train).
Pinion cartridge which includes: pinion gear and shaft, pinion bearings and pinion shaft seal.
V Belts: 6 belt system
Electric motor: 110KW
Oil Flow sensor.
Top shell
Bottom shell
Suspension nut assembly
Wear liners
Lube:
Oil cooler: which consists of a heat exchanger
Water system which consists of a water pump, storage tank, 5KW electric motor, and water lines.
Lubrication system which consists of: oil pump, drive coupling oil filter, reservoir, oil lines
Electric motor for the oil pump drive: 5KW

Table 12: Jaques Cone Crusher Sub Assemblies Detail, reference Figure 23

MACHINE SUMMARY

The Jaques gyratory cone crusher uses the mantle and concave wear liners to perform its primary function of reducing the input size of rock. Continuous movement is provided to the main shaft wear liner through the eccentric assembly which is driven by V belt and an electric motor.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, the parts sheet, and the operation of the Jaques Cone Crusher, that all components are all vital to the running of the entire machine, and further more the plant. The system can finish a shift with slight defects for example: 1 V belt broken, slight lube oil leaks, and slight cooling water leaks, with constant monitoring and full repairs to take place in a planned manner.

7.1.3 NORDBERG OMNICONE GYRATORY CONE CRUSHER

The primary function of the Omnicone, like the Jaques gyratory crusher, is to further reduce the size of the feed rock to a desired rock size through fracturing the material (Nordberg 1987). Again like the Jaques this function is performed through the mantle and concave, with the gyration caused by the eccentric assembly, which produces it movement through the pinion shaft, V belts and an electric motor. Structurally the concave is supported by the bowl, which is supported by the adjustment assembly and held in place by the tramp release system. The tramp release system relies on an electric motor driven oil pump. The tramp release system relies on the bottom shell for structural support.

Lubrication is supplied through the lube pump, which driven through a speed reducer and an electric motor. Oil is cooled by a fan cooled oil cooler. The fan is driven by an electric motor.

The CSS adjustment relies on the adjustment system, which is supplied oil flow by the same oil pump as the tramp release system.

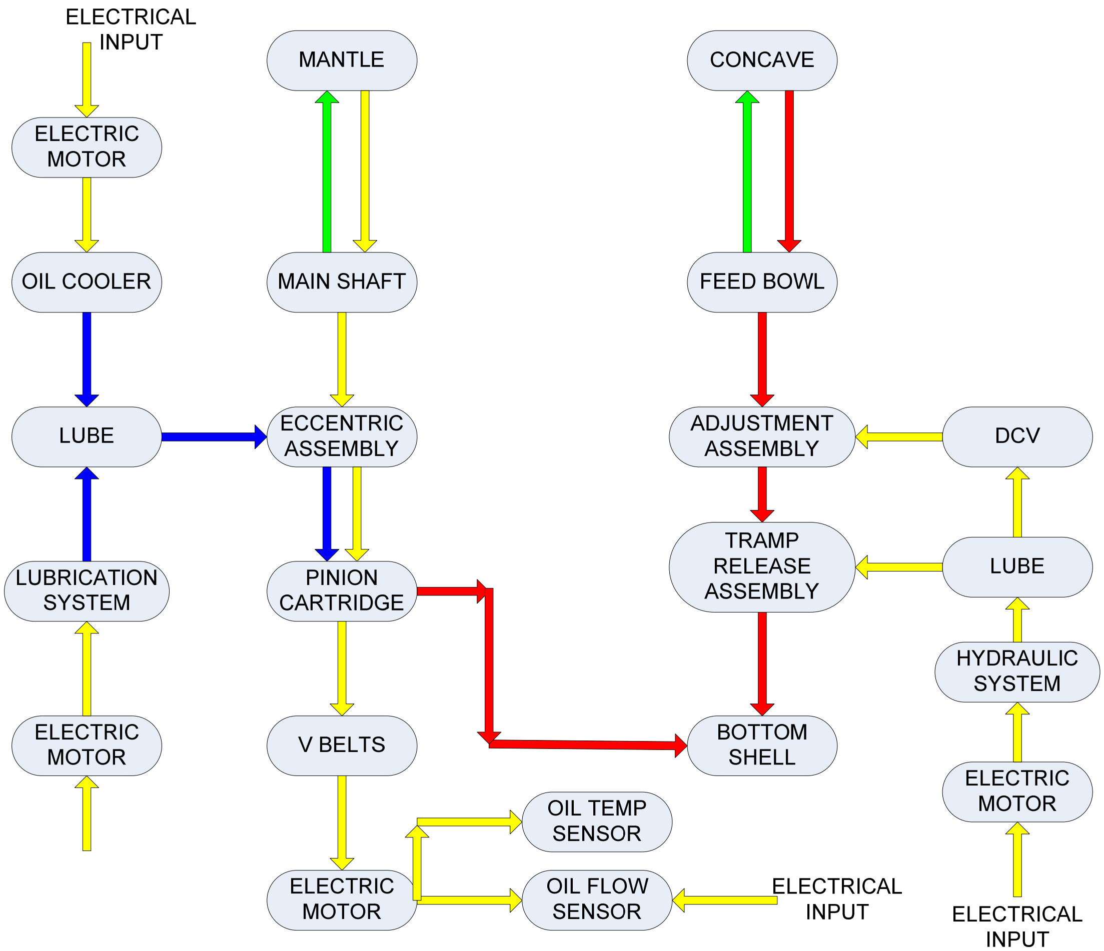


Figure 24: Flow diagram for Omnicone Gyratory Cone Crusher.

Component or Sub System Description
Mantle - wear liner
Concave - Wear liner
Main shaft
Eccentric assembly which includes: eccentric bushing, eccentric casing, crown wheel gear.
Pinion cartridge which includes: pinion gear and shaft, and pinion bearings.
V Belts: 6 belt system
Electric motor: 150KW
Oil Flow sensor: normally open switch, closes after oil flow
Oil temp sensor; closed between the temperatures 16 to 70 degrees Celsius.
Lubrication system which consists of: oil pump, speed reducer gear box, oil filter, reservoir, oil lines
Electric motor for the lube oil pump drive: 5KW
Oil cooler: which consists of a heat exchanger.
Electric motor: an electric motor to drive the fan: 5KW
Feed bowl
Bottom shell
Adjustment assembly which consists of: an adjustment ring, adjusting cylinders and oil lines.
Tramp release assembly which consists of: tramp cylinders, accumulators, oil lines and clamping edge.
DCV: directional control valve.
Lube: hydraulic oil
Hydraulic system which consists of: hydraulic pump, and oil lines.
Electric motor to drive the hydraulic pump: 5KW

Table 13: Omnicone Sub Assemblies Detail, reference Figure 24

MACHINE SUMMARY

The Omnicone gyratory cone crusher uses the mantle and concave wear liners to perform its primary function of reducing the input size of rock. Continuous movement is provided to the main shaft wear liner through the eccentric assembly which is driven by V belt and an electric motor. Adjustment of the CSS is provided through hydraulic cylinders which turn a large thread, which raises or lowers the concave.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, the parts sheet, and the operation of the Omnicone Crusher, that all components are all vital to the running of the entire machine, and further more the plant. The system can finish a shift with slight defects for example: 1 V belt broken, slight lube oil leaks, with constant monitoring and full repairs to take place in a planned manner. The system can operate if the hydraulic adjusting system has failed for a period of time, the failure scope being that the CSS cannot be adjusted. The period being approximately 1-2 shifts, as the plant become inefficient to run if the Omnicone CSS is too large, as the output rock size is mostly being return for further crushing cycles.

7.1.4 BARMAC ROTOPACTOR (VSI)

The primary function of the Barmac Rotopactor VSI is to shape the rock and to further reduce the size of the feed material (Allis Tidco 1988). The component that gives the rock its motion to reduce its size is the Rotor, this is shown at the top of the functional diagram. The rotor is supported by the bearing cartridge, which also allows the rotor to spin. The bearing cartridge relies on lubrication. Drive to the bearing cartridge is provided through multiple drive V belts and an electric motor. Structurally the bearing cartridge is supported by the Barmac frame. The Barmac rotor and internal body relies on wear plates to protect the components from unnecessary wear.

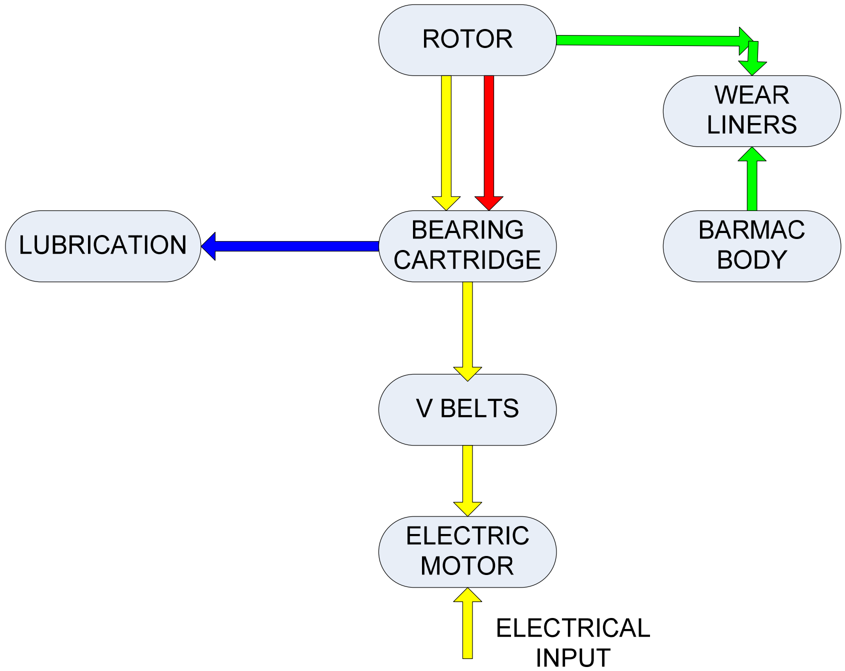


Figure 25: Functional Diagram For Barmac VSI

Component or Sub System Description
Rotor.
Bearing cartridge which consists of: 2 radial bearings and a thrust bearing.
V belts: 6 Belt drive system
Electric motor: 200KW
Lubrication: EP2 grease
Barmac body:
Wear liners: Which line the rotor and the internal Barmac body

Table 14: Barmac Sub Assemblies Detail, reference Figure 25

MACHINE SUMMARY

The Barmac Rotopactor VSI uses the rotor to perform its primary function of reducing the input size of rock. Continuous movement is provided to the rotor through the bearing cartridge which is driven by V belts and an electric motor.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, the parts sheet, and the operation of the Barmac VSI, that all components are all vital to the running of the entire machine, and further more the plant. The system can finish a shift with slight defects for example: 1 V belt broken, small vibrations, wear plate deficiencies with constant monitoring and full repairs to take place in a planned manner.

7.1.5 MALCO VIBRATING SCREENS

The primary function of the 8 Malco vibrating screens is the separate feed rock into different sizes (Malco 1986). This function is primarily performed by the screen cloths, which are shown at the top of the function diagram. The screen cloths are structurally supported by the screen body and are held in place by side rails and side rail bolts. The screens cloths also primarily rely on the counterweights and springs for the screen vibration. The vibration system relies on rotation which is provided through the main shaft which is mounted on bearings. These bearings rely on regular lubrication. The shaft is driven through V belts and an electric motor.

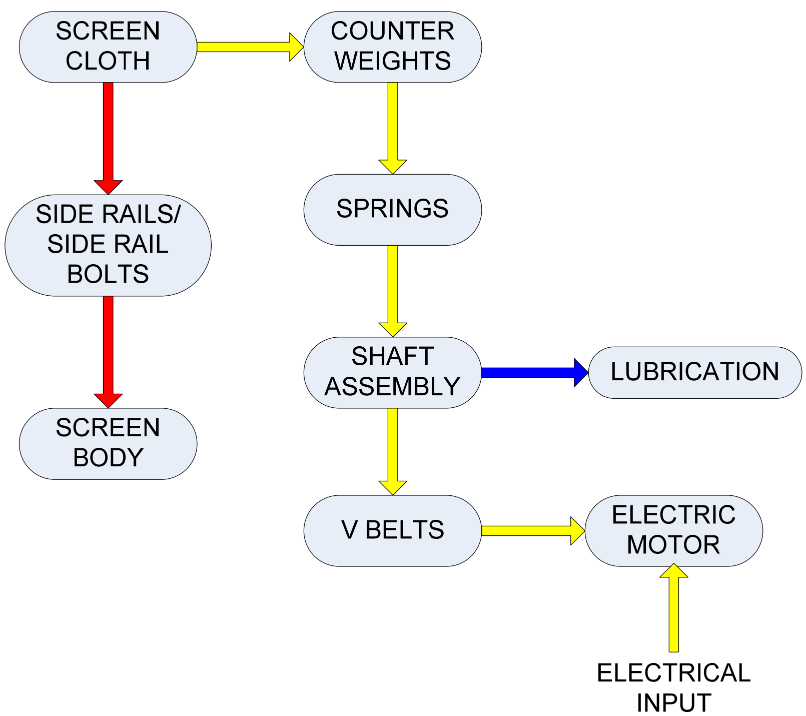


Figure 26: Functional Diagram For Malco Vibrating Screens

Component or Sub System Description
Screen cloth: screens of different sizes to separate the material
Side rails and side rail bolts: hold screens cloths in place to the screen body
Screen body:
Counter weights: vibration component
Springs: vibration component
Shaft assembly: which consists of the shaft, bearings and bearing cartridges.
Lubrication: EP2 grease.
V belts: 2 belt system
Electric motor: 7.5 KW

Table 15: Vibrating Screen Sub Assemblies Detail, reference Figure 26

MACHINE SUMMARY

The Malco vibrating screen uses the screen cloths to perform its primary function of separating material into different sizes. The counterweights which are mounted on the main shaft, together with the springs which are located on all 4 corners cause the screen body to vibrate. Continuous movement is provided to the main shaft through the bearing cartridge which is driven by V belt and an electric motor.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, the parts sheet, and the operation of the vibrating screens, that all components are all vital to the running of the entire machine, and further more the plant. The system can finish a shift with slight defects for example: 1 V belt broken, and small body cracks with constant monitoring and full repairs to take place in a planned manner.

