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OPTIMISING PRODUCTION TIME OF CONTINUOUS MINERS AT GOEDEHOOP COLLIERY

by

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Executive Summary

Anglo American and the rest of the mining landscape are confronted with a number of challenges such as the depressed economy and the relatively low selling price of coal. These affect profit margins. Anglo American changed its normal way of doing business by the implementation of the Asset Optimisation Programme. Major efforts focus on the optimisation and sustainability of the corporation's resources, employees and equipment.

The Continuous Miner (CM) is the most critical component in the underground coal mining process. An underground production section can only produce output if the CM is performing its primary function, namely to cut coal. In 2012, Goedehoop colliery's CMs operated only 35% of the total time available, and the colliery aims to improve it to 40%. The aim of the project is to improve the production time of the CMs at Goedehoop colliery.

The Six Sigma DMAIC (Define, Measure, Analyse, Improve and Control) methodology was used as an approach to structure the project. The aim of the project was addressed by means of critical analysis together with other supplementary tools and techniques.

Key Performance Indicators (KPIs) that had the most significant impact on the production time of the CMs were identified. It was identified that trunk conveyor downtime has a significant impact on the throughput of the process, as well as on the production time of the CMs. Solutions were proposed that will potentially improve and solve major causes of trunk conveyor downtime.

It was estimated that a total of 162.88 hours (per year) on trunk conveyor downtime can possibly be reduced if the proposed solutions had to be implemented. This would result in a potential benefit of R 8 417 107.29 per year for Goedehoop colliery. In view of the initial project aim, this will equate to a potential 1.5% improvement in the production time of the CMs

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List of terms and definitions

Variable: A variable is a factor that is subject to change. A variable is inconsistent and does not have a fixed pattern.

Independent variables: When the variation of the variables do not depend on another.

Dependent variables: A dependent variable's value depends on one or more variables.

Correlation: A measurement of relations between two or more variables.

Manifest variables: Variables measured by measurement tools.

Latent variables: Also known as non-measurable variables.

Treatment(s): Combination(s) of factor levels whose effect is compared to other treatments.

Key Performance Indicators (KPIs): Quantifiable measurements used by an organisation which reflect its critical success factors. Key Performance Indicators are measures of performance, aligned with the organisation's goals and targets. KPIs are usually long term considerations. What they are and how they are measured do not usually change.

List of abbreviations

AATC	Anglo American Thermal Coal
ANOVA	Analysis of Variance
CM	Continuous Miner
Cp	Process capability
DCHT	Chutes blocked
DMAIC	Define, Measure, Analyse, Improve and Control
dpm	defects per million
ECSS	Conveyor stop start
ELEC	Electrical unscheduled maintenance
EPUL	Pull key electrical
GDP	Gross Domestic Product
KPI	Key Performance Indicator
LOTC	Consequential trunk conveyor
LOUN	Consequential unit
MECH	Mechanical unscheduled maintenance
OBLO	Production stoppage due to blockage
OCBT	Conveyor tail end stuck
OPLL	Pull key pulled
OREP	Unscheduled production stoppage
ORJC	Conveyor belt joint
ORSC	Conveyor reset
PCA	Principal Component Analysis
Ppk	Process performance index
ROM	Run of Mine
SEM	Structural Equation Modelling
SIPOC	Suppliers, Inputs, Process, Outputs and Customers
SPC	Statistical Process Control
tLtB	the Lower the Better
VMP	Vehicle Management Plan

1. DEFINE

1.1. Introduction

1.1.1. The industry

Coal mining evolved during the Industrial Revolution based on the need to power steam engines. Since then coal has been a major energy source for power generation world-wide. Compared to other energy sources, such as liquid fuels and natural gas, coal became the dominant and cheapest source of energy in South Africa (Prevost, 2004).

The mining industry in South Africa creates about 1 million direct and indirect job opportunities. It also accounts for 18% of the Gross Domestic Product (GDP) and is a critical earner of foreign exchange. These factors make the mining industry a major contributor to the South African economy.

1.1.2. The company

The Anglo American Corporation moved into the coal mining industry in 1945 after taking control of the Vereeniging Estates in South Africa. In 1975 Anglo American strengthened its Corporation with the acquisition of eight coal mines, namely Arnot, Landau, Kleinkopje, Goedehoop, New Denmark, New Vaal, Bank and Kriel, known as Anglo Coal. Later, Arnot colliery was sold and Bank colliery merged with Goedehoop. Greenside, Mafube, Isibonelo and Zibulu were newly established mines which were acquired together with the others mentioned earlier, comprising the ten mines which Anglo American Thermal Coal (AATC) operates today. Five mines are opencast and five mines are underground operations. In 2010 Anglo Coal became AATC.

AATC became one of the top coal producers in South Africa. About 5.1 billion tonnes of coal are produced globally each year. In 2012 AATC mined 69 million tonnes of coal. AATC is also a major coal exporter. Globally, 40% of all electricity created is powered by thermal coal. The following collieries are export mines: Goedehoop, Greenside, Kleinkopje, Zibulo and Landau. Mafube, Kriel, New Denmark and New Vaal provide coal for Eskom Power Stations. Isibonelo produces thermal coal to Sasol for the conversion into synthetic fuel. Other operations include the Richards Bay Coal Terminal and the Phola Coal Processing Plant.

Anglo American and the rest of the mining landscape are confronted with a number of challenges such as the depressed economy and the relatively low selling price of coal. These affect profit margins. Anglo American changed its normal way of doing business by the implementation of the Asset Optimisation Programme. Major efforts focus on the optimisation and sustainability of the corporation’s resources, employees and equipment. Both operational excellence and Asset Optimisation are key strategic objectives for Anglo American. Pat Lowery, Group Head of the division of Asset Optimisation, said:

"Our challenge now is to implement and embed these practices at each one of our operations to truly translate the value being identified to the bottom line and to changing our culture to one that is continuously focused on operational excellence."

In their quest to improve production performance at Goedehoop colliery, which strongly relates to the quote mentioned above, the company accepted the student's request to conduct her final year's project at AATC. This Project Report covers:

- A background, definition of the opportunity for improvement, description of the project aim and the sponsor's expectations
- A description of the project environment and the sources of data
- A literature study on appropriate Industrial Engineering mechanisms (methods, skills, tools and techniques) which have been considered and used
- Data analysis and problem investigation which assisted in understanding the problem context
- A comprehensive list of proposed and alternative solutions, including a financial criteria, addressing the project aim
- Validation of the proposed solutions and how it assisted in determining the potential benefit for Goedehoop colliery

1.2. Background

1.2.1. Overview

Five of the ten mines which AATC operates are underground operations. These include: Kriel (50% opencast and 50% underground), Goedehoop, Greenside, Zibulo and New Denmark. The majority of these mines are located in the Mpumalanga, Witbank Coalfield. Each mine has a shaft(s) and each shaft(s) has production sections. A production section produces ± 600 000 – 1 million tonnes of ROM (Run Of Mine) coal/year. Each mine operates 3 x 8 hour shifts of which all are production shifts. Four hours of each day shift are used for maintenance. Greenside colliery on the other hand dedicates one of their 8 hour shifts to maintenance. Nine production operators are allocated to a shift.

Figure 1 provides an indication of the suppliers, inputs, process, outputs and customers (SIPOC) of the underground mines.

S	I	P	O	C
Suppliers	Inputs	Process	Outputs	Customers
Komatsu CAT Joy Global Eskom Power Stations Etc.	Machinery Employees Management Maintenance Fuel Electricity Etc.	Figure 2: Underground coal mining process	Coal	Export mines Eskom Power Stations Sasol Richards Bay Coal Terminal Phola Coal Processing Plant

Figure 1: SIPOC of suppliers, inputs, process, outputs and customers of the underground mines

Each of the production sections consists of the processes as depicted within the dashed line in Figure 2. The processes in the dashed line represent the sub-processes involved in a typical underground coal mining process. The cost of the equipment involved in the sub-processes equates to R 80 million.

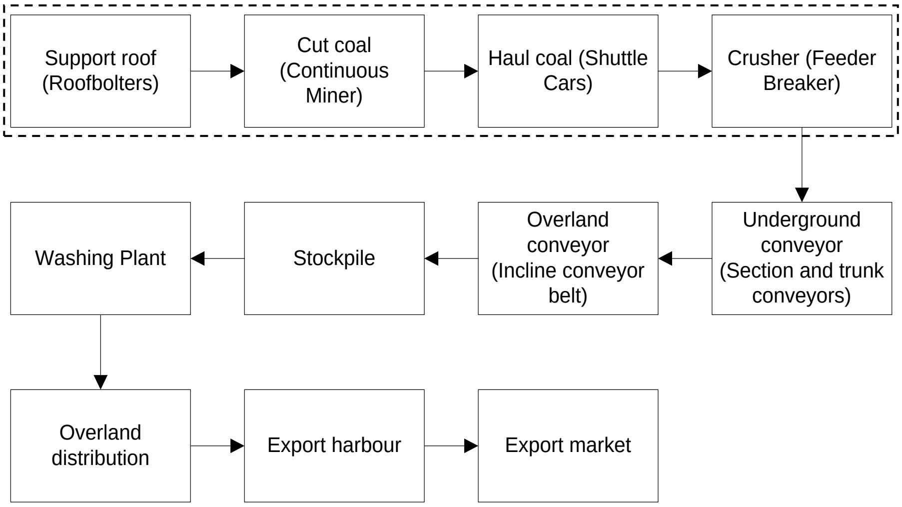


Figure 2: Underground coal mining process

A description of each of the sub processes involved in a underground section is given below:

1.2.1.1. Roof bolter

The roof bolter is supportive equipment which main function is to drill bolts in the roof to avoid any roof falls.

1.2.1.2. Continuous Miner

The Continuous Miner (CM) is a primary production machine which cuts coal.

1.2.1.3. Shuttle car

In a typical underground production section, three shuttle cars are used. Shuttle cars are haulers which transport coal from the CM to the Feeder Breaker.

1.2.1.4. Feeder Breaker

The Feeder Breaker serves as a dispatch point from the section to the internal belt system that ultimately conveys the coal product to the surface. The main function of the Feeder Breaker is to even the discharge load and reduce the product size.

This project's focus is on the Continuous Miner (CM).

1.2.2. Data sources

The company uses two complementing systems to monitor and control the performance of their underground operations. The first is a mine monitoring system known as Ellipse. The Total Availability Model, provided in Appendix D, is used to account for each downtime event and its duration. Information about each downtime is communicated from the production section underground to the surface control room where the downtime is booked against a predefined category.

In support of the Total Availability Model, the MCS Online Monitoring System is used to capture on-line information directly from the machine (CM). This on-line information is used to provide a detailed and accurate account of the production section's productivity. Simplistically, the Total Availability Model is used to report and account for each downtime event. Once all downtimes have been accounted for, the remainder is available for production time. On the other hand, whereas the Total Availability Model captures downtime events, the MCS Online Monitoring System is focused on productivity information during uptime. For the purpose of this project, Ellipse data will be analysed.

1.3. Project scope

Goedehoop colliery is the largest underground operation, consisting of 11 production sections. These production sections are indicated in Figure 3. Both shafts together with its respective production sections will form part and fall within the boundaries of the project scope. Please refer to Appendix E for the breakdown of the other underground operations.

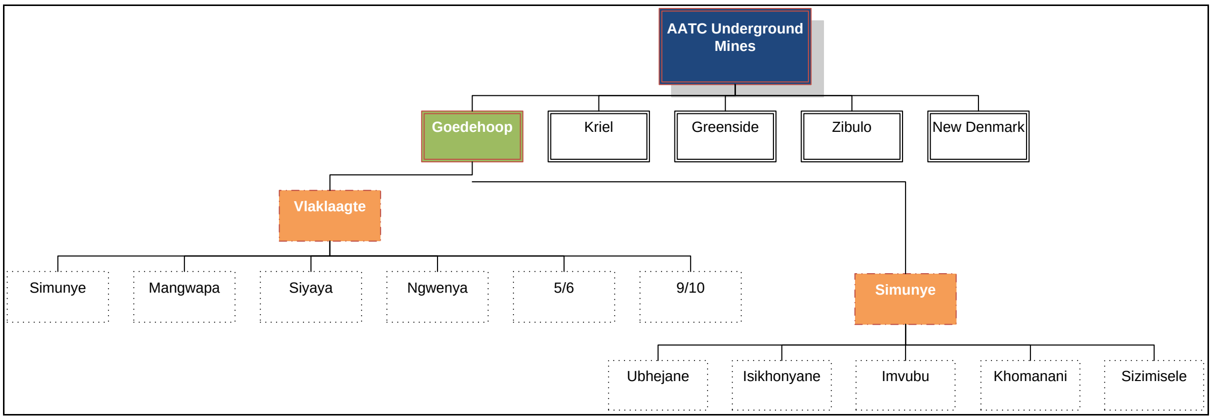


Figure 3: The shafts and production sections at Goedehoop colliery

1.4. Project motivation

The CM is the most critical component in the underground coal mining process. An underground production section can only produce output if the CM is performing its primary function, namely to cut coal. A previous study from July 2007 to August 2010, conducted by Wessels (2010), found that 67% of the total available production time results in non production time by the CM. Consequently, only two and a half hours out of a possible eight production hours per shift is utilised for actual production. This equates to equipment worth R80 million operating only 33% of the total time available. This does not only mean downtime of the CM, but also downtime when the CM is idle due to consequential downtime resulting from dependent downstream processes as indicated in Figure 2. Notwithstanding this issue, gaps exist between actual and targeted performance that lead to the underground operations' profit targets not being met. A 1% pitch point increase in the production time of the CMs at the export mines, will result in a profit gain of R 4.3 million per year. At Goedehoop colliery improvement initiatives have been implemented, which resulted in an increase of 2% in 2012, operating at a production rate of 35% of the total time. A further 1% improvement in the production time of the CMs was achieved in June 2013. Goedehoop colliery aims to increase its CMs' production time to 40% of the total time available. Resulting in an additional improvement of 4-5%. Therefore, an opportunity for improvement exists at Goedehoop colliery, to assist them in reaching their target.

1.5. Project aim

The aim of the project is to improve the actual production time of the CMs at Goedehoop colliery. Actual production time is a KPI measured by the mines as Direct Operating Time (DOT), also known as the Direct Operating Hours (DOH), which is the primary metric of the project. The figure (see circle) below shows the relevance of DOT/DOH within the context of Total time, as depicted by the Total Availability Model (Ellipse):

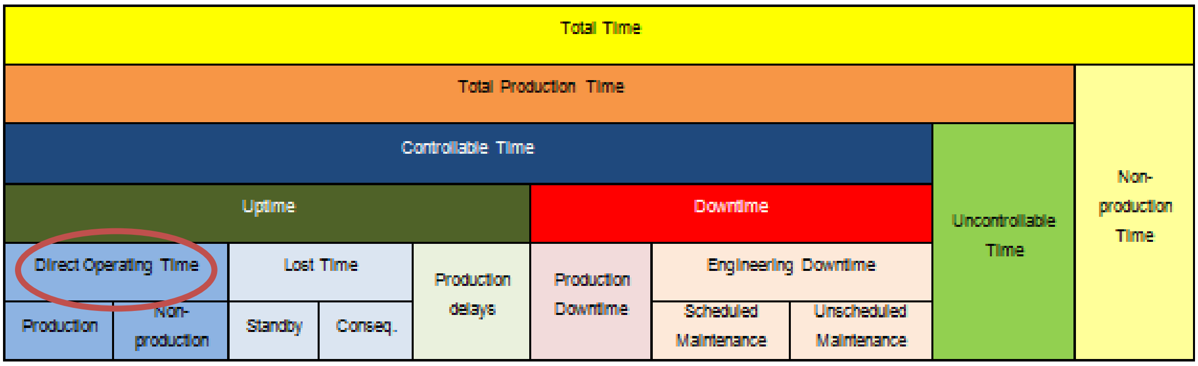


Figure 4: Summarised version of the Total Availability Model

According to the Availability Model (Ellipse), DOH is determined by the sum of the six main downtime KPIs which is subtracted from the total time. The six main downtime KPIs are listed in equation (1) and highlighted with red blocks in Appendix D:

DOH = Total time - (Lost time + Production delays + Production downtime + Engineering downtime + Uncontrollable time + Non production time) (1)

The total time equates to the following:

Total time (annualised) = 24 hours x 365 days = 8760 hours (2)

As shown in the Total Availability Model, the Lost time and Engineering downtime KPIs are further subdivided into two other sub main KPIs. The main KPIs and the two sub main KPIs are further subdivided into numerous sub-sub downtime codes. Each sub-sub downtime code is measured daily by the Ellipse monitoring system which affects the DOH. If the downtimes increase, the DOH decrease and vice versa. The total time is a constant and will always satisfy equation (2).

The main downtime KPIs in Figure 4 are defined as follows:

Non production time (B): Times when the operation is not budgeted or planned for.

Uncontrollable time (C): External factors beyond the control of the operation which impact the production cycle.

Downtime (E): Consists of the following two components:

Engineering downtime (E1): Equipment inoperable due to engineering reasons. Maintenance can be classified as scheduled or unscheduled.

Production downtime (E2): Production reasons that render the equipment inoperative.

Uptime (F): Consists of the following three components:

Production delays (F1): Production delays that occur when the equipment is available and operable but cannot be used for production.

Lost time (G): Time when the machine was available for production but was not utilised. Lost time can be classified as consequential or standby.

DOH (H): Time during which the equipment, section or module is operating. The time the equipment accrues costs.

Uncontrollable time and Non production time are not under the control of management and will therefore not be considered in the data analysis. The aim of the project is to identify the main downtime KPIs, sub main KPIs and/or sub-sub downtime codes that had the most significant impact on the DOH of the CMs in 2012 and to make a proposal to improve the actual performance of the identified downtime codes.

1.6. Project charter

The following project charter summarises all relevant details regarding the optimisation of DOH of the CMs:

<table>
<tr><td colspan="5" align="center">PROJECT TITLE
Optimising production time of Continuous Miners at Goedehoop colliery</td></tr>
<tr><td rowspan="2" align="center">PROBLEM/OPPORTUNITY STATEMENT
DOH of the CMs
A previous study from July 2007 to August 2010, conducted by Wessels (2010), found that 67% of the total available time results in non production time by the CM. Consequently, only two and a half hours out of a possible eight production hours per shift is utilised for actual production. The DOH of the CMs at Goedehoop colliery has improved by 2% from the established baseline with an additional gain of 1% from 2012 to June 2013.</td><td colspan="4" align="center">PRIMARY METRIC</td></tr>
<tr><td align="center"><u>Primary Metric</u>
DOH</td><td align="center"><u>Spec. limits</u>
Max. 24 hours per day</td><td align="center"><u>Base KPI</u>
<u>In 2010:</u>
33% of the time
<u>In 2012:</u>
35% of the time
<u>In 2013 (To June):</u>
36% of the time</td><td align="center"><u>Target KPI</u>
40% of the total time available</td></tr>
</table>

DESIRED OUTCOMES/GOALS

(1) Goedehoop colliery aims to improve its DOH by an additional 4-5%, resulting in a production rate of 40% of the total time available.

PROJECT SCOPE

The boundaries of the process are:

START: Continuous Miners

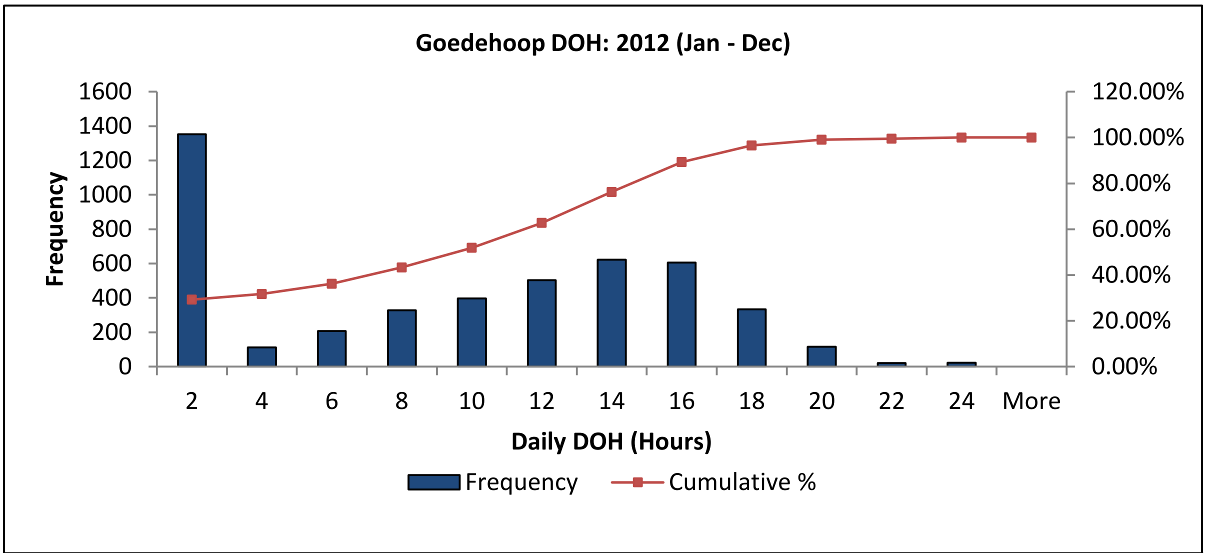
END: Trunk conveyors

What is in and out of 'scope'

IN: DOH of Continuous Miners

OUT: Downtime of shuttle cars, feeder breakers, roof bolters and section conveyors

PRIMARY METRIC CHART



The primary metric chart illustrates that the CMs operated quite frequently (1353 times) for 2 hours per day in 2012. For 622 times, the daily DOH were 14 hours per day. The maximum DOH of 24 hours per day occurred only 22 times.

