Quantification of logistics performance in ultra deep mining - A South Deep Gold Mine case study

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ABSTRACT

Ultra-deep mining internationally is constrained by various factors that are directly proportional to the operating depth below surface. One of these factors is the logistics related to personnel, material, and ore, specifically the function of transportation. This is primarily due to excessive vertical depths below surface and horizontal travelling distances to workplaces. A direct impact on production is subsequently caused by the inefficient utilisation of personnel to conduct core production activities. This inefficiency can be seen when comparing actual times spent by employees conducting core production activities, total time spent travelling, and overall shift duration. It is demonstrated throughout this research that, as mines become deeper, more time is spent on travelling and less on core production, as a result of increased travelling distances and logistical function ineffectiveness.

In terms of conventional Lean Six Sigma theory, the transportation function in a production mine could be considered a non-value-adding process or even waste (*muda*). In order to maximise time for primary production activities (maximise face time), waste must be minimised or waste processes optimised. This can be done using the set sequence methodology of the Lean Six Sigma DMAIC (Define, Measure, Analyse, Improve, and Control) Model, whereby the personnel logistics performance of any mine can, first, be quantified and thereafter optimised. South Deep Gold Mine is an ultra-deep mine; it is currently the seventh deepest in the world and is notoriously constrained by logistics challenges. This mine was therefore used as a known case study to quantify and optimise personnel logistics performance using conventional Lean Six Sigma theory, although this theory is not conventionally applied in ultra-deep mines.

Results of this research indicate that, through the correct implementation of Lean Six Sigma theory, personnel logistics performance can be quantified accurately and thereafter greatly improved. The face time efficiency factor developed for the purposes of this research and used as the primary metric for the quantification of personnel logistics performance is deemed a success, and could be applied to any underground mine to determine the efficiency of the transportation of persons to and from workplaces. The research, in the opinion of the researcher and subject matter experts in the ultra-deep mining environment, especially at South Deep Gold Mine, adds value to the international ultra-deep mining network, especially with regard to optimising time spent on core production activities (face time efficiency factor) and benchmarking/comparing ultra-deep mines on personnel logistics performance.

PREFACE

I have been engaged in this research since my statutory appointment as the engineer over the vertical and horizontal logistics processes of the operations of South Deep Twin Shaft gold mine since November 2015. The study was conducted in actual operational conditions at the seventh deepest mine in the world — South Deep Gold Mine. Being ultra-deep, the mine, operating at depths of up to three kilometres below surface, is notoriously challenged in terms of productivity since its acquisition by Goldfields International. The executive committee and senior engineering personnel, specifically Adriaan de Beer (Vice President) and Danie Bezuidenhout (Engineering Manager) in charge of the mine at this stage provided the 'why' for this research to be undertaken, which is, to enable our workforce, we needed to provide them with the best possible opportunity to achieve their daily production targets in a safe manner. The problem explained and demonstrated to me by these two key gentlemen was that employees simply did not have enough time to perform primary production activities, due to the horrendously ineffective personnel transport and logistics processes of the mine.

The impact of mine personnel and supply chain logistical challenges on production needed to be investigated and quantified. Optimisation of logistical processes through the implementation of conventional Lean Six Sigma methodologies, often implemented in the manufacturing industry around the world, were thereafter be explored. George Lee Sye, a Lean Six Sigma expert, inspired me to investigate the potential successes and continuous improvement that could be achieved in the ultra-deep mining environment through the implementation of this theory. Through the elimination of waste in the mine's personnel logistics processes, the potential for the maximisation of mine employee effectiveness could be unlocked. This is commonly referred to in industry as 'maximising employee face time.' George, provided me with the 'how' to solve this issue, which had crippled South Deep Twin Shaft from the start of operations.

ACKNOWLEDGEMENTS

To my research supervisor, Professor Harry Wichers, I am sincerely grateful, for it was through his belief, motivation, and guidance that I decided to pursue this degree. I owe this research in its entirety to my partner, Chanell; when the research became cumbersome, you motivated me to keep going. To all my employees, colleagues, managers, and the executive teams at South Deep Gold Mine who were directly involved in this research, your professionalism and technical support were imperative in the successful execution of this research endeavour. Michael Olivier, Johannesburg, November 2018

KEY TERMS

Personnel logistics performance: The performance of the mine logistics systems with regard to the efficient transportation of persons to and from the underground working of the mine

Face time efficiency factor (η_f): The primary metric for the quantification of personnel logistics performance comparing actual face time and total shift duration in the form of an efficiency measure

Supply chain efficiency factor (η_s): The primary metric for the quantification of material supply logistics performance in the form of an efficiency measure

Overall logistics efficiency factor (η_o): The means by which overall logistics performance is measured, derived from the product of face time and supply chain efficiency factors

DMAIC: Define, measure, analyse, improve, and control is a conventional Six Sigma model for process improvement to mitigate or eliminate waste in any process or variation in any stable process, and is commonly referred to by the acronym *DMAIC*

GLOSSARY OF TERMS

Actual face time achieved (AFT): The total time spent on primary/core production activities

Actual logistics process time (total lead time): The actual time spent travelling to and from the workface (the difference between total shift duration and actual face time achieved)

Cage: Mine jargon synonymous with the term *conveyance*, refers to the vehicle used to raise and lower men and material in a mine shaft, and does not include the hoisting of ore

Cage arrival times (CA): The cage/conveyance actual time of arrival at the signalled destination

Cage departure times (CD): The cage/conveyance actual time of departure to the signalled destination

Clock cards: Access control cards provided to each employee permitted to conduct work in a particular working area on the mine premises, both surface and/or underground; used at access control points to control free access and access time zones in working areas or other locations on or inside the mine

Conveyance: A structural container designed for the transportation of men, material, or ore in a mine shaft; men/material conveyance is termed a 'cage' and an ore conveyance is commonly termed a 'skip'

Counterweight: A conveyance operating in a mine shaft purely to house weights provided for the purpose of creating a counterbalance effect in double-drum hoisting systems to control rotational forces/torque during operation and braking

Current state: The condition of any given process in terms of time and space prior to any improvements being initiated or implemented

Deck: A level in a cage designed with more than one level/elevation for loading persons or material (comparable to a storey in a building)

Double drum: A winding plant or mine winder hoisting configuration consisting of two drums, one wound in an overlay and the other wound in an underlay manner, thereby ensuring that conveyances move in opposite directions to each other at all times

End of work (EOW): The moment in a shift when the employee ends primary production activities for that shift

Face time efficiency factor — η_f (%): The primary metric (developed by the author) used for the quantification of personnel logistics performance in an ultra-deep mine

Future state: The future condition of any given process in terms of time and space post-improvement initiation or implementation

Haulage: A tunnel in an underground mine developed for the transportation of men, material, and ore

Horizontal logistics duration (HLD): The total time spent by employees being transported or travelling the horizontal section of the mine

Hoisting: Raising and lowering men or material in a cage, or raising ore in a skip

Horizontal logistics process: The process of transporting employees within the horizontal haulages of an underground mine

Integrated personnel logistics schedule (IPLS): Personnel transportation model developed through the DMAIC process and holistic integration of all personnel logistics functions of the mine to ensure that a maximum face time efficiency factor is achieved

Logistical rigidity: Inflexibility with regard to contingency measures in any transportation process in the event of unplanned process variability

Man train arrival times (MA): The actual arrival time of the train at its scheduled destination

Man train departure times (MD): The actual departure time of the train to its scheduled destination

Man carriage: A rail-bound cart or carriage designed for the sole purpose of transporting persons in an underground rail-bound haulage

Man winder: Mine hoisting/winding plant used for raising and lowering of men and material in a mine shaft

Material: Any equipment, material, or explosives used in underground mining operations and lowered in the vertical shaft and transported horizontally to workplaces for use by end users

Mean time between failures (MTBF): Reliability engineering term used to describe the mean intervals between breakdowns of a particular plant

Mean time to repair (MTTR): Reliability engineering term used to describe the mean intervals between repairs of a particular plant that has broken down

***Muda*:** Japanese term developed by Toyota manufacturing used to describe process waste in the form of defect, inventory, motion, transport, over-production, waiting/queueing, and non-value-adding processes (aligned with Lean thinking principles)

Overall equipment effectiveness (OEE): A measure of the productivity of equipment or a plant by comparing various reliability and throughput productivity factors, such as quality, performance, and availability

Proximity detection systems (PDS): A system installed on self-propelled mobile machinery, which monitors and controls the interface between men and machinery, as well as between machinery, to mitigate the risk of collision

Radio frequency identification (RFID): Radio technology involving the use of electromagnetic fields/radio waves for receiving and transmitting information to monitor, identify, and control the interaction between persons, materials, and processes, usually through tags that contain electronically stored information

Rock stress: Geological stresses applied to sub-surface rock, which result in strain and deformation and are generally directly proportional to depth below surface

Rock winder: Mine hoisting/winding plant used only for raising broken ore in a mine shaft

SCADA: Supervisory control and data acquisition systems involving information technology, networked data communication; these systems use interfaces for high levels of process monitoring, supervision, and control

Service winder: Secondary mine hoisting/winding plant used for raising men and material in a mine shaft (ad hoc transport)

Shaft: A hole sunk/blasted, either vertically or at an incline angle, used as the primary means of ingress and egress from an underground mine

Shaft bank: The surface/uppermost landing of the shaft, on the same elevation as the mine's surface operations

Shaft station: The underground landings of the shaft on various elevations below surface feeding mine access levels

Single drum: A winding plant or mine winder hoisting configuration consisting of only one drum, which is wound in an overlay manner, thereby ensuring that conveyance moves in the direction of rotation of the drum at all times

Standard operating procedure (SOP): A step-by-step guide compiled by mine management to guide process operators and owners in conducting processes in a standardised manner to mitigate risk and process variability

Start of work (SOW): The moment in a shift when the employee initiates primary production activities for that shift

Total lead time (TLT): Time taken to complete an end-to-end process

Trackless mobile machinery (TMM): Self-propelled, mechanised mobile machinery that operates free from rail-bound or track-bound infrastructure

Train: A combination of one or more locomotives carriages, carts, or hoppers, coupled in a particular configuration and used for the horizontal transportation of men, material, or ore

Vertical logistics process: The process of transporting men, material, or ore in a vertical mine shaft by raising and lowering them using hoisting/winding plants.

Virgin rock temperature: The inherent temperature of the rock face underground; generally varies in direct proportion to depth below surface

Vertical logistics duration (VLD): The cumulative time spent raising or lowering persons in a mine shaft in a particular shift

Waiting-place arrival times (WA): The actual time of arrival of all personnel working in an area at that particular area's waiting place

Waiting place: A place where a production crew and miners meet at the commencement of work for the purposes of conducting roll call, safety meetings, planning, and safety declaration of the workplace prior to starting primary production activities

Waiting-place departure times (WD): The time of departure of all personnel working in a particular area from that area's waiting place to work, or back to the station

Waiting-place duration (WPD): The total time spent conducting safety meetings, planning, and workplace safety declaration activities at the waiting place by the miner and his/her crew, prior to starting primary production activities

Winder: A hoist used for raising or lowering men, material, and/or broken ore in a mine shaft to the surface or underground respectively

Winding cycle: The movement of a conveyance in a mine shaft from surface to destination and from destination back to surface

Winding trip: The movement of a conveyance in a mine shaft from surface to destination, or from destination to surface

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CHAPTER 1: INTRODUCTION

Ultra-deep mining due to the need to access mineral resources ever farther below the earth's surface comes with a unique set of challenges. These challenges typically manifest at depths below 2 500 metres. Excessive rock stress, extreme virgin rock temperatures, and transportation- and logistics issues are the main challenges experienced by deep and, especially, ultra-deep mines across the globe. Technological advancements and stringent safety measures are introduced to combat the effects of these challenges; however, these mitigation measures come at a cost. As mining is a business that operates on a normal profit-and-loss basis, with costs ever increasing in order to attain resources at these extreme depths, the very existence of ultra-deep mining is being threatened by poor business feasibility. It is therefore imperative that mining operations are optimised and operate in an economically and commercially sound manner. The particular ultra-deep mining challenge being addressed through this research is that of transportation and logistics.

In the literature review, the existence of the perceived logistics challenges in ultra-deep mines, both locally and internationally, is proven. An important observation was that mining at these depths, especially in the South African gold mining industry, is deemed unavoidable by virtue of the depths of the Witwatersrand Basin's deposits. Mining at ultra-deep levels was also found to be increasing internationally, with numerous such mines already in existence in North America and, particularly, Canada. Comparative studies and literature also clearly indicate that the ineffectiveness of logistics processes is a common concern in all these mines (UDMN, 2017; Vogt, 2015).

Mine logistics as a function comprises three main areas, namely material and equipment transport, ore transport, and personnel transport, the latter falling within the scope of this research. Although the overall logistics performance of any mine is quantified based on the combination of men-, material-, and ore-handling, only logistics performance will be examined in the present study; the material- and ore processes are earmarked for future research. The personnel transport/logistics function involves the movement of employees working underground to and from their working places and surface level respectively. Although this may seem a fairly straightforward task, the system interdependencies and cross-functional integration required between different transport departments vary according to mine infrastructure and inherent complexity. The quantification of personnel logistics and subsequent optimisation in the interest of maximising production output potential were deemed crucial.

South Deep Gold Mine, as with other ultra-deep gold mines, is constrained by personnel logistics processes in the following ways. Personnel are all provided with a fixed shift/work duration, which, in the case of South Deep Gold Mine, is nine hours and 30 minutes (hereafter expressed in the format '9h30m' for ease of reading, as is done with metres (m) and kilometres (km) hours (hrs) and minutes (mins)) . The present researcher, in conducting time and motion studies at South Deep Twin Shaft to determine how much of this time is spent travelling to and from working places, found the numbers to be as high as 4h30m. This concern is clearly demonstrated in the findings of this research.

If this were compared using an ordinary efficiency calculation, where efficiency is equal to the fraction of output as numerator and input as denominator, and converted to a percentage value, an efficient use of shift duration of approximately 50% would be the outcome, which is undesirable. In essence, this would mean that an employee would spend half of his or her working day simply travelling to and from the workplace and performing no actual value-adding work.

When considering the primary production activity in South Deep Gold Mine's operating model, which is supporting, drilling, charging up, and, ultimately, blasting (ore extraction), these activities combined have a total lead time of approximately 6h30m. This seems to offer a simple reason for South Deep Gold Mine's continuous underperformance: the required time to conduct the core production functions of the mine is in excess of the time available to employees on a single shift. It is not possible to achieve a blast per drill rig per shift as is required or planned to achieve set drill rig performance KPI and planned development, as well as destress advance in metres.

The primary problem here is the personnel logistics process design and the impact on available face time (production time). As the process design had not been undertaken using Lean or Six Sigma methodologies, throughput is severely constrained by waste activities. The personnel logistics process, when reviewed from start to end using Lean Six Sigma methodology, contains various forms of what is termed in Lean thinking fundamentals as waste or *muda*. This waste includes process defects, excess inventory, excess motion, transport, over-production, waiting or queueing, and non-value-adding activities. Should all waste in the process be quantified and eliminated or mitigated, the personnel logistics process could be shortened and optimised. Through reduction in travelling time, available face time could be increased, and travelling time (waste) could become a smaller fraction of shift/work duration in total. Maximising face time would, in turn, result in maximised production potential.

The objectives of this research were therefore defined by the need to quantify actual personnel logistics process performance, to mitigate or eliminate non-value-adding and wasteful steps in the process. In doing so, the available employee face time could be maximised. To achieve this, a quantification measure had to be developed, and face time would be the primary metric measure of the performance of the personnel logistics process, which could be used in in any ultra-deep mine. This measure, termed *face time efficiency factor* (expressed as a percentage (%)) would ultimately represent the efficiency of any personnel logistics process.

Finally, an optimised personnel logistics model will be developed in the present study, which will include the output findings of quantification and optimisation measures. Through the effective implementation of this model, South Deep Twin Shaft employees would experience an effective transportation system that is systematically designed, with cross-functional/-departmental integration at the centre of all design phases, and minimum process waste, with the desired output of maximum face time for optimised production potential.

Through the implementation of industrial engineering conventional theory, namely Lean and Six Sigma, the aforementioned objectives could be achieved. The DMAIC process as defined in the *key terms* section will be implemented in a sequenced research approach, where the mine's lethargic personnel logistics process will first be defined, measured, and analysed, in order to quantify baseline personnel logistics performance. Thereafter, the remaining DMAIC process steps will be implemented, namely improvement and control, in order to optimise and sustain personnel logistics process improvements made. It is hypothesised that, through the methodology proposed in this research, a face time efficiency factor improvement of at least 20% would be achieved, thereby ensuring more than adequate time to complete the core production activities to achieve a quality blast per drill rig per shift.

Conclusion

Chapter 1 provided the background to ultra-deep mining in South Africa and abroad, and detailed the risks and cost effects of a mining activity that will become increasingly prevalent as resources near the surface become depleted. Chapter 2 provides an overview of the very limited research available on the subject.

CHAPTER 2: LITERATURE REVIEW

The purpose of this chapter is to investigate the existing logistics constraints in ultra-deep mines, the rationale behind ultra-deep mining in South Africa, and why this mining method is necessary. Challenges in the local ultra-deep mining sector are also compared to those of other ultra-deep mines in the world. The chapter reviews and compares extant literature on logistics as a constraint across South Africa and worldwide, where after South Deep Twin Shaft (hereafter referred to as *Twin Shaft* for the sake of brevity) is examined in terms of the mine's logistical infrastructure.

In summary, this chapter is a review of literature related to ultra-deep mines and the logistics problems in these mines. The analysis of the aforementioned is included in the chapter presenting the results of the study (Chapter 6). Chapter 6 outlines research conducted using Lean Six Sigma methodology, the application of the methodology to the problem of quantifying personnel logistics performance, and the outcomes of such application. Had research on the application of the Lean Six Sigma methodology been included in Chapter 2, it would have adversely affected the flow of this paper, as the field is wide and there is limited such literature on ultra-deep mining specifically. It was therefore decided to discuss the relevant sources on the application of Lean Six Sigma methodology alongside the results of the relevant analyses, together with comprehensive references, in Chapter 6.

2.1 Ultra-deep mining — South African Rationale

The Witwatersrand Basin has considerable gold resources, and it has been estimated that only 40% of the available gold has been discovered. It has been postulated that, in the future, the single most important parameter in mining will be increased depth (Pickering, 1996:173-174). In 1996, when this was asserted, only 10% of South Africa's gold was mined at depths exceeding 2 500m. Data gathered at the time indicated that, by 2015, more than 50% of South Africa's gold production would be at depths greater than 2 500m, meaning that half or more of the national gold production would be executed in the ultra-deep mine environment.

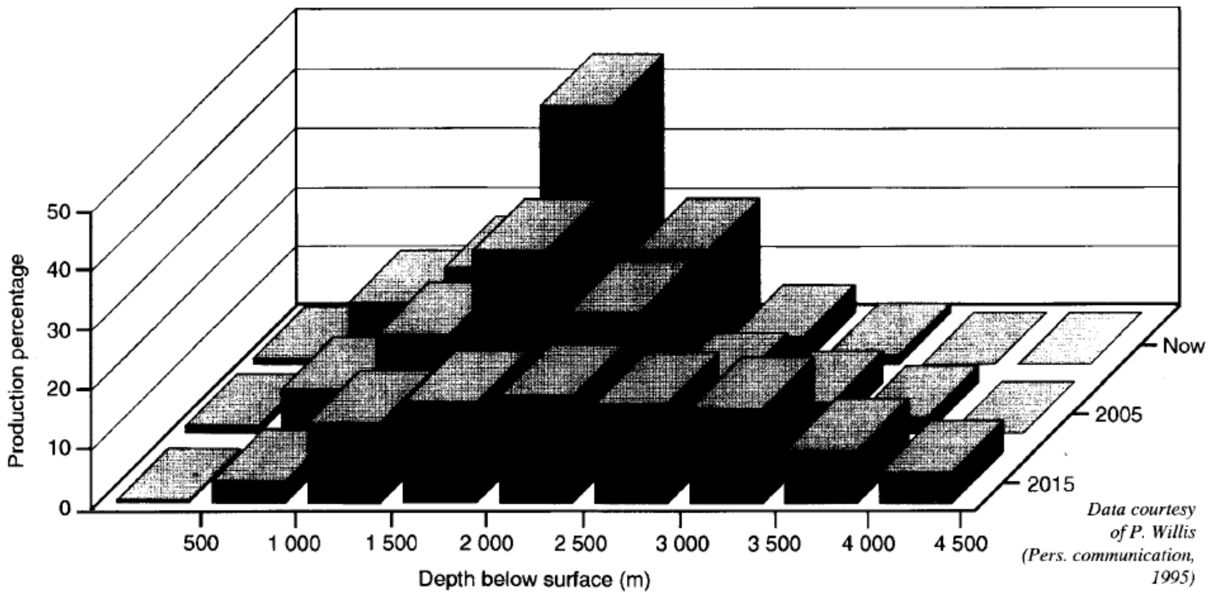


Figure 2.1: Percentage production versus time and depth below surface, as determined and projected for the gold production from the Witwatersrand basin by P. Wilis (Personal communication 1995)

More recent literature indicates the possibility that the prediction of Wilis (1995), presented above, in Figure 2.1, may have materialised. Of the ten deepest mines in the world, eight are located in a single region — South Africa's Witwatersrand Basin. Currently, the deepest mine in the world is AngloGold Ashanti's Mponeng Gold Mine, in South Africa, which extends over 3.9km below the surface (Goodbody, 2014:41-42).