7.1.6 MATERIAL HANDLING CONVEYORS

The primary function of a material handling conveyor is to move material over distances and up inclines or down declines. This function is carried out by the conveyor belt. The v shape given to the conveyor belt so that it holds material without spillage is provided by the trough rollers (IQA 2009). The motion of the conveyor belt is provided through a speed reducer which is connected to the head drum roller, which is supported by bearings. The speed reducer is driven through V belts and an electric motor. The tail end of the conveyor belt is also supported by a tail drum roller, which is supported by bearings. The conveyor belt alignment is provided by the tail drum roller allowing for adjustment. Conveyor belt tracking is also effected by return rollers.

The conveyor belt and all supporting components rely structurally on a frame.

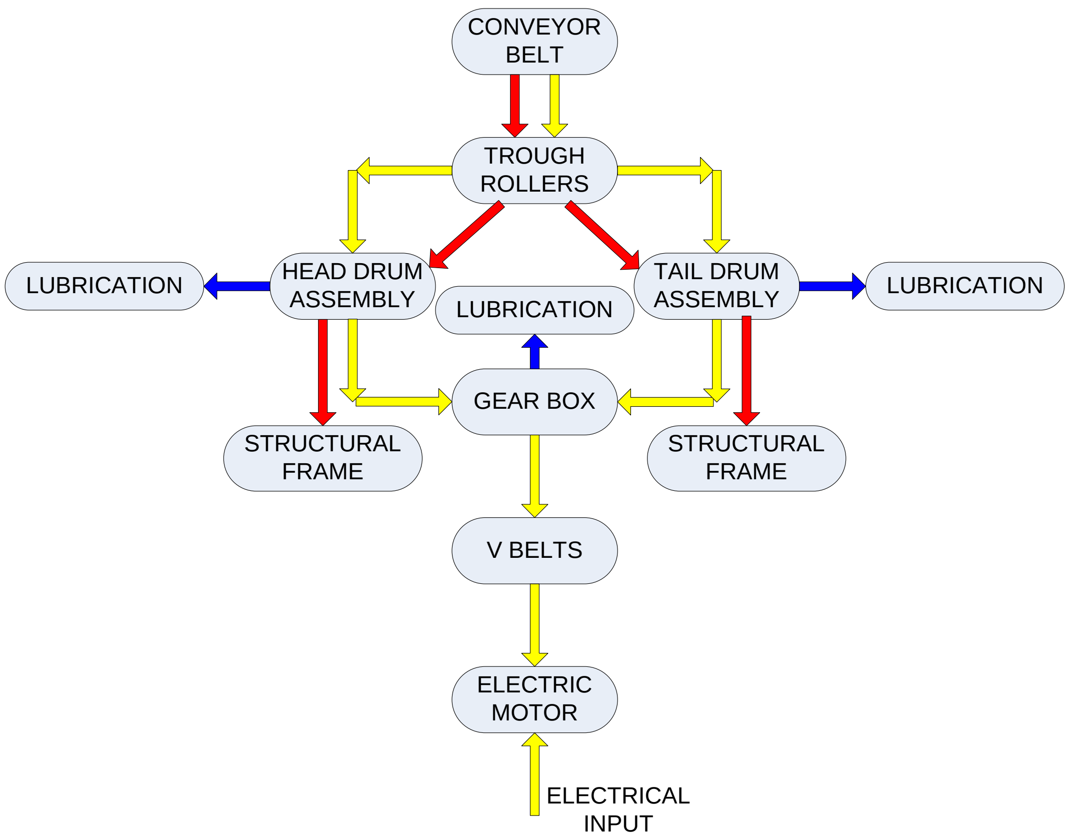


Figure 27: Functional diagram for Conveyor system by Author.

Component or Sub System Description
Conveyor belt: belt rubber of different sizes
Trough rollers: give the belt the V shape and allow the belt to carry more material.
Head drum assembly: consists of the head drum and 2 sets of bearings, one on either side of the drum
Tail drum assembly: consists of the tail drum and 2 sets of bearings, one on either side of the drum
Gear box: speed reducer of different ratios
V belts: 3 belt system, that links the electric motor and the gearbox
Electric motor: Sizes range from 30KW to 7.5kW
Head/tail drum bearing lubrication: EP2 grease
Gearbox lubrication: gear oil
Structural frame:

Table 16: Material Handling Conveyor Sub Assemblies Detail reference Figure 27

MACHINE SUMMARY

Material handling conveyors use the conveyor belt to perform its primary function of transferring material. The belt is shaped by the trough rollers and over the head and tail rollers. Continuous movement is provided to the conveyor through the use of speed reducing gear boxes driven through V belts by an electric motor.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, the parts sheet, and the operation of the material handling conveyors, that not all components are all vital to the running of the entire machine. Components that can fail and still allow full operation of the conveyor include: trough rollers, trough rollers can fail and allow operation, but do pose a threat to cutting the rubber conveyor belt. The system can finish a shift with slight defects for example: 1 V belt broken, slight lube oil leaks on the speed reducing gearbox, small cracks in the structural framing and a head or tail drum bearing failure can still allow operation, with a risk to structural and belt damage, with constant monitoring and full repairs to take place in a planned manner.

7.1.7 MATERIAL HANDLING TRANSFER POINTS

The primary function of a transfer point is to transfer material off one conveyor and onto another conveyor (Swinderman, Goldbeck, Marti 2002). This function is performed by the delivery chute, which is lined with sacrificial wear liners; the delivery chute is shown at the top of the functional diagram. Material containment is also provided through rubber dust seals. The entire transfer point is supported structurally.

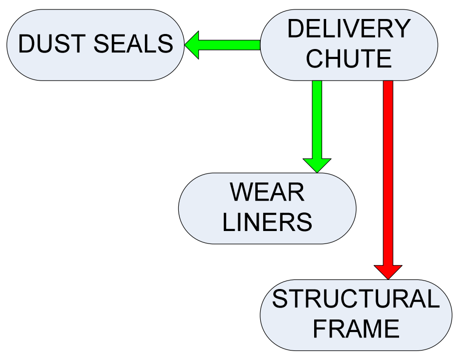


Figure 28: Functional Diagram For Material Handling Transfer Points System

Component or Sub System Description
Delivery chute: chute that directs material from a conveyor to another conveyor
Wear liners: the delivery chute is lined with sacrificial wear liners.
Dust seals: contain material inside the transfer point,
Structural frame

Table 17: Material Handling Transfer point Sub Assemblies Detail, reference Figure 28

MACHINE SUMMARY

Material handling transfer points use the delivery chute to perform its primary function of transferring material.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, the parts sheet, and the operation of the transfer points, that all components are vital to the operation of the component. It is permissible to continue running the plant if dust seals are worn and leaking material but it is not desirable, as it requires clean up costs.

7.1.8 MATERIAL HANDLING CHUTES

The primary function of a chute is to deliver material off various components like screens and conveyors onto other components like: aggregate bins, surge bins. This function is carried out by the chute, which is lined with a sacrificial wear liner. Chutes are also supported structurally. (Swinderman, Goldbeck, Marti 2002).

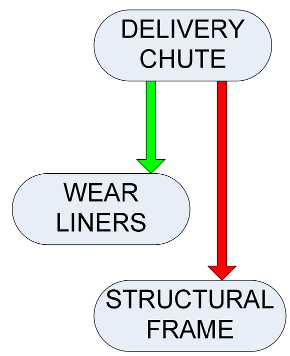


Figure 29: Functional diagram for Material Handling Chutes

Component or Sub System Description
Delivery chute: chute that directs material
Wear liners: the delivery chute is lined with sacrificial wear liners.
Structural frame.

Table 18: Material Handling Chutes Sub Assemblies Detail, reference Figure 29

MACHINE SUMMARY

Material handling chutes use the delivery chute to perform its primary function of transferring material.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, and the operation of material handling chutes that all components are required for the operation of the chute.

7.1.9 AGGREGATE STORAGE BINS

The primary function of the aggregate storage bins is to store aggregates. The component that performs this function is the bin walls, which are lined with sacrificial wear liners. The storage bins are emptied by the bin gates. The bin gates rely on sealed bearings for rotation.

The aggregate storage bins are supported by structural frames.

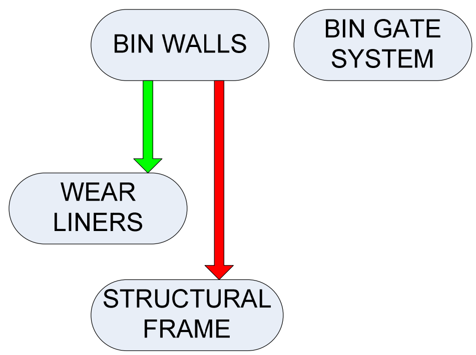


Figure 30: Functional diagram for Aggregate Storage Bins

Component or Sub System Description
Bin walls: The walls that make up the bin.
Wear liners: the internal bin walls are lined with sacrificial wear liners.
Structural frame.

Table 19: Aggregate Storage Bin Sub Assemblies Detail reference Figure 30

MACHINE SUMMARY

Aggregate storage bins use the bin walls to perform its primary function of holding and storing material.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, and the operation of the aggregate storage bins that all components are required for the operation of the component.

7.1.10 SURGE BIN

The primary function of the surge bin is to store secondary crushed and screened material before it travels to the tertiary crusher. The component that performs this function is the bin walls, which are lined with sacrificial wear liners. The surge bin is also supported by a structural frame.

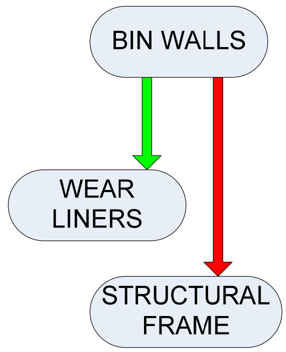


Figure 31: Functional diagram for Surge Bin

Component or Sub System Description
Bin walls: The walls that make up the bin.
Wear liners: the internal bin walls are lined with sacrificial wear liners.
Structural frame.

Table 20: Surge Bin Sub Assemblies Detail reference Figure 31

MACHINE SUMMARY

The surge bin uses the bin walls to perform its primary function of holding and storing material.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, and the operation of the surge bin that all components are required for the operation of the component.

7.1.11 AGGREGATE BIN LEVEL SENSOR

The primary function of the aggregate bin level sensor system is to indicate when the bin is full and ready to be emptied. The function is carried out by the tilt switch to close the circuit to a light. The system relies on power.

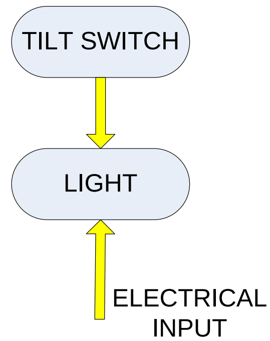


Figure 32: Functional diagram for Aggregate Bin Level Sensor system

Component or Sub System Description
Title switch: a system that when titled away from the vertical position closes an electrical circuit. The system will deviate from vertical when material builds up and moves the switch.
Light: a light which is connected to the tilt switch, and illuminates when the tilt switch is titled

Table 21: Bin Level Indicators Sub Assemblies Detail reference Figure 32

MACHINE SUMMARY

The bin level system uses the tilt switches to perform its primary function of indicating when the aggregate storage bin is full.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, and the operation of the bin level sensor that all components are critical to the operation of the system, however the plant can operate without it. If the bin level sensors fail the bin truck operators can still empty the bins roughly when required through experience with a loss in efficiency, as they may empty and transport the contents of a half full bin.

7.1.12 AGGRGATE STORAGE BIN GATE OPENING SYSTEM

The primary function of the aggregate storage bin gate opening system is to open the bin gates on demand of the bin truck driver. This function is carried out by the pneumatic cylinders and directional control valve. The direction control valve is operated either by the manual override or the signal receiver. The signal is sent from the transmitter. (B Fitzpatrick 2009, pers. comm., 02 June.)

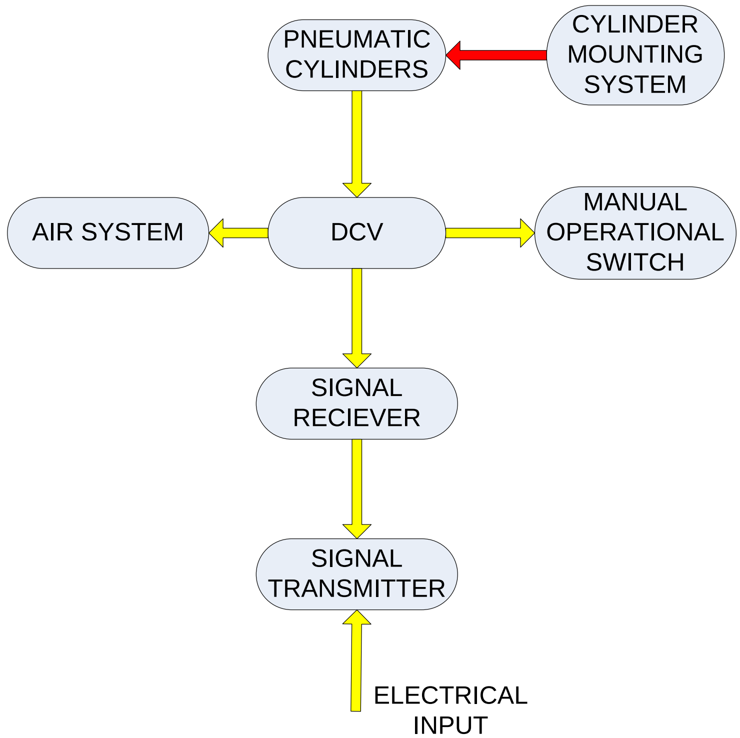


Figure 33: Functional diagram for Aggregate Storage Bin Gate Opening system by Author.

Component or Sub System Description
Pneumatic cylinders: a bin gate system consists of 4 pneumatic cylinders. The cylinders open and close the clam gate system
Cylinder mounting system: the pneumatic cylinder pivots at both ends of the cylinder.
DCV: directional control valve, directs air to the desired cylinder. There is a DCV for each bin gate
Air system: air supply from the air compressor
Manual operational Switch: safety that allows for the bins to be emptied if the wireless system is non functional.
Signal receiver: receives a particular signal, which is bin specific, and connects to the DCV for that particular bin.
Signal transmitter: located in the bin truck, transmits a bin specific signal to the receiver.