Daily DOH (35.03 % of the total time available)	Mean (Hours)	Standard deviation (Hours)
Goedehoop	8.407	6.410
Vlaklaagte	8.520	6.435
Simunye	8.472	6.324

Details

Baseline period: January - December 2012 (12 months)

Table 1: Project charter - Primary metric

1.7. Approach

The project will be executed using **Six Sigma's** DMAIC methodology as a broad guideline. Six Sigma is a business improvement methodology followed by businesses to ensure that their processes are as effective and efficient as they can possibly be. DMAIC is an acronym for Define, Measure, Analyse, Improve and Control. The Improve Phase will consist of making recommendations for improvement. Implementation of the proposals is not part of the scope of the project. Likewise, the control phase will consist of making recommendations only. The following figures provide brief explanations of each as well as an intended approach followed during the execution of Phase 1 & 2 of the project:

PHASE 1: BPJ 410 PRELIMINARY PROJECT INVESTIGATION AND DEVELOPMENT OF A CONCEPTUAL DESIGN

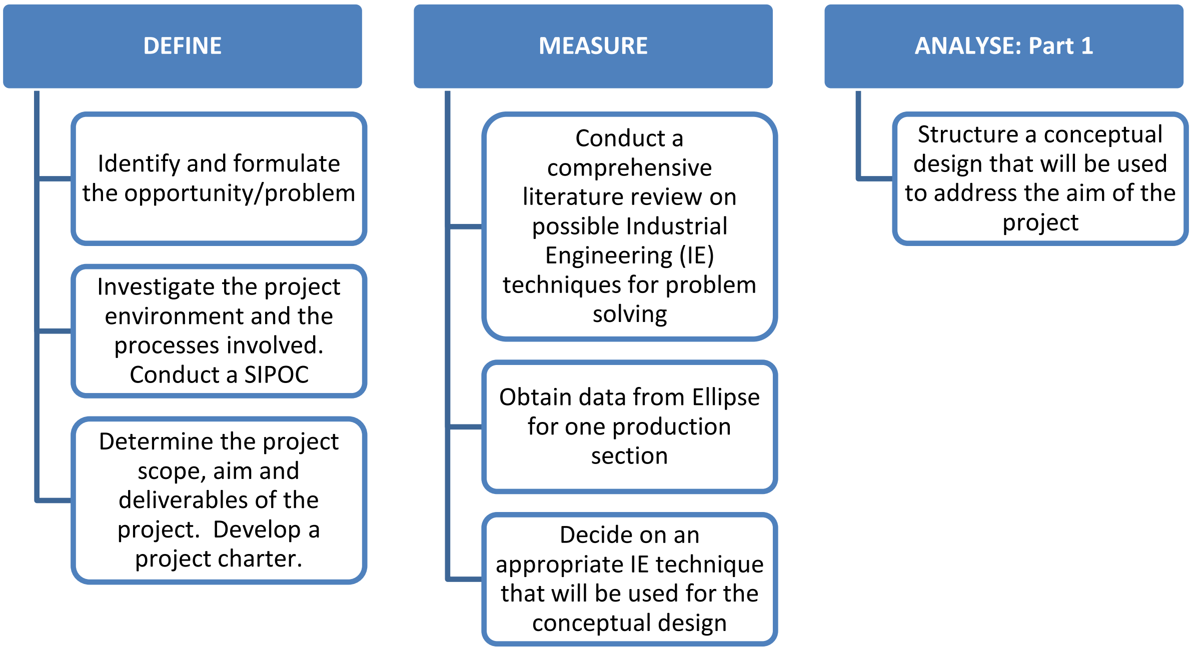


Figure 5: Approach (Phase 1)

PHASE 2: BPJ 420 PROJECT EXECUTION AND DEVELOPMENT OF SOLUTIONS, PROPOSALS AND CONTROL MEASURES

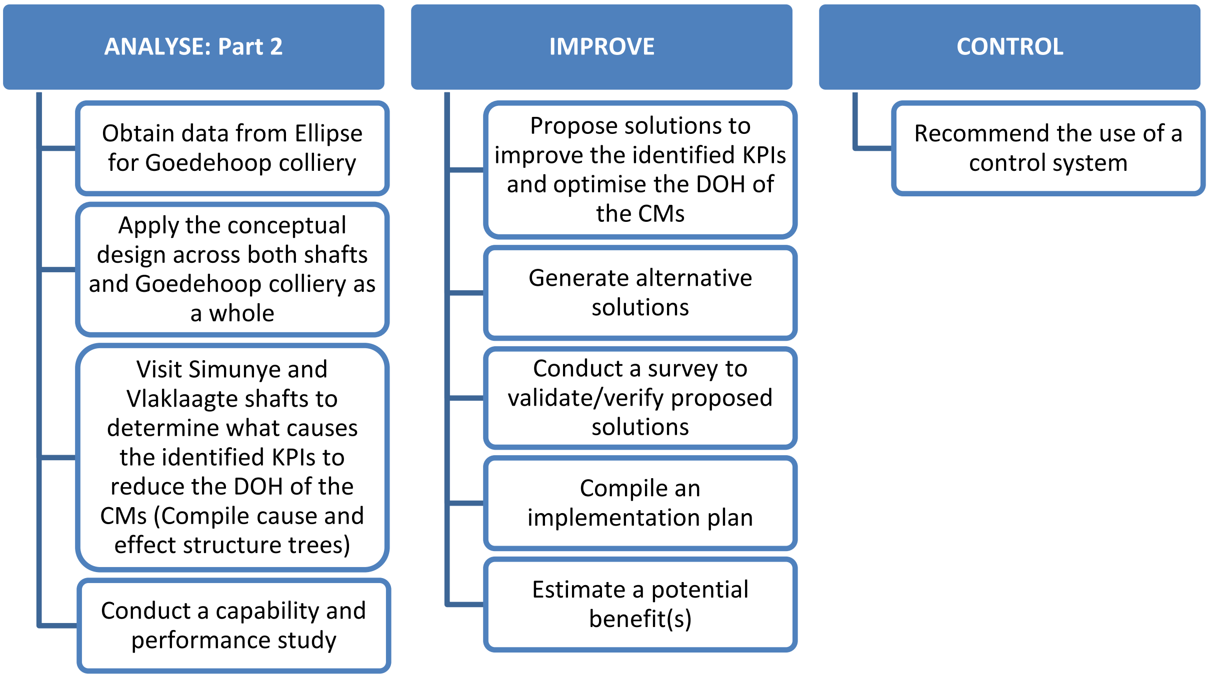


Figure 6: Approach (Phase 2)

The project further investigates certain aspects of **Lean** manufacturing that may play a role when recommendations for improvement are made. Lean is a powerful methodology used across various companies worldwide aimed at eliminating wastage in all its manifestations. The following **Lean Six Sigma** principles relates to the project:

1. "Continual Improvement is an on-going process of change followed by consolidation."

The project aims to research and suggest sustainable improvements that will allow the process to become stable after a minimum consolidation period.

2. *"$Y = f(X_i)$, where $i = (1, 2, …,n)$*; rapid improvement occurs when key *X's* are focused on."

This principle states that *Y*, the output of a process is a function of multiple variables (input variables), the *X_i's*, within a process. The variation or changes in *Y* is a direct result of variation or changes in the relevant *X_i's.*

The Ellipse measurement system can be structured as illustrated Figure 7:

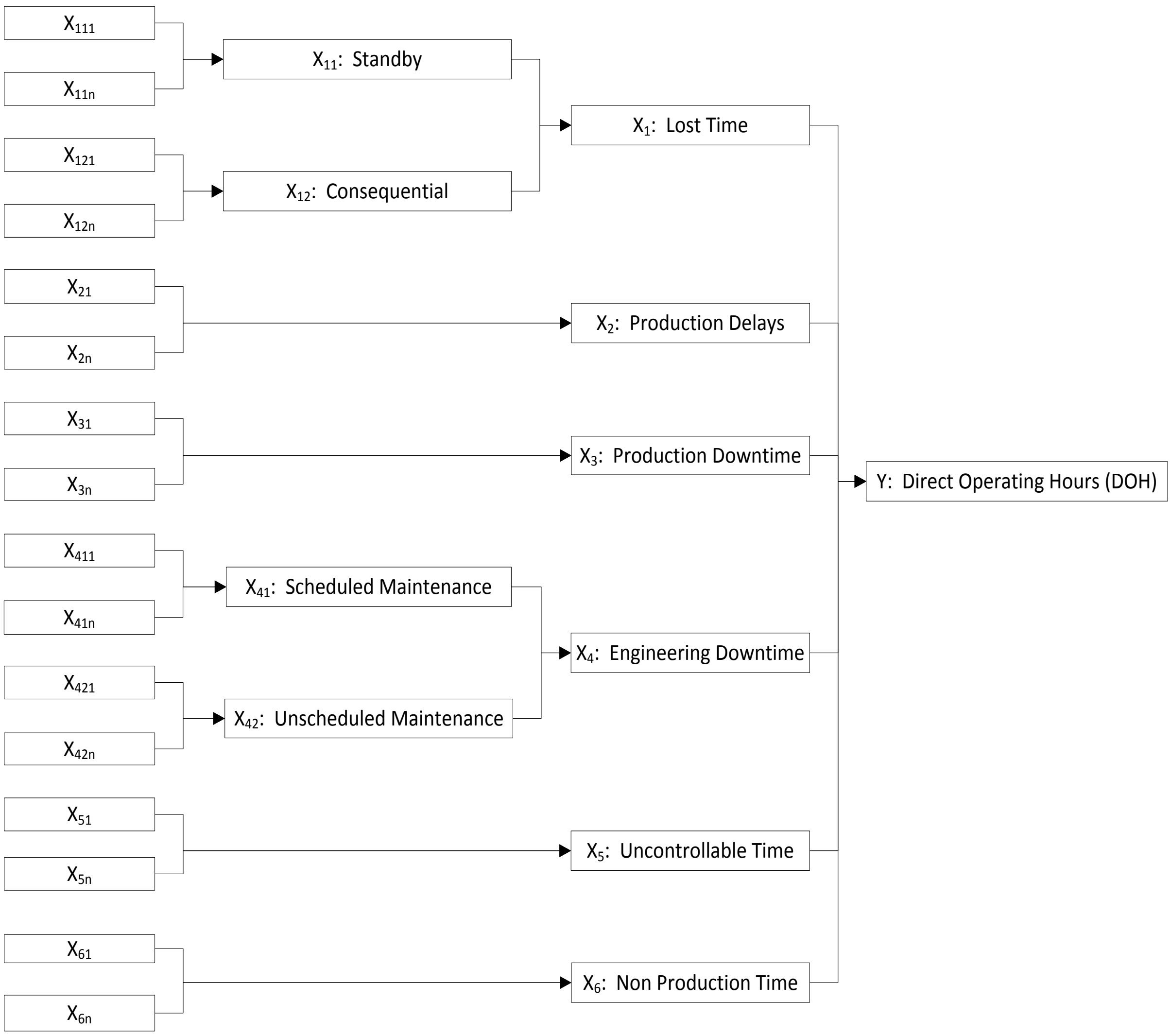


Figure 7: Main downtime KPIs, sub main KPIs and sub-sub downtimes that impact the DOH

The second principle of Six Sigma strongly applies to this project, since the Ellipse Monitoring model is structured as $Y = f(X_1,X_2,X_3,...,X_6)$, where Y is the DOH of the CM and $X_1,X_2,X_3.....,X_6$ are the main downtime KPIs. Each main downtime KPI, is in its turn a function of all its respective sub main KPIs and sub-sub downtime codes, e.g. $X_1 = f(X_{11},X_{12})$ and $X_{11} = f(X_{111},X_{112},X_{113},...,X_{11n})$.

1.8. Deliverables

The following will be accomplished as a result of the project:

- Identification of the main downtime KPIs which had the largest impact on the production time of the CMs at Goedehoop colliery in 2012
- Identification of the sub-sub downtime codes which are the drivers under each of the high impact main downtime KPIs
- Making proposals to optimise the DOH of the CMs at Goedehoop colliery, through suggested improvements at the identified sub-sub downtime codes
- Developing a control system by which deviations from target values and out-of-control conditions can be identified and addressed
- A project report on the work done and demonstrating that problem solving and engineering design took place to achieve the expected ECSA exit-level outcomes in order to pass BPJ 420

2. MEASURE

2.1. Literature review

2.1.1. Industrial Engineering techniques that were considered and applied during the execution of the project

The first focus of the literature study discussed in this section, is to identify IE techniques by which the main downtime KPIs and/or the sub-sub downtime codes, that had the most significant impact on the DOH of the CMs in 2012, can be identified. The following techniques were investigated as well as its relevance to the project. Thereafter, the most appropriate technique(s) was chosen.

2.1.1.1. Principal Component Analysis (PCA)

Principal Component Analysis is a statistical tool used to reduce the number of correlating variables to a smaller number of uncorrelated variables. Principal Component Analysis can also be used to determine the number of dimensions in a data set while ensuring minimum loss of information. Consider the following:

$$Y_1 = a_{11}X_1+a_{12}X_2+...+a_{1j}X_j+...+a_{1p}X_p$$
$$Y_2 = a_{21}X_1+a_{22}X_2+...+a_{2j}X_j+...+a_{2p}X_p$$
$$\vdots$$
$$Y_i = a_{i1}X_1+a_{i2}X_2+...+a_{ij}X_j+...+a_{ip}X_p$$
$$\vdots$$
$$Y_p = a_{p1}X_1+a_{p2}X_2+...+a_{pj}X_j+...+a_{pp}X_p$$

Where p original variables Xj is transformed to p new variables Y_i, with Y_i as the principal components

With PCA, the X-variables are grouped according to the component they relate to the strongest (Blunch,2013).

Relevance to this project:

Principal Component Analysis can be used to determine the underlying relationships between the number of measured KPIs. It can also be used to estimate the correlation structure of the KPIs.

2.1.1.2. Analysis of Variance (ANOVA)

If more than two independent samples exist, a statistical tool known as ANOVA is used to formally compare the effects of the different treatments or categorical factors on one or more measured quantitative variable(s). ANOVA is used to observe how the variability around the means of the response variable associated with the different treatments is distributed in order to estimate the separation or overlap suggestive of a notable effect or not. In short, the objective of ANOVA is to provide a statistical method to assess whether treatments are significantly different in their effect, given observed variability in a quantified measured variable (Bailey, 1981).

The following models exist for ANOVA:

- Fixed-effect models: One or more treatments are applied to the subject of the experiment in order to see whether the value of the response variable changes.
- Random-effect models: Used when treatments are not fixed due to factor levels sampled from a larger population.
- Mixed-effect models: Contains experimental factors of both models mentioned above but different interpretations and analysis of the two models are derived.

Relevance to this project:

ANOVA will only indicate whether the KPI data obtained from Ellipse represents equality in means or not. The significant KPIs can be identified using this statistical model, but not the impact (in numerical form) that the KPIs have on the DOH of the CMs. ANOVA can be useful when shafts are compared to each other.

2.1.1.3. Multiple Regression Analysis

Application of Multiple Linear Regression Analysis involves situations with more than one independent (regressor) variable. Multiple Regression Analysis is used to determine the relationship between Y (response variable) and each of the independent variables.

The following equation represents a Multiple Linear Regression model:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_k x_{ik} + \varepsilon_i \qquad i = 1, 2, \ldots, n$$

$$= \beta_0 + \sum_{j=1}^{k} \beta_j x_{ij} + \varepsilon_i \qquad j = 1, 2, \ldots, k \text{ and } n>k$$

Where:

x_{ij} = *the ith observation of variable* x_j

$y_i, x_{1i}, x_{2i}, \ldots, x_{ki}$ = The observations are usually presented in the following format:

y	X_1	X_2	X_k
Y_1	X_{11}	X_{12}	X_{1k}
Y_2	X_{21}	X_{22}	X_{2k}
⋮	⋮	⋮	⋮
y_n	X_{n1}	X_{n2}	X_{nk}

Figure 8: Representation of Multiple regression data

y_i = Dependent/response variable

E(y) = Deterministic component

β_0 = Y-intercept of the line

x_j where j = 1,2,3,...,k = Independent variables

β_j = Measures the expected change in Y per unit change in x_1, x_2, ..., x_k (regression coefficients)

A system of linear equations are set up and can be solved by any method appropriate for solving a set of linear equations.

Relevance to this project:

Multiple Linear Regression can be used to determine the correlations between the DOH and the main downtime KPIs, sub main KPIs and sub-sub downtime codes.

2.1.1.4. Structural Equation Modelling (SEM)

SEM is a combination of statistical methods. The following statistical methods are considered as special cases of SEM, namely Regression Analysis, Analysis of Variance, MANOVA, Discriminant Analysis and Canonical Correlation. SEM is used to analyse connections between a number of variables and focuses on co-variations between the variables. This is also known as Analysis of Covariance Structures. In SEM uncertainty exists on the connection between the variables. If a connection exists, SEM can be used to measure the strength of the connections in numerical form. SEM begins with a priori theory about the system which is then tested against empirical data and as a result will be able to measure the strength of the various connections. Structural Equation Models are used to illustrate how the variables (manifest and latent variables) are connected to each other. The Structural Equation Model can be translated into a set of equations and solved with appropriate software. The advantages of using SEM includes the presence of latent variables in the system and a broad spectrum of problems in many disciplines that could be analysed (Blunch,2013).

Relevance to this project:

SEM could be a useful method to solve the problem, since the connection strengths between the DOH (dependent variable) and the main downtime KPIs, sub main KPIs, sub-sub downtimes are to be analysed. It was however found that the DOH can be written as $Y = f(X_1, X_2, X_3, \ldots, X_6)$ in one single equation and that all of the variables are manifest (measureable) variables. The significant parameter(s) can be identified using ANOVA and can thereafter be estimated through application of Multiple Linear Regression.

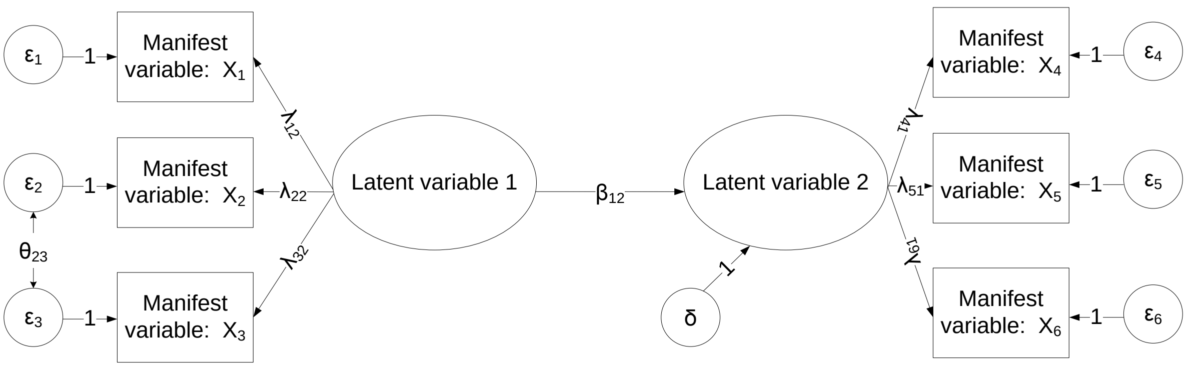


Figure 9: An example of a typical Structural Equation Model

2.1.1.5. Excel spreadsheet (Pivot tables)

A pivot table is a useful tool in MS Excel that combines and compares large amounts of data. The rows and columns can be rotated to obtain different summaries of the source data. With a highly visual interface the details of areas of interest are displayed in order to obtain specific questions about the data being analysed.

Relevance to this project:

Pivot tables can be used in the project to organise and categorise the raw data obtained from Ellipse. Thereafter, each downtime code can be sorted in respect of the date it occurred for a specific shaft or mine. The total duration for each downtime code is displayed in the very last row of the pivot table. This method can be used to determine which of the sub-sub downtime codes had the most significant impact on the DOH of the CMs, being the ones with the longest duration of downtime. However, it would only be in numerical value, after which the student will have to use an appropriate graph(s) to see the size relative to each other. Figure 10 is a screenshot of how the Ellipse data was categorised:

Area Description (Multiple Items)

Sum of Duration Column Labels

Row Labels	AAGT	AART	ASPA	BMAK	DOAC	DOCP	DODP	DOEG	DOEM	DOEV	DOGT	DOME	DOMS	DONA
2012/01/02							1.09		0.5		1.08			
2012/01/03							1.67		0.33		0.92			
2012/01/04							0.5		0.75		3.5			0.75
2012/01/05									2.99		1.83			
2012/01/06							0.67		1.5	0.75	4.49	0.5	0.67	0.91
2012/01/07							2.25		1.76		2.41		1	
2012/01/09									6.25		3.26			0.84
2012/01/10									2.66	0.5	4.08		0.33	
2012/01/12							0.67		2.41		2.83			1
2012/01/13				0.42					5.42		1.82			0.42
2012/01/14							0.67		1		2.67			
2012/01/16					0.75				3.41		3.92	0.5		
2012/01/17				0.75	0.08				3.41		4.91		1	1.16
2012/01/18		1					1.33		6.25		2.74		0.5	0.5
2012/01/19							0.17		3.91		5.08			0.5
2012/01/20							1.42		4.74		2.07			
2012/01/21									2.16		1.91			
2012/01/23							7.5		1.25		3.17		0.75	0.58
2012/01/24				2.58			0.33		3.67		1.34		0.5	
2012/01/25														
2012/01/26							0.83		4.83		1.75			0.33
Grand Total	7.17	64.42	143.51	29.67	134.46	5.34	153.85	10.24	1077.81	20	739.78	12.34	45.74	163.27

Figure 10: Screenshot of a Pivot table

Note 1: Ellipse data of the CMs sorted according to Simunye and Vlaklaagte shafts (Goedehoop colliery).

Note 2: Data sorted from January to December 2012.

Note 3: Some of the sub-sub downtime codes as they appear on the Total Availability Model.

Note 4: The grand total of the duration (in hours) of each of the sub-sub downtime codes.

2.1.1.6. Pareto Charts

The Pareto chart states that for many events, 80% of the effects derive from 20% of the causes. The Pareto diagram is an efficient tool for narrowing down potential root causes prior to problem-solving. Pareto charts are graphical displays that analyse a process of unequal distribution. Dr Joseph Juran implies that 80% of the problems are caused by 20% of its contributors. This is known as the universal ''80,20'' principal.

Relevance to this project:

Pareto charts can be used to estimate which of the KPIs had the largest impact on the DOH of the CMs.