Most of the orebodies that are closer to the surface, and therefore more easily accessible, have been depleted, giving rise to the need to go deeper to access new resources. It is therefore clear that ultra-deep-level mining cannot be avoided.

2.2 Ultra-deep mining — comparison of local and international challenges

2.2.1 The international position

According to the Canadian government, specialised metals are largely produced by underground mines that are deeper than 2km below surface (Government of Canada, Networks of Centres of Excellence (NCE), 2016:1). The Ultra Deep Mining Network (UDMN), which forms part of the NCE, noted that the challenge in ultra-deep mining is the need to fundamentally shift design, development, and operation of underground metal mines with consideration of three converging factors, namely:

- maintaining constant production levels while deepening mines;
- the need to pursue specialised industrial metals at greater depths; and
- the need to attract a new generation of socially diverse, well-educated employees.

Excavating to deeper depths creates serious challenges that must be overcome to prevent operations deeper than the set parameter of 2.5km becoming financially unfeasible. As described by Morrison (2014:1), ultra-deep mining's technological challenges vary according to a mine's geology, which often makes digging deeper uneconomical. The Canadian Mining Network (UDMN, 2017) formulated four strategic themes to address these technological challenges, with the goal of ensuring that ultra-deep mining remains economical and, most important, safe. These include:

- Rock stress risk reduction: Improve the control of stability in deep underground excavations;
- Energy reduction: Improve the energy consumption profile of deep mines;
- New methods of material transport and productivity: Increase the rates of development and production in mines; and
- Improved human health and safety: Use a human-centred approach to improving the environment in deep mines.

When reviewing the strategic position of the UDMN, it is clear that the main issues affecting ultra-deep mines internationally are: virgin rock stress, temperatures, health, environment and safety, and logistics and transport methodologies for production optimisation. Although improbable, the present researcher endeavoured to confirm whether the challenges experienced in South African ultra-deep mines were unique. If not, key learnings and solutions provided by the UDMN and other mining houses could be implemented to overcome the challenges experienced locally.

2.2.2 The local position

The technical point of view of Dr. Vogt, published in *Mining Review Africa* (2015:1), is that deep-level gold mines face three main technical challenges, namely high rock stress, heat, and distance to working places. These are exacerbated by other challenges, such as the gold price, energy (power) and labour costs, and logistics.

If considering the Canadian viewpoint, as stated by the UDMN (2017), and assuming the South African viewpoint to be that of Vogt (2015), it would seem that the technical challenges in ultra-deep mining operations occur worldwide.

Table 2.1: Comparison of challenges in ultra-deep mining environment

Challenge	International position	Local position
Rock stress	Yes	Yes
Virgin rock temperature	Yes	Yes
Energy (power)	Yes	Yes
Logistics (transportation)	**Yes**	**Yes**

2.3 Ultra-deep mining — Twin Shaft

Numerous research studies and investigations of Twin Shaft have proposed solutions to one of the technical challenges of the mine. Of the aforementioned technical challenges experienced by ultra-deep level mines, the biggest in the case of Twin Shaft is logistics. A Biecon Industrial Engineering report (2010) titled *Evaluating the logistics handling of men and material at South Deep* noted numerous constraints in the logistics process. According to Biecon (2010:25), logistics optimisation studies have revisited some aspects of personnel and material handling, but the results were inconclusive.

A document titled *Investigation into the feasibility of converting the main shaft man/material winder to a single drum winder and installation of a new single drum winder* (Collins, 2013:1), from the archives of Twin Shaft, proposed the following design changes to the men/material hoisting arrangements (commonly referred to as the *men/material winding plant*):

- "The conveyance and shaft station configuration, with one three deck and one two deck, has resulted in underutilization with the majority of the hoisting time being in single drum mode.
- The risk associated of having large numbers of personnel underground in the event of the winder being inoperable.
- Any mechanical or electrical component failure of the winder could result in delays in personnel and material transport with a consequential loss of production time."

From the above, it is clear that, as a result of the mine's men- and material-hoisting arrangements and shaft design, the transportation of men and material is constrained. Transportation distances impact productivity (Vogt, 2015:1). Furthermore, the constrained vertical transportation system is cause for concern. Although the suggestion of Collins (2013), submitted to the mine's board is possibly the most feasible solution to the constrained vertical transportation process of men and material in an already ultra-deep gold mine, the capital investment was estimated at approximately R300 million in 2013.

In conclusion, study evidence on men- and material transport at Twin Shaft gathered over the past decade, combined with current knowledge of the operation from an engineering management position, clearly indicates that the mine is severely constrained in terms of its current logistics processes. The fact that the shaft is considered ultra-deep, as well as the concerns of Collins regarding hoist- and shaft design, made it imperative, from an engineering management point of view, that the present research be conducted. One of the aims of the present study was to uncover the root causes of the logistics constraints and advise on implementation of sustainable solutions, in order for the mine to reach its full production potential.

2.4 Twin Shaft — Logistics optimisation and Lean Six Sigma principles

The logistics process of this ultra-deep-level gold mine was analysed using conventional industrial engineering theory. The analysis was conducted using the five principles of Lean Six Sigma and the Six Sigma traditional DMAIC model which is defined later. The identification of process waste, called *muda* in the Toyota Production System, was identified by the present researcher as a key aspect in resolving the men- and material logistics crisis on the mine.

Conclusion

Ultra-deep mining in South Africa and internationally is imperative to accessing rich mineral resource deposits located at depths in excess of 2 500m below surface. It has been demonstrated that, as mines become deeper, the problems experienced around heat generation, rock stress, energy consumption, and overall risk are amplified. This requires significant investment in technology to manage the related human health and safety and environmental aspects in these mines, which impacts negatively on the all-in cost of mining operations at these depths. The above background showed that logistics and transport processes are a problem in ultra-deep mines worldwide. It is therefore of utmost importance for the future of ultra-deep mining that tangible solutions to these logistical performance constraints are developed and implemented as best practice globally.

CHAPTER 3: PURPOSE AND PROBLEM STATEMENT

Excavating progressively deeper underground is a means of accessing and extracting additional resources in existing mines. This is necessary because new reserves are in increasingly short supply. Sometimes, new mines are excavated to such depths to access all available reserves. In both such cases, mining crossing the threshold between deep and ultra-deep is associated with similar challenges, thus, irrespective of whether a mine is in the process of being deepened or a new mine is being developed or sunk.

The threshold from deep to ultra-deep mining is defined by Wilis (1995) as the 2 500m (2.5km) point below surface datum (collar). For the purposes of this research, the vertical shaft mine design will be discussed, and open-cast mining activities as conducted across the world will not be considered. Ultra-deep mining operations across the globe vary in depth; the deepest in existence is over 4km deep, as illustrated by Figure 3.1, below, which shows the top ten deepest mines currently in existence.

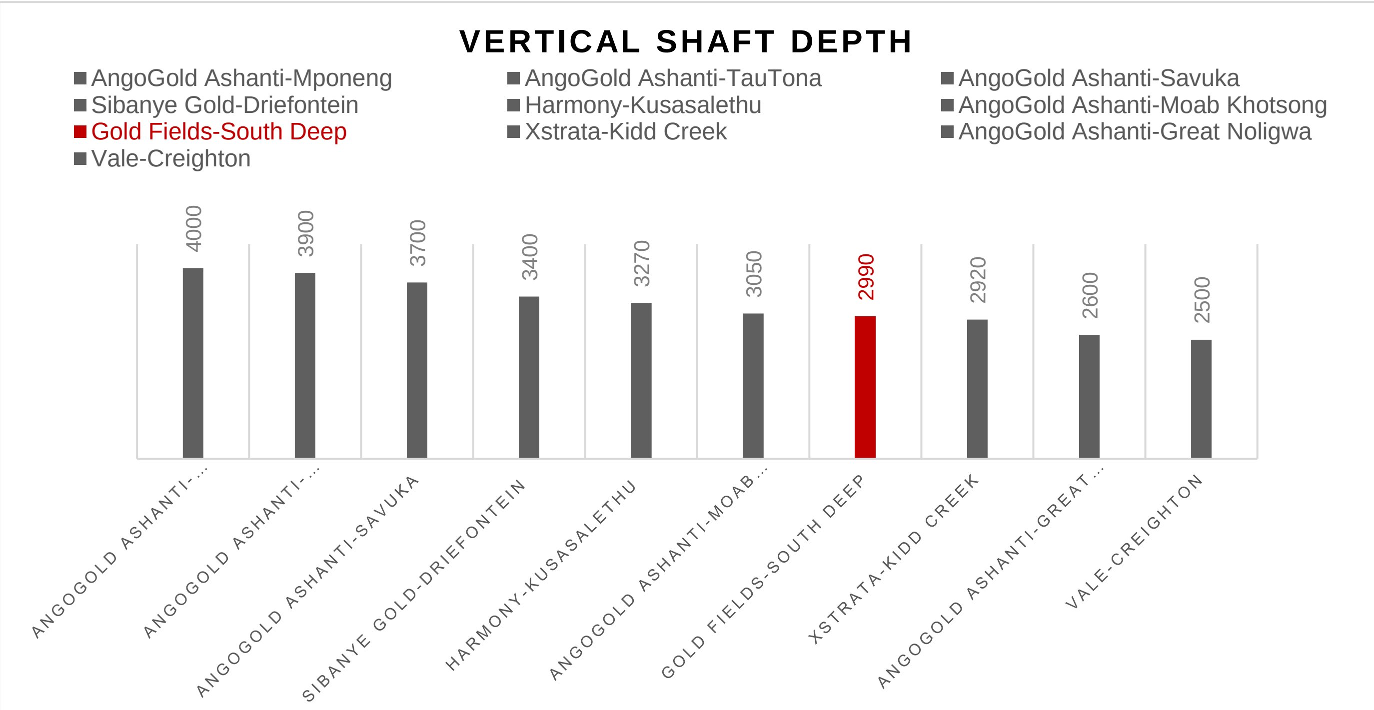


Figure 3.1: "The top ten deepest mines in the world." Mining-technology.com, 13 Sept. 2013 .www.mining-technology.com

Ultra-deep mining, although necessary for accessing mine reserves and subsequently extending the life of a mine, incurs a unique set of challenges. Mines operating and intending to operate at these depths must consider the following three major technical challenges:

- High rock stress, which leads to seismicity and rock bursts;
- Heat generation, which requires extensive cooling infrastructure;
- Logistics constraints and transportation distances, excessive vertical depths requiring more than a single vertical shaft, and excessive horizontal travelling distances, which may exceed 7km to working places in older mines.

3.1 Twin Shaft — Logistics constraints

As seen in Figure 3.2, below, Twin Shaft gold mine, is one such ultra-deep gold mine, with a vertical operating depth of 2 990m below datum. The mine has two vertical shafts (main and ventilation), both approximately 3km deep. Each of these shafts stretches from surface to the lowest level, which is very different to the shafts of other mines of the same depth. Mines such as AngloGold Ashanti Mponeng, for example, consist of multiple shafts, equipped to span the required depth. In other words, the shafts of Twin Shaft are termed *single-lift* or *single-drop shafts*, where the hoisting machinery is located on the surface. Each of these hoists must possess the capability of transporting broken ore, mining materials, and personnel (men) in one motion from the lowest level to surface, and vice versa (Refer to Annexure A: Main Shaft Hoisting Diagrams).

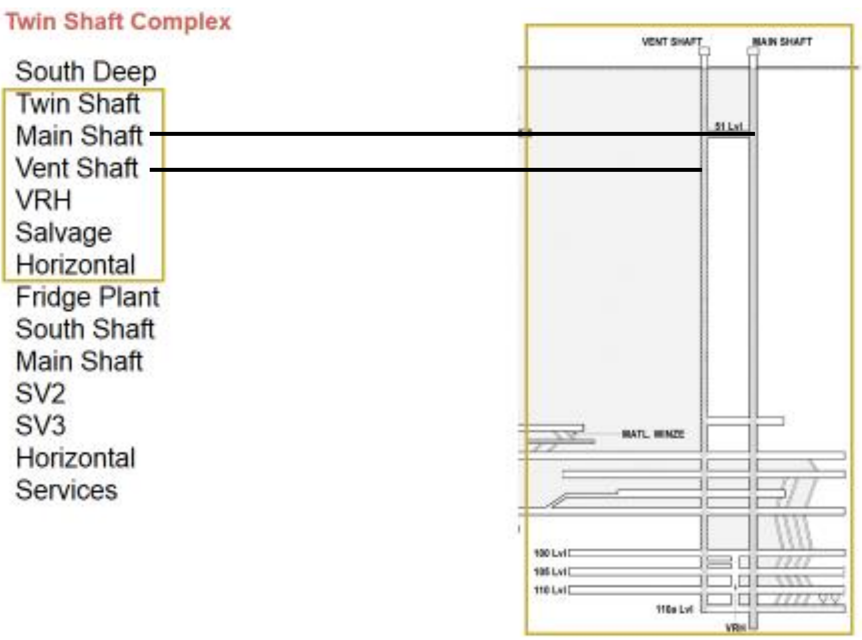


Figure 3.2: Twin Shaft infrastructure (September 2016, South Deep Gold Mine, Gold Fields)

Twin Shaft, as an ultra-deep gold mine, is subjected to the same technical challenges as its counterparts. These core technical challenges, as mentioned, include rock stresses, heat, and logistics. The Twin Shaft Complex, in particular, is severely constrained with regard to the third core technical challenge, namely logistics and travelling distances. When compared with other mines, such as AngloGold Ashanti's Mponeng or TauTona Gold Mine, vertical travelling distances of Twin Shaft are slightly shorter as seen in figure 3.1; however, the mine is notoriously challenged with regard to the efficient transportation of men and material. This can be attributed to the mine's inherent logistics process constraints, of which a high-level list is provided below.

- Shaft design and infrastructure;
- Men/Material hoisting infrastructure;
- Mine design and mining methodology;
- Operation of men/material hoisting infrastructure;
- Loading and offloading practices for men/material;
- Horizontal logistics design and infrastructure;
- Horizontal logistics and transportation systems;
- Logistics management systems;
- Continuous operations (CONOPS) production cycle; and
- Inadequate integrated planning of logistics processes between different departments.

These constraints collectively result in the men/material logistics and transportation process being ineffective and inefficient, impacting directly on the mine's productivity. The aforementioned constraints lie on a spectrum. Fixed constraints are the design and layout of the mine's infrastructure, which, without significant capital investment for reconstruction of the whole mine or parts thereof, cannot be improved. On the other end of the spectrum lie constraints that, through innovation, optimisation, and engineering and project management methodologies could be significantly improved upon, with a direct impact on production output. The latter was the focal point of this research.

3.2 Logistics constraints — Impact on mine productivity

Through the research and time and motion studies conducted in the present study (discussed in Chapter 6), the impact of the aforementioned logistics constraints can be seen when considering mine productivity. The following functions of Twin Shaft's logistics processes have the largest impact on productivity:

- Raising/Lowering of men to surface/working levels;
- Transporting of men to and from working places; and

- Transportation of material to and from working places.

The main problems arising as a result of the mine's lethargic logistics processes are discussed below.

3.2.1 Primary problem — Loss of face time

In mining, *face time* refers to the time spent on primary mining (production) activities, such as drilling and charging up the stope or development end for blasting to commence. This factor is measured per unit time, and may be compared to the mine workers' total working time spent underground (shift time). Through time and motion studies, the effective face time lost as a result of travelling vertically in shafts and horizontally in haulages/tunnels for some personnel was found to be in excess of 3hrs. The total time wasted when including travelling and meetings exceeded 4hrs. Mining personnel at Twin Shaft work a shift of 9h30m, which includes travelling time. Therefore, the effective face time/actual working time available for primary/core production activities is as low as 5hrs.

A primary example of this is presented by Figure 2.3, below. Time and motion studies were conducted over period of one week, monitoring the average walking time from the shaft station area to the working places. As can be seen, employees working in 1 West Corridor (working section/place), on average, travelled 55min before arriving at the waiting place to conduct their safety meeting before starting mining operations. It must be noted at this point that, as the logistics process is cyclic in nature, these personnel must also travel back to the shaft station area to be raised to the surface.

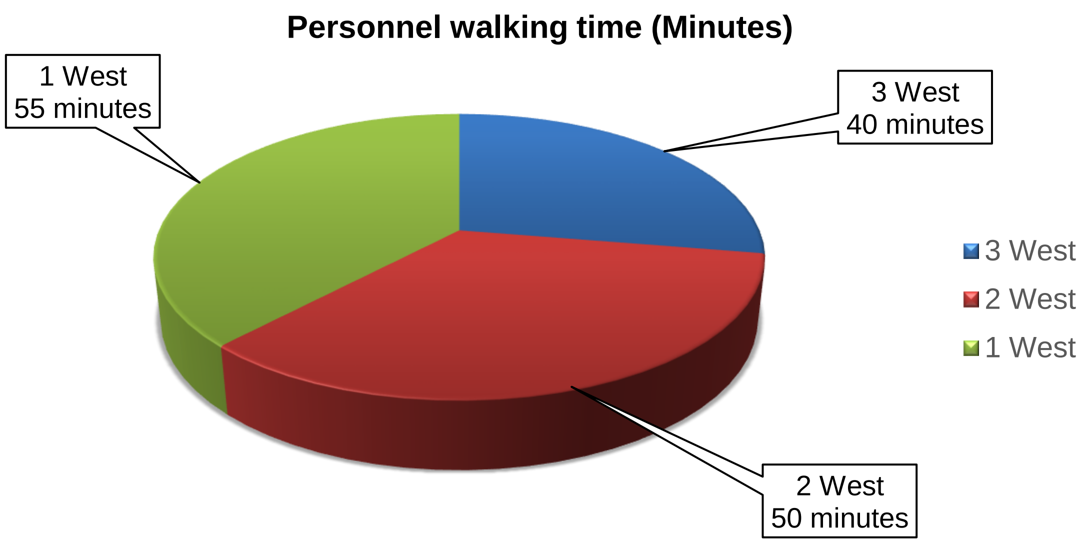


Figure 3.3: Twin Shaft horizontal travel times, Report: Logistics optimisation — maximising face time (Gold Fields, 2016)

The objective of the present research was to quantify logistics performance and to maximise effective face time by optimising the non-effective face time processes such as travelling, waiting, and queuing, which, for the purposes of this research, were considered logistics process waste or *muda*.

3.2.2 Secondary problem — Ineffective material supply

With regard to logistics, another factor that has a negative impact on production is material supply underground for primary mining activities. This includes supporting, drilling, charging up, and blasting, as well as various other secondary activities to service the mining process. As a result of the aforementioned constraints in the Twin Shaft's logistics system, acute inconsistencies in vertical and horizontal material transport performance exist. As seen in Figure 3.4, below, results from studies conducted in November 2015 (Gold Fields, 2016) showed that the vertical transport activities of the mine vary excessively and on an ongoing basis. There appears to be excessive variability in the time taken for each activity, namely material transport, shift- or personnel transport, and explosives transport, as these activities were undertaken for different percentages of available time each day.

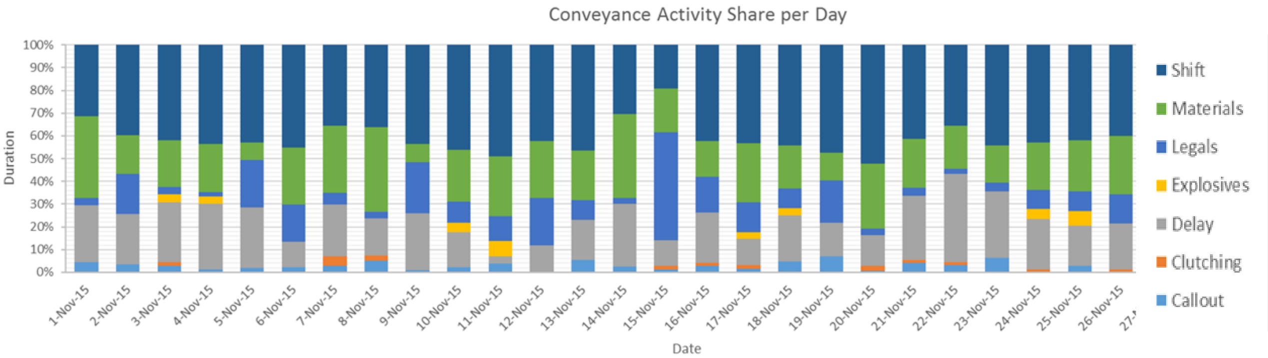


Figure 3.4: Twin Shaft: Daily conveyance activity share. Report: Logistics optimisation — maximising face time (Gold Fields, 2016)

Further investigation indicated that primary mining activities are continuously affected as a result of lethargic logistics management processes and constraints. Common effects included:

- interruption of the mining cycle in certain working places as a result of material shortages, where such material had not been transported underground on the previous cycle; and
- a negative impact on the reliability of trackless mobile machinery (TMM) as a result of maintenance parts or spares for breakdown maintenance being delayed in transport to site, or even remaining on the surface for extended periods. This, in turn, resulted in further loss of production as a result of poor machinery mean time to repair (MTTR).