Table 22: Aggregate Bin Gate Opening System Sub Assemblies Detail reference Figure 33

MACHINE SUMMARY

The bin gate opening system uses the pneumatic cylinders to perform its primary function of opening the bin gates.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, and the operation of the aggregate bin gate opening system, that all components are required for its operation.

7.1.13 THE AGGREGATE BIN TRUCK

The primary function of the aggregate bin truck is transport aggregates from the aggregate storage bins to the stock pile. The bin truck relies on a number of systems to accomplish this which are beyond the scope of this dissertation.

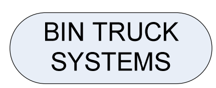


Figure 34: Functional diagram for Bin Truck system by Author.

Component or Sub System Description
Bin truck: a rigid body tipping truck

Table 23: Bin Truck Sub Assemblies Detail reference Figure 34

MACHINE SUMMARY

Serviceability of the bin truck systems is not permissible by onsite staff

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, and the operation of the Bin truck, and also following regulations, the entire bin truck is vital to the operation of the plant.

7.1.14 DUST SUPPRESION SYSTEM

The primary function of the dust suppression system is to reduce the amount of airborne dust particles caused by the crushing and screening plant. This function is primarily carried out by spray nozzles. Water is given flow by a water pump, which pumps water from a storage tank to the desired location through water pipes.

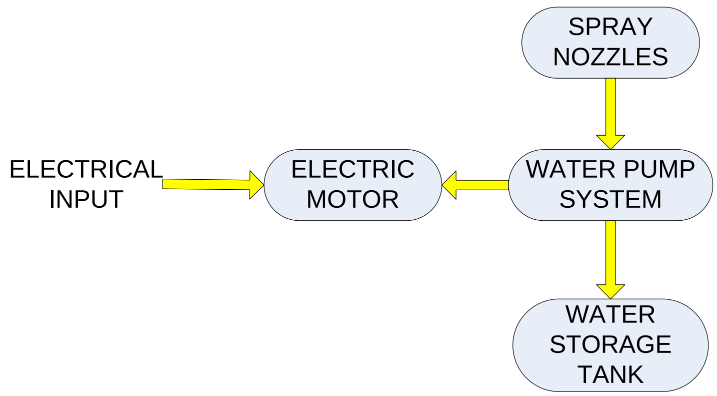


Figure 35: Functional Diagram For Dust Suppression System

Component or Sub System Description
Spray nozzles: spray nozzles of different spray types.
Water pump system: consist of the water pump, water filter, and water pipes.
Water storage tank:
Electric motor: 5KW

Table 24: Dust Suppression Sub Assemblies Detail reference Figure 35

MACHINE SUMMARY

The dust suppression system uses water, spray nozzles and the water pump system to perform its primary function of suppressing airborne dust particles.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, and the operation of the dust suppression system, that all components are critical to the operation of the system.

7.1.15 COMP AIR ROCK BREAKER

The primary function of the Rock breaker is to clear large rock from the jaw crusher. This function is carried out by the rock breaker attachment, which relies on the hydraulic system, which consists of: pump, oil, oil lines, electric motor, reservoir, direction control valves, levers, lever cables. The rock breaker is supported structurally by a structural frame.

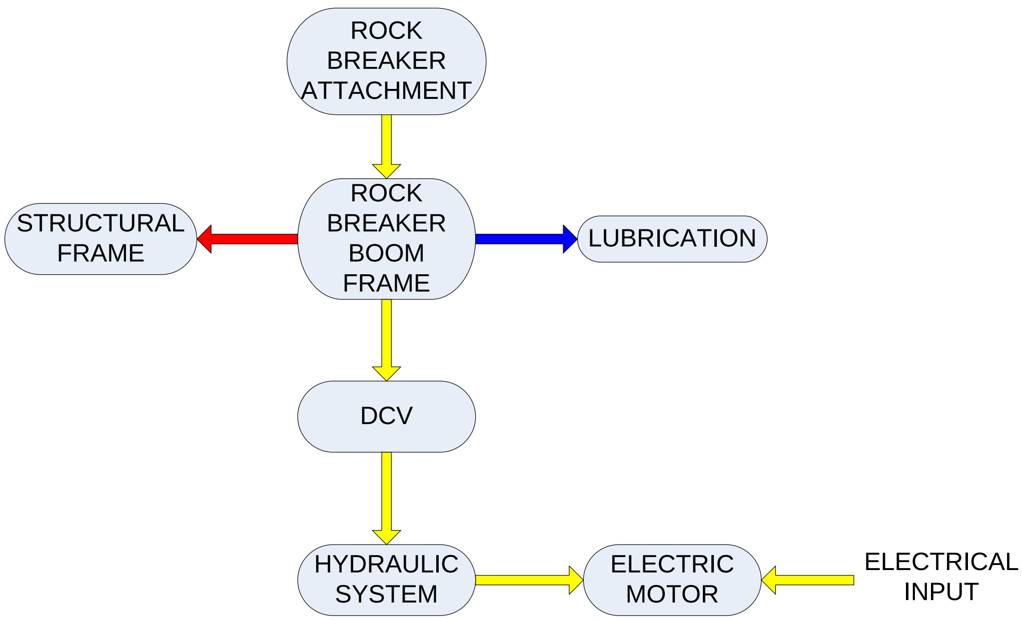


Figure 36: Functional Diagram For Rock Breaker System

Component or Sub System Description
Rock breaker attachment: impactor system.
Rocker boom frame: frame consists of 3 hinges and 1 rotational pivot.
Structural frame
Lubrication: EP2 grease
DCV: directional control valve for each hinge and rotational pivot.
Hydraulic system: consists of the reservoir, hydraulic pump, filters, oil cooler, and oil lines
Electric motor: 11KW

Table 25: Rock Breaker Sub Assemblies Detail reference Figure 36

MACHINE SUMMARY

The Comp Air Rock breaker system uses the rock breaker attachment to perform its primary function of dislodging large rocks that have blocked the jaw crusher.

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, and the operation of the rock breaker, that all components are critical to the operation of the system.

7.1.16 ATLAS COPCO AIR COMPRESSOR

The primary function of the air compressor is to supply the plant with a constant supply of air. The air compressor performs this function through many systems that are beyond the scope of this dissertation.

Figure 37: Functional Diagram For Air Compressor System

Component or Sub System Description
Air compressor systems: supply the plant with a constant flow of air

Table 26: Air Compressor Sub Assemblies Detail reference Figure 37

MACHINE SUMMARY

Serviceability of the air compressor systems is not permissible by onsite staff

CRITICAL MACHINE ITEMS

It can be seen by studying the functional diagram, and the operation of the air compressor that all components are required for its operation.

7.2 CHAPTER SUMMARY

The crushing and screening plant at Ormeau uses many different systems. The systems have been broken down into smaller systems. The systems were modeled using a top down approach to function diagrams. A complex system that requires Original Equipment Manufacturers expertise to service is modeled as a system comprising of many components, where a system that can be serviced by onsite personnel is broken down into smaller systems. Some systems used by the crushing and screening process can not be repaired by untrained onsite staff for example: bin trucks, air compressor, and electrical systems.

Critical items have been identified from the functional diagrams, and the operation of the machines. This information will be vital in evaluating the effect of failures in a machine to the overall outcome of the failure.

8. FMECA GORUND RULES

The FMECA process relies on engineering judgment to class and quantify failure frequency occurrences, failure severities, and failure detection. For this process to remain accurate and consistent there needs to be a standard.

8.1 FMECA STRUCTURE

The FMECA will be structured to use the following categories:

1. Infrastructure
2. Sub system and Function
3. Failure Mode
4. Effect of Failure
5. Cause of Failure
6. Frequency Occurrence
7. Severity
8. Detection
9. Recommended Priority Number (RPN)
10. Recommendation

This structure covers the Failure Mode, Effect, and Criticality analysis. The FMECA column breakdown originated from the IEC Standard 1985.

8.2 INFRASTRUCTURE

The column headed Infrastructure refers to the overall type of machine. The FMECA for the Ormeau plant will be split up into the following Infrastructure classifications:

1. Material Handling Conveyors
2. Crushing Equipment
3. Screening Equipment
4. Structure
5. Accessories
6. Electrical

All machines will fit into these 6 main Infrastructure classifications.

8.3 SUB SYSTEM

The column headed Sub System refers to the sub systems which lie in the Infrastructure category. The sub system is split into the following categories:

INFRASTRUCTURE	SUB SYSTEM	FAILURE MODE
Material Handling Conveyors	1. Material Handling Conveyors	
Crushing Equipment	1. Primary Jaw Crusher 2. Secondary and Tertiary Cone crushers 3. Quaternary Crusher VSI	
Screening Equipment	1. Screen	
Structure	1. Bins 2. Chutes 3. Transfer Points 4. Structural Steel 5. Dust Suppression 6. Bin Gate Opening System	
Accessories	1. Rock Breaker	
Electrical	1. Motor Control 2. Bin Level System	

Table 27: First three columns of the FMECA

8.4 FAILURE MODE

The failure mode column uses the functional diagrams and engineering judgment to detail failure modes. The functional diagrams are used to identify components and sub systems in a system. Engineering judgment is used to assess if the failure is appropriate for inclusion in the FMECA.

8.5 EFFECT OF FAILURE

The effect of the failure is simply, the effect that a particular failure mode will have on the plant. The possible effects of failure include:

1. Plant down, full loss of production, no redundancy
2. Plant down, some redundancy
3. Plant down, loss of drive
4. Plant down, structural damage
5. Plant down for temporary repairs
6. Plant down, product contamination
7. Product loss
8. Plant down, breaching operating license requirements
9. Machine fails to start or trips
10. Slowed bin truck operation, lessen efficiency

The term redundancy refers possible bypass of the failed machine. Within the Ormeau crushing and screening plant, the only redundancy that exists is the Barmac VSI. It is possible to bypass the Barmac, but it is not often done due to the effect that it has on the efficiency of the plant.

8.6 CAUSE OF FAILURE

The cause of failure uses engineering judgment to determine the possible causes of the failure mode.

8.7 FREQUENCY OCCURENCE

Frequency occurrence requires a rating from 1 to 5. The frequency of the failure can also be referred to as the likelihood of failure. It is necessary to create a standard for this rating so that the rating is consistent across the whole FMECA.

It is also necessary to use a time frame for the evaluation of the frequency of failure. Since the Quarry Reporting System (QRS) uses monthly data reviews and production targets. It is convenient to use the same time frame. Therefore the frequency of failure will be judged using a 1 month time frame.

RATING	DESCRIPTION	FREQUENCY
5	Almost certain	A failure is expected to occur in most circumstances. Once a month or more frequently.
4	Likely	A failure will probably occur in most circumstances. Once every 3 months
3	Possible	A failure might occur at sometime. Once every 6 months
2	Unlikely	A failure could occur at some time Once every 9 months
1	Rare	A failure may occur in exceptional circumstances. Once a year.

Table 28: Frequency value itemisation by Author.

8.8 SEVERITY

The severity of the failure requires a rating of 1 to 5. The severity of the failure is related to the effect of the failure. It is necessary to create a standard for rating these criteria.

RATING	DESCRIPTION	SEVERITY
5	Catastrophic	Plant down, all production lost
4	Major	Plant down, redundancies used, 50% loss of production
3	Border	50% loss of production output, inefficient to run, therefore plant down.
2	Moderate	25% loss of production output.
1	Minor	10% loss of production output

Table 29: Severity value itemisation by Author.

8.9 DETECTION

The detection value also requires a rating of 1 to 5. The detection refers to the ability to detect a particular failure. It is a rating of how detectable a failure is.

RATING	DESCRIPTION	DECTECTION
5	No detection	Fault is not detectable
4	Detection	Fault is detectable through experience.
3	Inspection	Fault is detectable through visual inspection
2	Operator Detection	Operator can detect the fault through an audio monitoring
1	Detectable	Fault is detectable through a protection system

Table 30: Severity value itemisation by Author.

8.10 RPN

The RPN is the Recommended Priority Number. The RPN can range from 1 to 125. The RPN serves as the criticality analysis. The RPN is the product of the frequency, severity and detection values. A Fault with a higher RPN is more critical. A high RPN will mean that a fault has a high frequency, high severity and is not detectable; this particular failure will require high action.

8.11 RECOMMENDATION

Engineering judgment based on experience is used to make a recommendation about each fault. The recommendation serves to reduce all assessment item values: frequency, severity and detection.

8.12 CHAPTER SUMMARY

The FMECA structure has been detailed, and each item in the structure has been described and defined. To keep the FMECA consistent the evaluation values of Frequency, Severity, and Detection have been summarised. The RPN has been defined and a description of how it is calculated has been given. The recommendation gives a small recommendation of how the failure can be reduced.