Conclusion:

After a comprehensive literature review was conducted on the above mentioned techniques and methods, it was found that Pivot tables and Pareto charts are the most appropriate methods to address the project aim and ultimately meet the deliverables of the project. Since

DOH = Total time - (Lost time + Production delays + Production downtime + Engineering downtime + Uncontrollable time + Non production time) (1)

it consist of all the KPIs deducted from total time which is a constant. Consequently, there are ± 100% correlations between the DOH and its KPIs due to the fact that DOH is made up of these KPIs. Therefore, the methods as investigated in sections 2.1.1.1. - 2.1.1.4., are not deemed the most appropriate methods to use in the project. This was verified after some of these techniques were applied to data and discussions were held with data analysts and the project leader after the submission of the Preliminary Project Report. Therefore, Pivot tables were used to sort the data after which Pareto charts were compiled to identify the major detractors from the DOH of the CMs at Goedehoop colliery.

2.1.2. Data analysis

In this section, the methods as chosen in section 2.1.1. were used to conduct a thorough data analysis in order to identify the area(s) where improvement initiatives should focus on, to ultimately optimise the production time of the CMs and help Goedehoop colliery to reach its target.

Figure 11 illustrates a summarised view of the routes the student followed during data analysis. The raw Ellipse data was sorted after which it was used to compile Pareto charts. As illustrated, production volume consists of time and rate. The largest detractor from production time of the CMs in 2012 was Lost time. Lost time was unpacked into its critical drivers, after which it was decided to focus on the trunk conveyors. Again, with the means of Pareto charts, the significant downtimes experienced by the trunk conveyors in 2012 were identified as well as the causes of these downtimes. Pareto charts for each of the components marked with **(A) to (D)** are provided in this section.

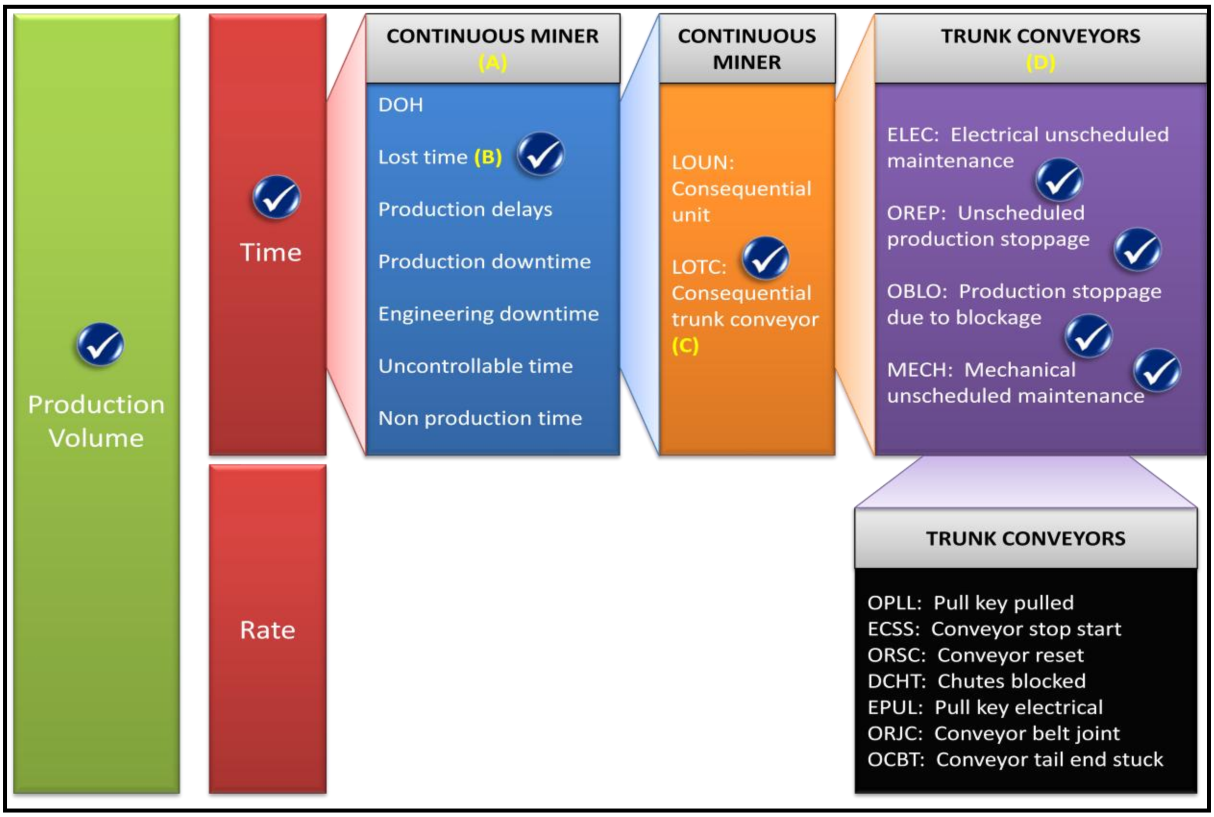


Figure 11: Roadmap of Pareto analysis

(A) Main downtime KPIs of the CMs

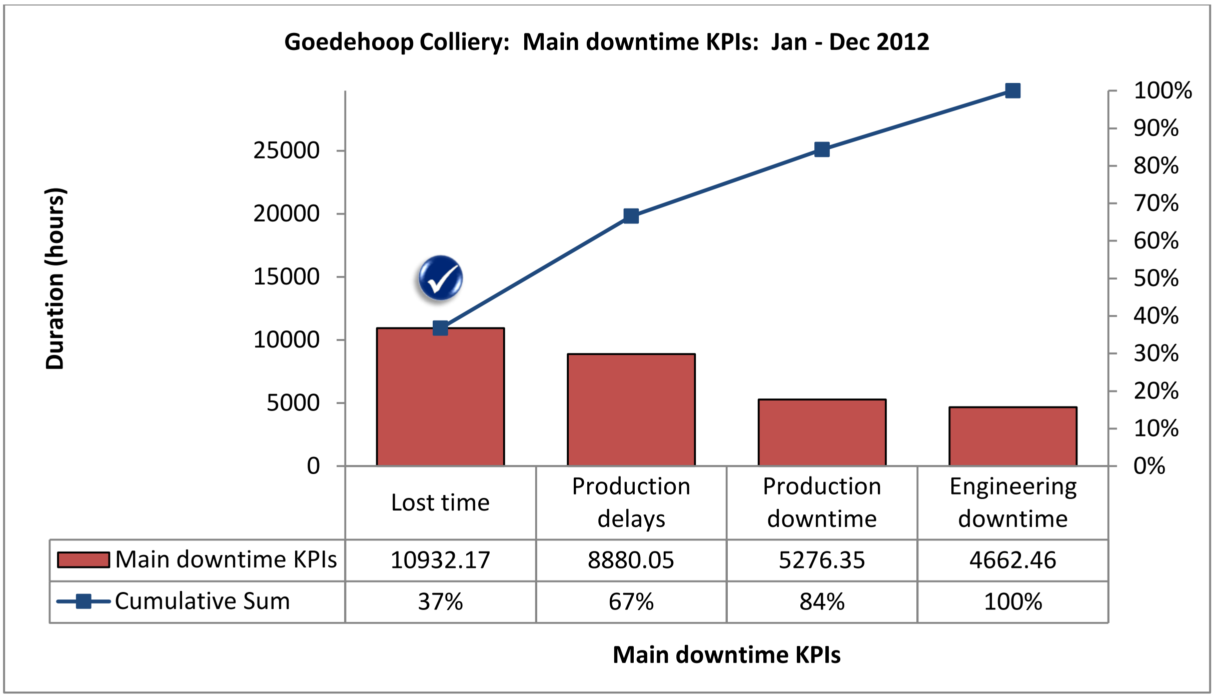
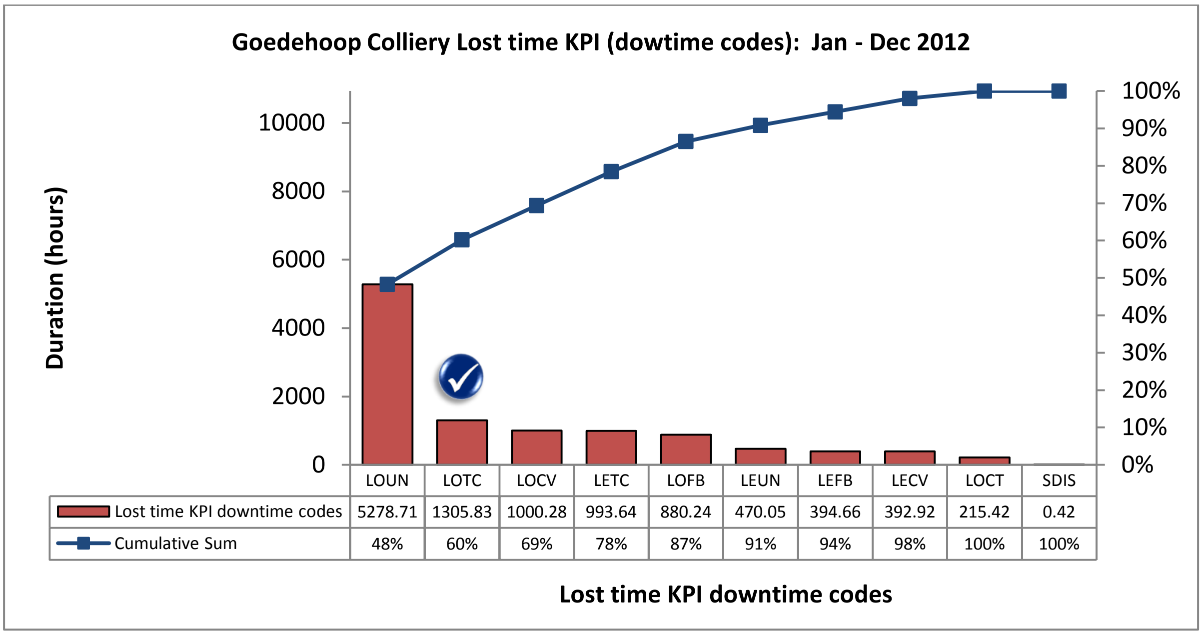


Figure 12: Main downtime KPIs

Figure 12 displays that Lost time was the largest detractor of the DOH of the CMs in 2012. Lost time is unpacked into its downtime codes as illustrated in Figure 13.

(B) Lost time downtime codes of the CMs

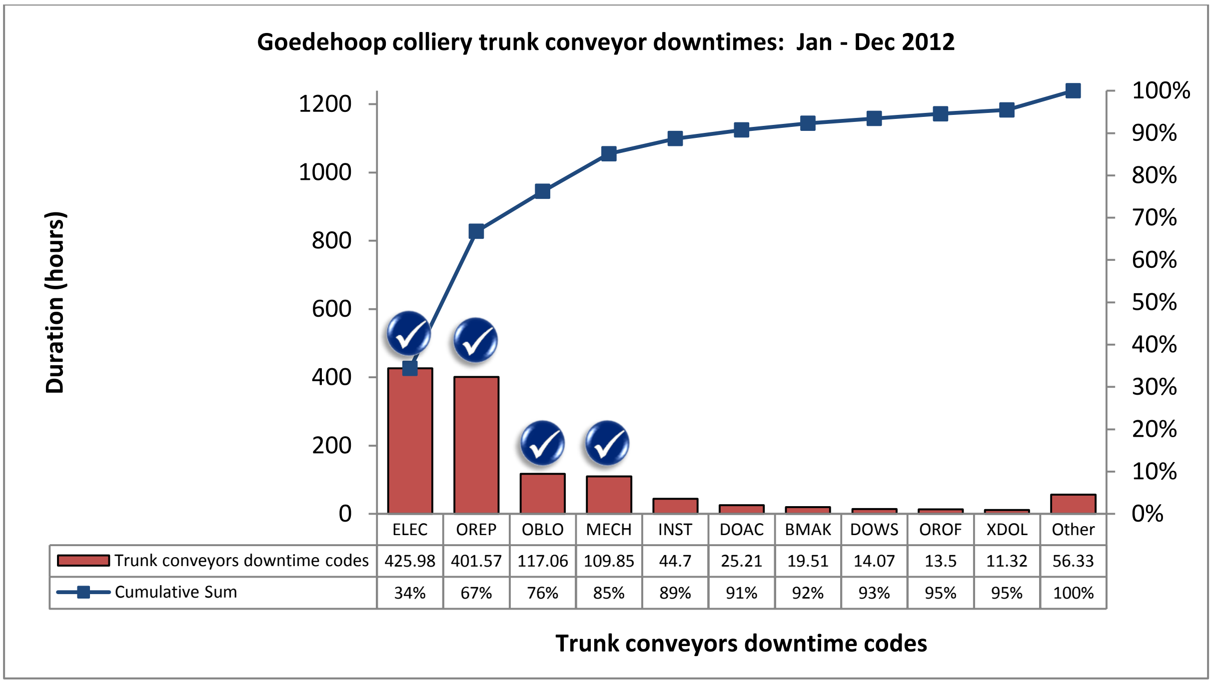


	LOUN	LOTC	LOCV	LETC	LOFB	LEUN	LEFB	LECV	LOCT	SDIS
Lost time KPI downtime codes	5278.71	1305.83	1000.28	993.64	880.24	470.05	394.66	392.92	215.42	0.42
Cumulative Sum	48%	60%	69%	78%	87%	91%	94%	98%	100%	100%

Figure 13: Lost time downtime codes

The main driver under the Lost time KPI is LOUN (Consequential unit) : The section in which the CM operates has no electricity, too much water or too little water causing the CM not to operate although the CM is operable. After a discussion with the industry sponsor, it was agreed that the student focuses on LOTC (Consequential trunk conveyor): A trunk conveyor is on breakdown causing a CM not to operate, since the material (coal) can't be moved by the trunk conveyor.

(C) Trunk conveyor downtime codes



	ELEC	OREP	OBLO	MECH	INST	DOAC	BMAK	DOWS	OROF	XDOL	Other
Trunk conveyors downtime codes	425.98	401.57	117.06	109.85	44.7	25.21	19.51	14.07	13.5	11.32	56.33
Cumulative Sum	34%	67%	76%	85%	89%	91%	92%	93%	95%	95%	100%

Figure 14: Trunk conveyor downtimes

ELEC: Unscheduled maintenance (electrical) and OREP: Unscheduled production stoppage are the critical downtimes on trunk conveyors. These two downtimes together with OBLO: Production stoppage due to blockage and MECH: Unscheduled maintenance (mechanical) will be analysed further in order to determine the causes of these downtimes. The ''other'' category consist of 21 other downtime codes, all with durations smaller than XDOL, which equates to 11.32 hours.

(D) Trunk conveyor downtime causes

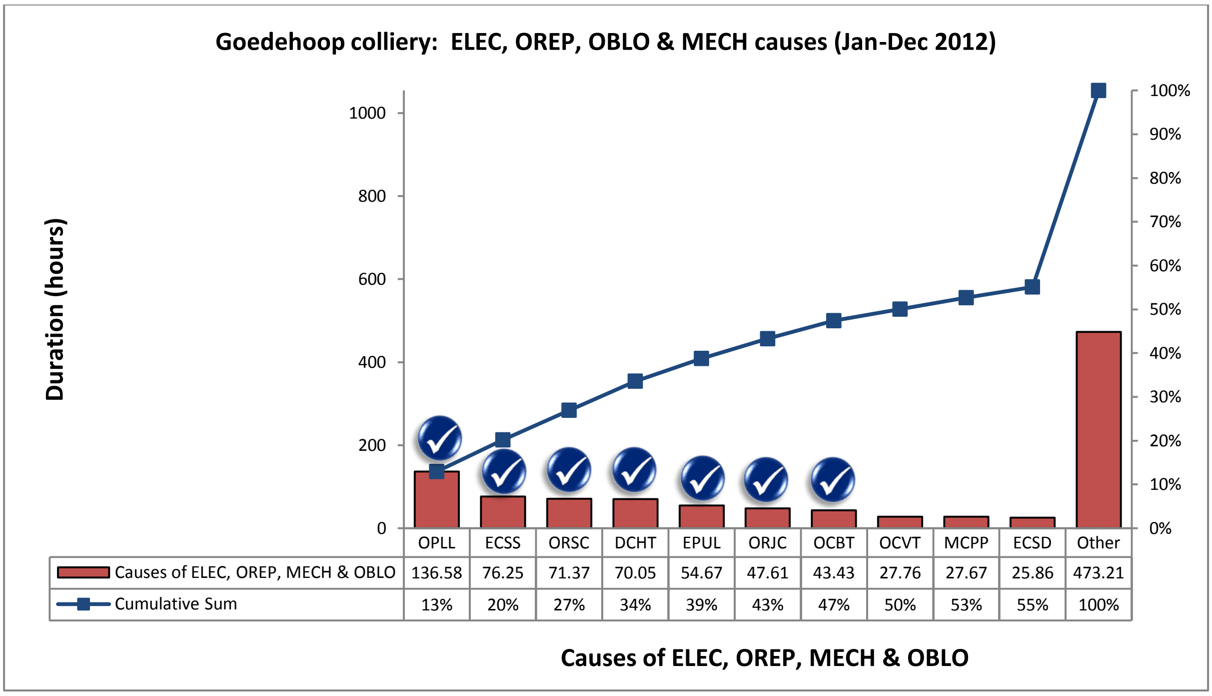


Figure 15: Trunk conveyor downtime causes

The following causes are the critical drivers under ELEC, OREP, OBLO & MECH: OPLL (Pull key pulled), ECSS (Conveyor stop start), ORSC: (Conveyor reset), DCHT (Chutes blocked), EPUL (Pull key electrical), ORJC (Conveyor belt joint) and OCBT (Conveyor tail end stuck). Cause and effect analysis will be done for each of these causes in the Analyse Phase. Please note that the trunk conveyor causes as mentioned above, will be referred to as trunk conveyor downtimes in the following phases. The ''other'' category consist of 79 other causes, all with durations smaller than ECSD, which equates to 25,86 hours.

2.1.3. Process analysis

2.1.3.1. Literature study on trunk conveyors

A bulk-materials handling operation is designed to accept an input of a certain raw material and to reliably deliver the same amount of material to one or more points at the other end of the process at a predetermined and established rate. Conveyors have been used for decades to transport large quantities of material over long distances. It is the most reliable and cost effective method for material movement. Spillage, emissions, blockages and material losses occur in the material handling process, resulting in production and revenue losses. The need for total material control is essential to address these problems. Figure 16 represents the common components of belt conveyors. A transfer point is where material moves from one piece of equipment to another or where one conveyor is feeding another. It consists of chutes that guide the flow of the material. A basic representation of a transfer point is illustrated in Figure 17. AATC uses trunk conveyors to transport the coal from the section conveyors to the washing plant where it gets washed and prepared.

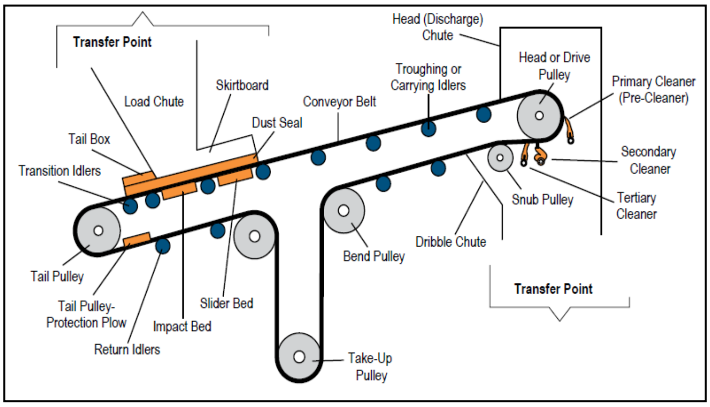


Figure 16: Common conveyor components

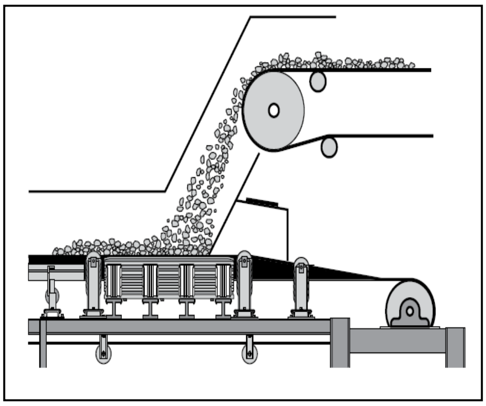


Figure 17: Transfer point

2.1.3.2. Importance of trunk conveyors

This section discusses the trunk conveyors at Goedehoop colliery as well as its importance and why it was decided by the student and industry sponsor to focus on.

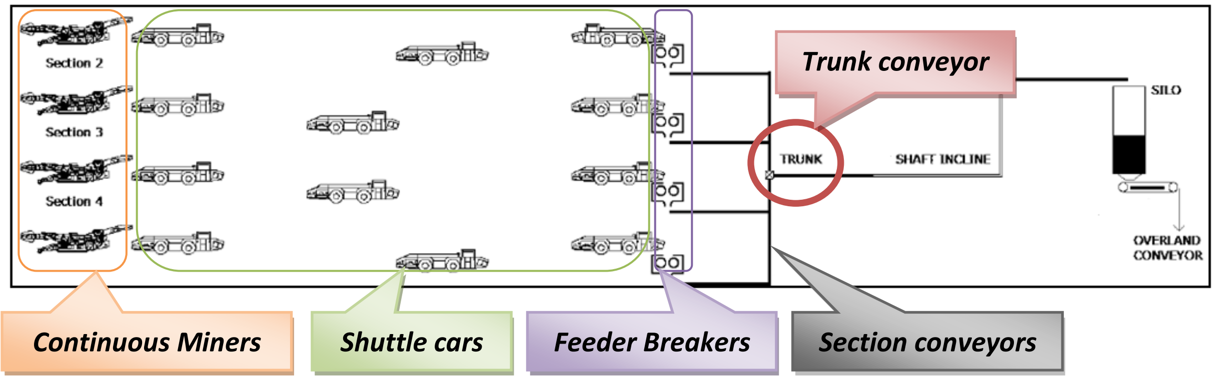


Figure 18: Location of a trunk conveyor in a typical underground coal mining process

At a high level, Figure 18 can be described as follows: The CM mines the coal, which is transported via shuttle cars to the Feeder Breakers. The coal is then transported via the section conveyors to a trunk conveyor common to one or more section conveyors. The trunk conveyor therefore plays a significant role in the throughput of the process. If the trunk conveyor experiences downtime, all downstream processes are rendered inoperative. This emphasises the importance of the effectiveness of the trunk conveyors.