Furthermore, material regularly remained on surface by the end of the 24-hour cycle for material transport. It was hypothesised that the demand for material underground to support the mining production profile was not being met by the current logistics supply processes.

A process of identification and mitigation/elimination of constraints in order to optimise the throughput of material supply to the end user is required. However, in terms of material supply, the problem is more intricate than simply increasing throughput. The entire supply chain system, including planning, procurement, and warehouse functions, requires comprehensive evaluation and redesign. By quantifying the material demand to meet the mining production profile throughout the life of the mine (life cycle), process improvements will be investigated and implemented, and the results monitored over time. However, it is imperative to note that, while materials supply was identified as impacting negatively on the mine's overall productivity, the phenomenon falls outside the scope of this research.

Conclusion

South Deep Gold Mine's Twin Shaft mine is one of the ten deepest mines in the world. The mine's infrastructure and logistics management processes are notoriously constrained, evidenced by reports and documentation of previous studies conducted at the mine. In terms of logistics processes, all ultra-deep mines rely on three main processes that ultimately determine logistics performance, namely ore transport, supply chain management, and personnel transport. The latter was the core focus of this research. Chapter 4 discusses the research objectives of the current study.

CHAPTER 4: RESEARCH OBJECTIVES

In order to achieve the overall desired outcome of personnel logistics optimisation in the ultra-deep mine under study, a framework of the order of execution of the research objectives was formulated. These objectives are listed in this order below and elaborated on in Chapter 5, which contains the discussion of the research design.

The achievement of the first three objectives are reported in this dissertation. The remaining two objectives are mentioned for the sake of completeness, and will be the focus of further studies. The point of including these in the objectives is that, to fully quantify any ultra-deep mine's overall logistics performance, it is imperative that both personnel- and material logistics performance are measured and the results combined.

4.1 Overall aim of the research

The overall aim of the present research was to quantify and thereafter maximise face time through optimisation of the personnel logistics process. To this end, the following research objectives were formulated:

4.1.1 Maximise face time

Research Objective 1: Maximise time for primary mining activities (face time) by determining the current-state logistics performance, identifying the sources of waste (*muda*), strategically eliminating or mitigating the identified sources, and developing means for continuously monitoring process performance and regression, with the aim of ensuring sustainable performance and continuous process improvement.

Conventional and modern-day Lean Six Sigma methodologies were implemented to achieve this objective.

4.1.2 Quantify personnel logistics performance

Research Objective 2: Develop an efficiency measure for the purposes of future benchmarking between different ultra-deep mines internationally.

This measure had to be unit less in nature and provide a clear and logical understanding of personnel logistics performance. Quantification of personnel logistics performance of any mine, including ultra-deep mines, had to be possible through the correct implementation of this measure.

4.1.3 Model for optimised personnel logistics

Research Objective 3: Develop a model for optimised personnel transportation that includes the integration of all personnel logistics functions, including vertical, horizontal, and mining logistics.

This model had to holistically consider the cross-functional interdependencies and cause–effect relationships between all logistics functions. The implemented model had to provide every employee working on the mine with maximum face time, given the current mine infrastructure.

4.2 Material transportation — optimise and stabilise material supply process

Research Objective 4 (future research): Using Lean Six Sigma methodologies, optimise the material transportation process, vertically and horizontally, by identifying and eliminating or mitigating sources of waste (*muda*). Evaluate common cause variation through Six Sigma methodologies to minimise or eliminate variability, thereby stabilising the supply of material to working places.

Research Objective 5 (future research): Develop mechanisms for continuously monitoring process stability, improvement, or regression, with the aim of ensuring sustainable performance and continuous improvement.

4.3 Benchmarking overall logistics performance in ultra-deep mines

Research Objective 6 (future research): In order to conduct benchmarking analysis of ultra-deep mines for the purposes of understanding overall logistics performance, the following unit less measures were developed, in addition to the face time factor:

- Supply chain efficiency factor (η_s)
- Overall logistics efficiency factor (η_o)

The overall efficiency factor is the product of the supply chain efficiency factor and the face time factor (supply chain efficiency factor x face time factor = overall efficiency factor).

Conclusion

Mining involves mechanised machinery, materials, and persons, all of which must arrive at the correct place at the correct time, in an efficient manner, to ensure that production continues unhampered. Research Objectives 4, 5 and 6 are earmarked for further studies and do not form part of the present research.

The next chapter discusses the methodology of the study, and provides a high-level overview of the instruments employed in analyses.

CHAPTER 5: RESEARCH DESIGN

The present study was quantitative in nature. Primary data were collected and analysed through time–motion studies conducted by the present researcher. This chapter provides a broad overview of the methods of data analysis employed to achieve the set research objectives. As mentioned, to prevent the literature review and the discussion of the analyses employed in this study becoming a disquisition that is disconnected from the results, extant research on application of these methodologies, where applicable, is referred to in Chapter 6 in the explanation of the application of the relevant method of analysis in the present study.

5.1 Research approach

The main research objective was the identification of opportunities to minimise or eliminate process waste and subsequently improving throughput — maximising face time. To this end, conventional Lean principles were applied.

5.1.1 Data collection

Time–motion studies were conducted to collect primary process data. Firstly, the personnel logistics process was clarified through process mapping, and each logistics function was defined at macro level. The macro-level processes included vertical, horizontal, and mining logistics, which were thereafter further defined at process level. The physical duration of each step or activity in every process was physically measured through time–motion studies. The log sheets and tally sheets utilised in collecting the process data were collated, and the average cycle times were calculated for every activity step. The data collection was scheduled over a period of 120 consecutive hours (five full production cycles for day shift and night shift), and was performed by four specialist engineers, two for the shaft- and vertical transport processes and two for horizontal and on-reef transport. This data were then collated in a data set and analysed.

In order to verify the accuracy of this data, the same team of engineers was then redistributed to re-measure process activity durations. During this second data-collection process, information was once again collected and collated in a second data set. This second set of data was thereafter analysed and compared with the original data set, to determine the level of error. Once the two data sets had been verified against each other and anomalies addressed or removed, a final data set was selected. This data set consisted of average time durations for every activity or step in the personnel logistics process. This time data were then utilised throughout the DMAIC Model phases for execution of the research objectives.

5.1.2 Data analysis

Lean methodologies were used to analyse optimisation of the transportation of persons to their working places, focusing on the elimination of waste and improving flow through the process. G.L. Sye, in his book *Process mastery with Lean Six Sigma* (2nd ed.) (2012:2), defines waste as "defects, inventory, motion, transportation, over production, waiting, non-value added processing." The process of investigating optimisation in the present study was based on the five Lean thinking principles of Sye, proposed in *Process alchemy* (2nd ed.) (2007), namely Zero waiting, Zero inventory, Maximum flow, Minimum time, and Customer pull.

Lean Six Sigma methodologies were used in the present study to quantify current process performance, in order to maximise throughput and minimise process variation when transporting workers to working places. The ultimate aim was sustainable process improvement through the employment of the conventional Six Sigma DMAIC process framework.

The DMAIC framework (Sye, 2012:25) consists of the following dimensions: *Define*, *Measure*, *Analyse*, *Improve*, and *Control*.

The second principle of Six Sigma, where the process output (y) is a function of a multitude of inputs and process variables (x), was used to optimise the personnel transportation process. Sye (2012:17) describes this second principle as follows: "y is a function of multiple x's, rapid improvement occurs when you focus on the key x's." Thus:

$$y = f(x_1, x_2, x_3, \dots x_n)$$

Vertical and horizontal transportation of personnel was also analysed using Lean principles. The inbound and return processes (from surface to working place and back to surface) were considered, as these all cause a loss of face time, which is the total duration of time spent performing value-adding work. The overall transportation process is therefore, according to Lean thinking fundamentals, pure waste. It is thus desirable to shorten the personnel transportation process as far as possible.

5.1.3 Scope of the research

The present study included the following aspects:

- surface transportation of personnel;
- vertical transportation of personnel;
- horizontal transportation of personnel to their working places; and
- the process of returning to the surface.

Considerations regarding transportation of material, equipment, and consumables were excluded.

5.2 Instruments used in the analyses

5.2.1 Lean Six Sigma DMAIC Model

Phase 1: *Define*

This phase of the DMAIC Model entails definition of the problem and identification of an improvement opportunity. The key performance metrics are defined and targets for output performance are set. The sequence of the process being investigated for improvement is documented. The steps taken in this phase of the DMAIC Model are as follows:

- Identify opportunity for improvement;
- Develop a research charter, including resources; and
- Document key elements of the process being researched.

Phase 2: *Measure*

In this phase, decisions are taken with regard to the data required. The measurement system to be used is selected, whilst ensuring that the collected data are of the required quality. The baseline performance (current state) of the logistics process is determined, to enable comparison of improvements. The steps in this phase are:

- Collect data; and
- Determine and measure baseline performance.

Phase 3: *Analyse*

The third phase of the model is process analysis to determine where the sources of waste are situated within the logistics process. When the process is throughput-based, as is the case in personnel logistics, the focus is on saving time. This analysis is more centred on a Lean, rather than a Six Sigma approach; Six Sigma is more concerned with variation than waste in a process. The steps in this phase are:

- Analyse process flow chart;
- Analyse process performance and identify bottlenecks and/or time traps;
- Identify where the greatest opportunities for efficiency improvement exist;
- Perform detailed analysis of identified sources of waste.

Phase 4: *Improve*

Sources of waste have been identified and selected for mitigation/elimination measures. Suitable ideas should now be generated and residual risks occurring as a result of implementation of these solutions assessed and controls implemented. Solution are implemented in this phase, and monitoring of results is planned and initiated. The steps are thus:

- Generate and select appropriate solutions;
- Mitigate potential errors or consequences; and
- Implement solutions and review results.

Phase 5: *Control*

The purpose of the final phase is to sustain the changes made. Once the required changes to a process have been implemented, monitoring and response to deviations from the required performance are important for ensuring sustainability of the changes. This requires:

- Process standardisation;
- Monitoring of performance; and
- Response to deviations.

In the present study, the quantification of personnel logistics performance was done according to the first three phases of the DMAIC Model: *Define*, *Measure*, and *Analyse*. The personnel logistics process's baseline performance was quantified following best practice Lean Six Sigma principles. The phases *Improve* and *Control* were applied in the maximisation of face time. The primary metric by which quantification and optimisation efforts were measured and compared to the already quantified baseline performance was the face time efficiency factor. This factor is discussed in the section below.

5.2.2 Face time efficiency factor

The face time efficiency factor (η_f) was formulated as a means to determine the level of efficiency with which the employees' shift duration is utilised. Shift duration is the set number of hours every employee is required to work. It is, however, imperative to note that shift duration does not translate to effective working time, especially in ultra-deep mines.

The face time efficiency factor was used as the primary metric of performance in measuring the level of success in achieving maximising face time (Research Objective 1). Therefore, the phases *Define*, *Measure*, and *Analyse* yielded the output of personnel logistics performance, quantified using the face time efficiency factor.

Table 5.1: Overview of methodology

The methodologies implemented within each phase of the DMAIC Model are summarised in sequence of implementation in the table below and elaborated on furthermore thereafter.

OVERVIEW OF METHODOLOGY according to DMAIC (*Define, Measure*, *Analyse*, *Improve*, *Control*) Six Sigma Model			
Purpose	**DMAIC phase**	**Research step**	**Instrument**
Quantification of personnel logistics performance	*Define*	Identify the improvement opportunity: Documenting the process Plot current logistics process	- SIPOC - CTQ Tree - Kano Analysis - Value stream mapping - Process flow mapping
	Measure	Collect cycle time data: Perform time–motion studies (5) of current logistics process (x 4 times = 20 datasets)	- Cycle time data sheet - Observation by researcher and field workers (engineers)
		Divide process into logical physical point-to-point activities	- Cross functional process map
		Establish baseline performance: Determine mean time of each activity	- Time value analysis - Process cycle efficiency - Observation by researcher and field workers (engineers)
	Analyse	Classify activity as value-adding (VA), value enabling (VE), or non-value-adding (NVA)	- Lean thinking methodology (DIMTOWN)
		Identify and select improvement activities	- Pareto analysis (opportunity)
Optimisation of personnel logistics performance	*Improve*	Improve activities Implement improved logistics process	- Cause and effect analysis - Root cause analysis - Work cell optimisation (Spaghetti diagrams) - Queueing theory
	Control	Ensure sustainability of new personnel logistics process (IPLS Model)	- Process performance control plan

SIPOC Model

The SIPOC Model, according to Sye (2009), is one of the most widely known Six Sigma tools. It is described as a framework for documenting a core business process, together with its associated inputs and outputs (in this case, personnel logistics). The SIPOC model is a Six Sigma technique and described by Sye (2009:112) as follows: "This tool provides a solid foundation for process owners to understand the entire process from its inputs through to its outputs, as well as the requirements the customer has of these outputs". The acronym SIPOC is for suppliers, inputs, process, outputs, and customer. Understanding these details assist in defining the needs of the business, customer, and process as described by Sye (2009). The model allows for data collection as well as clarifying actual performance with respect to the needs of the customer, business, and process.

Critical to Quality (CTQ) Tree

The primary purpose i to ensure that the customer's needs are met through the output of the process. As described by Sye (2009), the CTQ tree is based on relationships that exist between the product or service and the specific needs of the customer that are to be satisfied through the product or service.

Kano analysis

The Kano analysis is based on the level of satisfaction of the customer through the output of the product or service. The analysis, as described by Sye (2009), involves dissatisfies, satisfiers, and delighters when considering the customer's perception of the quality of the product or service. Customers' requirements are categorised in order of criticality with regard to perceived quality. These are then ranked in order of priority as requirements that must be met, then requirements that should be met, and, finally, requirements that are nice to have but with no actual impact on customer satisfaction.

Value stream analysis

Sye, in *Process alchemy* (2nd ed.) (2007: 120) states:

> *The value chain focused organisation is one that focuses on multiple processes from an end-to-end perspective. An organisation with this approach moves away from the traditional hierarchical structure to a structure based on a horizontal process flow. Primary relationships are customer–supplier based, and the style of leadership shifts from authoritarian to participative. Business leaders and managers aim to establish a seamless link between processes through optimising exchanges and interfaces.*

The interface between processes and customers will be the driving force for decision making and behaviour.

Sye, in *Process Mastery with Lean Six Sigma* (2009:108), defines a value stream as the consolidated sequence and flow of all the activities or operations required for the design, ordering, production, and delivery of products or services to a customer. Therefore, a value stream consists of the major process components occurring in a linear sequence from the most upstream point supply/source to the most downstream point of final delivery of the product or service to the customer.

A VSA enables the documentation of the flow of information, materials, and activities/processes in each value stream of a business or organisation. It also allows the developer/s of the VSA to analyse the actual performance of the process against customer/business requirements, as well as defined key performance indicators (KPI) or metrics, and distinguishes value-adding from non-value-adding activities (identifying waste).

Value streams in businesses may consist of single or multiple streams, depending on the nature of the business. In a mine, there are multiple value streams, and various products and services may be considered primary processes, such as inbound and outbound logistics of personnel, material and mineral (ore), mineral extraction processes, mineral processing, and delivery of the final product, gold bullion, to the customer. When considering the mine purely as producer of a single commodity, gold, the value stream analysis or map could be illustrated by a single stream of macro processes, demonstrating all core business processes in a single stream. This would be the most suitable method when value-stream analysing the mine based on the single product/commodity being produced as the only form of created value.

Process flow mapping

The purpose of process flow mapping (Sye, 2009) in documenting any process is to clarify process activity steps and identify the sequence in which these activities occur. Many complexities may be identified once the process is mapped at activity level; these include forms of waste, delays, and bottlenecks, which, according to Lean thinking principles, are to be eliminated to improve throughput. The process itself can be clearly described to any person in its actual form, and problems within the process are more likely to become obvious.

Time value analysis

When defining time in a process in terms of value, the value is considered from the point of view of the customer. Process time consists of three categories, namely

- value-adding time (VA);
- value-enabling time (VE); and
- non-value-adding time (NVA).

According to Paulin (2017), VA steps meet three criteria. First, the step transforms the product in a way that moves it towards the finished state. Second, customers would care about and pay for the step in the process if they knew about it. Third, the step cannot be a rework step that exists to rectify an earlier error.

VE activities are performed for various reasons, such as compliance with regulations, and provides the necessary data for the next step in the process to continue, and enables the internal customer to complete value-adding work. VE activities would not necessarily be paid for by the customers if they knew about these, as they do not add direct value for the customers.

NVA steps include all seven forms of waste in a process. These steps do not meet the criteria of adding or enabling value. These steps could be removed without negatively impacting value for the customer. In the process mapping and analysis, it is highly desirable to remove all steps that are not VA, in order to optimise throughput.

Process cycle efficiency

As defined by Sye (2009:336), "process cycle efficiency (PCE) is a measure of overall process health and is calculated as a percentage by dividing value added time (customers) by total lead-time." In simple terms, one could discuss this measure as the portion of total process time that is, in fact, value-adding in delivering the customer's product or service. It is a vital measure used in understanding whether a process is a lean process. If the PCE is below 25%, according to Sye (2009), it is not, by industry standards, a lean process, and thus requires optimisation.

Pareto analysis

As explained by Delers (2015), 80% of problems are a result of 20% of the faults or causes. The Pareto principle was used extensively in the selection of identified sources of waste or non-value-adding activities for elimination or mitigation during the *Improve* phase of the DMAIC process. It is understood that, as resources are limited, it is impractical to initiate attempts at eliminating all identified sources of waste simultaneously. Instead, the Pareto principle was implemented to ensure minimum input for maximum results output.

Cause-and-effect analysis and root cause analysis

As described by Sye (2009), the cause-and-effect analysis generates focused thinking around the identification of root causes to problems. This assists in preventing symptomatic issues from being addressed instead of the root cause issue. In addressing the root cause by implementing a sustainable solution, the prevention of reoccurrences of the same issues is more likely. As described by Sye (2009:460), "The quality of the questions you ask determines the quality of the answers you get. The most important skill of leadership may well be the skill of asking questions".

Work cell optimisation (Spaghetti diagrams)

As described by Sye (2009:456), "Spaghetti diagrams can be used at a high level or detailed level. They can be very effective in identifying waste when used to document flow and movement within each process step". Spaghetti diagrams are used to understand the flow within a work cell or work area. The flow of information, material, people, products, or services can be plotted, and, through an understanding of the flow and sequence of flow, changes may be made to minimise waste within the process.

Queueing theory

Little's Law (Little, 2011) for queuing systems was applied. Little (2011: 536) states:

> *A queuing system consists of discrete objects we shall call items, which arrive at some rate to the system. The stream of arrivals enters the system, joins one or more queues and eventually receives service, and exits in a stream of departures. Little's Law says that the average number of items in a queuing system, denoted L, equals the average arrival rate of items to the system, λ, multiplied by the average waiting time of an item in the system, W. Thus, $L = \lambda W$.*

Sye (2009: 335) describes Little's Law as follows:

> *The long-term average number of customers in a stable system (represented by N), is equal to the long-term average arrival rate (represented by λ) multiplied by the long-term average time customer spends in the system (represented by T).*

Takt time chart

Takt time charting, a constraints analysis methodology, was used to analyse process performance and identify bottleneck and/or time traps. Takt time charting entails plotting the time rates taken to complete each process step and then comparing these time rates to the actual rate of production necessary to meet customer demand.

5.3 Model of Optimised Personnel Logistics (IPLS)

The above model was developed in the form of a personnel transportation schedule. IPLS is the abbreviation of Integrated Personnel Logistics Schedule. This model was the culmination of all the research objectives, and can be used in any ultra-deep mine once the DMAIC phases related to quantification (*Define*, *Measure*, *Analyse*) and optimisation (*Improve*, *Control*) have been completed. The IPLS is the outcome of the optimisation processes of the DMAIC Model (*Improve* and *Control*).

5.3.1 Methodology to develop the IPLS

Twin Shaft had various transportation schedules in place for handling personnel, both on-surface and underground, as well as vertically and horizontally, which were defined, measured, and analysed (*D,M,* and *A*) in the present study. Analysis showed that these schedules were not aligned across different functional areas of transportation. Once the personnel logistics process had been re-modelled and optimised (*I* and *C*), the IPLS was developed, which encompasses all aspects of the different functional areas of personnel transport, to ensure that maximum face time is achieved.

Conclusion

This chapter explicated the framework used to quantify and optimise personnel logistics performance in an ultra-deep mine. The data collection portion of this research was conducted in the actual field through time–motion studies, which yielded large volumes of primary data. This data, after being verified using additional time–motion data gathered through replication of the process, were collated into average time durations for each activity of end-to-end logistics process. The data are of utmost importance in the correct application of the DMAIC Model. First, the quantification of current-state personnel logistics performance was performed, using DMAIC Model Phases 1 to 3 (*Define*, *Measure*, and *Analyse*), followed by maximisation of face time in

Phases 4 and 5 (*Improve* and *Control*). This culminated in a model of optimised personnel logistics — the IPLS. The next chapter reports the findings of the present study.