9. PLANT FMECA

Infrastructure Sub System	Subsystem Function	Failure Mode	Effect of Failure	Cause of Failure	Frequency Occurrenc	Severity	Detection	RPN	Recommendation
Material handling - conveyors	Conveyor aggregates through the process. All production stopped.	Mechanical damage to belting	Spillage, belt torn. Plant down - until belt repaired or replaced.	1. Poor housekeeping	5	3	1	15	Operator supervision
				2. Rock caught in structure or scraper	4	4	2	32	Limit switches on belt weighers.
				3. Roller failure	3	2	3	18	Routine inspections
				4. Skirt failure	4	2	3	24	Routine inspections
				5. Wear plate/ liner failure	3	3	3	27	Routine maintenance program
				6. Scraper failure	4	3	2	24	Routine inspection program
				7. Fatigue	2	4	4	32	
				8. Poor splice / splice failure.	4	4	2	32	Routine maintenance program
				9. Overload	3	4	2	24	Determine belt replacement interval
				10. Bearing failure	4	4	3	48	Routine maintenance
		Motor Failure	Loss Of Drive Plant Down	1. Bearing Failure	4	4	3	48	Critical spares.
				2. Fatigue	2	4	4	32	Run to failure
				3. Overload	2	3	2	12	Limit switches on belt weighers
				4. Water Entry	3	4	4	48	
				5. Over Temp	3	2	2	12	Thermal overloads on motors
		Gearbox Failure	Loss Of Drive Plant Down	1. Bearing Failure	4	4	3	48	Standardise box configuration and ratio; critical spare
				2. Lubrication Failure	4	4	2	32	Routine maintenance
				3. Fatigue	3	4	4	48	
				4. Overload	2	3	4	24	Limit switch on belt weigher
				5. Over Temp	2	3	3	18	Thermocouples

Infrastructure Sub System	Subsystem Function	Failure Mode	Effect of Failure	Cause of Failure	Frequency Occurrenc	Severity	Detection	RPN	Recommendation
		V-Belt Drive Failure	Loss Of Drive Plant Down	1. Misalignment 2. Contamination 3. Fatigue 4. Overload	4 3 3 3	3 2 3 3	2 2 3 4	24 12 27 36	Routine inspection Routine inspection of guards Critical spare
		Pulley / Roller / Drum Failure	Loss Of Drive Structural Damage	1. Fatigue / Age 2. Mechanical Damage 3. Poor Design / Quality	2 3 2	4 4 3	4 4 3	32 48 18	Critical Spare Housekeeping
Crushing equipment	Primary jaw Reduce input rock size	Structural failure	Machine down. No redundancy so full loss of production.	1. Fatigue 2. Poor maintenance 3. Overload 4. Contamination[1]	2 3 3 3	5 4 3 3	4 2 2 3	40 24 18 27	Routine inspection program Routine maintenance Chute to restrict top size Operator supervision
		Liner Failure	Machine Down / Plant Down	1. Worn Out 2. Mounting Connection Failure 3. Contamination 4. Loss Of Stroke	4 3 3 4	3 4 4 3	1 3 3 1	12 36 36 12	Routine inspection Maintenance Supervision Operator Supervision Routine inspection

[1] All crushers are effected by materials that have a higher tensile strength than rock, such as ground engaging tools, wear materials and some thermal modified source rock. Most crushers are protected by metal detectors or magnets.

Infrastructure Sub System	Subsystem Function	Failure Mode	Effect of Failure	Cause of Failure	Frequency Occurrenc	Severity	Detection	RPN	Recommendation
		Drive Failure	Machine Down / Plant Down	1. Motor Failure	2	4	3	24	Critical Spare
				2. Motor Bearing Failure	3	4	3	36	Critical Spare – Motor
				3. Pulley Fatigue	3	5	2	30	Routine Inspection
				4. Flywheel Fatigue	3	5	2	30	Routine Inspection
				5. Eccentric Bearing Failure	2	5	3	30	Critical Spare
				6. Shaft Bush Failure	3	4	3	36	Critical Spare
				7. Lubrication Failure	4	4	2	32	Routine Inspection
				8. V-Belt Failure	4	4	2	32	Routine Inspection/critical spare
				9. Toggle Plate Wear	3	3	1	9	Operator supervision/ inspection program
				10. Shim Plate Failure	4	3	3	36	Critical Spare
				11. Oversize Material	5	4	1	20	Chute to restrict top size
	Secondary & Tertiary Cones [2] Reduce input rock size	Structural Failure	Machine Down / Plant Down	1. Case Cracks From Fatigue/Exceed UTS	2	5	5	50	Routine inspection Testing of accumulators.
				2. Overload	3	3	3	27	Testing of motor overloads,
				3. Contamination	3	3	2	18	Install metal detectors/ operator supervision

[2] Secondary and Tertiary crushers are essentially the same machine in principle, with the secondary crusher being a heavy construction and larger size for the same product range.

Infrastructure Sub System	Subsystem Function	Failure Mode	Effect of Failure	Cause of Failure	Frequency Occurrenc	Severity	Detection	RPN	Recommendation
		Liner Failure	Machine Down / Plant Down	1. Wear 2. Poor Maintenance 3. Poor Feeding / Inconsistent Feeding 4. Fatigue 5. Metal To Metal Contact – Poor Operation 6. Suspension nut failure	4 2 2 2 3 3	4 3 3 4 4 4	1 2 2 4 2 4	16 12 12 16 24 48	Regular monitoring required, part of operator's routine. Install level indicators. Crusher clearance to be confirmed each shift with lead gauge. Critical spare
		Drive Failure	Machine Down / Plant Down	1. Lube System Failure 2. Motor Failure 3. V-Belt Failure 4. Gear Train Failure 5. Shaft bearing failure 6. Spider bush failure 7. Shaft failure	4 2 4 2 3 4 2	3 4 4 5 4 4 5	2 3 2 3 3 2 5	24 24 32 30 36 32 50	Flow switch – critical spare, routine inspection. Critical Spare Routine inspection/ critical spares Oil sampling of lube Oil sampling Critical Spare **Refer following**
		Lube Failure	Machine Down / Pant Down	1. Contamination 2. Poor maintenance 3. Pump Failure 4. Lube line failure 5. Over temp 6. Pump drive failure	3 3 3 4 4 3	3 3 4 3 3 4	2 2 4 4 2 4	18 18 48 48 24 48	Install chip indicators Routine maintenance Critical Spare Flow switch – critical spare Install temp cut out switch – critical spare Routine service of coolers. Critical spare – electric motor and water pump. Electric motor and coupling Critical spare
		Adjustment	Slowed	1. Poor maintenance	3	3	2	18	Routine maintenance

Infrastructure Sub System	Subsystem Function	Failure Mode	Effect of Failure	Cause of Failure	Frequency Occurrenc	Severity	Detection	RPN	Recommendation
		failure (Omnicone)	Production	2. Pump failure 3. Tramp cylinder leak 4. Adjustment cylinder failure 5. DCV failure	3 3 2 2	3 4 2 2	4 2 2 3	36 24 8 12	Critical spare Critical spare Inspection program Critical spare
	Quaternary Crusher (VSI) Reduce input rock size	Rotor Failure	Machine Down / Plant Down	1. Wear 2. Imbalance from wet materials poor operation 3. Poor maintenance 4. Oversize material	4 3 3 5	4 3 3 3	2 4 3 2	32 36 27 30	Routine Inspections Routine Inspections / routine maintenance on wear plates Maintenance supervision Routine inspections of
		Drive Failure	Machine Down / Plant Down	1. Motor Failure 2. Bearing Cartridge Failure 3. Pulley Failure 4. V-Belt Failure	2 4 2 3 4	4 4 4 3 3	4 4 3 2 2	32 64 24 18 24	Critical Spare Critical Spare - Vibration sensor Routine Inspection Routine Inspection
		Housing Failure	Outage to reline – temporary repair usually possible	1. Poor Maintenance 2. Poor operation 3. Failure of feed screen leading to oversize.	3 2 4	3 3 3	2 2 2	18 12 24	Routine Inspection Operator supervision Routine inspection of leading screens
Screening Plant	Screen Separate material by size	Media Failure	Temporary repairs until downtime to replace	1. Poor Operation 2. Run to failure 3. Contamination 4. Poor fitment 5. Overload	3 3 4 4 3	3 2 3 3 2	2 2 2 3 2	18 12 24 36 12	Operation supervision Routine inspections Clean screens – pegging Supervision / skills issue Operator surveillance

Infrastructure Sub System	Subsystem Function	Failure Mode	Effect of Failure	Cause of Failure	Frequency Occurrenc	Severity	Detection	RPN	Recommendation
		Deck Failure	Machine Down / Plant Down, Product contamination leading to devalued product	1. Fatigue 2. Overload 3. Excess vibration due to eccentric fault 4. Poor media fitment 5. Wear 6. Poor maintenance	3 2 3 4 5 3	4 2 4 3 4 4	3 2 2 2 2 2	36 8 24 24 40 24	Routine inspection Operator surveillance Vibration sensor – peak exceed Maintenance Supervision Routine inspection Routine maintenance
		Mechanism Failure / Drive Failure	Machine Down / potential Consequential damage	1. Fatigue 2. Bearing Failure 3. Imbalance due to weight coming off 4. Shaft Failure due to vibration 5. V-belt loss 6. Motor failure	3 3 3 2 4 2	4 4 3 4 3 4	4 3 4 2 4 4	48 36 36 16 36 32	Critical Spare Oil sampling, vibration analysis.. Peak Vibration Sensor Peak Vibration Sensor Critical spare. Critical spare.
Structure	Bins Hold material	Function failure	Product Loss	1. Poor maintenance 2. Poor Attachment 3. Excessive Vibration 4. Poor Design 5. Overloading 6. Excessive wear plate wear	3 4 2 2 3 3	3 3 3 3 3 2	2 4 2 2 4 2	18 48 12 12 36 12	Routine maintenance Maintenance supervision. Engineering involvement Adequate support Engineering involvement Limit chutes to discharge overload Maintenance program / inspection program
	Chutes Deliver material	Function Failure	Product Loss / Contamination	1. Poor Maintenance 2. Poor Design 3. Excessive Vibration 4. Material build up 5. Blockage 6. Excessive wear	4 4 3 5 4 3	3 3 3 3 3 2	2 2 2 3 4 2	24 24 18 45 48 12	Routine maintenance Engineering involvement Adequate support Limit switch in prone areas Limit switch in prone areas Routine maintenance /

Infrastructure Sub System	Subsystem Function	Failure Mode	Effect of Failure	Cause of Failure	Frequency Occurrenc	Severity	Detection	RPN	Recommendation
				plate wear					inspection program
	Transfer points Deliver material	Function failure	Product Loss / Contamination	1. Poor Maintenance 2. Side skirt condition 3. Poor Design 4. Excessive Vibration 5. Material build up 6. Blockage 7. Excessive wear plate wear	4 3 4 3 5 4 3	3 2 3 3 3 3 2	2 2 2 2 3 4 2	24 12 24 18 45 48 12	Routine maintenance Routine inspection program / critical spare Engineering involvement Adequate support Limit switch in prone areas Limit switch in prone areas Routine maintenance / inspection program
	Structural Steel Support plant machines and processes	Failure	Plant Down	1. Connection Failure 2. Design fault 3. Overload 4. Change in Operation 5. Poor Housekeeping 6. Poor Maintenance 7. Fire	2 2 3 4 5 4 1	5 5 5 4 4 4 5	4 4 2 2 1 1 4	40 40 30 32 20 16 20	Routine inspection program Engineer Engineering Involvement Belt weighers Supervision Supervision Suitable response equipment
	Dust Suppression Reduce airborne dust particles	Failure	Loss of dust control breaching operating license requirements. Plant down	1. Storage tank level 2. Pump system failure 3. Water line failure	3 1 2	5 5 4	2 2 2	30 10 16	Routine inspection program, Routine inspection/ maintenance program / critical spare Routine inspection program / critical spare
	Bin Gate Opening System Open bin gates when desired	Wireless System	Slowed bin truck operation / slowed production	1. Poor power connections 2. Poor transmitter condition 3. Poor receiver condition	3 3 3	2 2 2	5 5 5	30 30 30	Routine maintenance program Routine inspection program Routine inspection program
		Actuation	Plant down	1. Cylinder failure	2	5	3	30	Routine inspection program

Infrastructure Sub System	Subsystem Function	Failure Mode	Effect of Failure	Cause of Failure	Frequency Occurrenc	Severity	Detection	RPN	Recommendation
		system		2. DCV failure 3. Air line failure 4. Cylinder pivot mounts	1 2 1	5 5 5	4 2 2	20 20 10	Routine maintenance program – critical spares. Routine inspection program / critical spare Routine inspection program
Accessories	Rock Breaker Dislodge large rocks from jaw crusher	Hydraulic System	Machine Down	1. Contamination 2. Poor maintenance 3. Pump Failure 4. Hydraulic line failure 5. Over temp	3 3 3 4 4	3 3 4 3 3	2 2 4 4 2	18 18 48 48 24	Chip indicators Routine maintenance Critical Spare Flow switch / hold prone hydraulic lines in critical spares / routine inspection Temp indicator, Routine service of coolers.
		Drive failure	Machine down/ Plant down	1. Motor failure	2	4	4	32	Critical spare – vendor stock
		Impact Attachment Failure	Machine down/ Plant down	1. Attachment failure	2	5	3	30	Critical spare – vendor stock.
	Air Compressor Supply plant with air flow	Function Failure	Machine down / Plant down	1. Not serviced	1	5	4	20	Routine inspection / continued routine maintenance
	Bin Truck	Function failure	Plant down	1. System failure	3	5	3	45	System critical spare
Electrical	Motor Control	Motor Starter or contactor failure	Machine fails to start or trips	1. Dust 2. Poor Maintenance 3. Fatigue 4. Run to failure	4 4 3 4	3 3 4 3	3 2 3 3	36 24 36 36	Routine cleaning & maint. Supervision of contractors Critical spares Critical spares – vendor held
	Bin Level Sensor System	Tilt sensor	Slowed bin truck operation, lessen	1. Failed tilt sensor	2	2	5	20	Critical spares

Infrastructure Sub System	Subsystem Function	Failure Mode	Effect of Failure	Cause of Failure	Frequency Occurrenc	Severity	Detection	RPN	Recommendation
	Indicate when aggregate levels are high inside bins		efficiency						
		Indicator light	Slowed bin truck operation, lessen efficiency	1. Failed light bulb	2	1	5	10	Critical spares

10. RECOMMENDATIONS

Recommendations have been made to try to reduce the frequency, severity and detection values, which are combined to give the RPN, of failure modes based on the FMECA. It is necessary to further develop the recommendations for each machine that has been considered, which include:

- 1 Pegson jaw crusher, 1100mm x 850mm, as the primary crusher
- 1 900mm Jaques gyratory cone crusher in a secondary configuration
- 1 Nordberg Omnicone gyratory crusher as the tertiary crusher
- 1 Barmac Rotopactor Vertical Shaft Impact crusher (VSI) as the quaternary crusher
- 8 Malco 2.4m x 1.2m vibrating screens
- 11 material handling conveyors of different sizes
- Material handling transfer points
- Material handling chutes.
- 16 aggregate storage bins
- Surge bin
- Aggregate bin level sensors.
- Aggregate bin gate opening system
- Aggregate bin truck
- Dust suppression system
- Comp Air hydraulic rock breaker.
- 1 Atlas Copco air compressor.
- Structural framing
- Electrical

10.1 JAW CRUSHER

From the FMECA conducted on the Pegson Jaw Crusher: inspection programs, critical spares, operator supervision programs, maintenance supervision programs and engineering design have been recommended. These recommendations will be further discussed.