Goedehoop colliery experienced 1239.10 hours downtime on the trunk conveyors during 2012. The project therefore focuses on suggesting improvement initiatives for the causes of trunk conveyor downtime. The potential number of trunk conveyor downtime hours reduced, if the solutions were to be implemented, will be used to calculate an improvement in DOH and capital gain for the colliery.

2.1.3.3. Project charter

The following project charter summarises all relevant details regarding the optimisation of DOH of the CMs, whilst focussing on trunk conveyor downtime:

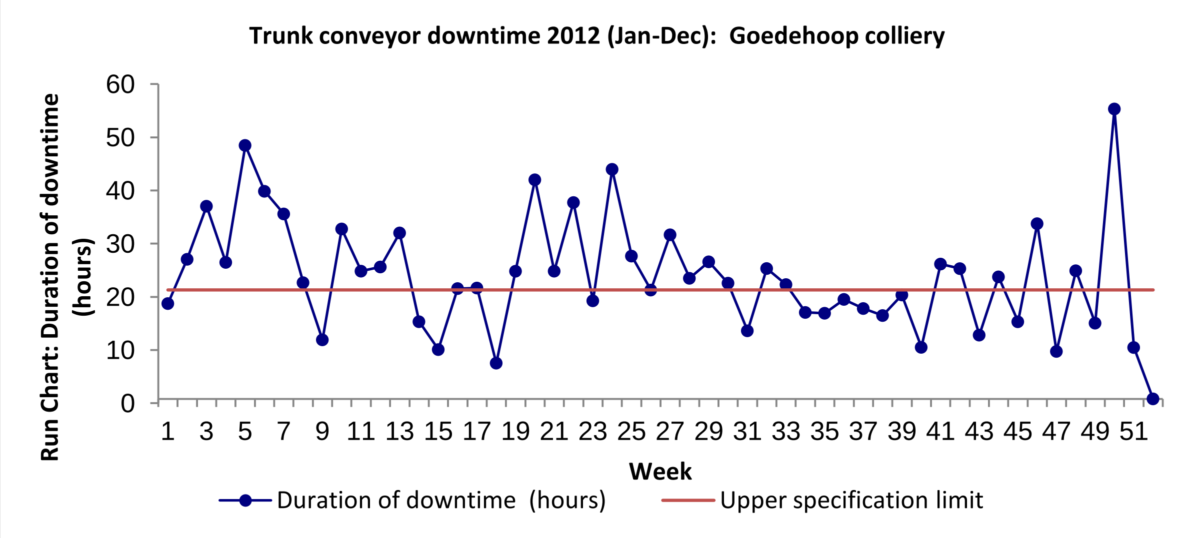
<table>
<tr><td colspan="5">PROJECT TITLE
Optimising production time of Continuous Miners at Goedehoop colliery</td></tr>
<tr><td rowspan="2">PROBLEM/OPPORTUNITY STATEMENT

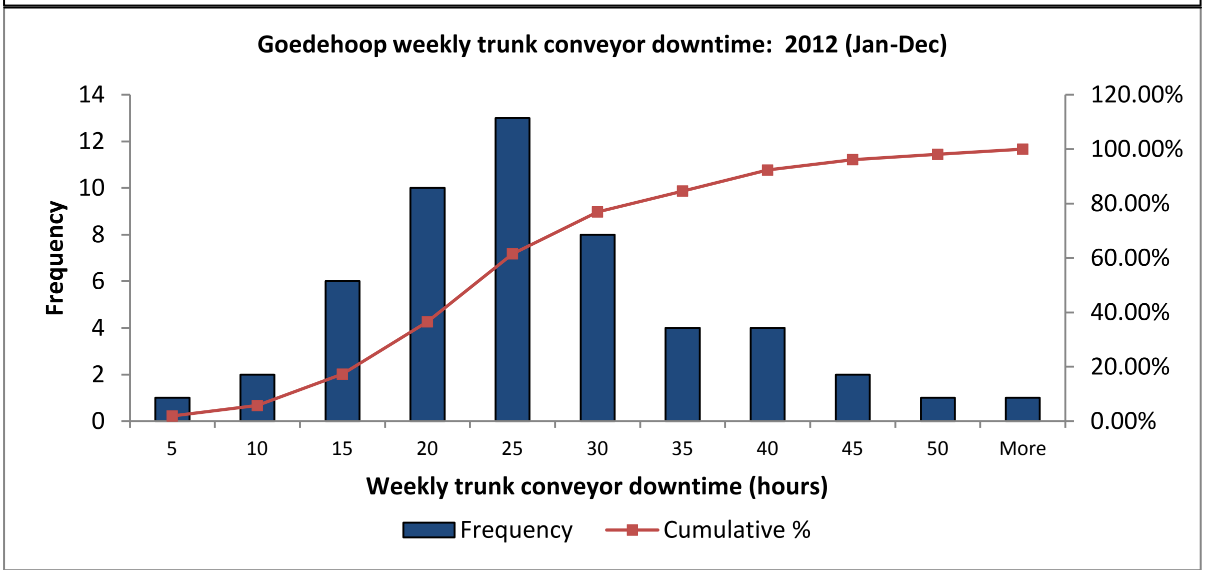
Downtime on the trunk conveyor
Goedehoop colliery experienced 1239.10 hours downtime on the trunk conveyors during 2012.

The project therefore focuses on suggesting improvement initiatives for the causes of trunk conveyor downtime.</td><td colspan="4">SECONDARY METRIC</td></tr>
<tr><td><u>Secondary Metric</u>
Trunk conveyor downtime hours</td><td><u>Spec. Limits</u>
Max. 24 hours per day</td><td><u>Base KPI January - December 2012</u>
1239.10 hours</td><td><u>Target KPI</u>
Not above 21.33 downtime hours per week per shaft on all trunk conveyors</td></tr>
<tr><td>DESIRED OUTCOMES/GOALS
(1) Improvement of downtime on trunk conveyors to ultimately increase the DOH of the CMs at Goedehoop colliery.

(2) Approach and reach target of operating at 40% of the total time available.</td><td colspan="4">DECISION CONSTRAINTS/LIMITATIONS
(1) The improve and control phases only consist of making recommendations for improvement and not actual implementation in order to see effect(s) of changes</td></tr>
<tr><td colspan="5">PROJECT SCOPE
<u>The boundaries of the process are:</u>
START: Continuous Miners
END: Trunk conveyors

<u>What is in and out of 'scope'</u>
IN: Downtime of trunk conveyors
OUT: Downtime of shuttle cars, feeder breakers, roof bolters and section conveyors</td></tr>
<tr><td colspan="5">SECONDARY METRIC CHARTS</td></tr>
</table>





The secondary metric chart (histogram) illustrates that the trunk conveyors experienced quite frequently (13 times) 25 hours downtime per week in 2012. A minimum of five hours trunk conveyor downtime per week and a maximum of more than 50 hours downtime per week occurred only once. There were many instances where the trunk conveyor downtime exceeded the upper specification limit of 21.33 hours downtime per week.

Weekly trunk conveyor downtime duration (hours)	Mean	Standard deviation
Goedehoop	23.829	10.731
Vlaklaagte	13.639	6.887
Simunye	10.190	6.869

Details
Baseline period: January - December 2012 (52 weeks)

Table 2: Project charter - Secondary metric

2.1.4. Supplementary tools and techniques

During problem investigation, it was found that certain supplementary tools and techniques that will assist in problem solving and which were not sufficiently mastered before the project, would also be needed. These supplementary tools and techniques will be described in this section.

2.1.4.1. Histograms

A histogram is a graphical representation of the distribution of the data. Adjacent rectangles are tabulated frequencies over discrete bins (intervals). The area is equal to the frequency of the observations in the interval. The frequency density of the interval is equal to the height of a rectangle. In this project, histograms illustrate historic data regarding a specific process as used in the project charters.

2.1.4.2. Statistical Process Control

Statistical Process Control (SPC) is a statistical tool which is used to analyse, control and reduce variation in a specific process. In order to effectively manage a process, the output must be measured and the variations must be traced back to their sources. SPC employs control charts, process performance studies and process capability studies. Control charts are used to separate common causes from special causes of variation and to monitor and control processes to detect deviations from standards. Two sources of variation exists, namely:

- Common causes of variation: Natural variation which tends to form distributions that are predictable and stable over time.
- Special causes of variation: Unpredictable and they cause the process output to be unstable.

Process control is also referred to as the ''voice of the process''. If only common causes of variation are present in a process, the process is known to be in statistical control. Control charts are used to estimate if a process is in control.

Process capability is also known as the ''voice of the customer''. It measures how well a process performs with respect to its specifications and requirements. Four commonly used process capability measures are listed below:

dpm = defects per million

σ_{level} = number of the standard deviations between the center of the process and the nearest specification

C_{pk} = proportion of 3σ between the center of the process and the nearest specification

C_p = specification width/process width

Statistical Process Control will be useful to analyse, control and reduce the variation present in the identified critical driver(s). Control charts can be used to identify the time(s) the process was out of control. Possible causes of variation can be identified and traced back to its sources.

2.1.4.3. Cause and effect structure trees

A cause and effect structure tree is a common tool used in the Analyse Phase of the DMAIC process. It helps a team or individual to identify root causes of a certain effect at a much deeper level. This tool is useful in the project, since certain trunk conveyor downtimes will be focussed on, explored and consequently improved. The student will consult with employees at Goedehoop colliery that will aid in the compilation of the cause and effect trees for each of the identified downtimes. The principle on which a cause and effect structure tree is compiled is illustrated in Figure 19.

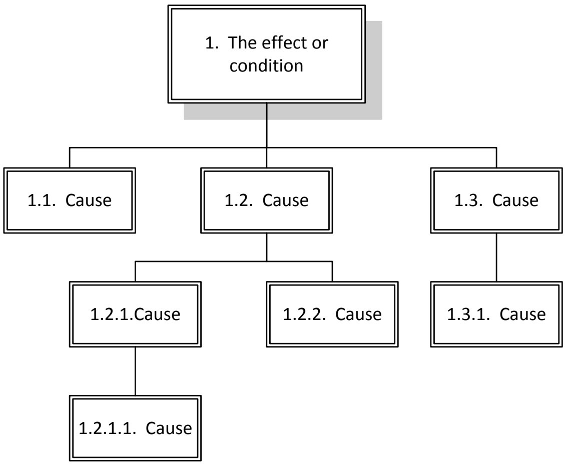


Figure 19: A basic representation of a cause and effect structure tree

As indicated in Figure 19, the effect or condition is caused by three factors. These causes/factors are in turn caused by other factors. The cause and effect structure tree applicable to the Pareto analysis conducted in Section 2.1.2., is illustrated in Figure 20. The shaded blocks represent the significant main downtime KPIs and downtime codes that were the largest detractors from the DOH of the CMs in 2012 at Goedehoop colliery.

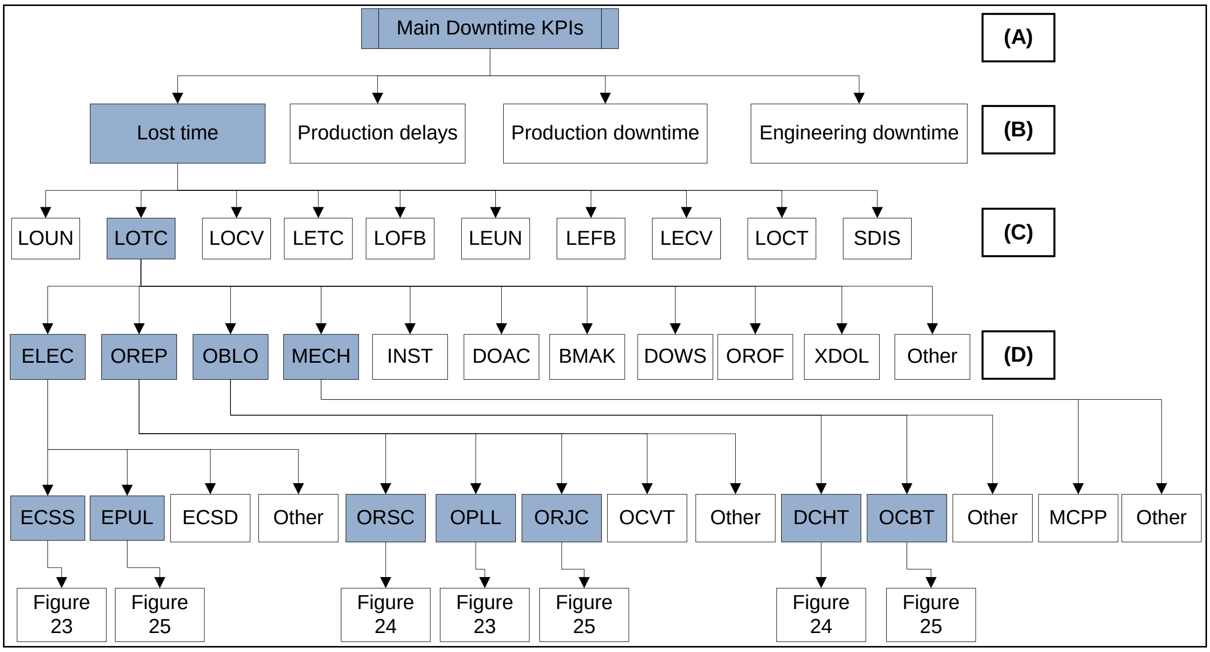


Figure 20: Cause and effect structure tree applicable to the Pareto analysis

2.1.4.4. Software

Microsoft Visio will be used to create professional diagrams to simplify complex information and processes. Microsoft Visio has a user friendly interface with updated shapes, collaboration tools and data-linked diagrams. Microsoft Visio will be used to create relevant figures and diagrams where necessary in the report. Other software that will be used is Sigma XL, which is an Excel add-in used for statistical and graphical analysis. It is easy to use with Six Sigma language. Other advantages include Monte Carlo simulation and optimisation. The student attended a statistics course during the first semester that assisted in using the tools available in Sigma XL.

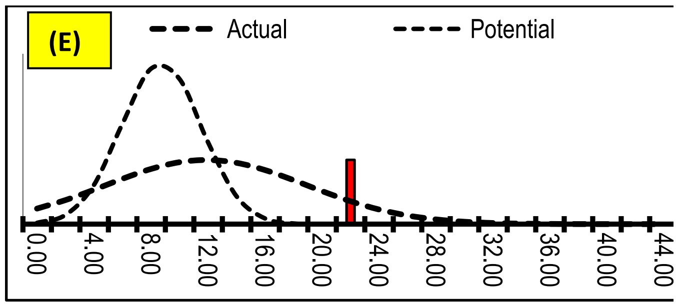
2.2. Capability and performance study on trunk conveyor downtime

Statistical Process Control (SPC) was used to conduct a capability and performance study on trunk conveyor downtime for Vlaklaagte and Simunye shafts. X-MR charts are provided in Figure 21 and Figure 22, as well as data on the capability and performance in Table 3 and Table 4. Ellipse data was collected from January 2012 to June 2013. The upper specification limit per shaft for trunk conveyor downtime is 21.33 hours per week. This upper specification limit was established by Goedehoop colliery.

2.2.1. Vlaklaagte shaft: Capability and performance study

In Table 3, the Ppk equals 0.4, which implies that Vlaklaagte is not conforming to the specification of 21.33 hours trunk conveyor downtime per week. At several instances during the observation period, trunk conveyor downtime exceeded the upper specification limit. Since the aim is to minimise trunk conveyor downtime, the Lower the Better (tLtB) concept was applied after which a target value of 8.73 hours downtime per week was estimated. Vlaklaagte has a Cp of 1.5, indicating that it has very good potential of conforming to 8.73 hours trunk conveyor downtime per week, based on best previous performance. Thus, if Vlaklaagte manage to maintain trunk conveyor downtime as illustrated on the X-chart in Figure 21 (week 64 - 75), this target can most certainly be reached. The actual and potential performances are illustrated in the figure labelled **(E)**.

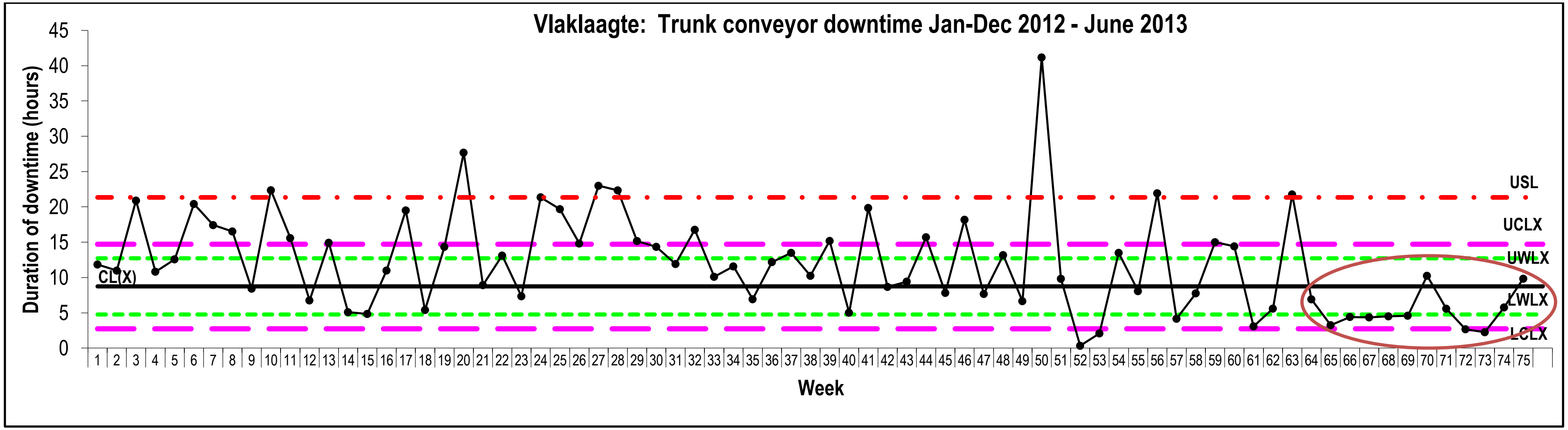
DATE	
25 July 2013	
SPECIFICATIONS	
Upper Spec Limit (USL) =	**21.33**
Lower Spec Limit (LSL) =	
Type of spec:	
The Lower-the-Better	
Target Value	
TV = Nominal spec =	**8.73**



BASIC STATS			**STANDARD 3σ LIMITS: MR CHART**		**STD 3σ LIMITS: X CHART**	
Stats to estimate Process Performance:	$\bar{X}$ =	11.88	UCL (MR) =	10.39	UCL(X) = CL(X) + 3σ^ =	14.71
	s_{LT} =	7.05	UWL (MR) =	7.99	UWL(X) = CL(X) + 2σ^ =	12.72
Stats to estimate Process Capability:	$\bar{X}_0$ =	8.73	CL (MR) = $\overline{MR}$ =	3.18	CL(X) = $\bar{X}_0$ =	8.73
	σ^ =	2.82	LWL (MR) =	1.06	LWL(X) = CL(X) – 2σ^ =	4.75
			LCL (MR) =	0	LCL(X) = CL(X) – 3σ^ =	2.75
PERFORMANCE INDICATORS			**Quality indices**		**Six Sigma indices**	
Process performance index, Ppk, using $\bar{X}$ and s			Ppk =	**0.45**	Actual σ Score =	**1.34**
Taguchi-index, Ppm, using s			Ppm =	**0.41**		
With Ppk = 0.4, the process is NOT CONFORMING to specifications						
The process is currently performing as a 1.3 SIGMA PROCESS						
INITIAL CAPABILITY INDICATORS: What if process would run on =					**With 1,5σ shift in $\bar{X}$**	
target with actual variation (TV & s)			Pp =	**0.60**	$Z_{ScoreLT}$® =	**2.84**
actual average with potential variation ($\bar{X}$ & σ^)			Cpk =	1.12	z_{ST}® =	3.35
target with potential variation (TV & σ^)			Cp =	1.49	**Without 1,5σ shift in $\bar{X}$**	
Taguchi-index, Cpm, using σ^			Cpm =	**0.75**		4.47
With Cp = 1.5, the process has a VERY GOOD POTENTIAL of CONFORMING to the specifications						
The process has the POTENTIAL to perform as 4.4 SIGMA PROCESS						

Table 3: Vlaklaagte: Capability and performance study

Vlaklaagte shaft:



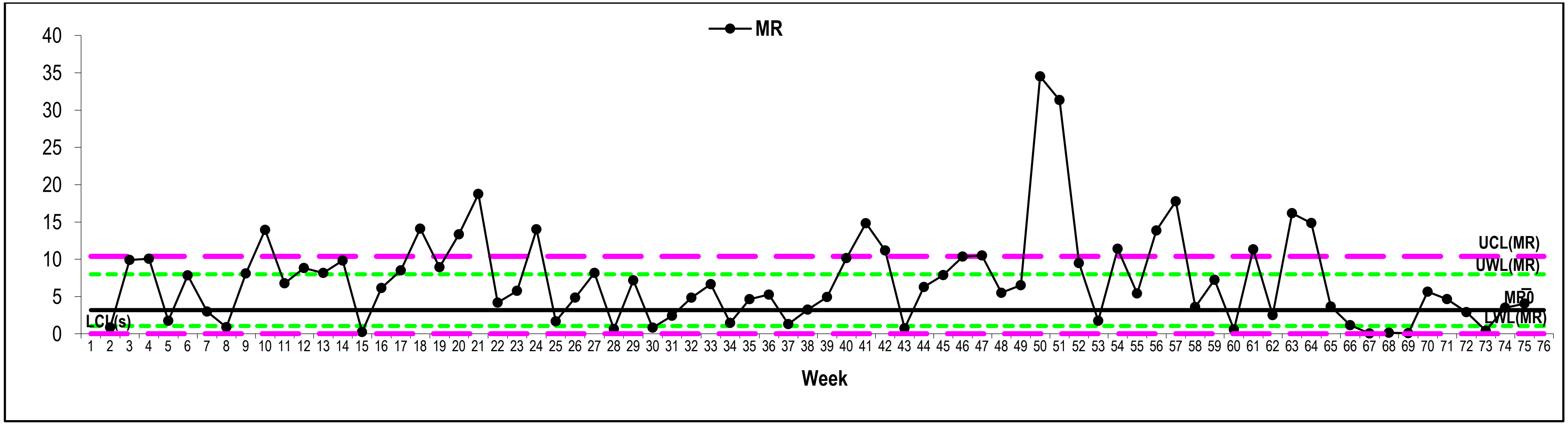
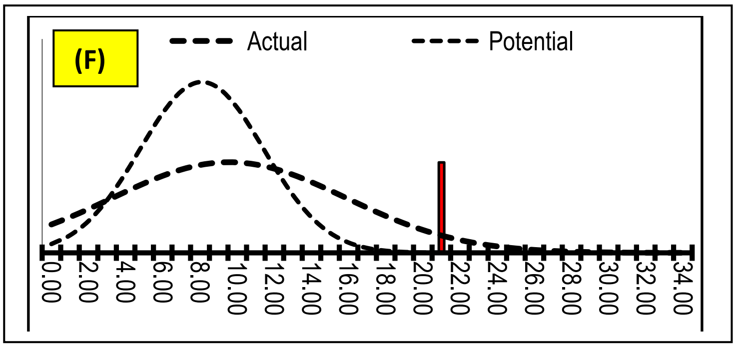


Figure 21: Vlaklaagte: X-MR charts

2.2.2. Simunye shaft: Capability and performance

Simunye shaft is also not conforming to the upper specification, since the Ppk equals 0.6. The Lower the Better (tLtB) concept was applied after which a target value of 8.10 hours downtime per week was estimated, based on best previous performance. Simunye has a Cp of 1.3, indicating that it has a marginal potential to conform to this target value. Thus, if Simunye maintain the trunk conveyor downtime as illustrated on the X-chart in Figure 22 (week 26 - 41), it has potential to reach this target. The actual and potential performances are illustrated in the figure labelled **(F)**.