CHAPTER 6: RESEARCH OUTCOMES

The process of Lean Six Sigma methodology, application, and the results are presented in this chapter.

First, the vertical and horizontal logistics processes at Twin Shaft are reviewed, to ensure that the processes applied in the present research are clearly articulated. Thereafter, the quantification of current-state/baseline performance is explicated, using the DMAIC Model Phases 1, 2, and 3 (*Define*, *Measure*, and *Analyse*), in achieving Research Objective 2.

Second, the optimisation of the current-state performance is reported, aligned with Phases 4 and 5 of DMAIC, namely *Improve* and *Control*. This is followed by the presentation of the IPLS Model developed from the last two phases, in achieving Research Objective 3.

6.1 Maximise Face Time — Personnel Logistics Process Optimisation

6.1.1 Raising and lowering personnel (vertical transport)

6.1.1.1 Introduction to the vertical transportation process

The purpose of this section is to familiarise the reader with operations of the main shaft, which is a vertical shaft. The infrastructure design and functionality is covered briefly, as well as the operation of the conveyances for the raising and lowering persons to surface and underground respectively.

At Twin Shaft, persons are transported to a depth of 2 990m below surface by means of hoisting machinery, commonly referred to in the South African mining industry as *winders* or *winding plants*. The vast majority of deep and ultra-deep mines across the globe make use of a two- or even three-shaft system, whereas Twin Shaft uses a single lift/drop shaft design. The schematic representation in Figure 6.1, below, demonstrates the significant difference between the shaft design of Twin Shaft in comparison to the majority of other deep and ultra-deep mines.

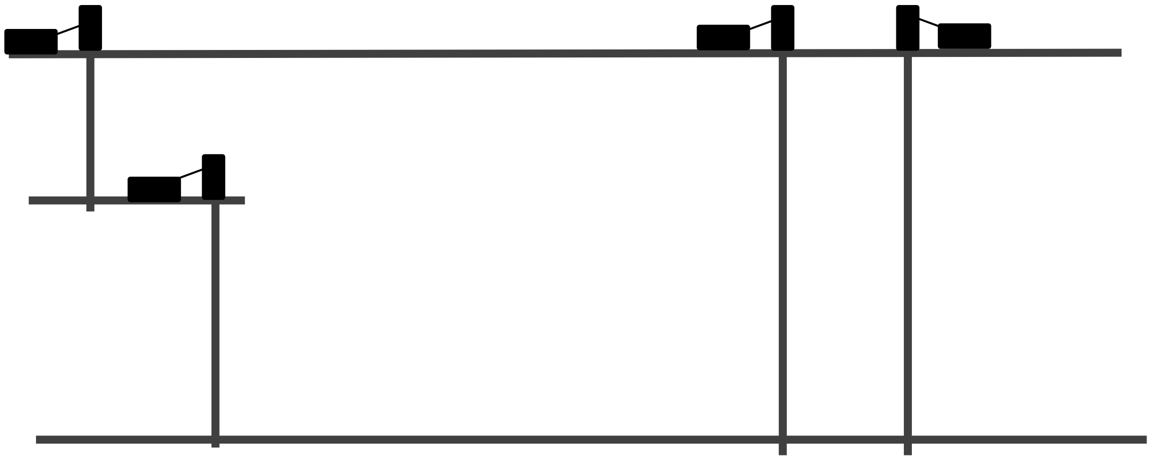


Figure 6.1: Comparison of shaft design between conventional an ultra-deep mine and Twin Shaft

As shown in Figure 6.1, the conventional mine shaft on the left, being of equal vertical depth to Twin Shaft (depicted on the right), is designed with a main shaft and a sub-vertical shaft to access the required depth below surface. The advantages of the Twin Shaft design is that personnel and material can be lowered and raised simultaneously, whereas, with the sub-vertical shaft design, personnel and material must first travel down the main shaft, then travel horizontally to the sub-vertical shaft, before being lowered again. It is would therefore seem that, in terms of logistical efficiency, the single-lift arrangement is superior. However, both designs have advantages and disadvantages. These are summarised in the table below.

Table 6.2: Comparison — ultra-deep single-lift versus sub-vertical shaft design

The table below provides a comparison of the advantages and disadvantages of single-lift and sub-vertical shaft design, as illustrated in Figure 6.1, above.

Shaft type	**Advantages**	**Disadvantages**
Single lift	Transportation time savings	Excessive rope stretch at depth
	Increased efficiency	Conveyance-arresting equipment required to steady conveyance at stations and control rope stretch
	Increased throughput per unit time	Rope oscillation during emergency trip outs of winding plant
	Single shaft to be examined (legislation)	Excessive rope length

	Fewer winders required	Rope maintenance and replacement is intensive
	Reduced capital expenditure	Advanced winding-plant equipment required for brake control
	Lower operational costs	Problematic rope dynamics and accelerated rope wear
Sub-vertical	Smaller, less advanced winding plants required	Loss of time during transfer from main to sub-vertical shaft
	Minimal rope stretch	Diminished efficiency
	Conveyance-arresting equipment not always required, depending on conveyance design	Lower throughput per unit time
	Less rope oscillation	Multiple shafts to be examined (legislation)
	Reduced rope dynamics and rope wear	Double the number of winders required, as shafts are doubled
	Shorter ropes, making rope maintenance and replacement less intensive	Higher capital expenditure for more winders

Thus, both the single-lift and the sub-vertical shaft design have inherent advantages and disadvantages; however, with regard to logistics optimisation in ultra-deep mines, the single-lift design making use of conveyance-arresting equipment to counteract rope stretch is deemed superior.

Mining is a highly dynamic process involving various multifunctional disciplines and activities that function together in a system-type model. The functions are highly interdependent, and the disruption of any function will almost certainly result in a loss of productivity. The system is therefore highly sensitive, requiring all functions to be in place in order for the final product (ore) to be brought to surface. Gold-bearing ore has to be of the required quality and volume for processing, in order to meet production targets and ultimately ensure a profitable business.

The critical flaw in the design of Twin Shaft will now be discussed and illustrated. Interestingly, it is not the depth of the mine or the single-lift design per se that results in the shaft being notoriously constrained in terms of personnel and material transport. The sensitivity of Twin Shaft lies in the rigidity (lack of flexibility) of the shaft design. This will be elaborated on throughout this dissertation and will be demonstrated as the key constraint in the vertical transportation process of Twin Shaft, with its direct impact on the mine's performance and, therefore, profitability. The design flaw is demonstrated by means of a schematic representation, in the figure below, of a comparison of Twin Shaft with a typical mine shaft.

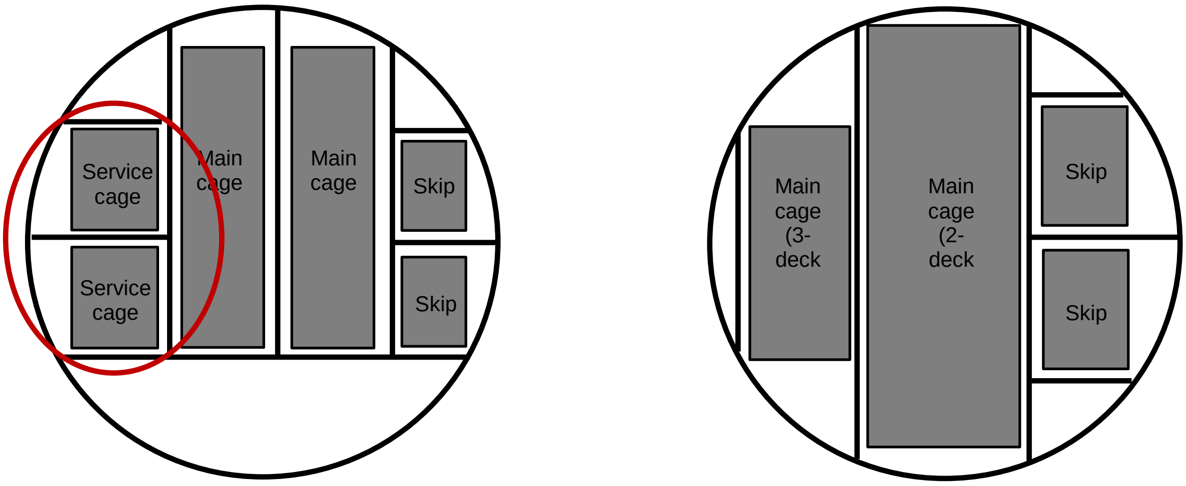


Figure 6.2: Comparison of shaft design between a conventional ultra-deep shaft (left) and Twin Shaft's main shaft (right), demonstrating the critical design flaw.

As can be seen from the above schematic representation, the shaft on the left-hand side is equipped with three double-drum winders — a service winder, a man winder, and a rock winder. Twin Shaft, however, is equipped with two double-drum multi-rope winders only — a man/material winder (commonly referred to as the *man winder*) and a rock winder that controls the two skips for raising broken ore. The critical flaw in the design of the shaft system, and perhaps the root cause of the majority of the vertical logistics constraints at Twin Shaft, is that the main shaft is not equipped with a service winder. The effect of this is that there is a critical lack flexibility in shaft logistics, which negatively impacts production and continually creates delays. This effect is demonstrated through scenarios that occur frequently at the mine.

1. Planned maintenance work is scheduled for the man winder, and it is shut down so that maintenance staff can execute the work. One of the Category 1 or primary production trackless mobile fleet develops a breakdown involving an uncommon component. The component is on-surface and must immediately be sent underground, because the underground spare was used during the previous shift. The winder must be powered up (which takes approximately 30min) and the component sent to the required level (which takes another 30min). The window period between raising and lowering morning-shift personnel is now depleted, and maintenance on the man winder must be postponed. This ultimately impacts overall equipment effectiveness of the winder, and its reliability may be

jeopardised. Alternatively, the primary production machine must be left unattended for the scheduled 4hrs of maintenance of the man winder, which impacts production for 4hrs and increases the MTTR of the primary production machine upon breakdown.

2. The man winder develops an electronic fault in the control circuit that requires fault-finding by maintenance personnel. Unfortunately, the fault develops 10min prior to the scheduled personnel lowering time for the production shift to start. It takes 2hrs to address the fault and start up the winder. The production shift is thus reduced by 2hrs. The entire production shift is subsequently lost, as the primary production activities cannot be completed in time.

3. Time scheduled for lowering of material cars has started. A report is received from underground that a person has become ill and must immediately be raised to the surface. The material car process must be halted immediately and the person evacuated.

It is clear from the above examples that, had the mine been designed with even a single-drum conveyance service winder, the interruption of planned logistics activities by unplanned/unforeseen events could be mitigated and, in some instances, even been eliminated. In summary, the exclusion of a service winder in the Twin Shaft design is the primary cause of the majority of Twin Shaft's vertical logistics constraints.

Per Figure 6.2, above, the man winder consists of a 2-deck and a 3-deck conveyance, the surface area of the 3-deck being smaller than that of the 2-deck. The primary purpose of this design was to ensure that the centre shaft compartment housing the 2-deck conveyance was large enough for the transportation of large trackless machinery and their components inside the shaft barrel. The mining method is considered massive mining, utilising only mechanised mobile plants for the execution of mineral extraction processes. As the man winder has a double-drum configuration, it is imperative that both conveyances have the same mass. Hence, the 3-deck conveyance consists of three levels for personnel loading, with each deck able to carry 60 persons. The 3-deck can carry 89 persons per deck, thereby ensuring the closest possible counterbalance effect between the 2-deck and 3-deck conveyances and the equalisation of winder motor/braking torques and subsequent power consumption. Refer to Figure 6.3, below, for an illustration of the deck configurations, which should be viewed in conjunction with Figure 6.2, above.

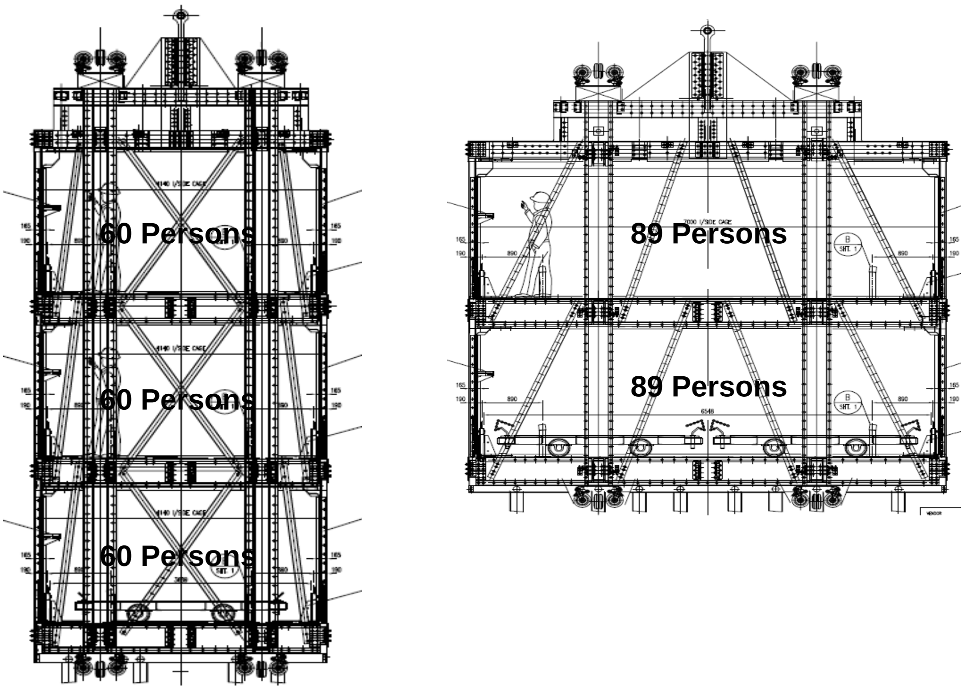


Figure 6.3: Side elevations of three-deck and two-deck conveyances of the man winder. Courtesy of Gold Fields International (Hatch design drawings)

6.1.1.2 Vertical handling of personnel — process description

The raising and lowering of personnel inside a conveyance (cage) that operates in a vertical inclination within the mine shaft barrel is the only means of ingress and egress in ultra-deep mines. At Twin Shaft, this is done using double-drum conveyance.

6.1.1.2.1 Double-drum conveyance of persons

The process of conveying persons in a double-drum winding/hoisting configuration is illustrated in the high-level schematic below.

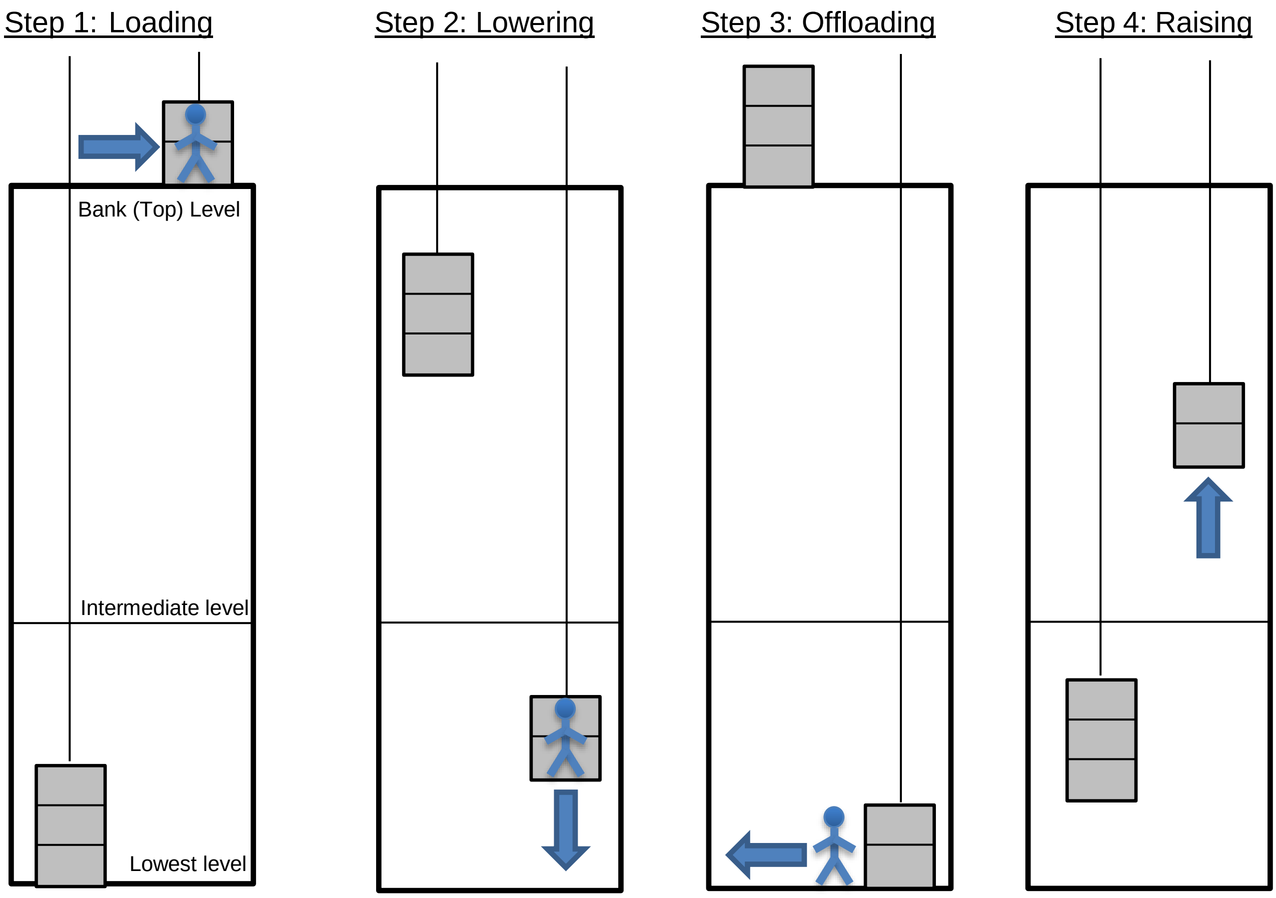


Figure 6.4: Schematic representation of double-drum configuration winding/hoisting of persons

From the above schematic, it is clear that the 2-deck and 3-deck conveyances move in opposite directions as a result of the two hoist drums being connected by a single-drum shaft and the winding ropes being wound around these drums in opposing directions. This is commonly termed *overlay*, which is always the right-hand-side drum, and *underlay*, which is always the left-hand-side drum, relative to the position of the winding engine driver.

The man winder, as is the case with all men/material double-drum hoists in the mining industry, is equipped with a mechanism, called a *clutching mechanism*, that allows any one of the two drums to move while the other remains stationary. The winding engine driver can clutch one conveyance to an intermediate level in the mine shaft, whilst the other remains stationary. When proceeding in the double-drum configuration once more, the conveyance that was stationary will naturally arrive at the position where the clutched conveyance was positioned. This is called *changeover*.

A changeover is when the overlay conveyance is lowered and the underlay conveyance is raised to a point where they swop/alternate positions in the mine shaft and arrive at each other's previous position. The clutching mechanism is imperative in allowing double-drum winding operations to be conducted between the surface and any intermediate level in the mine shaft. Should there be no clutching mechanism, double-drum winding would only be possible between the highest and lowest extremities, in other words, between the surface and the lowest level in the mine shaft.

A constraint in the clutching process that must be noted at this point is that no clutching may take place whilst any persons are inside any of the two conveyances, as it is prohibited by the Mineral Act 50 of 1991, Chapter 16, Winding Regulations, which remains in force in terms of the Mine Health and Safety Act (MHSA) 29 of 1996, Item 4 of Schedule 4.

The process of clutching to an intermediate level prior to continuation with the double-drum configuration winding/hoisting operations is illustrated by Figure 6.5, below.