MACHINE: JAW CRUSHER	
Critical Spares List	**DESCRIPTION**
1. Electric motor **Approximate cost:** $ 10k	• 110KW, 3 phase, standard mounting configuration. • Diagnosis and fitting by an electrician.
2. Eccentric bearing **Approximate cost**: $5k	• Supplied direct from OEM • Diagnosis and fitting by crusher contractor and maintenance staff
3. Eccentric shaft bush **Approximate cost:** $5k	• Supplied direct from OEM • Diagnosis and fitting by crusher contractor and maintenance staff
4. Shim plates **Approximate cost:** $ 0.3k	• Different thickness fabricated on site and shape specifications
5. V Belts **Approximate cost:** $0.5k	• At least 6 SPC 6000 belts to be held in inventory

Table 31: Critical spares list for jaw crusher

MACHINE: JAW CRUSHER	
Routine inspection Programs	**INSPECTION DESCRIPTION**
SAFETY	• Ensure all inspections are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Structural fatigue **Approximate labor contribution:** 0.1Hr **Frequency:** Weekly **Plant status:** Not running	• Inspect all structural surfaces for signs of cracking, take particular notice of welded joints and mounting areas. Inspect hold down mounting bolts for attachment and tension.
2. Jaw wear liners **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the mounting bolts, to check that they are secure. • Inspect the wear on the wear liners. This can be done by visually taking a measurement of the corrugation depths. When the corrugation depth becomes less than 20mm, it is time to rotate the liner or replace.

3. Loss of swing jaw stroke **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Running	• Check that the crusher still has adjustment available. If crusher is at the end of the its adjustment, it is time to change or rotate either, or both jaw liners.
4. Pulley fatigue **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the pulley, taking particular notice of the spokes, for cracks. • Inspect the clamping bolts for tension • Check that the end of shaft cap bolts are securely mounted.
5. Flywheel fatigue	**See Pulley fatigue Inspection**
6. Lubrication failure **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect all grease lines for deterioration, holes, and wear marks. • Inspect all grease nipples, check that they hold grease. • Ensure greasing is occurring daily, when the crusher is warm and running
7. V belt wear/condition/tension **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the V belts, ensure that they are all still present, inspect the underside for cracks, and check the belt tension by pushing on the belt between the longest span of the belt, there should be no more than 20mm of movement in the belt.

Table 32: Routine inspection program for jaw crusher

MACHINE: JAW CRUSHER	
Maintenance Supervision	**DESCRIPTION**
SAFETY	• Ensure all inspections are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Wear liner mounting bolt fitment **Approximate labor contribution:** 1Hr **Frequency:** After liner replacement or rotation **Plant status**: Not running	• Ensure that workers don't only use an air impact gun to secure the bolts, they must be tightened to a final torque by using a hammer impact. • Ensure that the threads of the bolt, and under the mounting side of the nut are lubricated to overcome some of the friction. • Ensure safe practices.

Table 33: Maintenance supervision program for jaw crusher

MACHINE: JAW CRUSHER	
Operator Supervision	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
Ensure that no metallic objects are feed into the plant **Frequency:** Constantly	• Ensure that front end loader operators create working piles, so that where possible metallic objects maybe identified and isolated. • Inform operators to constant check that all bucket ground engaging tools attached, and have not been feed into the plant.
Ensure that the plant operator is constantly conducting audio tests **Frequency:** Daily **Plant status:** Running	• Train the plant operator to listen to the jaw and to constant monitor the sound of the toggle plate. By listening to the sound that the jaw is making can give a good indication of the toggle seats. A worn toggle seat will have a definite knock on each stroke.

Table 34: Operator supervision program for jaw crusher

MACHINE: JAW CRUSHER	
Installation list	**Design Brief**
To design the feed chute to restrict the input rock size	• The chute would need to be strong enough to take large impacts of rocks rolling down the live tipping bin. • It would need to be able to restrict the input rock size but, to still allow smaller rocks through, while the larger rock was removed.

Table 35: Installation list for jaw crusher

10.2 900MM JAQUES GYRATORY CONE CRUSHER

From the FMECA conducted on the 900mm Jaques Cone Crusher the recommendations include: Routine testing programs, routine monitoring programs, critical spares, routine maintenance programs, installations and maintenance supervision programs.

MACHINE: JAQUES CONE CRUSHER	
Critical Spares List	**DESCRIPTION**
1. Electric motor **Approximate cost:** $ 10k	• 110KW, 3 phase, standard mounting configuration. • Diagnosis and fitting by an electrician.
2. Oil flow switch **Approximate cost**: $1k	• Supplied direct from Electrician • Diagnosis and fitting by electrician
3. Oil temperature switch **Approximate cost**: $1k	• Supplied direct from Electrician • Diagnosis and fitting by electrician
4. Spider bush **Approximate cost:** $3k	• Supplied direct from OEM • Diagnosis and fitting by crusher contractor and maintenance staff
5. Lube pump **Approximate cost:** $ 2k	• Supplied direct from OEM • Diagnosis and fitting by crusher contractor and maintenance staff
6. V Belts **Approximate cost:** $0.5k	• At least 6 SPC 6000 belts to be held in inventory
7. Suspension nut assembly **Approximate cost:** $5k	• Supplied direct from OEM • Diagnosis and fitting by crusher contractor and maintenance staff
8. Lube electric motor and coupling **Approximate cost:** $2k	• Supplied direct from Electrician • Diagnosis and fitting by electrician
9. Water pump and electric motor **Approximate cost:** $3k	• Supplied direct from Electrician • Diagnosis and fitting by electrician
10. Lube oil **Approximate cost:** $2k	• 220W gear oil

Table 36: Critical spares list for Jaques cone crusher

MACHINE: JAQUES CONE CRUSHER	
Routine inspections	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. V belt wear/condition/tension **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the V belts, ensure that they are all still present, inspect the underside for cracks, and check the belt tension by pushing on the belt between the longest span of the belt, there should be no more than 20mm of movement in the belt.
2. Lubrication failure **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the entire machine for oil leaks, inspect all oil lines for signs or deterioration, or wear marks. • Check that the oil level is within the specifications • Ensure that if oil needs to be added that the oil, oil container, and the oil cap are all clean before removing to prevent contamination. • Particularly check the pinion seal for oil leaks.
3. Structural fatigue **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect all structural surfaces for signs of cracking, take particular notice of welded joints and mounting areas. Inspect hold down mounting bolts for attachment and tension.
4. Liner irregularities **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the liners for cracks, holes, wear profile, mounting irregularities. The wear profile should be a straight edge, if the mantle has a belled shape profile, it is becoming to the end of its life.

Table 37: Routine inspection list for Jaques cone crusher

MACHINE: JAQUES CONE CRUSHER	
Routine monitoring	**DESCRIPTION**
SAFETY	• Ensure all inspections are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. CSS measurement **Approximate labor contribution:** 0.10Hr **Frequency:** Weekly **Plant status**: Running	• Measure the CSS, this can be done by lowering a lead gauge into the crushing chamber, removing, and measuring the width of the crushed lead. The thickness indicates the CSS and also a comparison with the previous weeks CSS will indicate the wear rate.
2. Pinion bearing temperature **Approximate labor contribution:** 0.10Hr **Frequency:** Weekly **Plant status**: Running	• Use a thermo gun to check the temperature of the pinion housing. Compare the temperature with the last and reading and consider the ambient temperature. If it is running above 80 degrees Celsius there may be a problem.

Table 38: Routine monitoring list for Jaques cone crusher

MACHINE: JAQUES CONE CRUSHER	
Routine testing	**DESCRIPTION**
SAFETY	• Ensure all inspections are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Motor overload settings **Approximate cost contribution: $**2k **Frequency:** Yearly	• Undertaken by an electrician
2. Oil sample testing **Approximate cost contribution: $**0.2k **Frequency:** Quarterly	• Oil sampling between oil changes, particularly test the metal content.

Table 39: Routine testing list for Jaques cone crusher

MACHINE: JAQUES CONE CRUSHER	
Installation list	**DESCRIPTION**
1. Temperature cut out switch **Approximate cost contribution: $**2k	• Install a temperature switch to only work between the 16 to 70 degrees Celsius, which would be the same switch as the Omnicone – standardizing parts.
2. Metal detectors **Approximate cost contribution: $**5k	• Fit a metal detector on the crusher feed conveyor, which will shut the conveyor and all components behind, until the metallic object can be cleared to restart.
3. Chip indictors **Approximate cost contribution: $**2k	• Install chip indicator in the oil system, for early detection internal components before further damage results.

Table 40: Installation list for Jaques cone crusher

MACHINE: JAQUES CONE CRUSHER	
Operator supervision	**DESCRIPTION**
Ensure that no metallic objects are feed into the plant **Frequency:** Constantly	• **See Jaw Crusher Operator supervision**

Table 41: Operator supervision list for Jaques cone crusher (By Author)

MACHINE: JAQUES CONE CRUSHER	
Routine maintenance	**DESCRIPTION**
Oil cooler servicing **Frequency:** yearly, before summer	• Remove oil cooler and clean professionally.
Oil/filter changes **Frequency:** every 1000 crushing hours.	• Change the oil every 1000hrs, or when it starts to discolor. 1000 hrs oil changes is based on staff experience.

Table 42: Routine maintenance list for Jaques cone crusher (By Author)

10.3 NORDBERG OMNICONE GYRATORY CRUSHER

From the FMECA conducted on the Nordberg Omnicone Crusher the recommendations include: Routine testing programs, routine monitoring programs, critical spares, routine maintenance programs, installations and maintenance supervision programs.

MACHINE: OMNICONE CRUSHER	
Critical Spares List	**DESCRIPTION**
1. Electric motor **Approximate cost:** $ 10k	• 150KW, 3 phase, standard mounting configuration. • Diagnosis and fitting by an electrician.
2. Oil flow switch **Approximate cost**: $1k	• Supplied direct from Electrician • Diagnosis and fitting by electrician
3. Oil temperature switch **Approximate cost**: $1k	• Supplied direct from Electrician • Diagnosis and fitting by electrician
4. Lube pump and speed reducing gear box **Approximate cost:** $ 2k	• Supplied direct from OEM • Diagnosis and fitting by crusher contractor and maintenance staff
5. V Belts **Approximate cost:** $0.5k	• At least 6 SPC 6000 belts to be held in inventory
6. Lube electric motor and coupling **Approximate cost:** $2k	• 5KW, 3 phase, standard mounting configuration • Diagnosis and fitting by electrician
7. Cooling fan electric motor **Approximate cost:** $2k	• 5KW, 3 phase, standard mounting configuration • Diagnosis and fitting by electrician
8. Lube/adjustment oil **Approximate cost:** $2k	• Caltex Meropa 150W gear oil
9. Adjustment oil pump **Approximate cost:** $2k	• Supplied direct from OEM • Diagnosis and fitting by crusher contractor and maintenance staff
10. Adjustment electric motor **Approximate cost:** $2k	• 5KW, 3 phase, standard mounting configuration • Diagnosis and fitting by electrician

Table 43: Critical spares list for Omnicone crusher

MACHINE: OMNICONE CRUSHER	
Routine inspections	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. V belt wear/condition/tension **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the V belts, ensure that they are all still present, inspect the underside for cracks, and check the belt tension by pushing on the belt between the longest span of the belt, there should be no more than 20mm of movement in the belt.
2. Adjustment failure **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the system machine for oil leaks, inspect all oil lines for signs or deterioration, or wear marks. • Check that the oil level is within the specifications • Ensure that if oil needs to be added that the oil, oil container, and the oil cap are all clean before removing to prevent contamination. • Particularly check the pinion seal for oil leaks.
3. Lubrication failure **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the entire machine for oil leaks, inspect all oil lines for signs or deterioration, or wear marks. • Check that the oil level is within the specifications • Ensure that if oil needs to be added that the oil, oil container, and the oil cap are all clean before removing to prevent contamination. • Particularly check the pinion seal for oil leaks.
4. Structural fatigue **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect all structural surfaces for signs of cracking, take particular notice of welded joints and mounting areas. Inspect hold down mounting bolts for attachment and tension.
5. Liner irregularities **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the liners for cracks, holes, wear profile, mounting irregularities. The wear profile should be a straight edge, if the mantle has a belled shape profile, it is becoming to the end of its life.

Table 44: Routine inspection list for Omnicone crusher

MACHINE: OMNICONE CRUSHER	
Routine monitoring	**DESCRIPTION**
SAFETY	• Ensure all inspections are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. CSS measurement **Approximate labor contribution:** 0.10Hr **Frequency:** Weekly **Plant status**: Running	• **See Jaques Cone Crusher Routine Monitoring**
2. Pinion bearing temperature **Approximate labor contribution:** 0.10Hr **Frequency:** Weekly **Plant status**: Running	• **See Jaques Cone Crusher Routine Monitoring**

Table 45: Routine monitoring list for Omnicone crusher

MACHINE: OMNICONE CRUSHER	
Routine testing	**DESCRIPTION**
SAFETY	• Ensure all inspections are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Motor overload settings **Approximate cost contribution: $**2k **Frequency:** Yearly	• **See Jaques Cone Crusher Routine Testing**
2. Oil sample testing **Approximate cost contribution: $**0.2k **Frequency:** Quarterly	• **See Jaques Cone Crusher Routine testing**

Table 46: Routine testing list for Omnicone crusher

MACHINE: OMNICONE CRUSHER	
Installation list	**DESCRIPTION**
1. Metal detectors **Approximate cost contribution: $**5k	• **See Jaques Cone Crusher Installation list**
2. Chip indictors **Approximate cost contribution: $**2k	• **See Jaques Cone Crusher Installation list**

Table 47: Installation list for Omnicone crusher

MACHINE: OMNICONE CRUSHER	
Operator supervision	**DESCRIPTION**
Ensure that no metallic objects are feed into the plant **Frequency:** Constantly	• **See Jaw Crusher Operator supervision**

Table 48: Operator supervision list for Omnicone crusher

MACHINE: OMNICONE CRUSHER	
Routine maintenance	**DESCRIPTION**
Oil cooler servicing **Frequency:** yearly, before summer	• **See Jaques Cone Crusher Routine Maintenance.**
Oil/filter changes **Frequency:** every 1000 crushing hours.	• **See Jaques Cone Crusher Routine Maintenance**

Table 49: Routine maintenance list for Omnicone crusher

10.4 BARMAC ROTOPACTOR VERTICAL SHAFT IMPACTOR (VSI)

From the FMECA conducted on the Barmac VSI, the recommendations include: routine inspection programs, critical spares, routine maintenance programs, installations, and operator supervision programs.