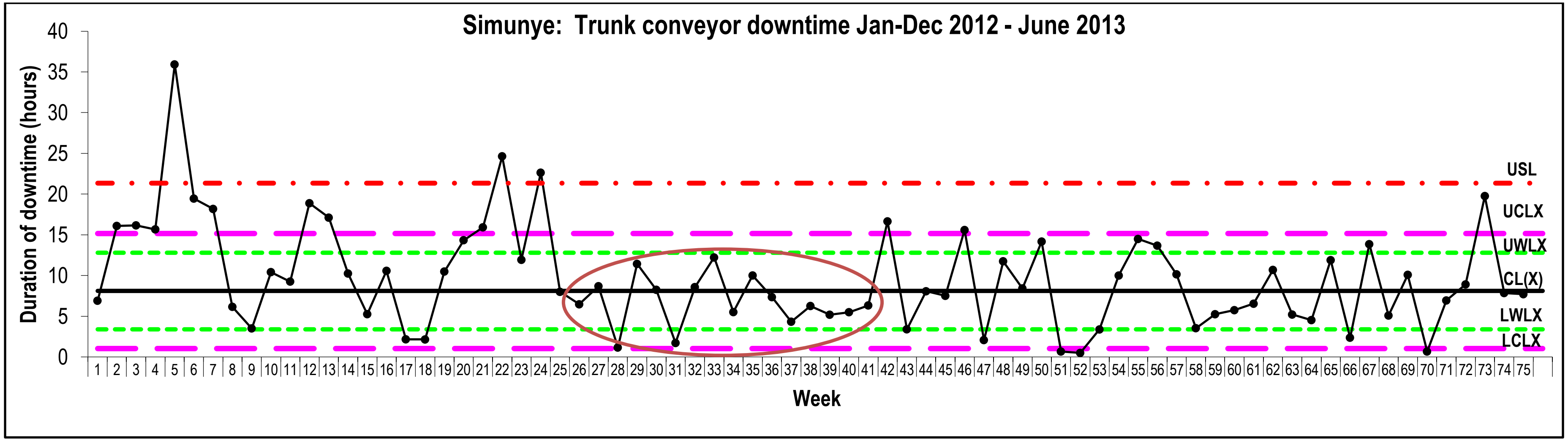
DATE	
25 July 2013	
SPECIFICATIONS	
Upper Spec Limit (USL) =	**21.33**
Lower Spec Limit (LSL) =	
Type of spec:	
The Lower-the-Better	
Target Value	
TV = Nominal spec =	**8.10**



BASIC STATS			**STANDARD 3σ LIMITS: MR CHART**		**STD 3σ LIMITS: X CHART**	
Stats to estimate Process Performance:	$\bar{X}$ =	9.58	UCL (MR) =	12.27	UCL(X) = CL(X) + 3σ^ =	15.16
	s_{LT} =	6.29	UWL (MR) =	9.43	UWL(X) = CL(X) + 2σ^ =	12.81
Stats to estimate Process Capability:	$\bar{\bar{X}}_0$ =	8.10	CL (MR) = $\overline{MR}$ =	3.76	CL(X) = $\bar{\bar{X}}_0$ =	8.10
	σ^ =	3.33	LWL (MR) =	1.25	LWL(X) = CL(X) – 2σ^ =	3.40
			LCL (MR) =	0	LCL(X) = CL(X) – 3σ^ =	1.04
PERFORMANCE INDICATORS			**Quality indices**		**Six Sigma indices**	
Process performance index, Ppk, using $\bar{X}$ and s			Ppk =	**0.62**	Actual σ Score =	**1.87**
Taguchi-index, Ppm, using s			Ppm =	**0.61**		
With Ppk = 0.6, the process is NOR CONFORMING to specifications						
The process is currently performing as a 1.8 SIGMA PROCESS						
INITIAL CAPABILITY INDICATORS: What if process would run on =					**With 1,5σ shift in $\bar{X}$**	
target with actual variation (TV & s)				**0.70**	$Z_{ScoreLT}$® =	3.37
actual average with potential variation ($\bar{X}$ & σ^)				1.18	z_{ST}® =	3.53
target with potential variation (TV & σ^)				1.32	**Without 1,5σ shift in $\bar{X}$**	
Taguchi-index, Cpm, using σ^			Cpm =	1.08		3.97
With Cp = 1.3, the process has a MARGINALLY POTENTIAL of CONFORMING to the specifications						
The process has the POTENTIAL to perform as 3.9 SIGMA PROCESS						

Table 4: Simunye: Capability and performance study

Goedehoop: Simunye shaft



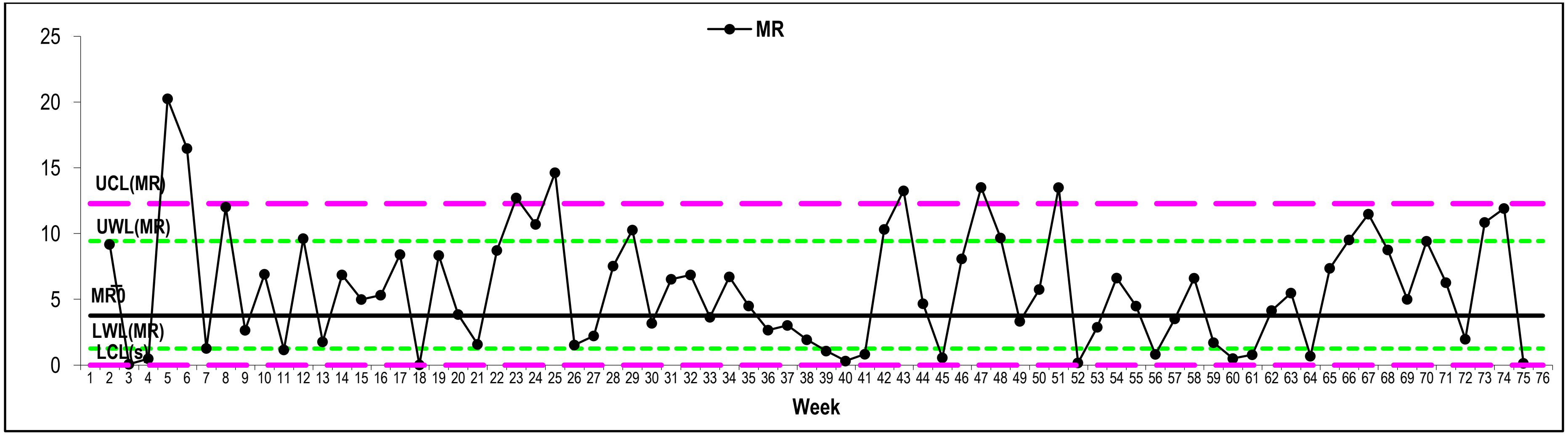


Figure 22: Simunye: X-MR chart

3. ANALYSE

3.1. Cause and effect structure trees

The following cause and effect structure trees were compiled after various interviews with relevant personnel at Goedehoop colliery. Research on trunk conveyors was also conducted to complete the cause and effect analysis. Solutions will be provided in the Improve Phase that will address specific causes, marked ***(a)-(s)***, for the below mentioned trunk conveyor downtimes.

3.1.1. OPLL: Pull key pulled & ECSS: Conveyor stop start

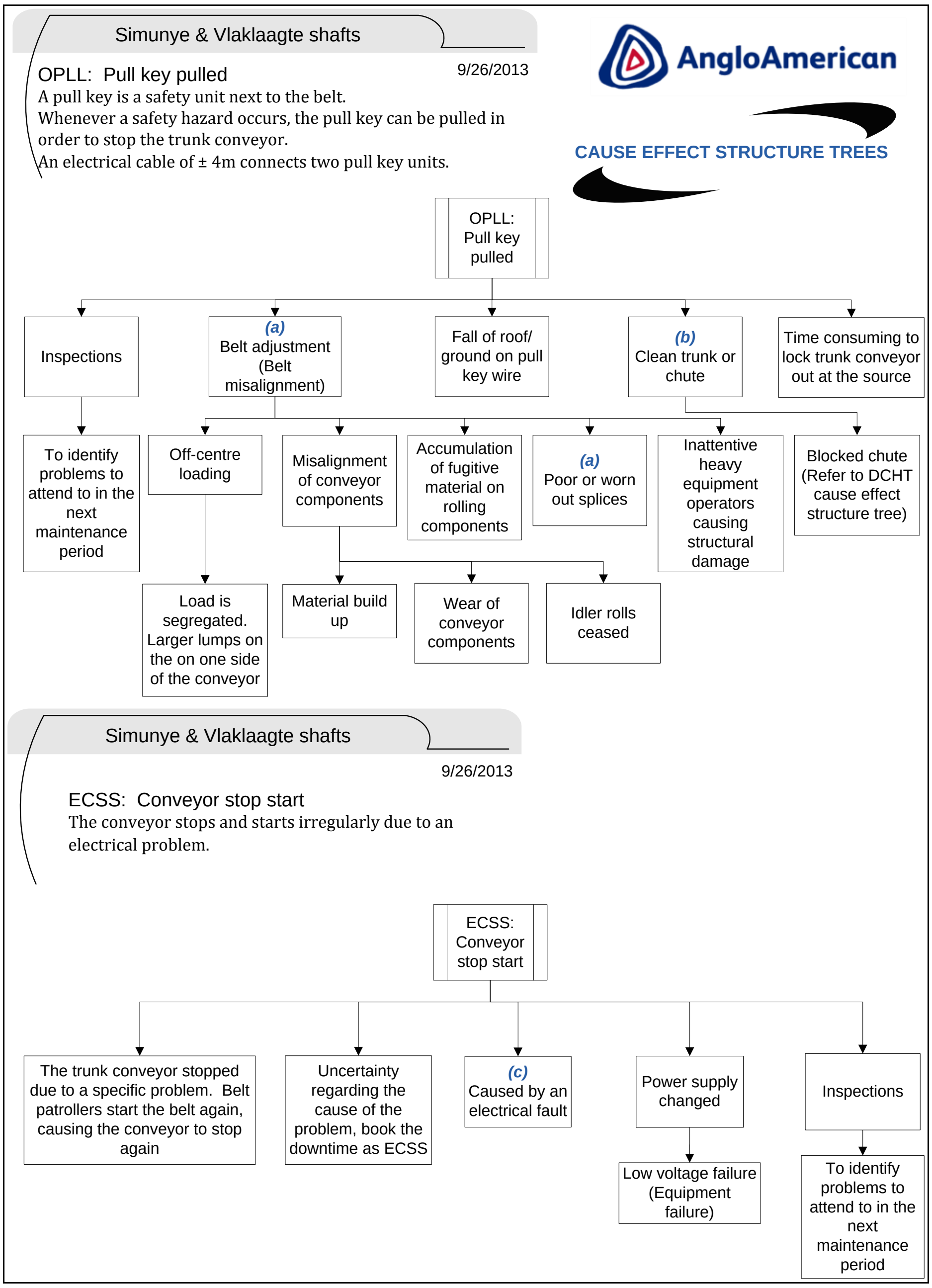


Figure 23: OPLL and ECSS Cause and effect structure trees

3.1.2. ORSC: Conveyor reset & DCHT: Chutes blocked

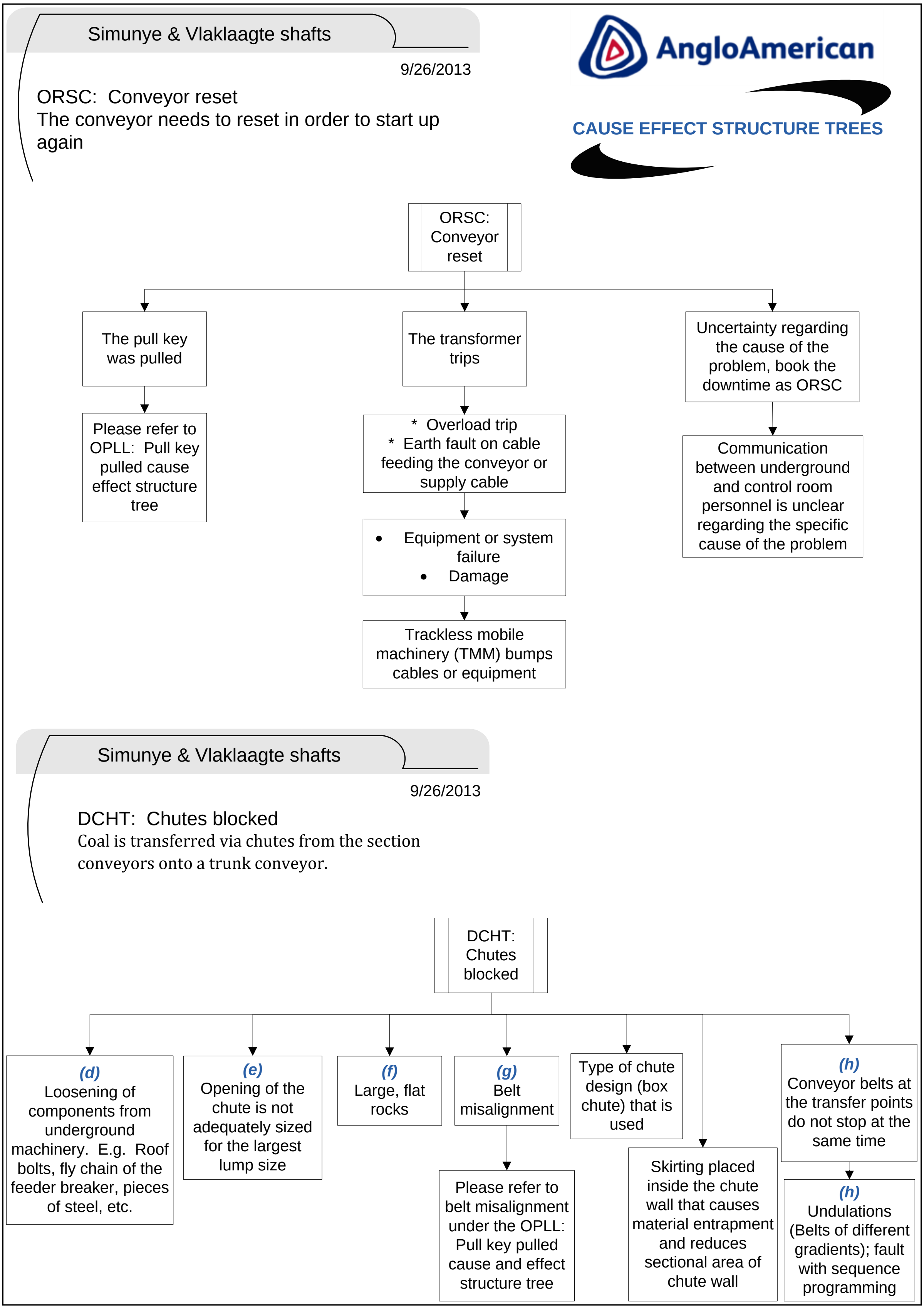


Figure 24: ORSC and DCHT Cause and effect structure trees

3.1.3. EPUL: Pull key electrical, ORJC: Conveyor belt joint & OCBT: Conveyor tail end stuck

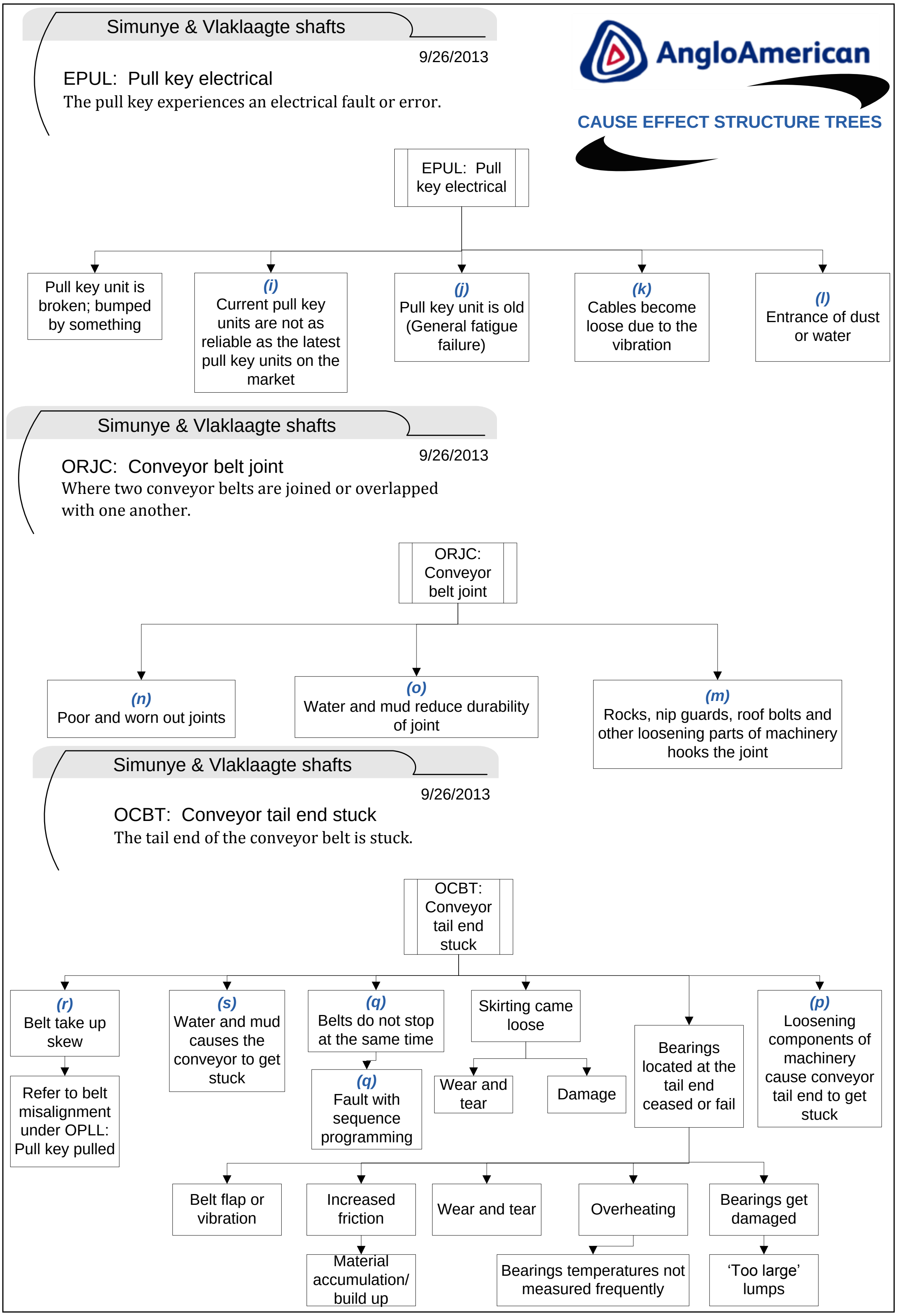
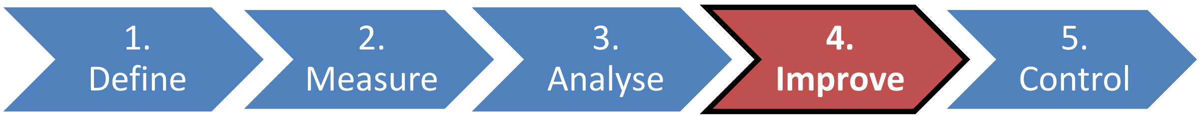


Figure 25: EPUL, ORJC and OCBT Cause and effect structure trees

4. IMPROVE



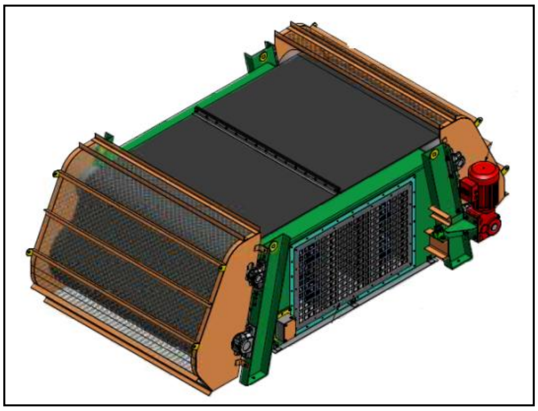
4.1. Generate and select solutions

After a thorough cause and effect analysis was completed in the Analyse Phase, the student consulted trunk conveyor experts, trunk conveyor suppliers and mechanical and electrical engineers to obtain possible solutions. The causes addressed by the proposed solutions will be provided in Table 5. A table containing the implementation cost of the solutions, potential benefits as well as an implementation plan, will also be provided in this section. A survey, provided in Appendix C, was compiled by the student which was sent to relevant personnel at Goedehoop collliery and Supplier XYZ. The survey was used to verify that the proposed solutions will potentially solve some of the identified causes and result in a potential benefit for the colliery.