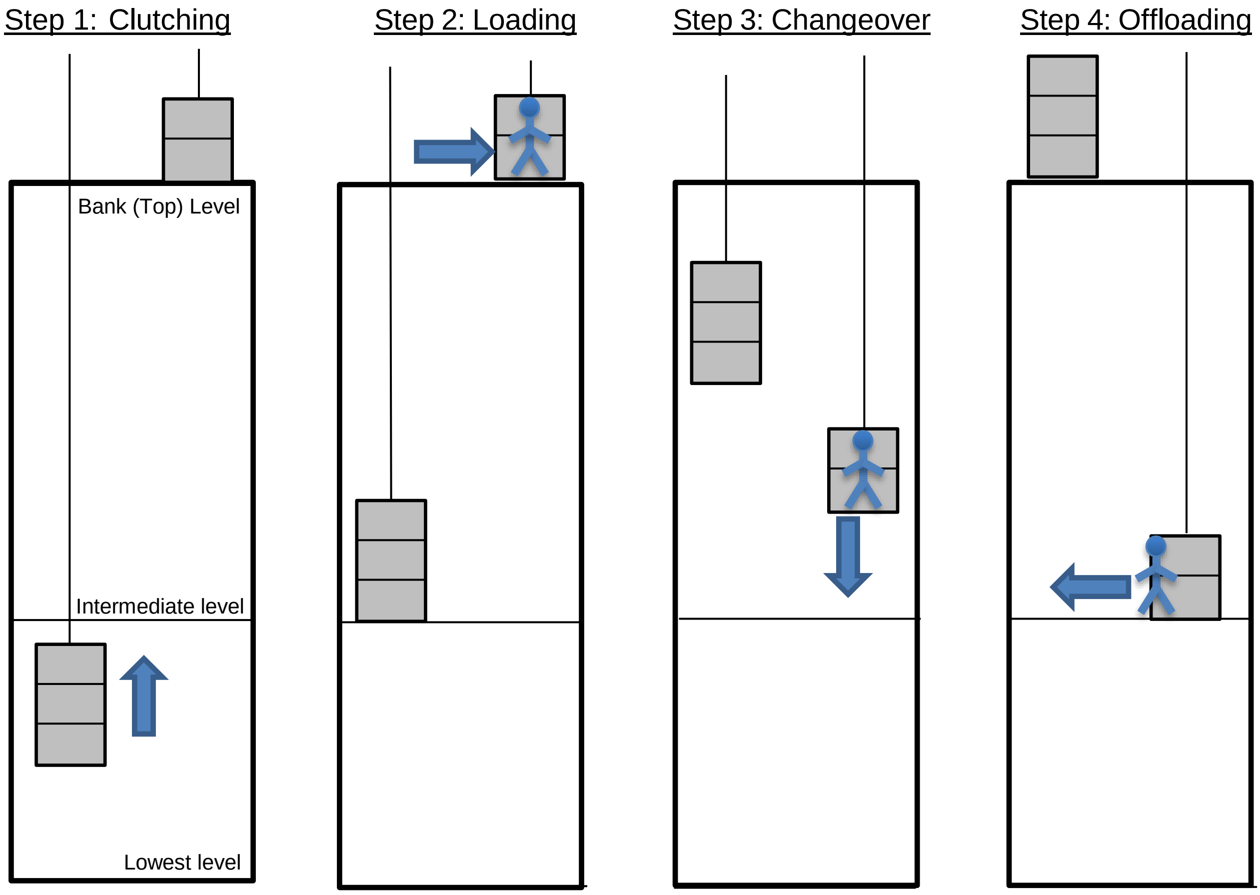


Figure 6.5: Schematic representation of double-drum configuration winding/hoisting of persons after clutching to an intermediate level

6.1.1.2.2 Subnormal shaft operation — background

The initiation of the shaft logistics optimisation project of Twin Shaft started in the first quarter of 2016, after the recruitment of a new shaft and logistics engineering management team of government-certificated engineers. The first phase of the project was to reinstate the original design and operational methodology of the main shaft, as it was discovered that various pieces of shaft infrastructure had been neglected to a point where some infrastructure was inoperable. As a result of the inoperable shaft infrastructure, the shaft logistics system was operating at an estimated 40% of normal capacity.

It was discovered during this period that, of the two available conveyances of the man winder, only the 2-deck conveyance was being used for the conveyance of personnel and material. This meant that the double-drum man winder was being used as a single-drum winder, thereby conveying only 180 persons per winding cycle, instead of the 360 persons per winding cycle for which it was designed. This meant that the 2-deck cage would need to load 180 men on-surface, transport them to the required level, and then return to surface to load the next group of 180 men. The intended process of any double-drum winder is to clutch the two conveyances (cages) to the required levels (i.e. surface and 95 level for example), then load the 2-deck cage on surface to the full 180-men capacity, while simultaneously loading the 3-deck cage on 95 level with 180 men, and make a single trip, thereby simultaneously landing the 3-deck on surface and the 2-deck on 95 level, where the men are offloaded and the cages are loaded again. The logistics engineering team found it disconcerting that the 3-deck cage was constantly used as a counterweight. At this point, the 3-deck cage was never loaded with men or materials; it was always run up and down the shaft empty, which, in theory, constitutes an immediate loss of 50% in design capacity.

Through further investigation into the alarmingly lethargic logistics performance of the men- and material-handling process of the vertical shaft, it was discovered that, although only the 2-deck cage was being used for men- and material transport, when the cage arrived at the desired level (station), only one deck was being offloaded at a time. This meant that the cage would be stopped on the station (level) and the bottom deck would be offloaded first. Thereafter, the cage would be moved downward, to align the top deck with the station landing, to offload the top deck. Each deck was thus being offloaded and loaded individually, although the shaft design allowed loading and offloading of both decks simultaneously. This was considered another severe constraint in the men-handling process.

Through further research and investigation into these dilemmas, the following root causes were identified:

1. On all stations, the station gates, which open and close to allow access to the conveyances when they are stopped in position on the station, were inoperable. This was the result of moving parts having seized due to corrosion and lack of maintenance. This meant that the 3-deck cage (all three landings) could not be used. On the side of the 3-deck cage, only the bottom landing station gates could open and close, and the top landing station gates were inoperable.

2. The Levelok system, which is installed on each cage, is applied when the cage stops on a station, to clamp/lock the cage in position on the shaft steelwork (guides), which will then prevent any cage movement during the increase or decrease of load inside the cage when loading or offloading the cage contents. The Levelok clamps are released when the cage doors have been closed after the loading or offloading process has been completed. The rope stretch (elongation) resulting from the variation of rope load will then occur in a safe, controlled manner, when no personnel or material are being loaded into or out of the cage. The Levelok system at Twin Shaft was inoperable, and had been decommissioned. This meant that, should both decks of the 2-deck cage be offloaded simultaneously, per the shaft design, the rope stretch occurring would be excessive, which could jeopardise the safety of personnel.

It was thus clear that operating the shaft using only one of the two available conveyances (half capacity) and using only one landing on all stations (offloading/loading individual decks) meant the shaft was running in a severely subnormal state (approximately 40% of what is considered normal for men transport and 50% for material transport). It was also clear that, to optimise the vertical transportation system, the shaft would need to be restored to the original design. The engineering management team immediately initiated a programme to reinstate the original shaft design infrastructure, to enable operation of the shaft per the design methodology. A summary of the execution of the programme and the results is provided in the table below.

Table 6.2: Summary of Twin Shaft rehabilitation programme activities

Activity	Execution
Replace 95 Level 3 deck station gates (Bottom)	Complete
Replace 95 Level 3 deck station gates (Middle)	Complete
Replace 95 Level 3 deck station gates (Top)	Complete
Replace 95 Level 2 deck station gates (Bottom)	Complete
Replace 95 Level 2 deck station gates (Top)	Complete
Replace 93 Level 3 deck station gates (Bottom)	Complete
Replace 93 Level 3 deck station gates (Middle)	Complete
Replace 93 Level 3 deck station gates (Top)	Complete
Replace 93 Level 2 deck station gates (Bottom)	Complete
Replace 93 Level 2 deck station gates (Top)	Complete

Replace 100 Level 3 deck station gates (Bottom)	Complete
Replace 100 Level 3 deck station gates (Middle)	Complete
Replace 100 Level 3 deck station gates (Top)	Complete
Replace 100 Level 2 deck station gates (Bottom)	Complete
Replace 100 Level 2 deck station gates (Top)	Complete
Replace Level 2 deck conveyance and refurbish Levelok clamps	Complete
Replace Level 3 deck conveyance and refurbish Levelok clamps	Complete
Replace Levelok station equipment, park, and pneumatic panels — 95 level	Complete
Replace Levelok station equipment, park and pneumatic panels — 93 level	Complete
Replace Levelok station equipment, park and pneumatic panels — 100 level	Complete
Commission original Levelok system — MK 5 System	Complete
Upgrade Levelok system — MK 7 System	Complete

The rehabilitation programme was completed in less than 11 months, including the commissioning of the original Levelok system. Upon completion of the programme, it was again possible to operate the 2-deck and 3-deck conveyances simultaneously. The optimisation of the vertical transportation process could then be investigated. The original Levelok system, however, caused numerous electrical reliability issues, which led to the system being upgraded to the latest MK 7 system. The programme, including the upgrade, was completed in April 2017, and the utilisation of both the 2-deck and 3-deck cages and the Levelok system was initiated in May 2017. Reliability issues were addressed and the system was optimised, and flawless dual-cage operation utilising Levelok technology was achieved in August 2018.

6.1.1.2.3 Shaft scheduling process

The process governing the raising and lowering of men and material in a vertical mine shaft of any kind is typically referred to as *shaft scheduling*. The shaft scheduling process involves various factors, such as volumes of personnel/material, personnel working hours or shift durations, required working times, length of shaft, hoisting profile, cycle time, loading and offloading time, and mine blasting initiation schedules. The design of the shaft schedule is paramount in ensuring personnel and material arrive underground and back on surface within the required time frames, based on the mine's overall production plan.

Twin Shaft -Shaft Schedule (Feb 2015)								
Shift Duration		Zone Time		Shaft Time		Duration	People	Action
		Open	Close	Start	Stop			
				04:45:00	04:50:00	00:05:00		Clutch to 110a
08:15:00	09:15:00	04h20	04h50	04:50:00	05:05:00	00:15:00	51/51/53	110a Belt crew D/S down and N/S out & 72/75# D/S down
09:30:00		04h45	05h05	05:05:00	05:22:00	00:17:00	72/75	95/2W and 95/3W Destress Down
				05:22:00	05:38:00	00:16:00		95L (Extra cage - increased numbers, 22 Oct 2014)
09:22:00		05h05	05h30	05:38:00	05:55:00	00:17:00	72/75	95 1W & Logistics Down
09:30:00		05h30	05h55	05:55:00	06:15:00	00:20:00	72/75	TM³ 93L, 94L D/S Down 110A 7/2 7/5 N/S out
09:30:00		05h55	06h15	06:15:00	06:45:00	00:30:00	72/75	100, 105, 110 L D/S Down (One cage)
01:15:00				06:45:00	08:00:00	01:15:00		Daily legals
06:05:00		07h45	08h00	08:00:00	08:30:00	00:30:00		All levels down & Officials
04:20:00				08:30:00	12:50:00	04:20:00		Shaft Work
08:15:00	09:30:00	12h35	12h50	12:50:00	13:05:00	00:15:00	51/51/53	110a Belt crew A/F down and D/S out & 72/75# A/F down
				13:30:00	14:05:00	00:35:00		110a Morning shift out
		09:15:00		14:05:00	14:35:00	00:30:00	72/75	95/2W and 95/3W Destress Out
				14:35:00	15:00:00	00:25:00	72/75	95 1W & Logistics Out
				15:00:00	15:25:00	00:25:00	72/75	TM³ 93L, 94L D/S Out
				15:25:00	15:45:00	00:20:00	72/75	100, 105, 110 D/S Out (One cage)
				15:45:00	17:40:00	01:55:00		Shaft Work
09:30:00		17h30	17h50	17:50:00	18:15:00	00:25:00	72/75	95/2W and 95/3W Destress Down
09:30:00		17h55	18h15	18:15:00	18:50:00	00:35:00	72/75	95 1W & Logistics Down
09:30:00		18h30	18h30	18:50:00	19:15:00	00:25:00	72/75	TM³ 93L, 94L D/S Down
09:30:00		18h55	19h15	19:15:00	19:40:00	00:25:00	72/75	100, 105, 110 L D/S Down (One cage)
01:10:00				19:40:00	20:50:00	01:10:00		Shaft Work
08:15:00	09:25:00			20:50:00	21:05:00	00:15:00	51/51/53	110a Belt crew N/S down and A/F out & 72/75# N/S down
				22:00:00	22:20:00	00:20:00	72/75	72/75 # A/F out
04:40:00				22:20:00	03:00:00	04:40:00		Shaft Work
				03:00:00	03:20:00	00:20:00	72/75	95/2W and 95/3W Destress Out
				03:20:00	03:45:00	00:25:00	72/75	95 1W & Logistics Out
				03:45:00	04:20:00	00:35:00	72/75	TM³ 93L, 94L D/S Out
				04:20:00	04:45:00	00:25:00	72/75	100, 105, 110 D/S Out (One cage)

Figure 6.6: Twin Shaft original shaft schedule (2015). Courtesy of Gold Fields International

The initial shaft schedule in use upon initiation of the logistics optimisation project at Twin Shaft is shown in Figure 6.6, above. The schedule was reviewed upon completion of the shaft rehabilitation programme; Figure 6.7 is the final shaft schedule implemented after completion of the rehabilitation programme.

Zone Colour	Cage Departs		Action
	4:20	4:50	110A, 100, 94 and 95 Level Day Shift Down, Night Shift Up
	4:50	5:05	93, 95 and 100 Levels Day Shift Down, Night Shift Up
	5:05	5:20	95 Level 2 West Day Shift Down
	5:20	5:35	95 Level 3 West Day Shift Down
	5:35	5:55	94 and 93 Level Day Shift Down
	5:55	6:30	100, 105, 110 and 110A Level Day Shift Down
	6:30	7:05	Officials Down - Last Cage
	7:05	7:55	Daily Examination - 30 Minutes(Reg 16.74)Shaft Examination - 4 Hours (Reg 16.73)
	12:50	13:25	93, 95, 100, 110A Levels Tramming, Engineering, Ore HandlingAfternoon Shift Down110A Ore Ha
	13:15	13:50	95 Level 2 West and 3 West Afternoon Shift Down Officials and 94 Level Up
	14:00	14:15	93, 95 and 100 Levels Tramming and EngineeringDay Shift Up
	14:15	14:30	95 Level 2 West Day Shift Up
	14:30	14:45	95 Level 3 West Day Shift Up
	14:45	15:05	94 and 93 Level Day Shift Up
	15:00	15:20	100, 105, 110 and 110A Level 4x4 Night Shift Down, Day Shift Up
	15:20	17:45	Material Cars - 3 Hours
	18:50	19:05	95 Level 2 WestNight Shift Down
	19:05	19:20	95 Level 3 West and 93 Level Night Shift Down
	19:20	19:35	94, 100, 105 and 110 Levels Night Shift DownAll Level Up
	19:45	21:00	Material Cars - 1 Hour
	20:50	21:20	93, 95 and 100 Levels Tram & Eng and 110A Level Night Shift Down, Afternoon Shift Up
	21:45	3:15	93, 95 and 100 Levels Tramming and Engineering Afternoon Shift Up
	22:00	3:30	95 Level 2 West and 3 West Afternoon Shift Up
	22:15	3:45	Material Cars - 5 Hours
	3:35	3:50	100, 105, 110 and 110A Level 4x4Night Shift Up
	3:50	4:05	95 Level 2 WestNight Shift Up
	4:05	4:20	95 Level 3 West and 93 Level Night Shift Up
	4:30	4:45	100, 105, 110 and 110A Levels Night Shift Up

Figure 6.7: Twin Shaft amended shaft schedule (2017). Courtesy of Gold Fields

An approximate reduction of 20min can be observed in the second schedule. Where the previous last bulk shift cage departed at 06:15, the new shaft schedule final bulk shift cage departed at 05:55, lowering the same volume of persons from 04:20, when the shaft schedule starts. The shaft infrastructure being brought back to original design state yielded this saving; employees spent less time waiting and travelling from the surface to their working level. Since the vertical shaft could now be considered to be in a stabilised state, further optimisation could be pursued.

6.1.2 Transportation of personnel underground to working places (Horizontal transport)

6.1.2.1 Introduction to the horizontal transport processes at Twin Shaft

Once employees are offloaded on the required working level by the conveyance or cage operated by the respective winding/hoisting machinery, these employees move horizontally to reach their working places and engineering workshops, which, in mine jargon, is termed *the face*. Twin Shaft consists of three main working levels, namely 93, 95, and 100 level, which are defined as main working levels due the volumes of persons employed on these levels and the extent of the mining activities undertaken there. The focus of this research was mainly 95 level and the optimisation of transport activities to access this level, both vertically and horizontally. 95 level accounts for more than 80% of mine personnel working underground. The horizontal travelling distances on 95 level are also the longest, where 93 and 100 levels' traveling distances are minimal. The schematic representation in Figure 6.8, below, illustrates a section view and basic layout of the main shaft's horizontal working levels, including vertical distances below the shaft collar (below bank level).

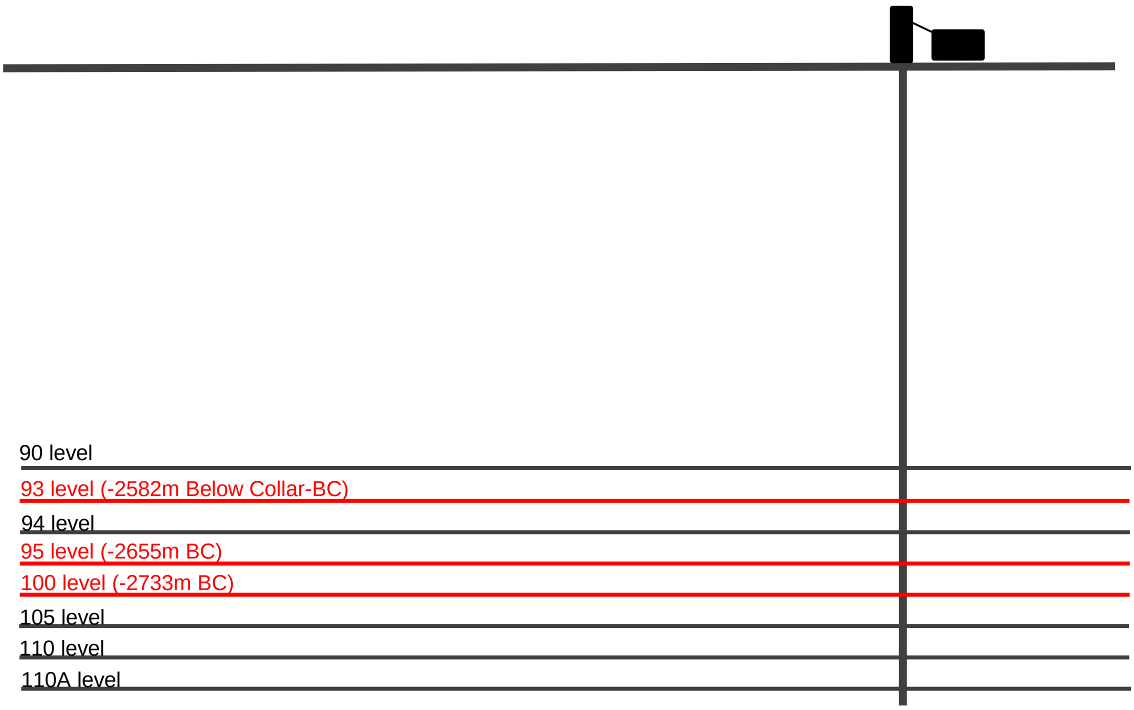


Figure 6.8: Schematic representation of the main production levels at Twin Shaft, including elevations below shaft collar (BC)

As seen in the figure above, once personnel are offloaded on the level, the vertical transportation process is completed for that particular cage of employees. These employees then proceed from the shaft station area to their working places by means of one of the following two methods:

- Walking: Employees commute on foot along the main ventilation intake haulages/tunnels toward their working places.

- Man carriage: This equipment is a locomotive-drawn carriage/cart, designed for the specific purpose of transporting personnel by means of rail track. Personnel wait for the man carriage near the station area, at the designated loading bay. Upon arrival of the carriage, the unit is brought to rest and the locomotive park brakes are applied, and personnel are then loaded into the carriage until the maximum permissible number of persons have been loaded (40 persons per carriage, per the design). The locomotive then transports these personnel to their respective working places. It is vital to note at this point that this equipment is only available on 95 level. Currently, 8-man carriages are utilised for this process on 95 Level; 93 and 100 level are not equipped with man carriages, due to minimal walking distances, and all employees walk to their respective working places within a reasonable time (less than 10min, on average).

Walking to working places on 95 level results in various undesired effects, such as:

- Employees arrive at their working places at irregular intervals, thereby delaying the initiation of waiting place safety, planning, and safety declaration meetings. This is described in detail further on.

- Some personnel become fatigued prior to arriving at their working places, which could diminish the productivity levels of their teams.

- The interface between rail-bound equipment and persons walking in the haulage creates a safety risk. Separation of man and machine is desirable in mining operations, especially with reference to haulages where locomotives are in operation.

- With regard to logistics effectiveness, numerous employees walking in a haulage to their working places is an activity with a very low level of controllability.

- The success of supervising these employees and ensuring their timeous arrival at their working places is improbable.

- Most importantly for this study, it was identified that face time is lost due to personnel walking to working places instead of utilising man carriages.

In conclusion of the research introduction to the vertical and horizontal personnel logistics processes, the shaft double-drum operation, shaft configuration, the critical design flaw with regard to the lack of a service winder, as well as the manner in which shaft logistics planning is conducted through shaft scheduling have been addressed. The horizontal transportation process was researched and defined, and the functionality as well as modes of transport were highlighted. These limitations indicated the need to optimise personnel's face time. As mentioned, the DMAIC framework was applied to address these issues. This is discussed below.

6.1.3 *Define* — Maximising face time (Quantification section)

The process of quantifying personnel logistics performance was initiated at this point, and included research on the application of specific Lean Six Sigma methodologies and tools.

6.1.3.1 Identifying the improvement opportunity

According to Sye (2012:106), identification of the improvement opportunity is one of the most important activities business leaders can undertake, yet, in the present researcher's opinion, is possibly the most undervalued and poorly performed task.

The business process at Twin Shaft related the overall personnel logistics process was studied in detail by means of the following Six Sigma tools:

- SIPOC (supplier, inputs, processes, outputs, and customers) model; and
- value stream analysis.