MACHINE: BARMAC VSI	
Critical Spares List	**DESCRIPTION**
1. Electric motor **Approximate cost:** $ 10k	• 200KW, 3 phase, standard mounting configuration. • Diagnosis and fitting by an electrician.
11. V Belts **Approximate cost:** $0.5k	• At least 6 SPC 6000 belts to be held in inventory
2. Replacement bearing cartridge **Approximate cost**: $5k	• Supplied direct from OEM • Diagnosis and fitting by crusher contractor and maintenance staff

Table 50: Critical spares list for Barmac VSI

MACHINE: BARMAC VSI	
Routine inspections	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. V belt wear/condition/tension **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the V belts, ensure that they are all still present, inspect the underside for cracks, and check the belt tension by pushing on the belt between the longest span of the belt, there should be no more than 20mm of movement in the belt.
2. Lubrication failure **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the entire machine for oil leaks, inspect all oil lines for signs or deterioration, or wear marks. • Check that the oil level is within the specifications • Ensure that if oil needs to be added that the oil, oil container, and the oil cap are all clean before removing to prevent contamination. • Particularly check the pinion seal for oil leaks.
3. Structural fatigue **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect all structural surfaces for signs of cracking, take particular notice of welded joints and mounting areas. Inspect hold down mounting bolts for attachment and tension.
4. Pulley failure **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect both the driven and the driver pulleys for irregularities, like correct mounting, and condition.

Table 51: Routine inspection list for Barmac VSI

MACHINE: BARMAC VSI	
Routine maintenance	**DESCRIPTION**
1. Rotor wear plates **Frequency:** 500 crushing hours	• Replace all rotor wear plates at 500 crushing hour intervals, to prevent, rotor wear and in balance caused by uneven wear. • 500 crushing hour intervals, is based on staff experience, it is matched to the flow rate and the material abrasive characteristics.
3. Bearing cartridge temperature **Approximate labor contribution:** 0.10Hr **Frequency:** Weekly **Plant status**: Running	• Use a thermo gun to check the temperature of the bearing cartridge. Compare the temperature with the last and reading and consider the ambient temperature. If it is running above 90 degrees Celsius there may be a problem. • To further test the condition of the bearing cartridge a Run Down Time test can be performed. Measure the time for the machine to come to a complete stop after pressing the OFF button. If the time is less than 2 minutes there is a bearing problem.

Table 52: Routine Maintenance List for Barmac VSI

MACHINE: BARMAC VSI	
Installation list	**DESCRIPTION**
1. Vibration sensor **Approximate cost contribution: $**5k	• Install a vibration to detect an imbalance failure early, and prevent further damage

Table 53: Installation list for Barmac VSI

MACHINE: BARMAC VSI	
Operator supervision	**DESCRIPTION**
Ensure proper operation **Frequency:** Constantly	• The Barmac should be operated with a current draw of 250A – this is specified by the OEM. • Train operators to watch the output material to watch for faults.

Table 54: Operator supervision list for Barmac VSI (By Author)

10.5 MALCO VIBRATING SCREENS

From the FMECA conducted on the Malco screens, the recommendations include: routine inspection programs, critical spares, installations, maintenance supervision, and operator supervision programs.

MACHINE: VIBRATING SCREENS	
Critical Spares List	**DESCRIPTION**
1. Electric motor **Approximate cost:** $ 2k	• 7.5KW, 3 phase, standard mounting configuration. • Diagnosis and fitting by an electrician.
2. Bearings **Approximate cost**: $5k	• Supplied direct from OEM • Diagnosis and fitting by crusher contractor and maintenance staff
3. Shaft **Approximate cost**: $5k	• Supplied direct from OEM • Diagnosis and fitting by crusher contractor and maintenance staff
4. V belts **Approximate cost**: $0.5k	• At least 6 SPC3000 belts to be held in inventory.
5. Screen mats, side rails and side rail bolts **Approximate cost**: $3k	• All sized used throughout the plant to be held in inventory

Table 55: Critical spares list for Malco vibrating screen

MACHINE: VIBRATING SCREENS	
Routine inspections	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. V belt wear/condition/tension **Approximate labor contribution:** 0.05Hr/screen **Frequency:** Daily **Plant status:** Not running	• Inspect the V belts, ensure that they are all still present, inspect the underside for cracks, and check the belt tension by pushing on the belt between the longest span of the belt, there should be no more than 20mm of movement in the belt.
2. Screen media condition **Approximate labor contribution:** 0.005Hr/screen **Frequency:** Daily	• Inspect the screen mats for each deck, check for hole, blockages, and screen wear. Inspect the side rails for wear. Check that the heads of the side rail bolts are not worn down to far that they may

Plant status: Not running	pull through the side rail and allow the screen mat to become lose.
3. Structural fatigue **Approximate labor contribution:** 0.1Hr/screen **Frequency:** Daily **Plant status:** Not running	• Inspect all structural surfaces for signs of cracking, take particular notice of welded joints and mounting areas. Inspect hold down mounting bolts for attachment and tension.

Table 56: Routine inspection list for Malco vibrating screen

MACHINE: VIBRATING SCREENS	
Routine maintenance	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Bearing lubrication **Approximate labor contribution:** 0.5hr for all **Frequency:** Bi daily **Plant status:** Not running	• Apply lubrication to the screen bearings. Apply 5grams of EP2 grease to each bearing
2. Bearing temperature checks **Approximate labor contribution:** 0.5hr for all **Frequency:** Weekly **Plant status:** Running	• Use a temperature gun to check the temperature of each bearing and record. If the bearing temperature is greater than 60 degrees Celsius, there is a problem, that requires further investigation. • Conduct an audio inspection on each bearing. Make note of irregularities
3. Housekeeping **Approximate labor contribution:** 0.25hr for all **Frequency:** daily **Plant status:** Not running	• Enforce housekeeping throughout the plant area, this would include: under tail drums, walkways, structural feet, screen interference.
4. Screen media	• Collect data on the time to failure for each particular screen deck. • Change screen decks as the information found. • Start a screen log, which details when each screen was last changed.

Table 57: Routine maintenance list for Malco vibrating screen

MACHINE: VIBRATING SCREENS	
Operator supervision	**DESCRIPTION**
1. Ensure proper operation **Frequency:** Constantly	• Train operators to watch the output material to watch for contamination of larger rocks that the screened size.

Table 58: Operator supervision list for Malco vibrating screen

MACHINE: VIBRATING SCREENS	
Maintenance supervision	**DESCRIPTION**
1. Ensure proper fitting of screen mats **Frequency:** Constantly	• Train workers to ensure that the side rails are correctly bottomed out in the mating shape of the screen mat, to prevent the screen from working loose. • Ensure that the side rail bolts are tight.

Table 59: Maintenance supervision list for Malco vibrating screen

MACHINE: VIBRATING SCREENS	
Routine testing	**DESCRIPTION**
1. Lubrication sampling **Frequency:** 6 monthly	• Take a sample of the lubrication and test for metal content.

Table 60: Routine testing list for Malco vibrating screen

MACHINE: VIBRATING SCREENS	
Installation list	**DESCRIPTION**
1. Peak vibration sensor **Approximate cost contribution:** 2K	• A screen has a high vibration under normal conditions, but if a peak vibration sensor is fitted it may detect if a fault has occurred.

Table 61: Installation list for Malco vibrating screen

10.6 MATERIAL HANDLING CONVEYORS

From the FMECA conducted on material handling conveyors, the recommendations include: routine inspection programs, routine maintenance program, critical spares, installations, housekeeping, maintenance supervision, and operator supervision programs.

MACHINE: MATERIAL HANDLING CONVEYORS	
Critical Spares List	**DESCRIPTION**
1. Electric motor **Approximate cost:** $ 2k	• 30KW, 15KW X 2, 11.5KW X 3, 7.5KW X 2, 5KW, 3 phase, standard mounting configuration. • Diagnosis and fitting by an electrician.
2. Head and tail drum bearings **Approximate cost**: $5k	• Supplied direct from SKF • Diagnosis and fitting by maintenance staff
3. Speed reducing gearboxes **Approximate cost**: $5k	• Supplied direct from preferred supplier • Diagnosis and fitting by maintenance staff
4. V belts **Approximate cost**: $2k	• A selection of the required belts are necessary
5. Head and tail drums **Approximate cost**: $3k	• All sizes used throughout the plant to be held in inventory

Table 62: Critical spares list for Material handling conveyors

MACHINE: MATERIAL HANDLING CONVEYORS	
Routine inspections	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. V belt wear/condition/tension **Approximate labor contribution:** 0.05Hr/conveyor **Frequency:** Daily **Plant status:** Not running	• Inspect the V belts, ensure that they are all still present, inspect the underside for cracks, and check the belt tension by pushing on the belt between the longest span of the belt, there should be no more than 20mm of movement in the belt. • Also inspect the V belt alignment. Check that the belt is running straight and there does seem to be a fault with the taper lock, which holds the pulley to the shaft.
2. Screen media condition	• Inspect the screen mats for each deck,

Approximate labor contribution: 0.05Hr/ conveyor **Frequency:** Daily **Plant status:** Not running	check for hole, blockages, and screen wear. Inspect the side rails for wear. Check that the heads of the side rail bolts are not worn down to far that they may pull through the side rail and allow the screen mat to become lose.
3. Structural fatigue **Approximate labor contribution:** 0.1Hr/ conveyor **Frequency:** Daily **Plant status:** Not running	• Inspect all structural surfaces for signs of cracking, take particular notice of welded joints and mounting areas. Inspect hold down mounting bolts for attachment and tension.
4. All guarding **Approximate labor contribution:** 0.1Hr/ conveyor **Frequency:** Daily **Plant status:** Not running	• Inspect all guarding for condition and correct attachment. • Check that there is not material build up on the inside of the guard, which may damage the belt.
5. Roller operation **Approximate labor contribution:** 0.5Hr/ conveyor **Frequency:** Daily **Plant status:** Running	• Inspect that all trough rollers are operational, by carefully walking beside all conveyors and visually inspecting. If a roller is found to be faulty, tag the roller for replacement, and organize for this to happen after shut down.
6. Scrapper adjustment **Approximate labor contribution:** 0.1Hr/conveyor **Frequency:** Daily **Plant status:** Not running	• Inspect all belt scrappers, check that they are in good condition and are making good contact with the conveyor belt. • Check that there are no rocks jammed in the scrapper segments.

Table 63: Routine inspection list for Material handling conveyors

MACHINE: MATERIAL HANDLING CONVEYORS	
Routine maintenance	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Bearing lubrication **Approximate labor contribution:** 0.5hr for all **Frequency:** Weekly **Plant status:** Not running	• Apply lubrication to the head and tail drum bearings of all conveyors. Apply 5grams of EP2 grease to each bearing
2. Bearing temperature checks	• Use a temperature gun to check the temperature of each bearing and record. If

Approximate labor contribution: 0.5hr for all **Frequency:** Weekly **Plant status:** Running	the temperature is greater than 60 degree Celsius there is a problem that requires further investigation. • Conduct an audio inspection on each bearing. Make note of irregularities
3. Head and tail roller bearing replacement **Approximate labor contribution:** 2-3hr for 1 bearing **Frequency:** Bi yearly **Plant status:** Not running	• Replace head and tail drum bearings at scheduled intervals, provided no evidence of failure is found first. • Data must be collected first to set the schedule up, but the interval will be approximately bi yearly.
4. Belt recommended replacement interval	• Research, and collect data on how long each particular belt lasts in its application. • Once data is collected, change belt on interval.
5. Housekeeping	• Enforce housekeeping through the plant area, this would include: under tail drums, walkways, structural feet.

Table 64: Routine maintenance list for Material handling conveyors

MACHINE: MATERIAL HANDLING CONVEYORS	
Installation list	**DESCRIPTION**
1. Limit switches on belt weighers **Approximate cost contribution:** 2K	• Limit switches on conveyors to either stop the feed to the conveyor that is reading a heavy weight, or to stop the conveyor.
2. Thermal overloads on electric motor **Approximate cost contribution:** 5K	• Thermal overloads on electric motors, to indicate when the motor is running hot. When the motor is running hot it is an indication of motor condition.

Table 65: Installation list for Material handling conveyors

10.7 MATERIAL HANDLING TRANSFER POINTS

From the FMECA conducted on material handling transfer points, the recommendations include: routine inspection programs, routine maintenance program, maintenance supervision, and installations/engineering judgment.

MACHINE: MATERIAL HANDLING TRANSFER POINTS	
Installation list	**DESCRIPTION**
1. Side skirt rubber **Approximate cost contribution:** 0.5K	• A role of side skirt rubber needs to be held in inventory at all times.

Table 66: Critical spares list for Material handling transfer points

MACHINE: MATERIAL HANDLING TRANSFER POINTS	
Routine inspection	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE. • Works carried out by maintenance staff
1. Side skirts **Approximate labor contribution:** 0.15 Hr/trans p. **Frequency:** Daily **Plant status:** Not running	• Inspect all side skirts, for condition and belt contact. If the side skirt is not contacting the belt, adjust it, by releasing the side clamps, pushing the rubber down and tightening the side clamps again. If the side skirt is in bad condition, replace it; using the same sequence as when adjusting the side skirt • Works carried out by maintenance staff
2. Wear liners **Approximate labour contribution:** 0.15 Hr/trans p. **Frequency:** Weekly **Plant status:** Not running	• Inspect the transfer point wear liners. Check that they are attached correctly and are not excessively worn. Excessive wear will be evident when the wear plate has thin sections in it. • Collect data on wear liner replacement intervals, and create a log to predetermine the wear. • Works carried out by maintenance staff
3. Blockages	• Inspect all transfer points for material build up which may lead to a blockage during the day. If so remove with appropriate tooling. • Works carried out by maintenance staff

Table 67: Routine inspection list for Material handling transfer points

MACHINE: MATERIAL HANDLING TRANSFER POINTS	
Maintenance supervision	**DESCRIPTION**
1. Side skirts **Approximate labor contribution:** 0.15 Hr/trans p. **Frequency:** Daily **Plant status:** Not running	• It may the case that side skirts need to be adjusted at least once a week. So for this reason, workers may get complacent, so ensure that all side clamp bolts are correctly tensioned, and that side skirts are fitted properly

Table 68: Maintenance supervision list for Material handling transfer points

MACHINE: MATERIAL HANDLING TRANSFER POINTS	
Routine maintenance	**DESCRIPTION**
1. Wear plate replacement **Approximate labor contribution:** 3Hr/plate **Frequency:** Scheduled **Plant status:** Not running	• **See Routine Inspections Material Handling Transfer Points**

Table 69: Routine maintenance list for Material handling transfer points

MACHINE: MATERIAL HANDLING TRANSFER POINTS	
Installation list	**DESCRIPTION**
1. Limit switches in prone blockage areas **Approximate cost contribution:** 2K	• Limit switches inside the transfer points, that constantly block, strategically placed to indicate if a blockage is about to occur, so that the plant can be stopped and the material removed without causing damage to the belt.
2. Structural enhancements **Approximate cost contribution:**	• Conduct an audit on the structural members of the transfer points, to identify unsound components.
3. Redesign problem transfer points	• Redesign transfer points that may be causing blockages.