4.1.1. Proposed solution 1: Implement over-belt magnets on the trunk conveyors to separate the loosening components from underground machinery from the product.

Currently Goedehoop has no underground over-belt magnets. Over-belt magnets are implemented on trunk conveyors for underground tramp iron removal.

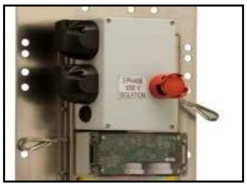
Advantages include:



- Separate steel or loosening components from underground machinery (roof bolts, CM picks, guards and the flychain of the Feeder Breaker) from the product on the conveyor belt
- Reduced damage to conveyor belt joints
- Reduced blocked chutes and the tail end of conveyors getting stuck due to the loosening components
- Fireproof, which is ideal for underground coal mining operations
- Complies with SANS 10108 Edition 5, which refers to flameproof equipment used underground

4.1.2. Proposed solution 2: Replace broken or faulty pull key units with Supplier ABC IPS 3000 pull key units.

Goedehoop colliery has the following pull key units installed at different locations: Supplier ABC Bull dog, IPS1000 and IPS2000. Supplier ABC is a leading mining electronics company, with expertise in the design, development and implementation of electronic mining systems. Goedehoop colliery uses Supplier ABC's pull key units. Replacing all broken or faulty pull key units with Supplier ABC IPS 3000 units at Goedehoop colliery will include the following benefits:



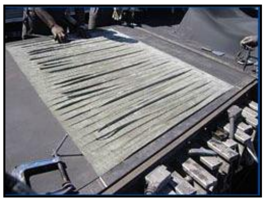

- Increased reliability
- Lower power consumption to maximise the number of pull keys in the system
- Reduced number of electrical and nuisance faults
- Easier identification of the location and the number of the faulty pull key unit, supplied by the IPS 3000 controller
- Meet all requirements of the Anglo American Conveyor Belt Protection Systems Standard that was installed post March 2012 on AATC operations

4.1.3. Proposed solution 3: Acquire a specialist splice team from Supplier XYZ to perform splicing where clip joints are present and repair any damaged or worn out splices.

Clip joints are temporarily applied to conveyor belts that have torn, after which finger splicing needs to be done by a specialist splice team. The student went for a factory visit on 8 August 2013.

Advantages include:

- Do not have to change joints during the maintenance period
- Splices do not damage the conveyor components and vice versa
- More permanent solution



4.1.4. Proposed solution 4: Replace existing box chutes with spiral chutes, where possible.

A number of mechanical engineers at Goedehoop colliery stated that since box chutes were replaced with spiral chutes during July 2012, the number of chute blockages declined. However, there are still box chutes present at some of the transfer points. After Figure 26 was compiled, it was clear to the student that from the middle of 2012 until May 2013 the number of chute blockages declined:

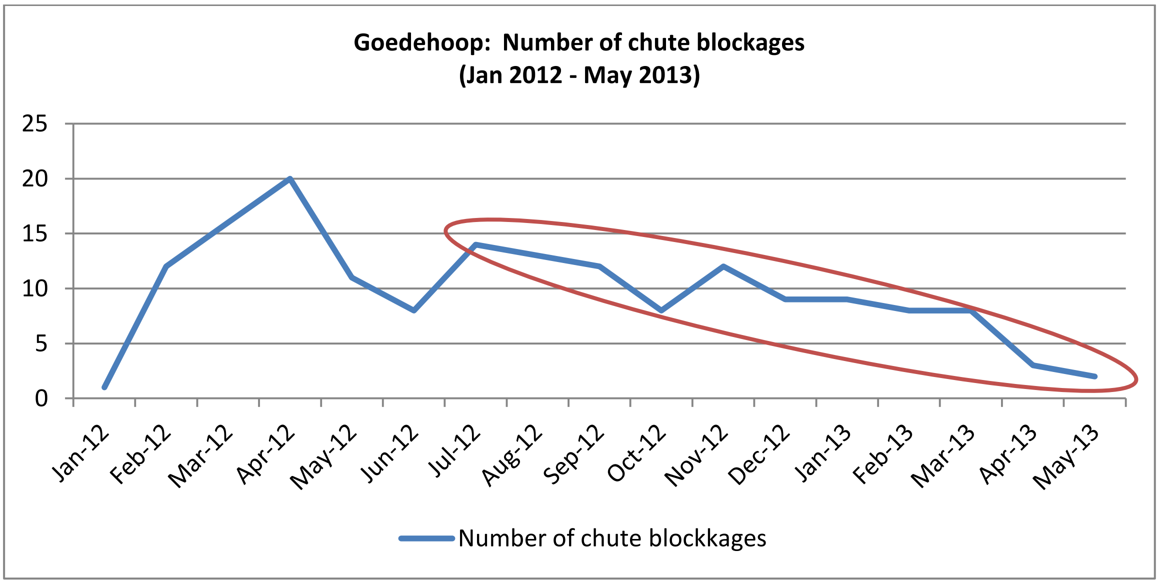


Figure 26: Number of chute blockages Jan 2012 - May 2013

Replacing all existing box chutes with spiral chutes will therefore include the following advantages:

- Reduced chute blockages
- Improved flow of the product
- Reduced material build up
- More area for the product to move, not limited to a fixed box structure

4.1.5. Proposed solution 5: Contact Supplier XYZ to conduct a time study at Goedehoop colliery's trunk conveyors and provide a full report on the correct sequence programming.

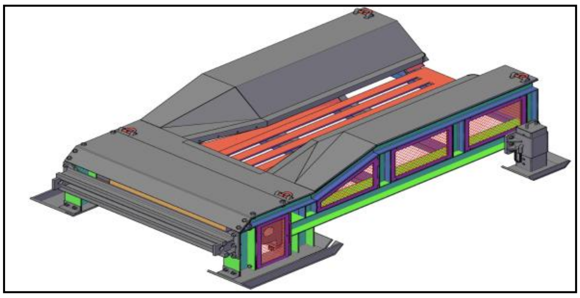
At Goedehoop colliery, trunk conveyor belts run at different gradients. Whenever an descending belt feeds onto another belt (flat belt), which has stopped for a particular reason, the product on the descending belt causes the conveyor belt to move resulting in spillage. Currently, brakes are installed on the descending belts to avoid this. It is crucial to estimate the correct sequence programming of the run down time of the conveyors. This solution will:

- Cause conveyors to stop at the same time
- Reduce spillage, blocked chutes and tail end of conveyors getting stuck
- Help the personnel at Goedehoop colliery to monitor and control the sequence programming specified by Supplier XYZ

4.1.6. Proposed solution 6: Implement the redesigned tail ends on the conveyors.

A redesigned tail end which was implemented and tested at Goedehoop colliery, has the following advantages:

- Reduced spillage
- More stabilized belt alignment
- Improved centre loading



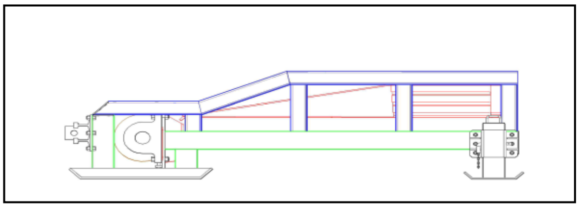


Table 5 lists the downtimes with is respective causes that will potentially be solved by implementing a specific proposed solution:

Trunk conveyor downtime	**Cause (Also marked as *(a)-(s)* on the respective cause and effect structure trees in the Analyse Phase)**	**Proposed solution**					
		1	**2**	**3**	**4**	**5**	**6**
OPLL	*(a).* Belt misalignment due to poor or worn out splices			✓			
	(b). Clean trunk or blocked chute				✓		
ECSS	*(c).* Caused by an electrical fault		✓				
DCHT	*(d).* Loosening components from underground machinery. E.g. Roof bolts, fly chain of feeder breaker, pieces of steel, etc.	✓					
	(e). Opening of the chute is not adequately sized for the largest lump size				✓		
	(f). Large, flat rocks				✓		
	(g). Belt misalignment				✓		
	(h). Conveyor belts at the transfer points do not stop at the same time due to undulations with faulty sequence programming					✓	
EPUL	*(i).* Current pull key units are not as reliable as the latest pull key units on the market		✓				
	(j). Pull key unit is old (General fatigue failure)		✓				
	(k). Cables become loose due to vibration		✓				
	(l). Entrance of dust or water		✓				
ORJC	*(m).* Rocks, nip guards, roof bolts and other loosening parts of machinery hooks the joint	✓					
	(n). Poor and worn out joints			✓			
	(o). Water and mud reduce durability of joint			✓			
OCBT	*(p).* Loosening components of machinery cause conveyor tail end to get stuck	✓					
	(q). Belts do not stop at the same time due to faulty sequence programming					✓	
	(r). Belt take up skew						✓
	(s). Water and mud causes the conveyor to get stuck						✓

Table 5: Trunk conveyor downtime causes addressed by the respective proposed solutions

Downtimes:
OPLL: Pull key pulled
ECSS: Conveyor stop start
DCHT: Chutes blocked
EPUL: Pull key electrical
ORJC: Conveyor belt joint
OCBT: Conveyor tail end stuck

Solutions:
Proposed solution 1: Implement over-belt magnets on the trunk conveyors to separate the loosening components from underground machinery from the product.

Proposed solution 2: Replace broken or faulty pull key units with Supplier ABC IPS 3000 pull key units.

Proposed solution 3: Acquire a specialist splice team from Supplier XYZ to perform splicing where clip joints are present and repair any damaged or worn out splices.

Proposed solution 4: Replace existing box chutes with spiral chutes, where possible.

Proposed solution 5: Contact Supplier XYZ to conduct a time study at Goedehoop colliery's trunk conveyors and provide a full report on the correct sequence programming.

Proposed solution 6: Implement the redesigned tail ends on the conveyors.

Figure 27: Summary of the trunk conveyor downtimes and the proposed solutions

4.2. Alternative solutions

The following alternative solutions are also suggested:

- Update the current VMP (Vehicle Management Plan) and ensure equipment does not follow the routes on which the cables are located. This will aid in limiting equipment failure caused by damage. This solution will address ORSC: Conveyor reset, which is not addressed in the above mentioned solutions

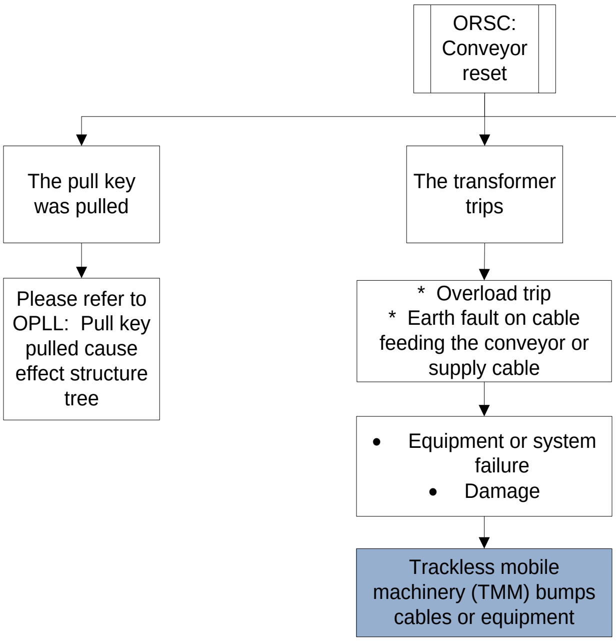


Figure 28: ORSC cause addressed by an alternative solution

- Train the control room personnel to ask the correct questions on the downtime that is booked e.g. What caused the specific downtime to occur?
- Water must be pumped out before mining takes place. This will reduce the mud and water that causes damage to the conveyor components
- Ambiguous downtime codes should be eliminated from the system. More specific and precise codes for the causes of downtimes should be used

4.3. Cost and potential benefit

Personell at Goedehoop colliery and Supplier XYZ provided the student with relevant information to estimate implementation costs per proposed solution. The completed surveys were used to estimate the potential benefits the solutions will bring if it had to be implemented. The costs and potential benefits are summarised in Table 6. The potential benefit is calculated as illustrated in equation (3):

Benefit = Potential amount of TC downtime hours reduced *(DOH/Controllable time) * CM rate (3)

Proposed solution	Cost of implementation (once off)	Potential benefit (per year)
4.3.1. Implement over-belt magnets on the trunk conveyors to separate the loosening components from underground machinery from the product	R 19 500 000.00	R 1 224 653.84
4.3.2. Replace broken or faulty pull key units with Supplier ABC IPS 3000 pull key units	R 3 842 576.53	R 2 230 688.77
4.3.3. Acquire a specialist splice team from Supplier XYZ to perform splicing where joints are present and repair any damaged or worn out splices	R 773 742.00	R 1 455 606.51
4.3.4. Replace existing box chutes with spiral chutes, where possible	R 323 800.00	R 2 244 227.47
4.3.5. Contact Supplier XYZ to conduct a time study at Goedehoop colliery's trunk conveyors and provide a full report on the correct sequence programming	R 36 000.00	R 723 294.14
4.3.6. Implement the redesigned tail ends on the conveyors.	R 3 150 000.00	R 538 636.56
Total	**R 27 626 118.53**	**R 8 417 107.29**

Table 6: Costs and potential benefits per proposed solution

If all pull key units had to be replaced at Goedehoop colliery, it would cost approximately R3 842 576.53. The benefit gained will equate to R 2 230 688.77 per year, which implies that the investment will pay for itself within two years time. The pull key units can be used for eight years which indicates that this is a viable solution. Proposed solutions numbered 4.3.3. - 4.3.5., indicate large potential gains for the company as the benefits exceed the total estimated cost of implementation. On the other hand, solution 4.3.1. and 4.3.6. are not as viable as the others since the cost of implementation significantly exceeds the potential benefit to be gained from it. The cost breakdowns and benefit calculations are provided in Appendix F. How the benefits relate to the initial project aim will be discussed in the conclusion of this report.

4.4. Solution validation

Five surveys were sent to the relevant personnel at Goedehoop and consultants at Supplier XYZ. This survey is provided in Appendix C and the individual ratings in Appendix F, Section 8.6.2.1. Table 7 consists of the average rating (out of 10) for each question in the survey, as well as the average rating per proposed solution.

Proposed solution	Cause	Question number	Average rating/10	Average rating per solution/10
1	DCHT	1.1.	7.20	7.13
	ORJC	1.2.	7.20	
	OCBT	1.3.	7.00	
2	ECSS	2.1.	7.80	7.28
	EPUL	2.2.	7.40	
	EPUL	2.3.	6.80	
	EPUL	2.4.	7.20	
	EPUL	2.5.	7.20	
3	OPLL	3.1.	8.00	7.67
	ORJC	3.2.	8.00	
	ORJC	3.3.	7.00	
4	DCHT	4.1.	7.00	7.4
	DCHT	4.2.	7.60	
	DCHT	4.3.	7.00	
	OPLL	4.4.	8.00	
5	DCHT	5.1.	8.20	8.1
	OCBT	5.2.	8.00	
6	OCBT	6.1.	6.80	7.2
	OCBT	6.2.	7.60	

Table 7: Survey ratings

According to the average ratings per solution, there is a ± 70-80% chance that the proposed solutions can improve or eliminate specific causes of the identified trunk conveyor downtimes. Consequently, the project aim and deliverables were met and will definitely add value to Goedehoop colliery.

4.5. Implementation plan

Table 8 represents the consequential tonnes lost on each of the trunk conveyors of Simunye and Vlaklaagte shafts during 2012. It is advised that if any solutions are to be implemented in the future or if entire upgrades are not possible (due to cost constraints), the solutions should be implemented on the trunk conveyors that caused the highest tonnes lost during 2012. These are indicated in red and with ✖ on Figure 29 and Figure 30. The implementation plan calculations are provided in Appendix G.

Simunye Trunk	Consequential tonnes lost	Vlaklaagte Trunks	Consequential tonnes lost
BUCVR4S1	**36753.17**	H4CTB73	**25977.37**
BUCVG13	**26692.06**	H4CV008	**25303.12**
BUCVG14	**17071.04**	H4CV023	**22837.50**
BUCVG10	**16990.31**	H4CV009	**18797.77**
BUCVG11	**15401.71**	H4CV006	**18339.29**
BUCVG04	**14043.75**	H4CV004	**17666.85**
BUCVG07	**11656.51**	H4CV003	**14619.86**
BUCV4S3	**9206.58**	H4CV002	**13008.12**
BUCVG12	**8972.32**	H4CV010	**11976.57**
BUCV4S5	**8286.74**	H4CV016	**9740.20**
BUCV4S2	**6289.48**	H4CV036	**8191.55**
BUCVG05	**6034.40**	H4CT024	**7990.24**
BUCV4S6	**3983.81**	H4CV019	**6387.75**
BUCVG06	**3877.82**	H4CV026	**4829.10**
BUCVG15	**0.00**	H4CTBS4	**2054.17**
BUCVG16	**0.00**	H4CT038	**683.10**
Red: Implementation preference high Orange: Implementation preference medium Green: Implementation preference low		H4CTB74	**0.00**
		H4CV037	**0.00**
		H4CV058	**0.00**

Table 8: Consequential tonnes lost per shaft

The following figures indicate the locations of the trunk conveyors, section conveyors and sections at Simunye shaft (2 Seam and 4 Seam) and Vlaklaagte shaft:

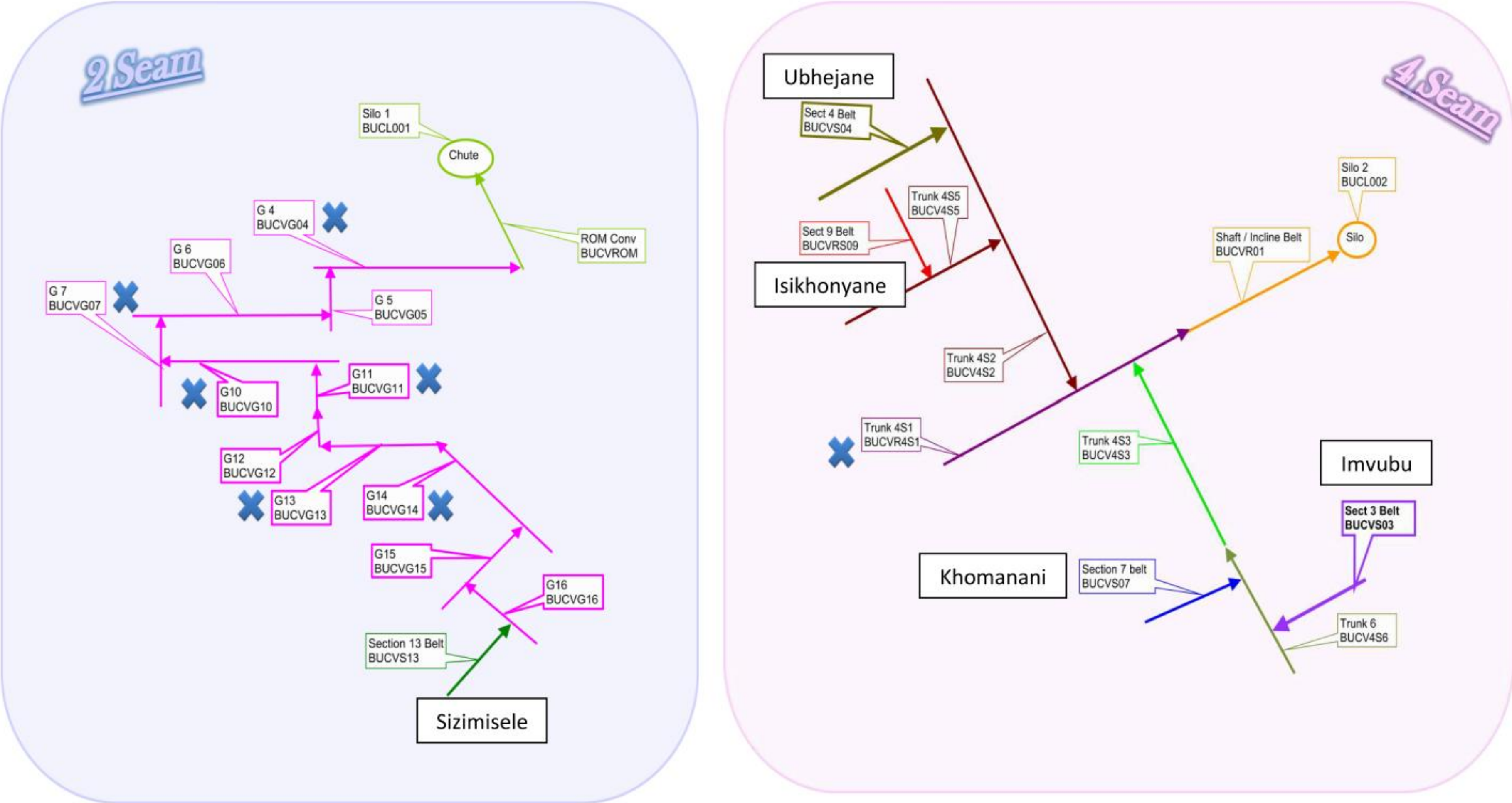


Figure 29: Trunk conveyors at Simunye shaft

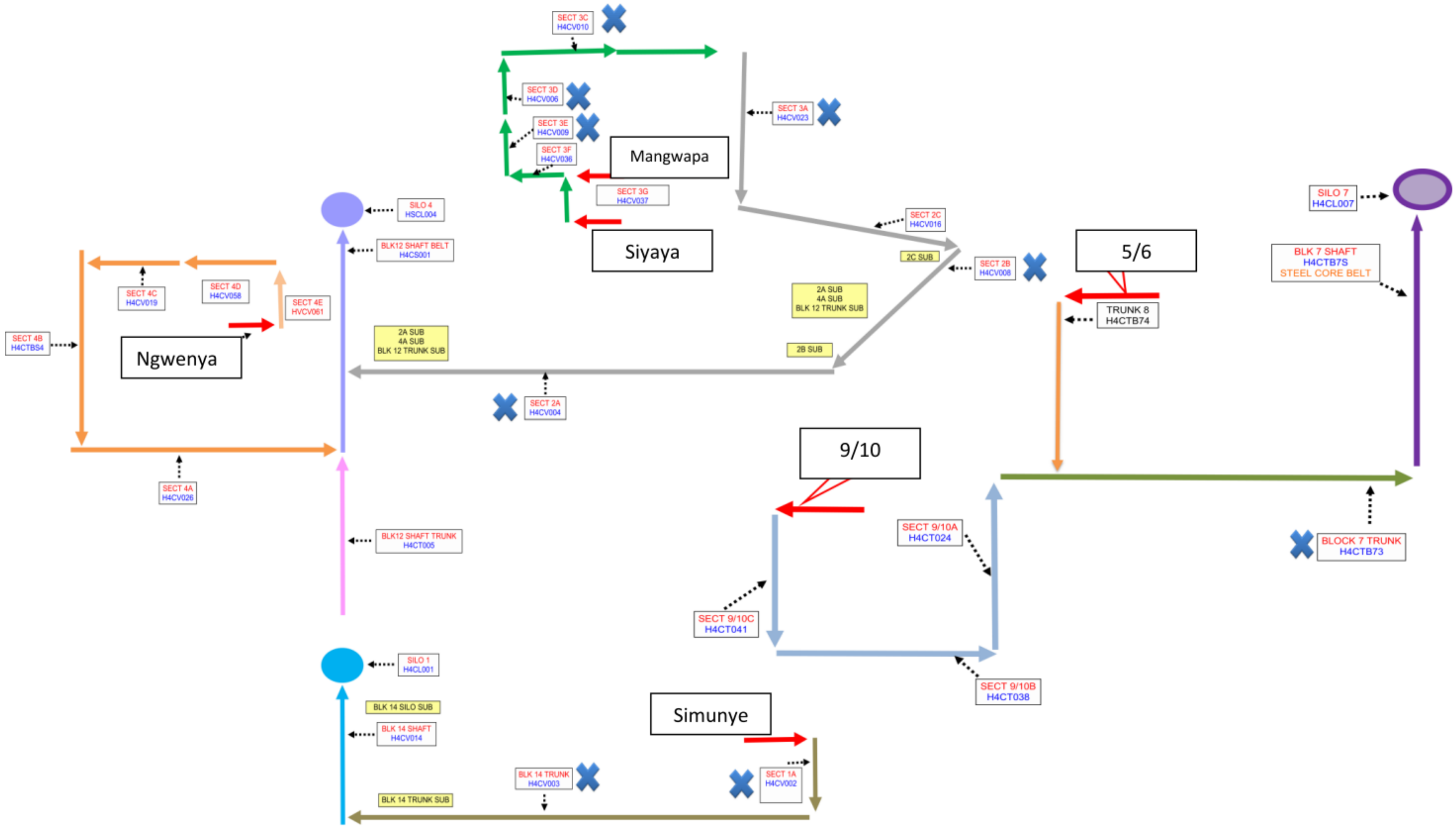
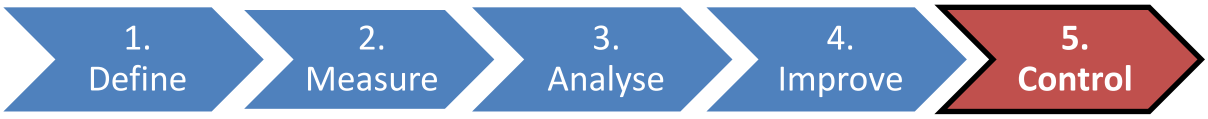