As described by Michael Porter and presented in the textbook *The strategy process — concepts, contexts, cases: Porter's generic strategies* (Mintzberg, H., Quinn 1996), business processes are differentiated into and primary and secondary processes.

Secondary processes support primary processes by means of providing certain inputs or resources to the primary process. These functional inputs include, e.g., information technology, control and instrumentation, supply chain management, and human resource management, to name a few, all of which do not create actual value, but enable the creation of value in the primary process. Primary processes, on the other hand, directly create value through the creation of an actual product or rendering of a service, and include sales and aftermarket service.

Porter (1985), in *Competitive advantage: Creating and sustaining superior performance*, notes that primary activities include inbound logistics, operations, outbound logistics, marketing, sales, and service. Porter (1985) further noted that operations are involved with managing the processes that change inputs (in the forms of raw materials, labour, and energy) into outputs (in the form of goods and/or services).

South Deep Gold Mine, as an ultra-deep mine, relies on mechanised mining machinery for all on-reef mining processes, including supporting, drilling, charging up, cleaning, loading, hauling, dumping, and rock breaking; however, unlike many other large-scale mines in operation at present, it is completely un-autonomous with regard to the operation of machinery. The process of transporting machinery operators to their working places at this particular mine can therefore be considered a primary activity. It is important to note that no value-creating activities can be initiated without the machinery operators being stationed at their machines. Any time spent by the operator between the mine access control point for reporting to work and starting up the respective machine for actual work can be considered waste (motion, transport, and waiting). This waste had to be reduced to a bare minimum. Lean and Six Sigma principles, as well as a SIPOC model, were applied in order to optimise what was, in the case of Twin Shaft, the 'primary' activity of transporting personnel to the face.

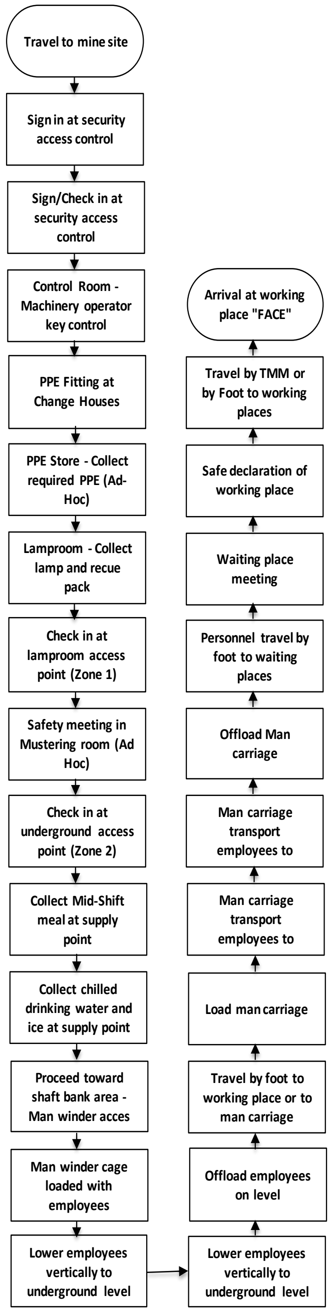
6.1.3.1.1 SIPOC Model

The end-to-end personnel logistics process at Twin Shaft was explored, and is illustrated (in Figure 6.9) according to the Six Sigma SIPOC methodology. As can be seen from the SIPOC worksheet, the focus was on primary production employees who perform primary process activities, such as machinery operators, miners, and artisans working on 95 level (highlighted in grey in the figure). This research was focused on these employees, as they require maximum time at the face to safely and effectively execute primary production and supporting activities within the available shift time, to ensure the mining cycle is successful.

The high-level process was mapped through observation and involvement of personnel employed across the organisation and involved directly in the process. The various input sub-categories included materials (in this case, the 'material' being transported was personnel), information, and resources. All inputs were defined and the suppliers or sources identified. The business requirements to ensure maximum output of primary production activities were: maximum face time and personnel arriving safely at the face.

South Deep Gold Mine - Twin Shaft Personnel Logistics Process

Supply/Source	Input	Process	Output	Customer
	Material			
Mine village/town **Mine Hostel** **Local townships**	**Primary Production Personnel/ Employees**		**Arrival at working places without delay**	**Mine/Employees**
Mine Vendors/Suppliers	Contract employees/ Consultants		Arrival at working places without delay	Mine/Employees
Head office/ Management	Visitors		Arrival at desired destination without delay	Mine
	Information			
HR Department	Employee working cycles		Correctly assigned	Mine/Employees
Time and attendance (T&A) Department	Shift Access times (Zone times)		System accuarte and functional	Mine/Employees
Surface Transport Department	Employee Bus Schedules		Schedule strictly complied with	Mine/Employees
Security Department	Access control records		System functional at all times	Mine/Employees
Shaft Logistics Department	Shaft Schedule		Schedule strictly complied with	Mine/Employees
Horizontal Logistics Department	Man Carriage Schedules		Schedule strictly complied with	Mine/Employees
Mining Department	Waiting place arrival and departure schedule		Schedule strictly complied with	Mine/Employees
	Resources			
Surface Transport Department	Buses/Shuttle service		Arrival on time	Mine/Employees
Security Department	Mine Access Control Point		System operational	Mine/Employees
Control Room	Machinery Key Control/Issuing Point		System operational	Mine/Employees
Facilities Management Department	Change houses		In good condition	Mine/Employees
Facilities Management Department	Mid-shift meal supply point		System operational	Mine/Employees
Safety Department	Personal Protective Equipment (PPE) Store		System operational	Mine/Employees
Shaft Logistics Department	Lamproom		System operational	Mine/Employees
Shaft Logistics Department	Man Winder (Vertical transport by cage)		Arrival on time	Mine/Employees
Horizontal Logistics Department	Man Carriages (Horizontal transport by carriage)		Arrival on time	Mine/Employees
Mining Department	Waiting place safety meeting and supervision		System operational	Mine/Employees
Mining Department	Trackless Mobile Machinery (Transport on reef to working places)		Arrival on time	Mine/Employees
Control and instrumentation (C&I) Department	Check in access points (All card readers - Zoning points)		System operational	Mine/Employees
Shaft Logistics Department	Chilled water and ice dispensers		System operational	Mine/Employees



Input Requirements	Business Requirements	Customer Requirements
Employees to arrive on time according to scheduled. Employee working cycles to be correct, employees to be zoned, transportation schedules to be well communicated, all transportation modes to be reliable and available according to approved schedules.	Employees arrive at their working places safely , yet as fast as possible. (Face time to be maximised)	All transportation schedules to be fully and strictly adhered to. *Further investigation by CTQ Tree Technique (Fig 6-10)*

Figure 6.9: SIPOC model — Twin Shaft Personnel Logistics Process

As highlighted in the red border in Figure 6.9, above, in defining customer requirements, the customer was the employee who has to utilise the available transportation modes. The mine as a business, the second customer in the process, considers the employees' best interests as the core of its business policy. Both customers require compliance with transportation schedules. It was therefore of vital importance that schedules were correctly and accurately defined, and that these schedules were derived by means of process design that took into consideration motion, transportation, waiting, and personnel volumes, as well as unforeseen circumstances and unplanned delays.

No multifaceted organisation with such vast cross-functional interdepartmental dependencies can operate effectively and predictively with personnel transportation schedules that are executed with high levels of process variability. Therefore, the personnel logistics schedules of Twin Shaft all have to be aligned and easily repeatable, without excessive common cause variation, in line with the Lean principle of minimising waste, otherwise the business requirement of maximum face time will never be realised.

Further investigation into customer requirements was performed utilising the Critical to Quality (CTQ) Tree technique shown in Figure 6.10, below.

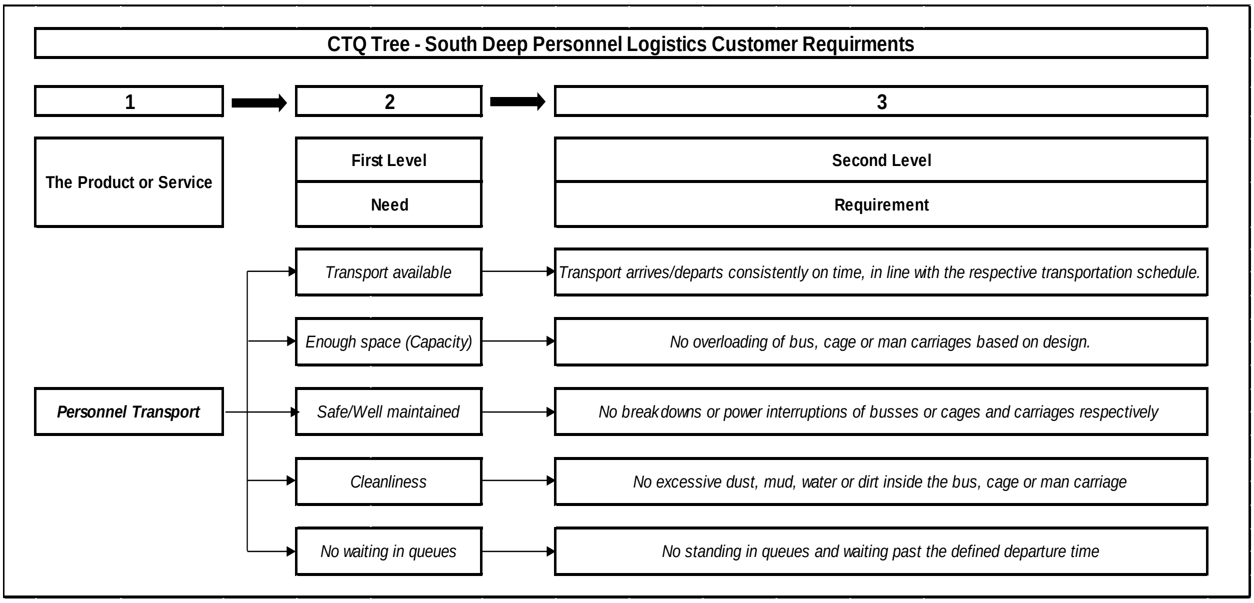


Figure 6.10: Critical to Quality (CTQ) Tree — Twin Shaft personnel logistics process customer requirements

South Deep Personnel Logistics Process Customer Priorities- Kano Analysis			
Customer 1	**Customer 2**		
Mine	Employee		
Priority	**Priority**	**Need**	**Requirement**
A	A	Transport available	Transport arrives/departs consistently on time, in line with the respective transportation schedule.
A	B	Enough space (Capacity)	No overloading of bus, cage or man carriages based on design.
A	A	Safe/Well maintained	No breakdowns or power interruptions of busses or cages and carriages respectively
B	A	Cleanliness	No excessive dust, mud, water or dirt inside the bus, cage or man carriage
A	A	No waiting in queues	No standing in queues and waiting past the defined departure time

Legend

A	Must be met - Critical to Quality requirements
B	Should be met - more is better
C	Nice to meet

Figure 6.11: Kano analysis of customer priorities

As indicated in Figure 6.10, above, multiple customer needs that have to be satisfied by the process outputs were identified. Sye (2009:782) notes that it is often not possible to satisfy all customer requirements at all times. The customer priorities worksheet in Figure 6.11 was therefore developed, which would guide decision-making in the optimisation process. The Kano analysis technique (Sye, 2009:782) to prioritise customer requirements using the CTQ Tree as a guideline is illustrated below.

As the SIPOC model (see Figure 6.9) indicates, both the employee and the mine (employer) can be considered a customer. During the completion of the Customer Priorities Sheet, it was decided to consider the employer's priorities separately from those of the employee, in the interest of health and safety and legislative compliance with the Mine Health and Safety Act 29 of 1996. The employer has a legal responsibility to take reasonable measures to protect the health and safety of employees working at the mine, as well as those not working at the mine but who may be affected by mining activities. Overloading, as mentioned in Figure 6.11, although considered a Priority B for employees, was noted as Priority A for the employer (also reflected as such in the final Customer Requirement Sheet, below), due to the related health and safety regulations and legislative implications. Regulatory requirements listed in Chapter 16 (Winding Plant) of the Minerals Act 50 of 1991, in force in terms of Item 4 of Schedule 4 of the Mine Health and Safety Act 29 of 1996 and the National Road Traffic Act of 1996, prohibit the overloading of conveyances and vehicles alike.

The final Prioritised Customer Requirements List to be included in the SIPOC model (see Figure 6.9) is shown in Table 6.3, below. The table is a summary of customer requirements selected for priority from the CTQ Tree and Kano analyses. The requirements were ranked in order of priority for consideration in the DMAIC Model decision-making process. Furthermore, these requirements were categorically rated in terms of safety and optimisation, always placing safety at a higher priority level. This would ensure that no optimisation efforts negatively impacted the safety of persons.

Table 6.3: Customer requirements for the personnel logistics process at Twin Shaft

Priority	Customer requirements	Category
1	No overloading of bus, cage, or man carriages, based on design	Safety
2	No breakdowns or power interruptions of busses or cages and carriages respectively	Safety
3	Arrival/Departure consistently on schedule	Optimisation
4	No standing in queues and waiting longer than the defined departure time	Optimisation

In short, the aim is to achieve the business requirement of maximisation of available face time, whilst utilising the prioritised customer requirements (see Table 6.3, above) in decision-making and trade-off decisions.

6.1.3.1.2 Value Stream Analysis (VSA)

For the purposes of this research, the individual value stream focussed on was the personnel logistics processes at Twin Shaft. As previously described, this mine is totally dependent on machinery operators (personnel) arriving at their respective working places (face) as a prerequisite to any other value-generating activities taking place (primary mining activities). The mine is fully un-autonomous, and machinery cannot be operated on a large scale by remote from the surface, although research and development of a single impact breaker operated from the surface has been undertaken. New technology of this kind is being pursued by the mine's in-house business improvement and technology departments as part of the overall operational organisational strategy. However, this type of technology, especially with regard to implementation, is a highly sensitive subject with both employees and organised labour/representative trade unions, due to the perceived replacement of critical skills by this technology. For the purposes of this research, the concept of operating machinery from surface in a remote manner, or having machinery operate semi/fully-autonomously by means of on-board machinery control, radio frequency, and wireless technology will not be considered. It is, however, in the opinion of the present researcher, a key focus area for ensuring profitable and sustainable mining activities at Twin Shaft when considering the 70-year life of the mine plan.

At present, 60% of the current operational expenditure can be attributed to labour costs. The mine has, furthermore, been unable to achieve and sustain a profit for more than one year since its inception. Converting to a fully mechanised, semi-autonomous mine is, at this point, considered a medium- to long-term endeavour, but should be implementation as rapidly as possible. This research provides a more attainable solution in the short term, which, if effectively implemented, may alleviate production losses as a result of mining activities being hampered by wasteful activities in personnel transportation. Available employee face time must be maximised for the value-creating processes (mining) to be maximised. This relationship can be expressed as follows:

$$Employee\ Available\ Face\ Time\ \propto Mining\ Process\ Output$$

As previously defined in the SIPOC model, the organisation requires the maximum possible face time whilst ensuring the health and safety of personnel being transported. If successful, the metric should show improvement is overall gold to market.

A VSA of Twin Shaft's personnel logistics value stream was conducted next, illustrated by the Current State ('As is') Value Stream Map (VSM) in Figure 6.12, below. The VSM, when interpreted from upstream (left, also known as *source* or *supplier end*) to downstream (right, *customer end*), shows the sequential flow of materials, in this case mine personnel, as well as the flow of information between departments and processes. Additional time- and process data were also mapped out (at the bottom of the map), indicating information such as total lead time, total processing time, and cycle times for each individual process. Further information uncovered included high-level process steps within the identified macro logistics processes. These are further defined in the DMAIC sequence when documenting the process in more detail.

Employees/personnel depart their residences (hostels, mine villages, local towns, and nearby cities) for the mine site. This process takes, on average, 15–30min for more than 80% of the mine's personnel. Certain employees travel longer than 30min; however, the majority of these employees are employed in management or senior supervisory roles. Upon arrival at the mine, employees gain access through the security access points (turnstiles), making use of their access cards (clock cards). Machinery operators collect keys for their respective machinery before moving to the change houses to prepare their mandatory personnel protection equipment (PPE) for underground. Finally, the Lamp Room is accessed, where self-contained self-rescuers (SCSR) and cap lamps are collected, as well as any PPE they may require (ad hoc).

It is imperative to note that these employees have not yet clocked into the *risk-on* or underground access point. Once Zone 1 is accessed, just past the Lamp Room but before the actual vertical shaft area, the employee's shift duration will begin counting down. This is a critical point for this research, as employees' total shift duration is counted from Zone 1 until employees reach the surface after their shift. In order to optimise face time, it is clear that the maximum possible available shift duration time must be spent on the face, not conducting wasteful activities such as travelling, being transported, or waiting. Zone 1 is also considered the beginning of the next process, the shaft access process (see Figure 6.12). In summary, an employee's actual shift duration is unaffected by the first process, termed *mine access/surface activities*.

Shaft access includes Zone 1 clocking point (access point), where shift duration begins counting down. Next to the Zone 1 clocking point is a general safety meeting point, in a hall positioned before the shaft — the Mustering Room. A meeting is conducted here on a daily basis by mine management and leadership of organised labour. The employees thereafter proceed out of the Mustering Room to a second set of turnstiles, known as Zone 2 or risk-on access point, where they are now entered into the underground area per the time and attendance (T&A) system. Employees proceed past the mid-shift meal collection point, where they collect a mine-provided meal. They them move across the main tunnel from the Lamp Room's building to the shaft bank area. Upon arrival at the shaft bank area, employees wait for the banksman to call the respective employees toward the shaft barrel area, to enter the cage. This communication from the banksman to employees is conducted by means of a public announcement (PA) system. Once the cage is stopped in position on the bank, the banksman calls the respective employees over the PA system; he/she then unlocks the final set of turnstiles positioned at the shaft bank area. These turnstiles are locked and unlocked by the banksman through the bank access control system screen. The banksman can also select the number of turnstile rotations per cage deck, to prevent overloading. If the 2-deck cage is at the bank, the banksman will select 89 persons for the bottom- and middle-level shaft barrel access turnstiles, then unlock them and allow the cages to be filled (surface loading process).

Thereafter, the employees travel to their respective levels according to the shaft schedule, and are offloaded on the level (station). Employees are offloaded from the cage by the onsetter, who is a specialised, certificated employee appointed for this task by the mine manager. This task, as well as those of the banksman, may, in terms of South African mining legislation, only be performed by the holder of the Onsetters' Certificate issued by the Department of Mineral Resources Inspectorate, in accordance with the Mine Health and Safety Act 29 of 1996. Once offloaded on the level, employees proceed to the man carriage waiting area approximately 200m from the shaft barrel. Through this research, it was discovered that the majority of employees walk to their respective waiting places, while the rest wait for extended periods for the man carriage to transport them inside.

Personnel eventually arrive at their waiting places (a mine term for a meeting room). Section supervisory personnel discuss safety, conduct pre-work risk assessments, and declare the working places safe, as required by legislation. General discussions are resumed thereafter, in some instances continuing in excess of 45min if the mining team members and machine operators have issues to discuss. These general discussions do not form part of the mine's policies, standards, or procedures, and supervisory staff are continuously challenged in maintaining order and discipline in their teams. The final process step involves the travelling of personnel from their waiting places to their respective places of work (development ends, longhole stopes, workshops, to name a few). This movement/transport is primarily by means of walking.