Table 70: Installation list for Material handling transfer points

10.8 MATERIAL HANDLING CHUTES

From the FMECA conducted on material handling chutes, the recommendations include: routine inspection programs, routine maintenance program, maintenance supervision, and installations/engineering judgment.

MACHINE: MATERIAL HANDLING CHUTES	
Routine inspection	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Wear liners **Approximate labour contribution:** 0.15 Hr/trans p. **Frequency:** Weekly **Plant status:** Not running	• **See Material Handling Transfer Points, routine inspections.**

Table 71: Critical spares list for Material handling chutes

MACHINE: MATERIAL HANDLING CHUTE	
Routine maintenance	**DESCRIPTION**
1. Wear plate replacement **Approximate labor contribution:** 3Hr/plate **Frequency:** Scheduled **Plant status:** Not running	• **See Material Handling Transfer Points Routine inspections**

Table 72: Routine maintenance list for Material handling chutes

MACHINE: MATERIAL HANDLING CHUTES	
Installation list	**DESCRIPTION**
1. Limit switches in prone blockage areas **Approximate cost contribution:** 2K	• **See Material Handling Transfer Points, Installations list**
2. Structural enhancements **Approximate cost contribution:**	• **See Material Handling Transfer Points, Installations list**
3. Redesign problem transfer points **Approximate cost contribution:**	• **See Material Handling Transfer Points, Installations list**

Table 73: Installation list for Material handling chutes

10.9 16 AGGREGATE STORAGE BINS AND THE SURGE BIN

From the FMECA conducted on the aggregate storage bins and the surge bin, the recommendations include: maintenance supervision programs, routine inspection programs, routine maintenance programs and installations/engineering judgment.

MACHINE: AGGREGATE STORAGE BINS AND SURGE BIN	
Maintenance supervision	**DESCRIPTION**
1. Fitting **Approximate labor contribution:** **Frequency:** Daily **Plant status:** Not running	• Ensure that all fitting works are carried out correctly: all fasteners are in place and are all secure.

Table 74: Maintenance supervision list for aggregate storage bins and surge bin

MACHINE: AGGREGATE STORAGE BINS AND SURGE BIN	
Routine inspection	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Wear liners **Approximate labor contribution:** 0.15 Hr/trans p. **Frequency:** Weekly **Plant status:** Not running	• **See Material Handling Transfer Points, routine inspections.**

Table 75: Routine inspection list for aggregate storage bins and surge bin

MACHINE: AGGREGATE STORAGE BINS AND SURGE BIN	
Routine maintenance	**DESCRIPTION**
1. Wear plate replacement **Approximate labor contribution:** 3Hr/plate **Frequency:** Scheduled **Plant status:** Not running	• **See Routine Inspections Material Handling Transfer Points**

Table 76: Routine maintenance list for aggregate storage bins and surge bin

MACHINE: AGGREGATE STORAGE BINS AND SURGE BIN	
Installation list	**DESCRIPTION**
1. Limit switches in prone blockage areas **Approximate cost contribution:** 2K	• **See Material Handling Transfer Points, Installations list**
2. Structural enhancements **Approximate cost contribution:**	• **See Material Handling Transfer Points, Installations list**
3. Redesign problem transfer points **Approximate cost contribution:**	• **See Material Handling Transfer Points, Installations list**

Table 77: Installation list for aggregate storage bins and surge bin

10.10 AGGREGATE BIN LEVEL SENSORS

From the FMECA conducted on the aggregate bin level sensors, the recommendations include: critical spares. Since the system is electrical the serviceability is reduced. The wirering has been designed so that if a tilt level sensor fails, a new one can be fitted by plugging a new sensor into an ordinary power socket

MACHINE: AGGREGATE BIN LEVEL SENSORS	
Critical Spares List	**DESCRIPTION**
1. Tilt level sensors **Approximate cost:** $ 0.5k each	• Supplied by electrician. • Diagnosis and fitting by an electrician.

Table 78: Critical spares list for aggregate bin level sensors

10.11 AGGREGATE BIN GATE OPENING SYSTEM

From the FMECA conducted on the aggregate bin gate opening system the recommendations include: critical spares, routine inspection programs, and routine maintenance programs.

MACHINE: AGGREGATE BIN GATE OPENING SYSTEM	
Critical Spares List	**DESCRIPTION**
1. 10mm quick release air fittings and 10mm air line **Approximate cost:** $ 0.5k	• Supplied by preferred supplier. • Diagnosis and fitting by maintenance staff.
2. DCV **Approximate cost:** $ 1k each	• Supplied, diagnosed and fitted by electrician.

Table 79: Critical spares list for aggregate bin gate opening system

MACHINE: AGGREGATE BIN GATE OPENING SYSTEM	
Routine inspection	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Transmitter **Approximate labor contribution:** 0.15 Hr/trans **Frequency:** Quarterly **Plant status:** Not running	• Carried out by the electrician in accordance with the OEM. The entire system was designed, supplied and fitted by the electrician, and therefore has the required data.
2. Receiver **Approximate labor contribution:** 0.15 Hr/recei **Frequency:** Quarterly **Plant status:** Not running	• **See receiver routine inspections.**
3. Actuating cylinder **Approximate labor contribution:** 0.15 Hr/cylinder, including the cylinder mount inspection which would be concurrently. **Frequency:** Monthly **Plant status:** Not running	• Inspect the cylinder ram for surface material defects, like chips. • Inspect the ram dust seal for condition. • Inspect the exhaust breather, check that it is not blocked.
4. Cylinder mounts See actuating cylinder inspection details	• Inspect the cylinder mount condition; check that there are no cracks forming in the adjoining welds.

Table 80: Routine inspection list for aggregate bin gate opening system

MACHINE: AGGREGATE BIN GATE OPENING SYSTEM	
Routine maintenance	**DESCRIPTION**
1. DCV **Approximate labor contribution:** 0.2hr/DCV **Frequency:** Scheduled **Plant status:** Not running	• Routine maintenance carried out by the electrician.

Table 81: Routine maintenance list for aggregate bin gate opening system

10.12 AGGREGATE BIN TRUCK

From the FMECA conducted on the bin truck, the recommendations include: critical spares. Due the lack serviceability of the bin truck by staff, the entire truck is recommended as a critical spare.

MACHINE: AGGREGATE BIN TRUCK	
Critical Spares List	**DESCRIPTION**
1. Operational bin truck **Approximate cost:** $ Maintenance costs.	• Hold a complete operational bin truck in critical spares. It is a feasible option as bin trucks are transport truck that have been taken off the road and therefore come at no capital cost.

Table 82: Critical spares list for aggregate bin truck system

10.13 DUST SUPPRESSION SYSTEM

From the FMECA conducted on the dust suppression system, the recommendations include: critical spares, routine inspection program and routine maintenance program.

MACHINE: DUST SUPPRESSION SYSTEM	
Critical Spares List	**DESCRIPTION**
1. Water pump and electric motor assembly **Approximate cost:** $ 2k	• Hold an electric motor and pump in inventory. • Supplied by preferred supplier. • Fitted by electrician.
2. Water pipe and fittings **Approximate cost:** $ 1k	• 75mm poly pipe and fittings to suits.

Table 83: Critical spares list for dust suppression system

MACHINE: DUST SUPPRESSION SYSTEM	
Routine inspection	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Water pipes, connections and storage tank. **Approximate labor contribution:** 1 Hr **Frequency:** Monthly **Plant status:** Running	• Inspect all water lines and fittings for leaks and damage.. • Inspect the water tank for holes, leaks, or damage to its exterior walls.

Table 84: Routine inspection list for dust suppression system

MACHINE: DUST SUPPRESSION SYSTEM	
Routine maintenance	**DESCRIPTION**
1. Water pump and water filter **Approximate labor contribution:** 0.25hr **Frequency:** Scheduled **Plant status:** Not running	• Clean the water filter at regular intervals, and replace the water filter at regular intervals. Clean: Weekly, Replace: Monthly.
2. Water pump **Approximate labor contribution:** 2hr **Frequency:** Scheduled **Plant status:** Not running	• Dismantle the water pump, clean the impeller, and possibly replace the shaft bearings at regular intervals. • Replace water pump at regular intervals.

Table 85: Routine maintenance list for dust suppression system

10.14 COMP AIR HYDRAULIC ROCK BREAKER.

From the FMECA conducted on the rock breaker, the recommendations include: critical spares, routine inspection program routine maintenance program, and installations.

MACHINE: COMP AIR ROCK BREAKER	
Critical Spares List	**DESCRIPTION**
1. Electric motor **Approximate cost:** $ 3k	• Hold an electric motor in inventory. • Diagnosed, supplied and fitted by electrician.
2. Rock breaker attachment **Approximate cost:** $ 7k	• Hold a complete rock breaker attachment in inventory or a spares kit.
3. Prone Hydraulic lines **Approximate cost:** $ 0.5k	• Hold in inventory spare hydraulic lines, that are prone to defects by operation.
4. Hydraulic pump **Approximate cost:** $ 1k	• Hold in inventory a hydraulic pump, or spares kit

Table 86: Critical spares list for Comp Air rock breaker

MACHINE: COMP AIR ROCK BREAKER	
Routine inspection	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Hydraulic system **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Inspect the oil level, using the sight glass, ensure that the oil level is within the marked specifications. • Inspect all oil lines for leaks and damage. • Inspect the hammer for oil leaks

Table 87: Routine inspection list for Comp Air rock breaker

MACHINE: COMP AIR ROCK BREAKER	
Routine maintenance	**DESCRIPTION**
1. Oil and oil filter changes **Approximate labor contribution:** 1hr **Frequency:** Scheduled **Plant status:** Not running	• Change the hydraulic oil filter at scheduled intervals.
2. Oil cooler **Approximate labor contribution:** 2hr **Frequency:** Scheduled **Plant status:** Not running	• Remove and clean the oil cooler at scheduled intervals.

Table 88: Routine maintenance list for Comp Air rock breaker

MACHINE: COMP AIR ROCK BREAKER	
Installation list	**DESCRIPTION**
1. Chip indicators **Approximate cost contribution:** $1K	• Install chip indicators into the hydraulic system, to indicator an internal failure in the hydraulic system.
2. Flow switch **Approximate cost contribution:** $1k	• Install a flow switch in the hydraulic system to indicate when there is low oil flow.

Table 89: Installation list for Comp Air rock breaker

10.15 ATLAS COPCO AIR COMPRESSOR.

From the FMECA conducted on the air compressor, the recommendations include: routine inspection program routine maintenance program. The air compressor is unserviceable by staff, and is maintained using scheduled maintenance set by the Original Equipment Manufacturer (OEM), with the works carried by the OEM.

MACHINE: ATLAS COPCO AIR COMPRESSOR	
Routine inspection	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. General system **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Not running	• Walk around the air compressor and inspect the machine. Look for any irregularities like: oil leaks, water leaks, air leaks, loose bolts, guards in place etc.
2. Air lines **Approximate labor contribution:** 0.1Hr **Frequency:** Daily **Plant status:** Running	• Inspect all air lines for leaks and damaged piping.

Table 90: Routine inspection list for Atlas Copco air compressor

10.16 STRUCTURAL FRAMING

From the FMECA conducted on the structural framing, the recommendations include routine inspection program, and routine housekeeping.

MACHINE: STRUCTURAL FRAMING	
Routine inspection	**DESCRIPTION**
SAFETY	• Ensure all inspections and operations are carried out safely. Lock Out Tag Out where necessary, wear the appropriate PPE.
1. Structural joints **Approximate labor contribution:** 1Hr **Frequency:** Monthly **Plant status:** Not running	• Inspect all structural joints. Ensure that there are no signs of corrosion, cracks, and that all mounting bolts are secure.
2. Excessive vibration **Approximate labor contribution:** 1Hr **Frequency:** Monthly **Plant status:** Running	• Inspect the plant for excessive vibrations by walking all components while the plant is running.
3. Firefighting equipment in place. **Approximate labor contribution:** 1Hr **Frequency:** Monthly **Plant status:** Running	• Conduct an audit to ensure that all fire extinguishers are in place.

Table 91: Routine inspection list for structural framing

MACHINE: STRUCTURAL FRAMING	
Routine house keeping	**DESCRIPTION**
1. Remove material spillage from walkways **Approximate labor contribution:** 1Hr **Frequency:** Daily **Plant status:** Running	• Remove all material spillage from walkways to prevent trip hazards.
2. Remove material from structural frame hold down plates. **Approximate labor contribution:** 1Hr **Frequency:** Daily **Plant status:** Running	• Remove all material build up from the structural frame hold down plates to prevent accelerated corrosion.

Table 92: Routine inspection list for structural framing

10.17 ELECTRICS

From the FMECA conducted on the plant electrics, the recommendations include routine inspection program, and critical spares. Electricians will be consulted for critical spares

MACHINE: ELECTRIC SYSTEM	
Critical Spares List	**DESCRIPTION**
1. Switches, fuses, and starters **Approximate cost:** $ 2k	• Liaise with the electrician to hold in the suppliers inventory, critical spares of the required sizes.