Figure 30: Trunk conveyors at Vlaklaagte shaft

5. Control



It is suggested that the control charts, as illustrated in the Measure Phase, are implemented at Goedehoop colliery. An industrial engineer should plot the downtime of the trunk conveyors on a weekly basis, in order to monitor and control the process. If at any instance the process is out of control, investigations should be done to determine the problem and make the necessary changes to avoid it from occurring again. It is also advised that the cause and effect structure trees are made available to the trunk conveyor crew to identify more causes of these trunk conveyor downtimes, expand it and in some manner collect data on each of the causes. This will help the engineers to propose and implement solutions that will solve specific causes and problems at hand.

6. Conclusion

The aim of the project was to improve the actual production time (DOH) of the CMs at Goedehoop colliery. In order to help Goedehoop colliery reach its target of operating 40% of the total time available, the student identified areas where improvement initiatives should be implemented.

It was identified that trunk conveyor downtime has a significant impact on the throughput of the process, as well as on the production time of the CMs. As mentioned earlier, downtime on trunk conveyors cause CMs to be idle. Solutions were proposed that will potentially solve the major causes of trunk conveyor downtime. A total of 162.88 hours (per year) on trunk conveyor downtime can possibly be reduced if the proposed solutions were implemented. This results in a potential benefit of R 8 417 107.29 per year for Goedehoop colliery.

In view of the initial project aim, this will equate to a potential 1.5% improvement in DOH, if the proposed solutions were to be implemented. The significant 1.5% improvement in DOH could be achieved, if the downtime on trunk conveyors were to be improved being only one part of the whole process. The other 3.5% improvement in DOH required to reach Goedehoop colliery's target, can be achieved if the other components in the process are improved, by applying a similar approach as illustrated in this project. Focussing on and improving only one component of a process at a time, can make a significant difference and help a colliery reach its targets.

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8. Appendices

8.1. Appendix A: Signed industry sponsorship form

Department of Industrial & Systems Engineering
Final Year Projects
Identification and Responsibility of Project Sponsors

All Final Year Projects are published by the University of Pretoria on *UPSpace* and thus freely available on the Internet. These publications portray the quality of education at the University and have the potential of exposing sensitive company information. It is important that both students and company representatives or sponsors are aware of such implications.

Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide the best guidance to the student on the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

Project Sponsor Details:

Company:	Anglo American Thermal Coal
Project Description:	Optimising production time of continuous miners at Goedehoop colliery
Student Name:	Yovanka Kraucamp
Student number:	29233519
Student Signature:	Kraucamp
Sponsor Name:	Wessel Wessels
Designation:	Asset optimisation Manager
E-mail:	wessel.h.wessels@angloamerican.com
Tel No:	(011) 638 2759
Cell No:	0823387757
Fax No:	086 578 7439
Sponsor Signature:	[illegible]

8.2. Appendix B: Budget and resources

8.2.1. Budget

The following table is a rough estimate of the student's expenses in order to execute and complete the project:

Expense	Cost
Transport during July 2013 holidays	R 2000.00
Internet access	R 200.00
Printing (colour and black and white cartridge)	R 700.00
Poster printing	R 250.00
Binding	R 40.00
Stationary (paper, pens, etc.)	R 100.00
Total cost	**R 3290.00**

Table 9: Budget

8.2.2. Resources

The following resources were used during execution and completion of the project:

- Access to the internet (a laptop with internet connection) to conduct a comprehensive literature review and research on the project. The internet will also be used as a tool to communicate to the project leader and the industry sponsor, via emails
- Access to the library
- Car and fuel to visit the underground operations and the Anglo American Head Office in Johannesburg
- A printer to print intermediate and final reports
- Print company to print the poster required

8.3. Appendix C: Survey

Goedehoop Colliery

AngloAmerican

Survey: Solutions to causes of trunk conveyor downtime at Goedehoop Colliery

Final year Industrial Engineering student at the University of Pretoria

Purpose of the survey: The purpose of the survey is to verify whether the proposed solutions will solve the causes of trunk conveyor downtime.

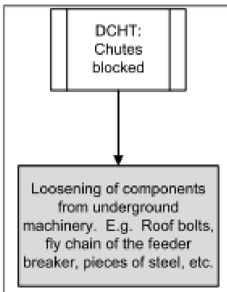
Please complete the following table:

Name and surname:	
Position:	
Email address:	
Date completed:	

Instructions:

- Please answer all questions
- The rating scale is from 1 - 10 of which:
  1: The solution will not solve the problem at all
  10: The solution will solve the entire problem
- The following major causes to trunk conveyor downtime during 2012 were identified:
  OPLL: Pull key pulled, ECSS: Conveyor stop start, ORSC: Conveyor reset, DCHT: Chutes blocked, EPUL: Pull key electrical, ORJC: Conveyor belt joint and OCBT: Conveyor tail end stuck. A cause and effect structure tree was drawn up for each of these downtimes in order to estimate what causes it to occur. Please indicate on a scale of 1-10 how the proposed solution will solve the downtime caused by the shaded block.

  E.g. Proposed solution: Implement over-belt magnets on the trunk conveyors. Please indicate on a scale of 1-10 how it will solve the blocked chutes problem caused by the shaded block:



Please indicate on the scale below to what extend the proposed solution will solve the blocked chutes problem caused by the shaded block:

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Thank you for taking the time to complete the survey! Please contact me on 0727242539 if any uncertainties persists. Have a nice day.

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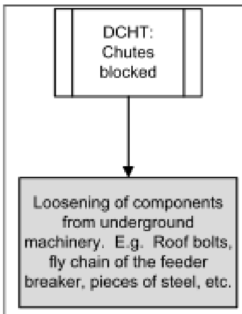
Proposed solution 1: Implement over-belt magnets on the trunk conveyors to separate the loosening components, from underground machinery, from the product.

1.1. DCHT: Chutes blocked



Please indicate on the scale below to what extend the proposed solution will solve the blocked chutes problem caused by the shaded block:

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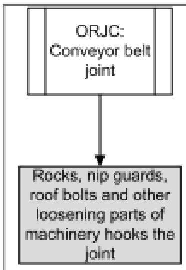
1.2. ORJC: Conveyor belt joint



Please indicate on the scale below to what extend the proposed solution will solve the conveyor belt joints problem caused by the shaded block:

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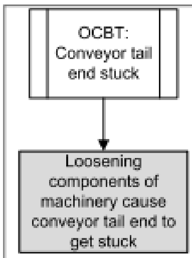
1.3. OCBT: Conveyor tail end stuck



Please indicate on the scale below to what extend the proposed solution will solve the conveyor end stuck problem caused by the shaded block:

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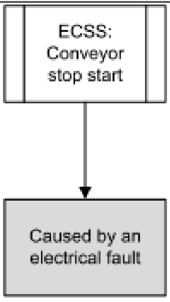
Proposed solution 2: Replace broken or faulty pull key units with Supplier ABC IPS 3000 pull key units.

2.1. ECSS: Conveyor stop start



Please indicate on the scale below to what extend the proposed solution will solve the conveyor stop start problem caused by the shaded block:

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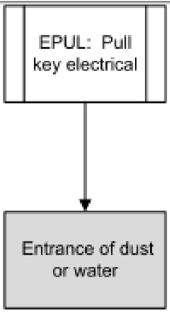
2.2. EPUL: Pull key electrical



Please indicate on the scale below to what extend the proposed solution will solve the pull key electrical problem caused by the shaded block:

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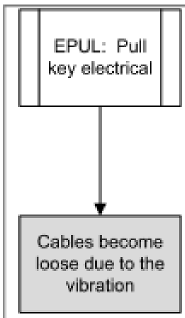
2.3. EPUL: Pull key electrical



Please indicate on the scale below to what extend the proposed solution will solve the pull key electrical problem caused by the shaded block:

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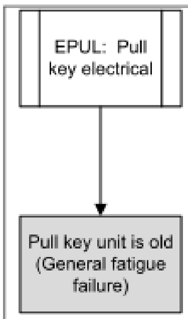
Proposed solution 2: Replace broken or faulty pull key units with Supplier ABC IPS 3000 pull key units.

2.4. EPUL: Pull key electrical



Please indicate on the scale below to what extend the proposed solution will solve the pull key electrical problem caused by the shaded block:

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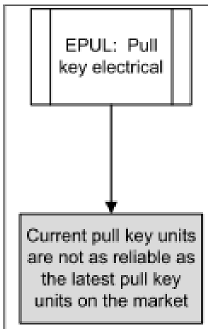
2.5. EPUL: Pull key electrical



Please indicate on the scale below to what extend the proposed solution will solve the pull key electrical problem caused by the shaded block:

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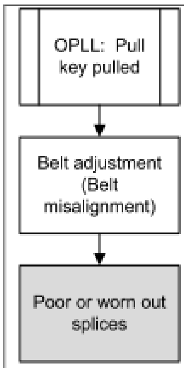
Proposed solution 3: Acquire specialist splice team from Supplier XYZ to perform splicing where joints are present and repair any damaged or worn out splices.

3.1. OPLL: Pull key pulled



Please indicate on the scale below to what extend the proposed solution will solve the BELT MISALIGNMENT PROBLEM caused by the shaded block:

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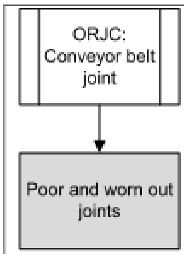
3.2. ORJC: Conveyor belt joint



Please indicate on the scale below to what extend the proposed solution will solve the conveyor belt joint problem caused by the shaded block:

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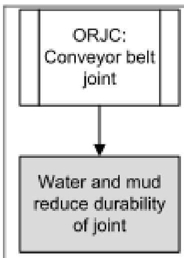
3.3. ORJC: Conveyor belt joint



Please indicate on the scale below to what extend the proposed solution will solve conveyor belt joint problem caused by the shaded block:

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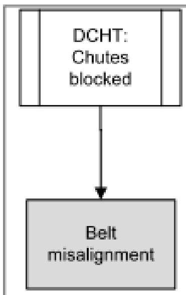
Proposed solution 4: Replace existing box chutes with spiral chutes.

4.1. DCHT: Blocked chutes



Please indicate on the scale below to what extend the proposed solution will solve the blocked chutes problem caused by the shaded block:

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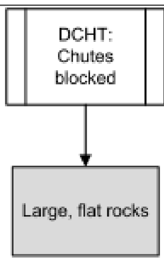
4.2. DCHT: Blocked chutes



Please indicate on the scale below to what extend the proposed solution will solve the blocked chutes problem caused by the shaded block:

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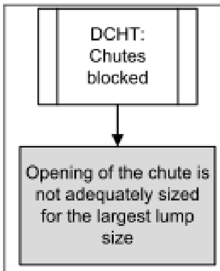
4.3. DCHT: Blocked chutes



Please indicate on the scale below to what extend the proposed solution will solve the blocked chutes problem caused by the shaded block:

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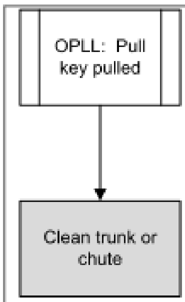
Proposed solution 4: Replace existing box chutes with spiral chutes.

4.4. OPLL: Pull key pulled



Please indicate on the scale below to what extend the proposed solution will solve the pull key pulled problem caused by the shaded block:

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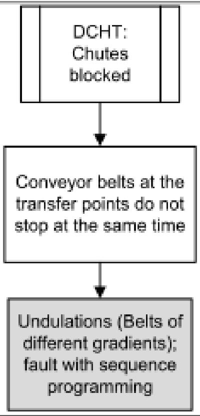
Proposed solution 5: Contact Supplier XYZ to conduct a time study at Goedehoop Colliery's trunk conveyors and provide a complete report on the correct sequence programming.

5.1. DCHT: Chutes blocked



Please indicate on the scale below to what extend the proposed solution will solve the PROBLEM OF CONVEYOR BELTS NOT STOPPING AT THE SAME TIME caused by the shaded block:

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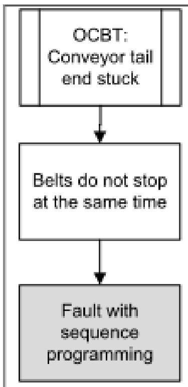
5.2. OCBT: Conveyor tail end stuck



Please indicate on the scale below to what extend the proposed solution will solve the PROBLEM OF CONVEYOR BELTS NOT STOPPING AT THE SAME TIME caused by the shaded block:

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Survey: Solutions to causes of trunk conveyor downtime at Goedehoop Colliery

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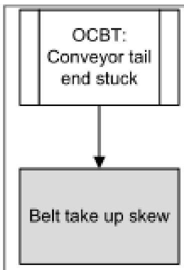
Proposed solution 6: Implement the redesigned tail ends on the conveyors.

6.1. OCBT: Conveyor tail end stuck



Please indicate on the scale below to what extend the proposed solution will solve the conveyor tail end stuck problem caused by the shaded block:

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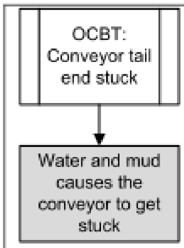
6.2. OCBT: Conveyor tail end stuck



Please indicate on the scale below to what extend the proposed solution will solve the conveyor tail end stuck problem caused by the shaded block:

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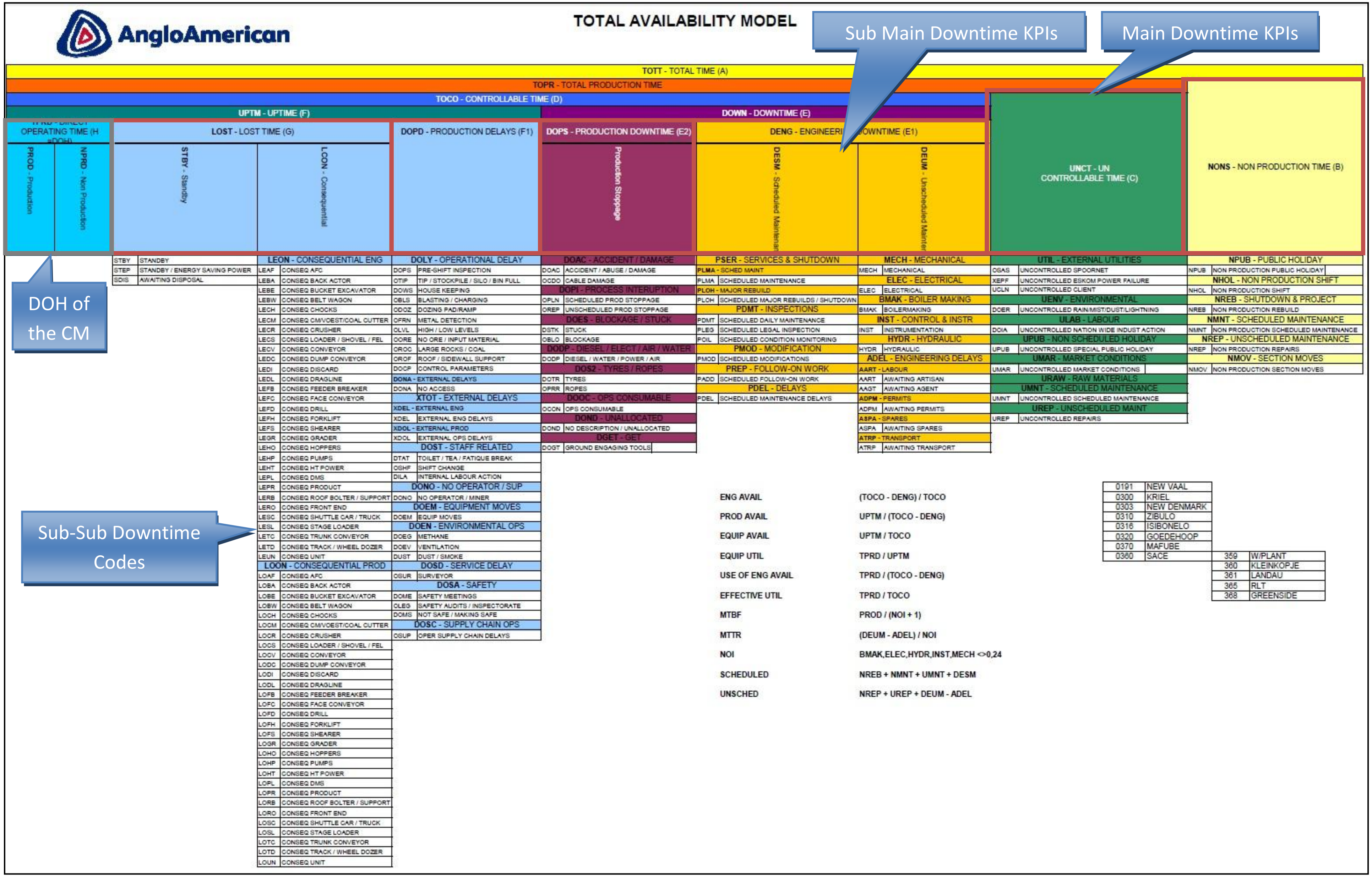
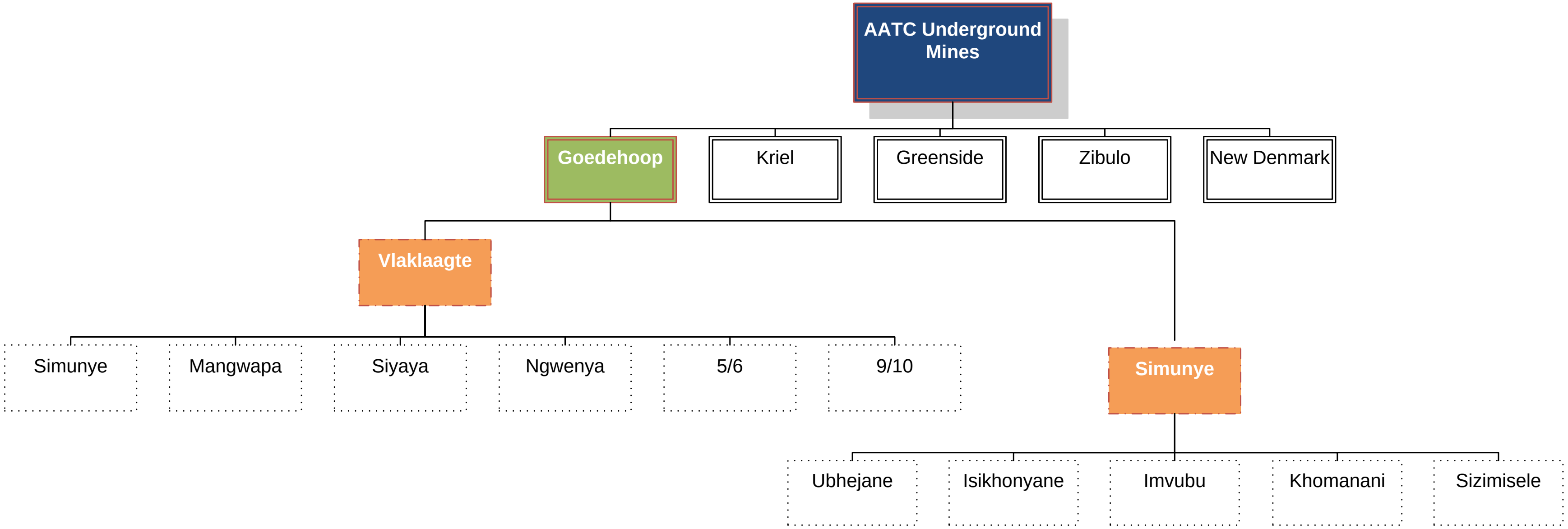
The end

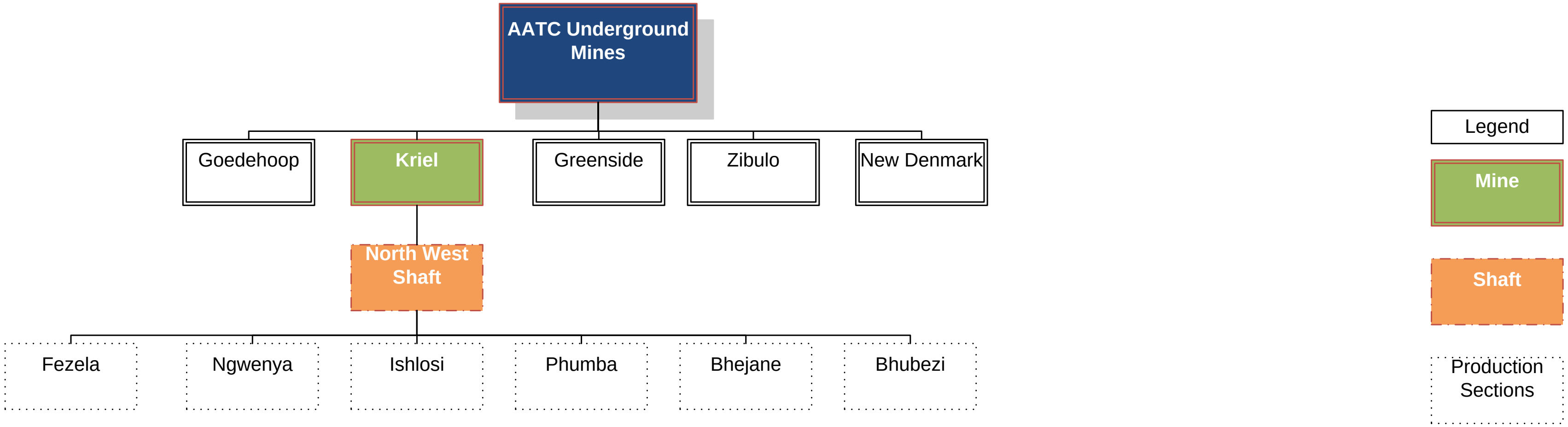
Thank you!