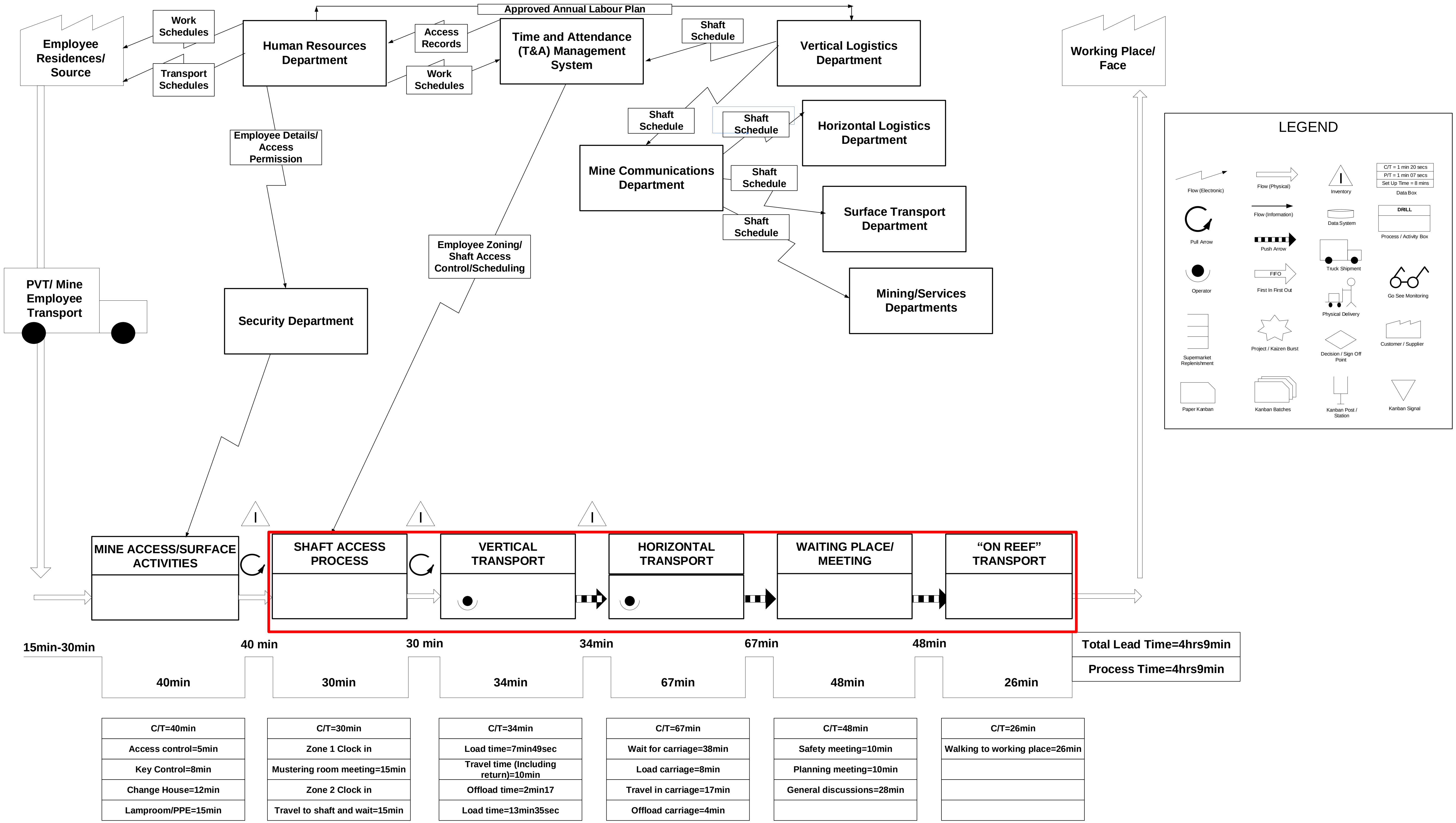


Figure 6.12: Value stream map – Personnel logistics process

Figure 6.12, above, illustrates five of the six processes (in the red border) of interest in the present research. The prior processes of transportation to the mine site, mine access control, and surface activities were not considered part of the immediate value stream. Zone 1, has an exact 'time in' affixed to it for all personnel working on different levels and in various mining sections underground. The shaft schedule itself is designed with zoning as an inherent control system to ensure personnel arrive at the shaft barrel on time for their cage. Therefore, should an employee be late for his or her zone time, the Zone 1 turnstile will not unlock for the employee, and the employee is deemed late for work.

As the intention is to maximise the effective utilisation of an employee's shift duration when measured from Zone 1 to the face and back to surface, the initial two processes may be considered irrelevant at this point. To illustrate the reasoning, if the time spent on surface activities could be reduced from 40min to 20min through Lean principles and tools, the employee would arrive at the Lamp Room 20min earlier and would not be able to access Zone 1 yet. If Zone 1's time were then moved 20min earlier for this employee, the respective cage coming out of the mine at the end of shift would also have to be moved 20min earlier, as the overall shift duration of the employee may not, according to the mine's agreement with organised labour, be increased to more hours than stipulated in the agreement. Hence, the only manner in which to maximise face time is to eliminate waste in motion, transport, and waiting between the two battery limits, i.e. Zone 1 and arrival on surface at the end of the shift, commonly termed from *bank to bank*. Shift duration is a constant value (x), the variable transportation inputs (x's) of the process can all be considered waste, and the output to be optimised (y) is face time. The input x's with the greatest value were the focus.

As previously described, the VSM highlighted the flow of material and information. The approved annual labour plan, including employee shift durations, working places, volumes of personnel per section, and production targets, derived from the mine business plan, is delivered electronically to the logistics engineer, at which point the shaft schedule is revised in line with the labour plan. The finalised shaft schedule is distributed to the mine communications department after approval by senior operational management. The schedule is communicated through the required departments, namely Human Resources (HR), Horizontal Logistics, Surface Transport, and Mining Departments. These departments then develop their transportation schedules in line with the shaft schedule. The HR, Time & Attendance, and Shaft Logistics Departments together redefine the zoning access point times in line with the approved shaft schedule, to ensure employees cannot arrive late or at the incorrect time for their respective cages to be transported to the required working levels. HR, with assistance from organised labour (representatives from trade unions), communicate all other relevant information regarding working cycles and shift/zoning times with personnel. Security access control is set up after the required information has been shared with the Security Department by HR.

Process and cycle-time information is now reviewed from the VSM, with the aim of identifying high-level forms of waste and potential opportunities for improvement. The table below summarises the value stream pertinent to high-level process and time-related information, taking into account that all processes up to shaft access processes are deemed irrelevant, as there are presently no opportunities for improvement. These processes may be reviewed in future, as optimisation and streamlining opportunities do exist within the areas of mine access and surface activities.

Table 6.4: Logistics VSM — pertinent time and process data

Process	Cycle time	Lead time	Estimated potential waste to be removed (%)
Shaft access	30min	30min	66
Vertical transport	21min31sec	21min31sec	26
Horizontal transport	67min	67min	57
Waiting place/Meeting	48min	48min	58
On-reef transport	26min	26min	TBD
Return to surface	58min	58min	58
Total lead time (min)		**192min31sec**	
Total lead time (hrs)		**3h12min31sec**	
Including return		**4h10min31sec**	

The estimated potential waste to be removed in each process included unnecessary motion, transportation, and waiting. When reviewing the horizontal transportation process as an example, we note the fact that waiting for a man carriage was considered a complete waste in the process:

$Waiting\ time / Cycle\ time$

$(38/67)\ x\ 100$

$\underline{= 56.71\%}$

Approximately 57% of this process could already be deemed waste to be removed. The same rationale was applied to the other four processes, barring on-reef transport, which requires more detailed investigation. Through the implementation of VSA methodologies, the Twin Shaft personnel logistics process was defined, and various forms of waste, their locations, and improvement opportunities were highlighted.

6.1.3.2 Development of Research Charter

<table>
<tr><td colspan="4">Table 6.5: Research Charter — Twin Shaft personnel logistics</td></tr>
<tr><td>Research objective: Maximise face time</td><td colspan="3">Date revised: 31 May 2018</td></tr>
<tr><td colspan="4">Team
Team leader: D. Bezuidenhout
Champion: M. Olivier
Process Owner: South Deep Twin Shaft</td></tr>
<tr><td rowspan="5">Problem / opportunity statement

Employees at South Deep Twin Shaft, on average, only spend 56% of their working hours on their primary functions. The remaining 44% of their shift duration is spent travelling from surface to their working places and back. The main/primary production activity of supporting and drilling requires a minimum of 6hrs30mins, where the current average face time available is 5hrs20mins. South Deep Twin Shaft has not met the annual mine production plan since mine inception.</td><td colspan="3">Primary metric</td></tr>
<tr><td><u>Metrics</u></td><td><u>Base KPI</u></td><td><u>Target KPI</u></td></tr>
<tr><td>Average time wasted</td><td>4h10min</td><td>2h40min</td></tr>
<tr><td>Average face time</td><td>5h20min</td><td>6h50min</td></tr>
<tr><td>Face time efficiency factor (average)</td><td>56% (0.561) on a 7-2; 7-5 cycle</td><td>72% (0.719) on a 7-2; 7-5 cycle</td></tr>
<tr><td>Desired outcomes/goals

• The time spent on non-value-adding activities must be reduced to a minimum of 2h40minutes.

• A minimum of 6h50minutes face time must be created.</td><td colspan="3">Decision constraints/limitations

• Shift cycle 7-2;7-5 (shift duration is 9h30min)

• Blasting times/Re-entry periods (1h per blast)</td></tr>
<tr><td>Scope of research

• In scope: Surface shaft access process to the working place (face) and back to surface

• Out of scope: Travel to mine, surface activities prior to shaft access</td><td colspan="3">Benefits

• Productivity: Increased blasting frequency, improved machinery utilisation, and improved mining quality

• Financial: Increased revenue through increased production output and cost reduction through less mining quality-related defects

• Morale: Adequate time available to employees to complete daily mining and maintenance tasks</td></tr>
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PRIMARY METRIC CHART

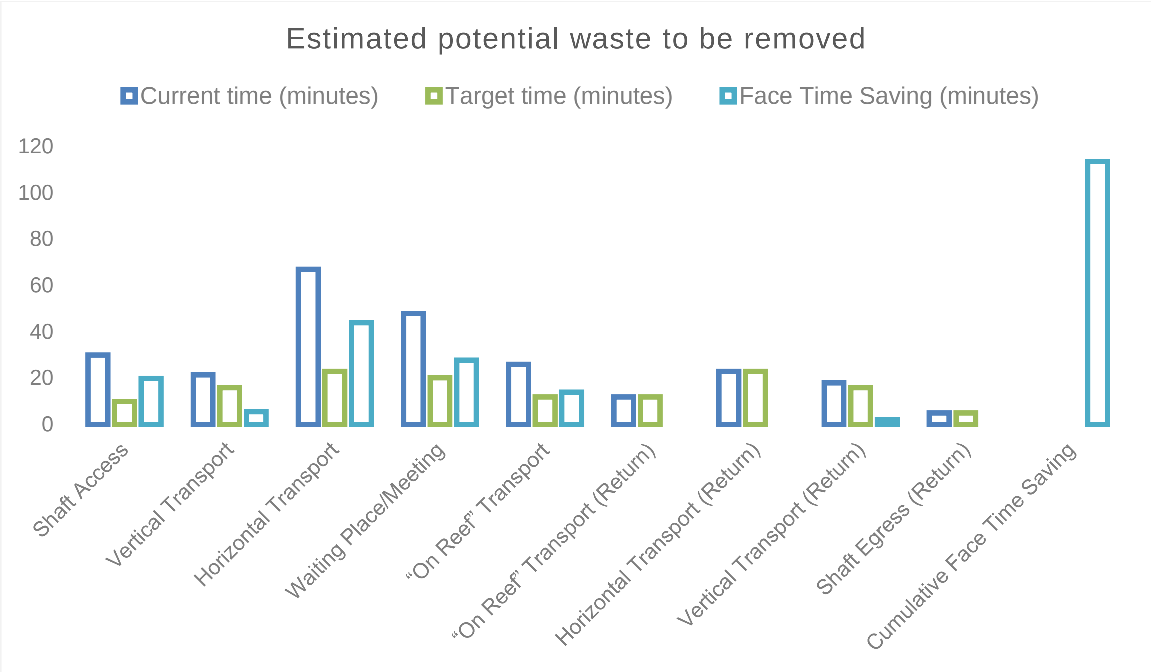


Figure 6.13: Estimated potential face time saving per process — primary metric of the Research Charter

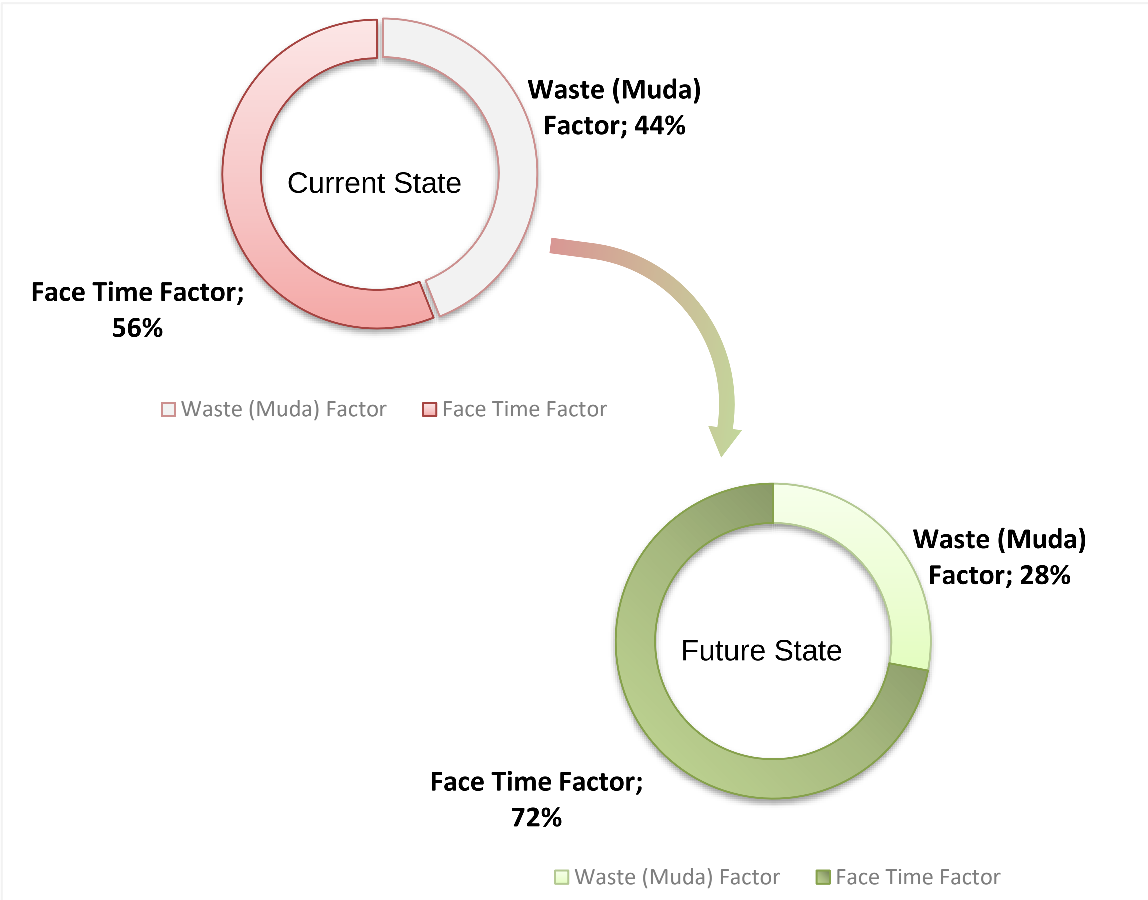


Figure 6.14: Pie chart of current and future-state face time factors — primary metric of the Research Charter

The Research Charter in Table 6.5, above, defines the key inputs and output requirements, as well as KPIs and performance metrics. The persons responsible for the research are defined in the table, together with the team leader, champion, and process owner. The present researcher was allocated the role of research champion in this case, and was responsible for achieving the research objectives. The team leader was accountable for the research and for successful execution and/or implementation of suggested improvements. As a holistic approach was taken in conducting the VSA of the logistics process, with numerous departments falling within the VSM, the mine (organisation) was deemed the owner of the process.

The problem and/or opportunity statement defines the overall purpose of the research. It was clearly stated that there is inadequate time available to conduct the core production activity (supporting and drilling) in destress and development ends of the mine. This results in inadequate blasting (rock breaking), and, hence, overall productivity is hampered. Primary metrics were defined, firstly, to determine current baseline performance, and, secondly, to set research outcome targets that are specific, measurable, attainable, and realistic. The three defined metrics are:

1. average time wasted, which is the sum of all travel-related activities;
2. average face time, which is the time available for primary production activities once average time wasted has been subtracted from total shift duration; and
3. the average face time factor, which is a unit less measure developed for this research. The face time factor is merely the percentage of time spent on the face (primary production activities) compared to the total shift duration, and is therefore a measure of logistical process efficiency. This factor is vital in conducting benchmarking studies of the logistical process efficiencies of similarly constrained mines, as indicated by Figure 3.1, as well as in quantifying personnel logistics performance.

The limitations and constraints of the logistics process are also defined in Table 6.5, above, as the shift cycle and blasting re-entry periods. The shift cycle defines the set working arrangements of mine employees through specific shift rosters and working hours. In the case of the 7-2; 7-5 cycle (seven days on – two days off; seven days on – five days off), the total shift duration of an employee may not exceed 9h30min underground (From Zone 1 back to bank). Blasting activities on the mine are conducted twice per day, at the end of night shift and at the end of day shift. This creates a constraint from this point onward, defined as the *re-entry period*. The re-entry period is when no person may enter an end that has been blasted for a period of one hour. This allows hazardous blasting fumes and dust to be cleared from the end by mine ventilation. The significance of this re-entry period can be seen further on in the paper, where the logistics processes are further defined through activity process flowcharting (discussed below).

The scope of the research is detailed in the above table. The purpose of the terms *in scope* and *out of scope* are used in determining where the research focus will be allocated when viewing the end-to-end VSM. Outside of the scope of research, as defined during the VSM process, is the activities of travelling to the mine, mine access, and surface activities prior to Zone 1. It is imperative that the expected benefits of the research are defined; in this case, the benefits are vast, and include the expected enhancement of financial aspects, morale, and overall productivity.

6.1.3.3 Documenting the process

With reference to the DMAIC process as described in Section 5.1.4.1, within the *Define* phase, the final step is the documentation of the key elements of the process being researched. According to Sye (2009:45), process documentation involves an improvement tool known as *activity flowcharting* or *process mapping*. Process mapping is the practice of identifying all process activities and arranging them in the correct sequence.

Sye (2009:181), lists the benefits of flowcharting as:

- identification of unexpected complexity;
- visualisation of non-value-adding steps in the process;
- identification of unplanned decision points in a process that alter its course and, hence, generate unwanted variation;
- improved understanding of the process, thereby making improvement opportunities more conspicuous;
- reveals how the process actually works, instead of how it is perceived to work; and
- identification of waste (*muda*), such as rework, bottlenecks, excessive waiting/queueing, motion, and transport.

The various forms of process mapping methodologies include macro-level, activity-level, and cross-functional flowcharting. A high-level or macro-level process flowchart of the logistics process of Twin Shaft was provided in the SIPOC model in Figure 6.9. This process flow diagram contains multiple functions and departments across which employees/personnel are transported. According to Sye (2009), a cross-functional flowchart is used to:

- identify hand-off/transfer points between people or functions (in this case, functions); and
- clarify individual roles and interdependencies.

In the VSM in Figure 6.12, it is shown that personnel are transferred from one functional area of transportation medium to another across the value stream. These transfer points may generate sources of waste in the process, and could also cause undesirable non-continuous process flow. In order to understand the personnel logistics process, both in detail and overall, cross-functional process mapping methodology was adopted in the present research, as it would provide research information identifying the greatest opportunities to mitigate process waste.

In Figure 6.15, below, there are five clear horizontal function lines, referred to as *swim lanes*. Each swim lane represents a separate function and/or department in the overall process. Oval-shaped activity icons represent the start and end steps in the process (end to end), and the rectangular activity icons represent further steps in the process. The diamond-shaped icons represent decision points, where the process's flow direction may change, depending on the outcome of the decision taken. Only one decision point was identified. The arrows depict the flow direction of the process from one activity step to another, in sequential order. An arrow crossing a swim lane is indicative of a change in functional area or department responsible for the process flow. The process flow map below may be considered cyclic in nature, as the flow of personnel is from surface to the face and back to surface. The entire process must be covered, as previously explained, within the agreed employee shift duration of 9h30min.

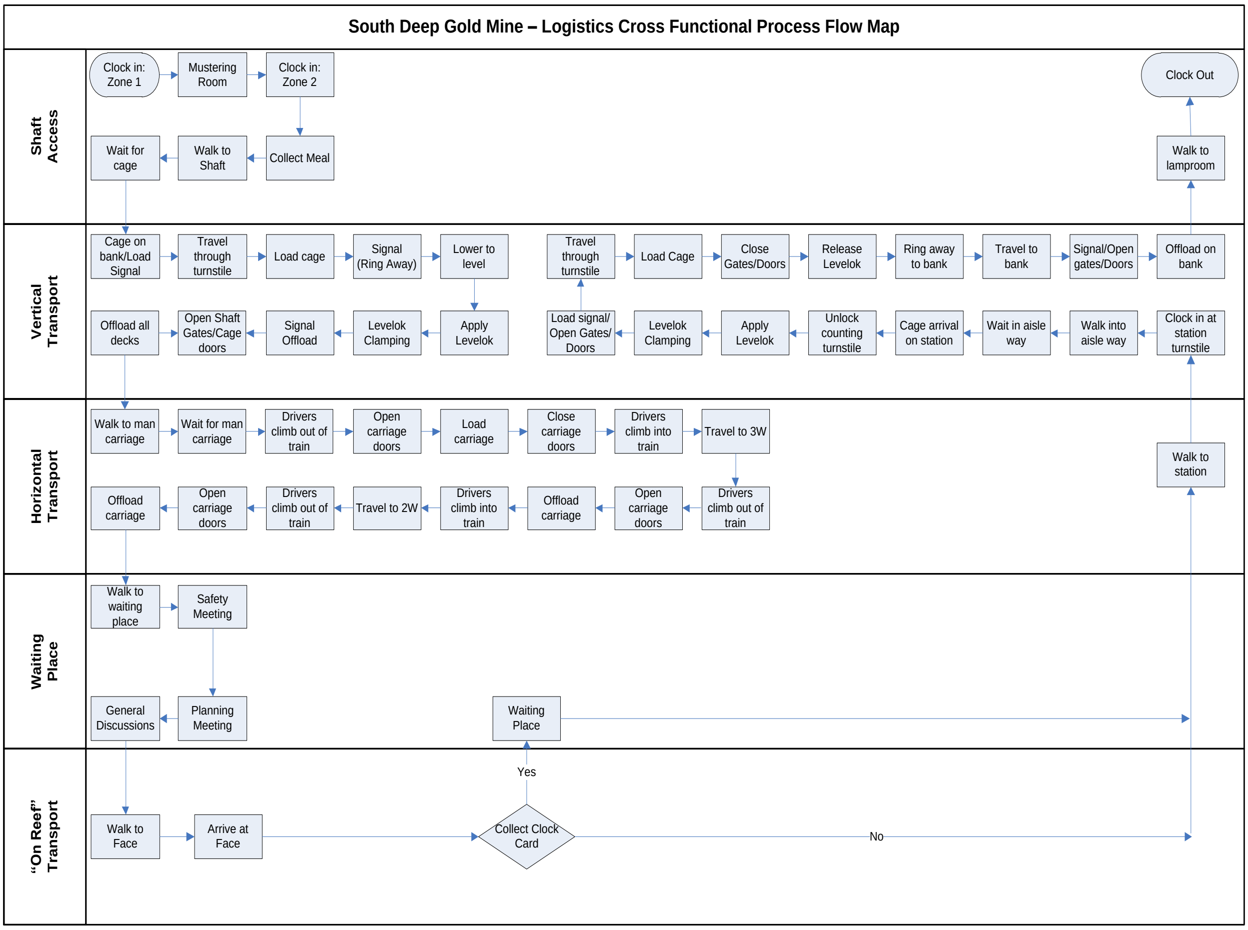


Figure 6.15: Process mapping — Twin Shaft personnel logistics process excluding cycle time data

It is imperative to note that the process flow map is that of the second cage being lowered down the mine shaft. The first cage being lowered was not considered for analysis, as it does not entail queueing/waiting activities. This is due to the fact that the first 180 personnel simply travel to the shaft and enter the cage, which is already waiting at the bank. However, with the second and remaining cage trips, personnel could wait for the cage to arrive at the bank area to load them. As queueing is a pure form of waste, it was desirable to identify all areas where it exists or could exist, and to quantify the magnitude of face time lost due to this queueing/waiting time.