Table 93: Critical spares list for electrics

MACHINE: ELECTRIC SYSTEM	
Routine maintenance	**DESCRIPTION**
1. Electrical system **Approximate labor contribution:** On going. **Frequency:** Scheduled **Plant status:** Not running	• Liaise with the electrician to develop a suitable maintenance program from the electrical system

Table 94: Routine maintenance list for electrics

11. CONCLUSIONS

An aim was developed to reduce the unscheduled downtime of the crushing and screening plant at the BORAL Quarry site at Ormeau. Unscheduled downtime being undesirable due to the lost of profits accumulated while the plant is down, and the prospect of running out of material during a major construction job that BORAL is suppling. To try to reduce the unscheduled downtime figure it was decided to undertake an FMECA process on the entire plant. The FMECA, or Failure Mode, Effect and Criticality Analysis, is a simple systematic procedure to preventing failures, predicting failures, identifying problems, helping to plan maintenance, and helping to develop measures to quickly repair failures by having the required parts, and staff knowledge to be able to do some of the repairs.

The first step in the FMECA process was to review the current plant downtime data, it revealed some problem machines, which were identified by large downtime contributions of the downtime graphs. This helped in evaluating the 'Frequency of Failure' in the FMECA. The next step was to define the entire plant requirements, which included, the regulations that it must operate within, the expected system performances, and what constitutes a failure for this plant. It was decided that a 25% loss in production constitutes a failure. The next step in the FMECA process was to study and define the plant. This identified that all machines were on the critical production path and that no machine could fail and still allow the plant to produce. This piece of information is proportional to the 'severity' rating used in the FMECA. Any complete system failing will result in the plants full loss of production and therefore has a high severity. The next step was to understand the operation of each machine. This entailed a detail study into every component of the plant process. This understanding of the machines used allowed the next step, which was to develop functional diagrams. The functional diagrams showed if there were any dependencies with in a machine. What could fail and still allow the machine to run and further the plant process. There were not a lot of component that could fail and still allow the plant to function, all components were identified and stated in chapter 6.

This information was useful to determine what could possibly fail, and the severity of a failure.

It was decided that the items of evaluation for each failure would include: frequency of occurrence, severity, detection, and an RPN. It was necessary to develop ground rules for the FMECA, to obtain consistency across the report. The evaluation process relied on engineering judgment, experience, downtime data, critical path analysis, dependency analysis, and knowledge of the plant. After the RPN was calculated, recommendations were made to combat that particular failure. Some recommendations include: routine inspection programs, routine maintenance programs, maintenance supervision programs, operator supervision programs, critical spares, installations, and many more.

The recommendations were expanded to give particular details. The recommendations could be implemented by staff to improve plant maintenance. An estimate as to how long an action may take and the frequency works.

The FMECA process was conducted on the crushing and screening plant at Ormeau. Recommendations were made and implementation instruction were given. Therefore a process has been undertaken and applied to a real situation.

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APPENDIX A – PROJECT SPECIFICATION

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

TOPIC: CONDUCT A F.M.E.C.A ON MAOJOR EQUIPMENT OF THE CRUSHING AND SCREENING PLANT AT WEST BURLEIGH

SUPERVISOR: CHRIS SNOOK

ENROLMENT: ENG 4111 – S1, X, 2009
ENG 4112 – S2, X, 2009

PROJECT AIM: Boral has undertaken limited prior research into the FMECA of individual plant equipment in their crushing and screening plants throughout South East Queensland. It is the objective of this project to build on this knowledge base and expand the FMECA to incorporate the entire crushing and screening process at the West Burleigh site.

SPONSORSHIP: SOUTH EAST QUEENSLAND (SEQ) BORAL QUARRIES

PROGRAMME

1. Critical literature review of the F.M.E.C.A technique.
2. Review SEQ Quarries downtime data
3. Review prior research.
4. Interview management, maintenance and operational staff.
5. Review BORAL industrial equipment at the West Burleigh site
6. Implement the F.M.E.C.A.
7. Propose recommendation based on the FMECA, suitable for the BORAL staff to implement.
8. Analysis and discussion of possible improvements.

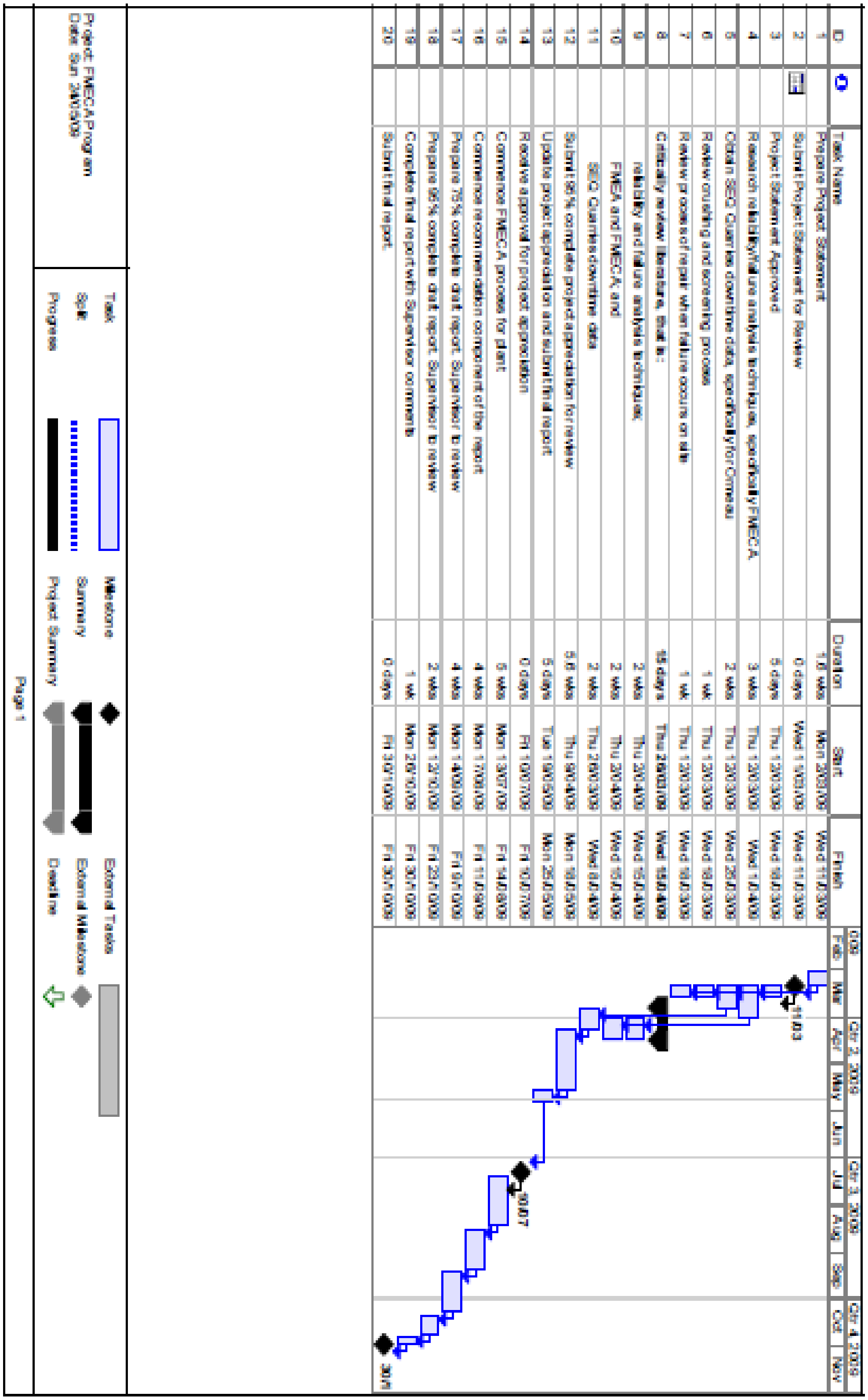
AGREED:

________________________________(Student)
________________________________(Supervisor)

DATE: / /2009 DATE: / /2009

Examiner/Co-examiner____

APPENDIX B – PROJECT PROGRAMME



ID	Task Name	Duration	Start	Finish
1	Prepare Project Statement	1.6 wks	Mon 2/03/09	Wed 11/03/09
2	Submit Project Statement for Review	0 days	Wed 11/03/09	Wed 11/03/09
3	Project Statement Approved	5 days	Thu 12/03/09	Wed 18/03/09
4	Research reliability/failure analysis techniques, specifically FMECA	3 wks	Thu 12/03/09	Wed 1/04/09
5	Obtain SEQ Quarries downtime data, specifically for Ormeau	2 wks	Thu 12/03/09	Wed 25/03/09
6	Review crushing and screening process	1 wk	Thu 12/03/09	Wed 18/03/09
7	Review process of repair when failure occurs on site	1 wk	Thu 12/03/09	Wed 18/03/09
8	Critically review literature, that is:	15 days	Thu 26/03/09	Wed 15/04/09
9	reliability and failure analysis techniques;	2 wks	Thu 2/04/09	Wed 15/04/09
10	FMEA and FMECA; and	2 wks	Thu 2/04/09	Wed 15/04/09
11	SEQ Quarries downtime data	2 wks	Thu 26/03/09	Wed 8/04/09
12	Submit 95% complete project appreciation for review	5.6 wks	Thu 9/04/09	Mon 18/05/09
13	Update project appreciation and submit final report	5 days	Tue 19/05/09	Mon 25/05/09
14	Receive approval for project appreciation	0 days	Fri 10/07/09	Fri 10/07/09
15	Commence FMECA process for plant	5 wks	Mon 13/07/09	Fri 14/08/09
16	Commence recommendation component of the report	4 wks	Mon 17/08/09	Fri 11/09/09
17	Prepare 75% complete draft report. Supervisor to review	4 wks	Mon 14/09/09	Fri 9/10/09
18	Prepare 95% complete draft report. Supervisor to review	2 wks	Mon 12/10/09	Fri 23/10/09
19	Complete final report with Supervisor comments	1 wk	Mon 26/10/09	Fri 30/10/09
20	Submit final report	0 days	Fri 30/10/09	Fri 30/10/09

APPENDIX C – PROJECT RISK REGISTER

FMECA - Crushing and Screening Plant

Date risk register last reviewed: 13-May-09 **Risk register prepared by: Simon Jeffery**

PROJECT RISK REGISTER - Section 1

1. Risk Category	2. Risk Description Details	3. Likelihood		4. Consequence		5. Risk Factor		6. Risk Treatment		7. Responsibility
						See Comment		Strategy	Detail of Treatment	
Quality	Not receiving approval for project statement	Unlikely	0.20	Major	0.70	0.76	High	Retain & Manage	* Submit statement to supervisor for early approval. * Seek early feedback * Amend statement as necessary	Simon Jeffery
Quality	Not finding adequate information on FMECA	Rare	0.05	Major	0.70	0.72	Medium	Retain & Manage	* Commence research early * Undertake broad research e.g professional magazines, standards and resource books	Simon Jeffery
Quality	Not finding adequate information on quarry performance	Unlikely	0.20	Major	0.70	0.76	High	Retain & Manage	* Liase with quarry management and maintenance staff early. * Seek training for use of Boral data base	Simon Jeffery & Neil Bellamy (Quarry Manager)
Stakeholder	Inability to review failure mode and repair process at Boral quarry	Rare	0.05	Moderate	0.50	0.53	Low	Retain & Manage	* Have active role in day to day running of plant * Provide assistance during repair process * Assist in failure detection	Simon Jeffery & Neil Bellamy (Quarry Manager)
Safety	Possible injury during site observation	Unlikely	0.20	Catastrophic	0.95	0.96	High	Reduce likelihood & consequence	* Observe Qurry safety management plan and safe work method statements * Undertake Quarry induction * Wear required personal protective equipment * Undertake any required training	Simon Jeffery & Safety Manager
Communication	Not receiving timely feedback from supervisor	Moderate	0.50	Moderate	0.50	0.75	High	Retain & Manage	* Submit required information promptly * Submit any questions in a clear and concise format * Follow up any outstanding queries, comments, actions	Simon Jeffery & Supervisor (Chris Snook)
Time	Not completing assignment on time	Rare	0.05	Catastrophic	0.95	0.95	High	Retain & Manage	* Creat project delivery timeline and review performance continually * Allow sufficient float * Allow sufficient time for assistance and review periods	Simon Jeffery
Quality	Not completing assignment to a acceptable quality	Unlikely	0.20	Catastrophic	0.95	0.96	High	Retain & Manage	* Obtain adequate resources * Seek expert input and review * Allow sufficient time and resources	Simon Jeffery

APPENDIX D – DAILY CRUSHING DATA SHEET

LOCATION ____________ DATE ____________

PRODUCTION RUN				RAW FEED TYPE		NOTES
MODE	START	STOP	TONNES	WET		
				DRY		
				FINE		
				MEDIUM		
				COARSE		

DOWNTIME						
Reason #	Equipment (where)	Stoppage Start	Stoppage End	Planned	Unplanned	Total Mins
				Total Minutes Downtime		

#	Reason	Planned	Unplanned	Type
1	General Maintenance	✓	✓	Equipment
2	Crusher	✓	✓	Equipment
3	Conveyors	✓	✓	Equipment
4	Screens	✓	✓	Equipment
5	Clean-up	✓	✓	Equipment
6	Bin Hoppers	✓	✓	Equipment
7	Feeders	✓	✓	Equipment
8	Plant Change	✓	✓	Equipment
9	Electrical/ Process Control	✓	✓	Equipment
10	Pumps & Systems	✓	✓	Equipment
11	Metal Detector Trip		✓	Equipment
13	Electricity Supply	✓	✓	Equipment
14	Other Equipment Downtime	✓	✓	Equipment
15	Meetings	✓	✓	Process
16	Meal Breaks	✓	✓	Process
17	Early Finishes	✓	✓	Process
18	Pre-start Checks	✓	✓	Process
19	Shot Firing	✓		Process
20	Staff Shortages	✓	✓	Process
21	OH&S Issue		✓	Process
22	Raw Feed Delay		✓	Process
23	Blockages		✓	Process
24	Oversize Delays		✓	Process
25	Spillage		✓	Process
26	Weather Delays		✓	Process
27	Statutory Limits		✓	Process
28	Other Process Downtime	✓	✓	Process
30	Bin Levels		✓	Process
31	Production ramp down	✓		Process
32	Nil Surge		✓	Process