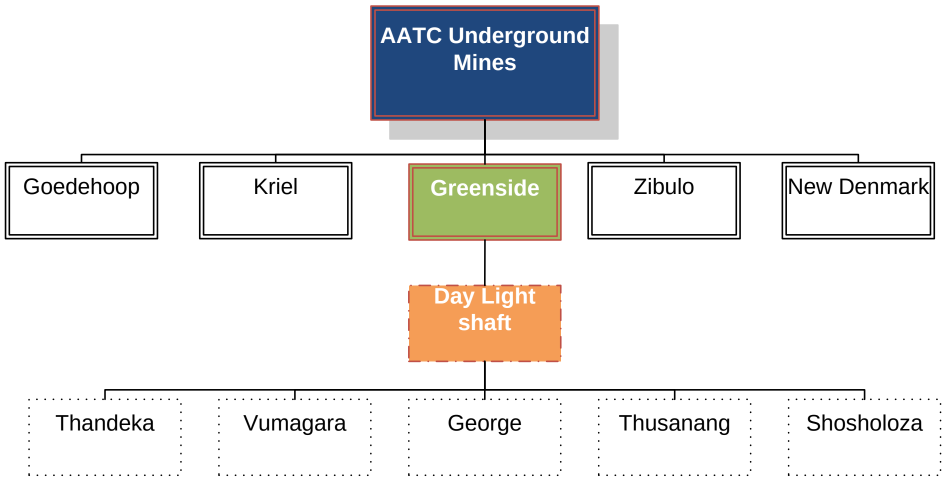
8.4. Appendix D: Total Availability Model

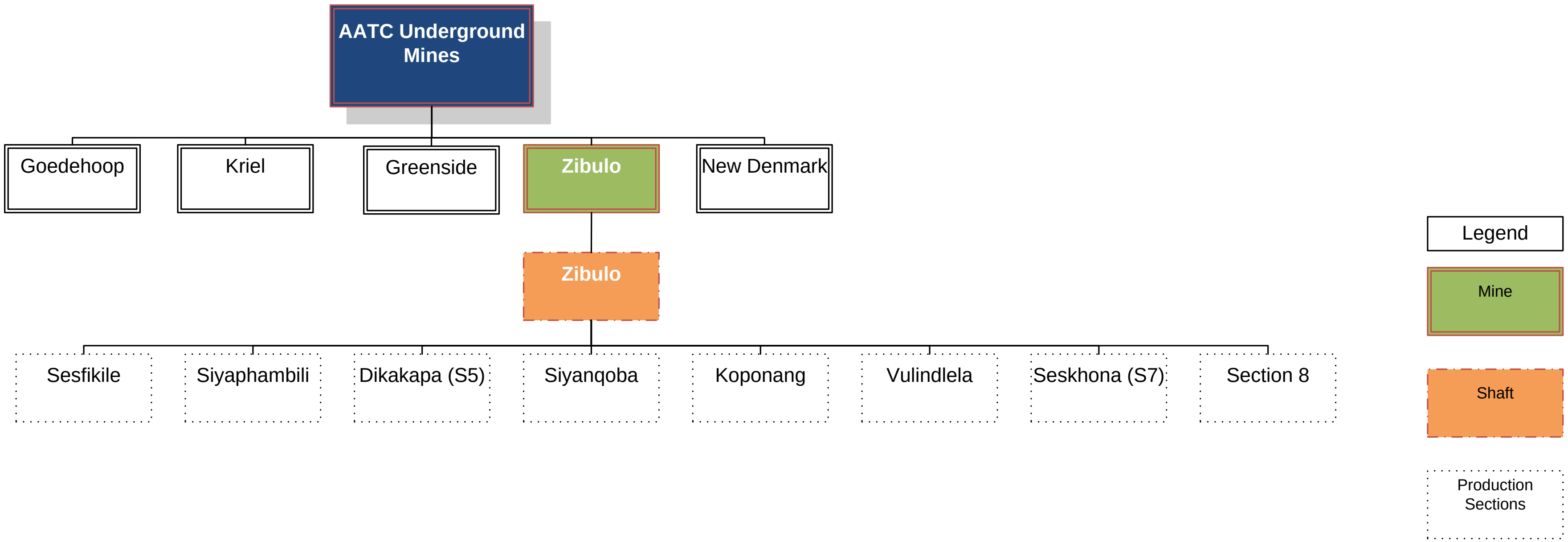


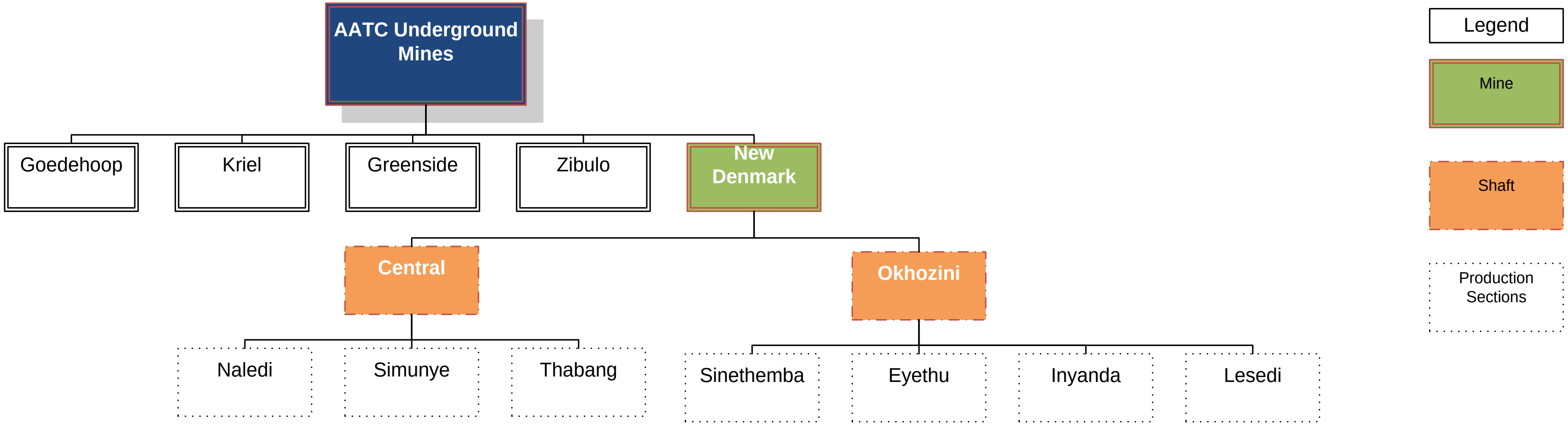
8.5. Appendix E: Mines, shafts and production sections






AATC Underground Mines
Goedehoop
Kriel
Greenside
Zibulo
New Denmark
Day Light shaft
Thandeka
Vumagara
George
Thusanang
Shosholoza


AATC Underground Mines
Goedehoop
Kriel
Greenside
Zibulo
New Denmark
Zibulo
Sesfikile
Siyaphambili
Dikakapa (S5)
Siyanqoba
Koponang
Vulindlela
Seskhona (S7)
Section 8
Legend
Mine
Shaft
Production Sections


AATC Underground Mines
Goedehoop
Kriel
Greenside
Zibulo
New Denmark
Central
Okhozini
Naledi
Simunye
Thabang
Sinethemba
Eyethu
Inyanda
Lesedi
Legend
Mine
Shaft
Production Sections

8.6. Appendix F: Cost and benefit calculations

8.6.1. Cost breakdowns:

Solution 1: Implement over-belt magnets on the trunk conveyors to separate the loosening components of underground machinery from the product.	
Cost per over-belt magnet	**R 650 000.00**
Number of trunk conveyors	**30**
Total estimated cost (Vlaklaagte and Simunye shafts)	**R 19 500 000.00**

Solution 2: Replace broken or faulty pull key units with Supplier ABC IPS 3000 pull key units.			
Cost per pull key unit	**R 5 432.03**		
Cost per controller	**R 31 464.00**		
Simunye shaft:	**Number of pull keys required**	**Controller required**	**Cost (R)**
Trunk 3	26	1	R 172 696.78
Trunk 4	22	1	R 150 968.66
Trunk 2	21	1	R 145 536.63
G4	40	1	R 248 745.20
G5	38	1	R 237 881.14
G6	12	1	R 96 648.36
G7	20	1	R 140 104.60
G10	28	1	R 183 560.84
G11	6	1	R 64 056.18
G12	16	1	R 118 376.48
Total estimated cost (All pull key units replaced at Simunye shaft)	**R 1 558 574.87**		
Vlaklaagte shaft: **Trunk conveyors**	**Number of pull keys required**	**Controller required**	**Cost (R)**
BLK 14 Trunk	50	1	R 303 065.50
2C	16	1	R 118 376.48
2B	38	1	R 237 881.14
2A	16	1	R 118 376.48
3E	18	1	R 129 240.54
3D	16	1	R 118 376.48
3C	16	1	R 118 376.48
3B	14	1	R 107 512.42
3A	18	1	R 129 240.54
4C	16	1	R 118 376.48
4B	22	1	R 150 968.66
4A	6	1	R 64 056.18
BLK 8 Trunk	22	1	R 150 968.66
9/10 C	6	1	R 64 056.18
9/10 B	14	1	R 107 512.42
9/10 A	14	1	R 107 512.42
73	20	1	R 140 104.60
Total estimated cost (All pull key units replaced at Vlaklaagte shaft)	**R 2 284 001.66**		
Total estimated cost (All pull key units replaced at Vlaklaagte and Simunye shafts)	**R 3 842 576.53**		
Solution 3: Acquire a specialist splice team from Supplier XYZ to perform splicing where clip joints are present and repair any damaged or worn out splices. *Splicing can only be done on Nitral belts.			

Price per splice	**R 12 895.70**	
Simunye Nitral Belts*	**Number of clip joints**	**Cost**
BUCVR4S1	1	R 12 895.70
BUCVG10	10	R 12 8957.00
BUCVG04	6	R 77 374.20
BUCVG07	4	R 51 582.80
BUCV4S2	12	R 154 748.40
BUCVG05	10	R 128 957.00
BUCVG06	2	R 25 791.40
Total estimated cost: Simunye shaft	**R 580 306.50**	
Vlaklaagte Nitral Belts*	**Number of clip joints**	**Cost**
H4CTB73	2	R 25 791.40
H4CV008	3	R 38 687.10
H4CV023	0	R 0.00
H4CV004	1	R 12 895.70
H4CV003	0	R 0.00
H4CV016	2	R 25 791.40
H4CTBS4	3	R 38 687.10
H4CTB74	4	R 51 582.80
Total estimated cost: Vlaklaagte shaft	**R 193 435.50**	
Total estimated cost: Goedehoop colliery	**R 773 742.00**	

Solution 4: Replace existing box chutes with spiral chutes, where possible.		
Cost per spiral chute	**R 64 760.00**	
Simunye trunk conveyors	**Number of box chutes present, that can be replaced by a spiral chute**	**Cost**
BUCVG10	1	R 64 760.00
BUCVG07	1	R 64 760.00
BUCVG06	1	R 64 760.00
BUCVG13	1	R 64 760.00
Total estimated cost: Simunye shaft	**R 259 040.00**	
Vlaklaagte trunk conveyors	**Number of box chutes present, that can be replaced by a spiral chute**	**Cost**
H4CV004	1	R 64 760.00
Total estimated cost: Vlaklaagte shaft	**R 64 760.00**	
Total estimated cost: Goedehoop colliery	**R 323 800.00**	

Solution 5: Contact Supplier XYZ to conduct a time study at Goedehoop colliery's trunk conveyors and provide a full report on the correct sequence programming.	
Cost per time study	**R 18 000.00**
Simunye shaft	R 18 000.00
Vlaklaagte shaft	R 18 000.00
Total estimated cost: Goedehoop colliery	**R 36 000.00**
Solution 6: Redesign the tail ends of the conveyors.	

Cost per tail end	**R 105 000.00**	
Simunye trunk conveyors	**Number of tail ends that can be redesigned**	**Cost**
BUCVR4S1	1	R 105 000.00
BUCVG10	1	R 105 000.00
BUCVG04	1	R 105 000.00
BUCVG07	1	R 105 000.00
BUCV4S2	1	R 105 000.00
BUCVG05	1	R 105 000.00
BUCVG06	1	R 105 000.00
BUCVG13	1	R 105 000.00
BUCVG14	1	R 105 000.00
BUCVG11	1	R 105 000.00
BUCV4S3	1	R 105 000.00
BUCVG12	1	R 105 000.00
BUCV4S5	1	R 105 000.00
BUCV4S6	1	R 105 000.00
BUCVG15	1	R 105 000.00
BUCVG16	1	R 105 000.00
Total estimated cost: Simunye shaft	**R 1 680 000.00**	
Vlaklaagte trunk conveyors	**Number of tail ends that can be redesigned**	**Cost**
H4CTB73	1	R 105 000.00
H4CV008	1	R 105 000.00
H4CV023	1	R 105 000.00
H4CV009	1	R 105 000.00
H4CV006	1	R 105 000.00
H4CV004	1	R 105 000.00
H4CV003	1	R 105 000.00
H4CV010	1	R 105 000.00
H4CV016	1	R 105 000.00
H4CV019	1	R 105 000.00
H4CV026	1	R 105 000.00
H4CTBS4	1	R 105 000.00
H4CTB74	1	R 105 000.00
H4CV037	1	R 105 000.00
Total estimated cost: Vlaklaagte shaft	**R 1 470 000.00**	
Total estimated cost: Goedehoop colliery	**R 3 150 000.00**	

8.6.2. Benefit calculations

8.6.2.1. Surveys

Survey ratings								
Cause	**#**	**Alan Thysse**	**Kevin Rooth**	**Gerrie Dalgleish**	**PJ Oosthuizen**	**Ben Snyman**	**Average rating**	**Average rating %**
DCHT	**1.1.**	6	6	10	8	6	7.20	0.72
ORJC	**1.2.**	6	6	10	7	7	7.20	0.72
OCBT	**1.3.**	6	6	10	8	5	7.00	0.70
ECSS	**2.1.**	7	8	10	9	5	7.80	0.78
EPUL	**2.2.**	8	6	10	8	5	7.40	0.74
EPUL	**2.3.**	4	6	10	9	5	6.80	0.68
EPUL	**2.4.**	8	6	10	5	7	7.20	0.72
EPUL	**2.5.**	6	6	10	9	5	7.20	0.72
OPLL	**3.1.**	9	8	10	7	6	8.00	0.80
ORJC	**3.2.**	9	8	10	7	6	8.00	0.80
ORJC	**3.3.**	7	6	10	6	6	7.00	0.70
DCHT	**4.1.**	4	7	10	10	4	7.00	0.70
DCHT	**4.2.**	8	4	10	10	6	7.60	0.76
DCHT	**4.3.**	7	4	10	10	4	7.00	0.70
OPLL	**4.4.**	7	7	10	10	6	8.00	0.80
DCHT	**5.1.**	8	9	10	8	6	8.20	0.82
OCBT	**5.2.**	8	9	10	8	5	8.00	0.80
OCBT	**6.1.**	9	8	5	6	6	6.80	0.68
OCBT	**6.2.**	8	7	10	6	7	7.60	0.76

8.6.2.2. Benefit calculations per solution

		Probability of occurring; assuming causes have equal probability to occur						
Cause	**Duration (Hours) Jan-Dec 2012**	**Solution 1**	**Solution 2**	**Solution 3**	**Solution 4**	**Solution 5**	**Solution 6**	
OPLL	136.33			0.04	0.2			
ECSS	76.25		0.2					
DCHT	70.05	0.14			0.43	0.14		
EPUL	54.67		0.8					
ORJC	47.61	0.33		0.67				
OCBT	43.43	0.17				0.17	0.33	
Per year:		**Solution 1**	**Solution 2**	**Solution 3**	**Solution 4**	**Solution 5**	**Solution 6**	**Totals**
Potential TC hours reduced		23.698	43.166	28.168	43.428	13.997	10.423	**162.880**
Potential benefit (ROM tonnes)		2632.890	4795.769	3129.416	4824.876	1555.014	1158.018	**18095.982**
Potential Benefit (Saleable tonnes)		1527.076	2781.546	1815.061	2798.428	901.908	671.650	**10495.670**
Potential Benefit (R)		**R 1 224 653.84**	**R 2 230 688.77**	**R 1 455 606.51**	**R 2 244 227.47**	**R 723 294.14**	**R 538 636.56**	**R 8 417 107.29**

Constants:
CM Rate (t/hr) (2012 CM rate) = 202
DOH/Controllable time (2012-March 2013 ratio) = 0.55
Yield (2013 Yield) = 0.58
$/tonne (2013) = 82
R/$ (August 2013) = 9.78

8.7. Appendix G: Implementation plan calculations

8.7.1. Vlaklaagte shaft

Trunk	Downtime 2012	Consequential sections down	Average t/hr	Consequential tonnes lost
H4CT024	28.19	1	283.44	7990.24
H4CT038	2.41	1	283.44	683.10
H4CTB73	41.8	2	621.47	25977.37
H4CTB74	0	1	338.03	0.00
H4CTBS4	6.84	1	300.32	2054.17
H4CV002	59.24	1	219.58	13008.12
H4CV003	66.58	1	219.58	14619.86
H4CV004	34.68	2	509.42	17666.85
H4CV006	36	2	509.42	18339.29
H4CV008	49.67	2	509.42	25303.12
H4CV009	36.9	2	509.42	18797.77
H4CV010	23.51	2	509.42	11976.57
H4CV016	19.12	2	509.42	9740.20
H4CV019	21.27	1	300.32	6387.75
H4CV023	44.83	2	509.42	22837.50
H4CV026	16.08	1	300.32	4829.10
H4CV036	16.08	2	509.42	8191.55
H4CV037	0	1	236.15	0.00
H4CV058	0	1	300.32	0.00

8.7.2. SIMUNYE - 2 SEAM

Trunk	Downtime 2012	Consequential sections down	Average t/hr	Consequential tonnes lost
BUCVG04	48.71	1	288.31	14043.75
BUCVG06	13.45	1	288.31	3877.82
BUCVG07	40.43	1	288.31	11656.51
BUCVG05	20.93	1	288.31	6034.40
BUCVG10	58.93	1	288.31	16990.31
BUCVG11	53.42	1	288.31	15401.71
BUCVG12	31.12	1	288.31	8972.32
BUCVG13	92.58	1	288.31	26692.06
BUCVG14	59.21	1	288.31	17071.04
BUCVG15	0	1	288.31	0.00
BUCVG16	0	1	288.31	0.00

SIMUNYE - 4 SEAM

Trunk	Downtime 2012	Consequential sections down	Average t/hr	Consequential tonnes lost
BUCV4S5	21.85	1	379.26	8286.74
BUCV4S2	10.41	2	604.18	6289.48
BUCVR4S1	28.52	4	1288.68	36753.17
BUCV4S3	13.45	2	684.50	9206.58
BUCV4S6	5.82	2	684.50	3983.81

8.8 Appendix H: Plagiarism form

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DEPARTEMENT BEDRYFS- EN SISTEEMINGENIEURSWESE

DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

FRONT PAGE FOR FINAL PROJECT DOCUMENT (BPJ 420) - 2013	
Information with regards to the mini-dissertation	
Title	Optimising production time of Continuous Miners at Goedehoop colliery
Author	Kraucamp, Y
Student number	29233519
Supervisor/s	Breytenbach, W.P.
Date	November 2013
Keywords	Continous miners, Goedehoop colliery, Ellipse, KPIs, DOH, DMAIC, Six Sigma, Pareto charts, Trunk conveyors, Process and capability study, ORJC, DCHT, OCBT, ECSS, OPLL, EPUL, ORSC.
Abstract	Optimising the production time of the CMs at Goedehoop colliery by means of focussing on improving downtime on the trunk conveyors.
Category	Quality assurance
Declaration	
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