With regard to the set function of shaft access, personnel clock in at Zone 1, which is a turnstile arrangement positioned immediately before the Mustering Room. At this point, shift duration (full potential face time) begins diminishing. A brief sit-down safety meeting is conducted in the Mustering Room; 15min is scheduled for this activity. Employees then move to the Zone 2 turnstile, clock, and immediately move to the meal-collection area. Two lines are formed to clock again and collect a mid-shift meal at the meal-collection counter (hatch). Personnel thereafter walk across the shaft access tunnel (approximately 50m) to the shaft bank area, and wait for their respective cages to arrive.

For the vertical transport process, personnel wait until the cage arrives at the bank level. The banksman gives signals to the winding engine driver, and then unlocks the shaft access gates and the cage sliding doors. Thereafter, the banksman unlocks all decks' loading turnstiles with the pre-set rotation number he or she had selected (89 per deck for the 2-deck cage and 60 per deck for the 3-deck). Personnel then travel through the turnstile and proceed to board the cage. This is typically termed the *cage loading process*. After loading, the banksman closes and locks the cage's sliding doors and the shaft access gates, the required signals are given, and the cage is then lowered to the scheduled level.

Upon arrival on the level, the onsetter positioned on the level will give the signal to the winding engine driver to stop the cage when it is perfectly aligned with the station level landing. The onsetter then activates the Levelok system to arrest the cage in position for unloading. To activate the Levelok system, the onsetter first unlocks and opens the shaft access gates and connects the system's pneumatic supply hose to the cage by means of a quick coupler (quick hitch). The Levelok system is installed on top of the cage roof, and consists of a pneumatically driven hydraulic pump (power pack) that drives the cage's arresting clamps. The clamps approach the guides (rails) upon which the cage runs, until contact is made. The hydraulic positive displacement pump then begins to extend cylinders, which force the clamp shoes onto the guides. This clamping force is exerted perpendicular to the guides until the specified system pressure is achieved. This specified system pressure relates to the required clamping force to hold steady a fully laden cage (13 500kg) whilst being loaded or offloaded. Once the clamping pressure is achieved, the red indication light turns green, and the winder brakes are interlocked with the Levelok clamps, so that the winder drum cannot be moved accidentally or purposefully by the winding engine driver. The onsetter then gives the required signals to the winding engine driver to offload the cage, unlocks and opens the cage sliding doors on all decks, and personnel are offloaded, completely isolated from the obvious hazards presented by elastic rope stretch. Elastic rope stretch in excess of 3m is possible at the lowest levels. Once all personnel have been offloaded, they walk to the man carriage loading/offloading bay area, where the next travel process, horizontal transport, is initiated.

From observation data collected, the second and remaining cages travelling underground all wait substantial periods for the man carriage (train) to arrive at the loading bay area. A portion of the personnel then proceed to their working places by walking. Another concerning observation regarding the first cage arriving on the station was that a portion of the personnel tend to walk to their working places anyway, despite a train being available and waiting for personnel to transport. The portions of personnel using the second and remaining cages wait for the carriage to arrive at the loading bay. Upon arrival, the locomotive drivers alight from their units, walk toward the man carriages coupled in the train, and begin opening the doors of the 4-man carriages. Personnel are then loaded into the man carriages; the drivers close the doors and lock them once the train is loaded to capacity or all available personnel are loaded inside. The train then travels to the first offloading bay, where drivers stop, climb off, unlock the doors, and offload the train. All personnel working in this area are offloaded; the drivers then close and lock the doors once more, and proceed back to their units to travel to the final offloading point, where the same process is followed to offload the final passengers.

Personnel then walk to their waiting places, where they are seated and wait for the full crew and supervisors to arrive. Personnel also arrive at the waiting place on foot, which results in time spent waiting for crew members to arrive. Once the full teams are assembled, the supervisor initiates the safety meeting, planning meeting, working place safety declaration, and general discussions, the extent of which is dependent on the overall morale and discipline of the crew. The general discussions may be viewed as a non-value-adding process when considering the primary metrics of this research. Although the resolution of problems and motivational discussions do form an integral part of the supervisor's function, it is clear that these discussions must be minimised and dealt with upon arrival on surface or prior to the shift, as far as possible.

On-reef transport encompasses all personnel movement from the waiting place to the respective working places, namely development ends, destress areas, longhole stopes, tipping points, and haulages/ramps (the face), where primary production activities take place. Through observation, it was established that the primary mode of movement from the waiting places to the working face was walking. Once personnel arrive at their respective working places, actual face time activities are initiated. After conducting their production activities for the shift, personnel begin the return route, back to the shaft, in order to egress from the mine. Personnel walk back from the face, either to the waiting place to collect their clock cards from their miner or supervisor, who retains all clock cards of persons working in his/her section, or directly back to the station. In travelling back to the station, personnel walk, and do not use a man carriage. Upon arrival at the respective station areas, personnel sit down and wait for the cage to arrive. The first turnstile on the station area is zoned; therefore, personnel must clock to enter into an aisle way, where a predefined number of personnel will wait for the cage to arrive. Should an employee attempt to access the zoned turnstile earlier than the scheduled time for his or her cage, the turnstile will not unlock. Once the aisle way is full, the remaining personnel wait on the station area and sit on the benches provided. Once the cage arrives, the onsetter applies the Levelok, rings the required signals, and then unlocks the counting turnstile, allowing 180 persons to pass through. All personnel must travel through this single turnstile and then climb the stairs of the top- and middle-deck station landings to access the respective decks of the cage, whilst the remaining personnel are loaded into the bottom deck of the cage, which is aligned with the station. Once the cage is fully loaded, the onsetter closes the shaft gates and cage doors, and then releases the Levelok clamps. The onsetter then rings the cage away to surface.

Once the cage arrives on surface, the winding engine driver gives signals to offload the cage, and the banksman responds, unlocking and opening the shaft gates and cage sliding doors to allow personnel to be offloaded. Employees travel directly to the Lamp Room from the shaft area and clock out from underground. This completes their working shift for the day, and they then proceed conducting all surface activities in preparation for leaving the mine. These activities are not considered part of the employees' shift duration.

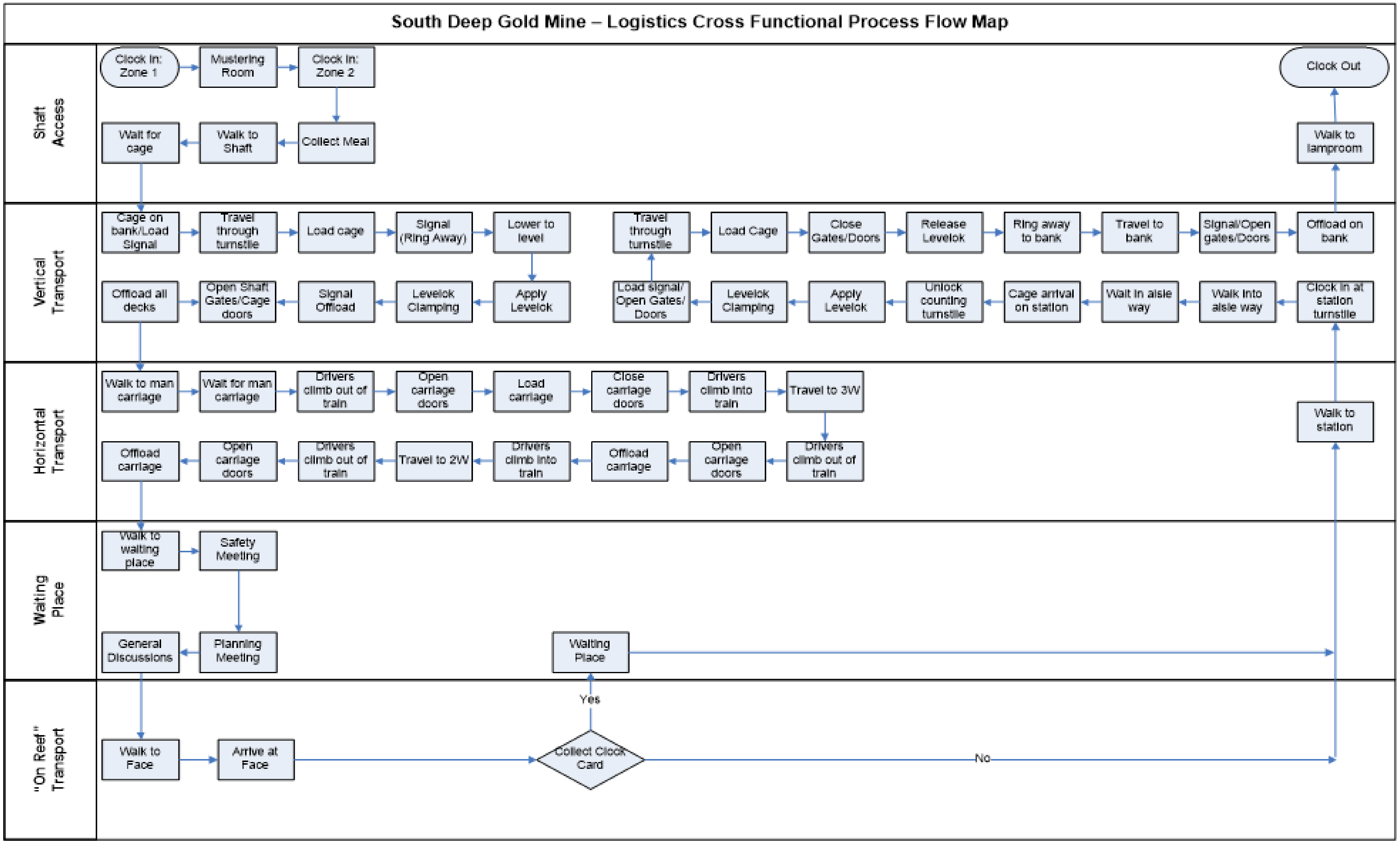


Figure 6.15: Process mapping — Twin Shaft personnel logistics process excluding cycle time data

6.1.4 *Measure* — maximising face time (quantification section)

6.1.4.1 Collect data and measure baseline performance

In the *Measure* phase of the DMAIC process, the conventional Six Sigma approach requires an extensive plan for data collection and the validation of the measurement system prior to conducting data collection and measuring/establishing baseline performance. Sye (2009:327), in comparing Six Sigma with Lean, introduced the concept of process analysis, rather than data analysis, describing it as follows:

> *In the process of identifying the greatest causes of variation in the quality of an end product or service, Six Sigma focuses on data analysis. Lean on the other hand tends to focus more on process analysis than data analysis. The goal is ultimately to identify the greatest opportunities for minimising or even eliminating waste from the process itself.*

As Research Objective 1 was focused on process efficiency improvement, the research was mainly focused on Lean principles.

After completion of the current-state logistics process flow map, shown in Figure 6.15, above, the *Measure* phase was initiated. Determining the process's baseline efficiency or current performance required inclusion of detailed process information. As the primary metric associated with Research Objective 1 was concerned primarily with the notion of time, the current logistics process map required collection of cycle time data. As described earlier, cycle time data were collected through physical time–motion studies of the end-to-end process, and converted into average times per process activity or process step. The time data were collated (see Table 6.6, below), and utilised in the following step of the process — establishing baseline performance. The identification of value-adding time in the logistics process was then completed by means of a time value analysis, prior to calculating total lead times and process cycle efficiency.

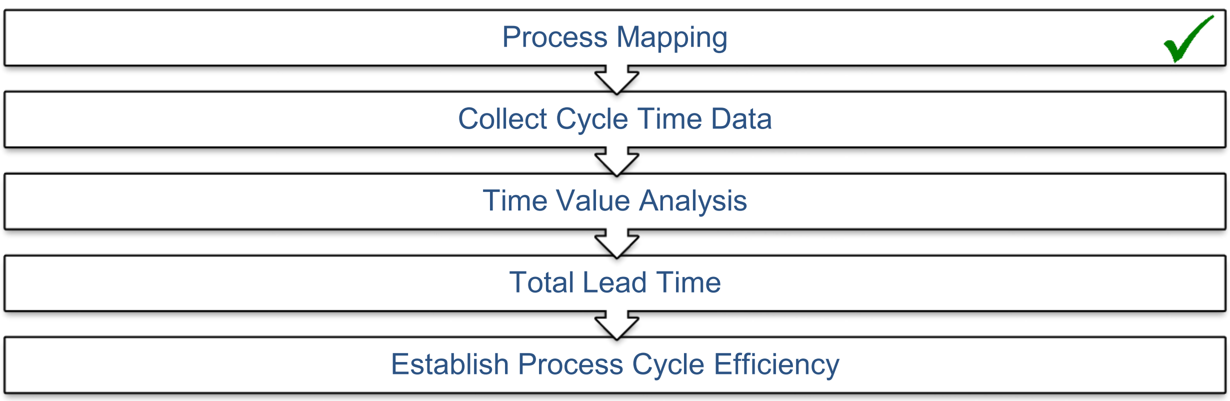


Figure 6.16: *Measure* phase — establishing baseline performance

6.1.4.1.1 Collect cycle time data

The table below contains all cycle time data for each activity step in the personnel logistics process. The data collection methodology implemented, as discussed earlier, was physical observation of the process and recording time–motion data. The log sheets and tally sheets utilised in collecting the process data were collated, and the average cycle times were calculated for every activity step.

Table 6.6: Twin Shaft personnel logistics — cycle time data sheet

Process sequence no.	Functional area	Functional area No.	Process step code	Process step name	Ave. cycle time
1	**Shaft access (in)**	1	1.1	Clock in: Zone 1	0:00:04
2			1.2	Mustering Room	0:15:00
3			1.3	Clock in: Zone 2	0:00:04
4			1.4	Collect meal	0:11:00
5			1.5	Walk to shaft	0:02:00
6			1.6	Wait for cage	0:02:00
7	**Vertical transport (down)**	2	2.1	Cage on bank/open gates/doors	0:00:29
8			2.1.1	Offload all decks	0:01:17
9			2.2	Travel through turnstile	0:00:04
10			2.2.1	Close and open gates	0:00:29
11			2.3	Load cage	0:04:18
12			2.3.1	Close door and gates	0:00:17
13			2.4	Signal (ring away)	0:00:20
14			2.4.1	Cage departs	0:00:40
15			2.5	Lower to level	0:05:00
16			2.6	Apply Levelok	0:00:40
17			2.7	Levelok clamping	0:01:22
18			2.8	Signal offload	0:00:02
19			2.9	Open shaft and cage doors	0:00:12
20			2.10	Offload all decks	0:02:17
21	**Horizontal transport (in)**	3	3.1	Walk to man carriage	0:02:00
22			3.2	Wait for man carriage	0:38:00
23			3.3	Drivers deboard train	0:00:35
24			3.4	Open carriage doors	0:00:15
25			3.5	Load carriage	0:06:15
26			3.6	Close carriage doors	0:00:15
27			3.7	Drivers board train	0:00:40
28			3.8	Travel to Three West (3W)	0:13:00
29			3.9	Drivers deboard train	0:00:35
30			3.10	Open carriage doors	0:00:15
31			3.11	Offload carriage	0:02:00
32			3.12	Drivers board train	0:00:40
33			3.13	Travel to two west (2W)	0:02:00
34			3.14	Driver deboard train	0:00:35
35			3.15	Open carriage doors	0:00:15

36			3.16	Offload carriages	0:02:00
37	**Waiting place**	4	4.1	Walk to waiting place	0:18:40
38			4.1.1	Wait for crew	0:18:50
39			4.2	Safety meeting	0:10:00
40			4.3	Planning meeting	0:10:00
41			4.4	General discussions	0:19:00
42	**On-reef transport (in and out)**	5	5.1	Walk to face	0:26:00
43			5.2	Arrive at face/work	0:00:00
44			5.3	Travel to waiting place	0:09:00
45			5.4	Collect clock card	0:12:00
46	**Horizontal (out)**	6	6.1	Walk to station	0:20:10
48	**Vertical Transport (up)**	7	7.1	Clock in at station turnstile	0:00:08
49			7.2	Walk into aisle way	0:00:30
50			7.3	Wait in aisle way	0:01:00
51			7.4	Cage arrival on station	0:00:05
52			7.5	Unlock counting turnstile	0:00:09
53			7.6	Apply Levelok	0:00:40
54			7.7	Levelok clamping	0:01:22
55			7.8	Load signal/Open gates, doors	0:00:12
56			7.9	Travel through turnstile	0:00:04
57			7.10	Load cage	0:07:49
58			7.11	Close gates, doors	0:00:15
59			7.12	Release Levelok	0:01:03
60			7.13	Ring away to bank	0:00:27
61			7.13.1	Cage departs	0:00:32
62			7.14	Travel to bank	0:05:00
63			7.15	Signal/Open doors, gates	0:00:29
64			7.16	Offload on bank	0:02:17
65	**Shaft access (out)**	8	8.1	Walk to lamp room	0:02:00
66			8.2	Clock out at turnstile (security search)	0:02:00
Totals	hours: minutes: seconds				4:46:35
	minutes: seconds				286min35sec
Actual Face Time	**Verified post-cycle time data collection process**				**50.26%**

As illustrated in Table 6.6, above, there were 66 sequential process steps in the overall personnel logistics process. Eight functional areas were delineated where cross-functional activities occur, and each activity/process step was assigned a process step code to simplify referencing. The sum of all process-step times in the end-to-end process amounted to 4h46sec. The face time determined through the value stream analysis process had been 56%. Using process mapping and cycle time data, the actual average face time was found to be 6% less — 50.26%. The cross-functional process flow diagram uncovered unidentified steps in the overall process, as well as additional forms of waste. The time magnitude of each process step was determined and further opportunities to eliminate or minimise waste in the process were identified.

In Lean and Six Sigma methodology, it is imperative to determine whether process steps are important, and to consider the processes in terms of value add for the customer. For the purposes of Twin Shaft's personnel logistics process, by using the SIPOC Model, the mine's customer/s had been defined as primarily the employer and secondarily the employee. In order to proceed with the process of establishing baseline performance (per Figure 6.16, above), a time value analysis of the process was conducted.

6.1.4.1.2 Detailed time value analysis

As noted, when defining time in a process in terms of value (value-adding (VA), value-enabling (VE), or non-value adding (NVA), the value is considered from the point of view of the customer.

Table 6.7: Twin Shaft personnel logistics — time value analysis (full working day)

The time value analysis when considering the overall personnel logistics cycle, including actual time spent on the face, is demonstrated below. The entire working day or full shift duration of the employee was considered (9h30 min). When considering the position of the customer, in this case the employer, the only VA time in the cycle is time spent on primary production activities. As can be seen in the final row of the table, the VA time (face time) was 49.7% of the total shift duration, VE time was 15.5%, and the total NVA accounted for the remaining 34.7%. It would be highly desirable for the employer that this NVA time be reduced or converted to VA time.

Process step code	Process step name	Time	VA	VE	Non-value-adding						
					D	I	M	T	O	W	N
1.1	Clock in: Zone 1	0:00:04									
1.2	Mustering Room	0:15:00									
1.3	Clock in: Zone 2	0:00:04									
1.4	Collect meal	0:11:00									
1.5	Walk to shaft	0:02:00									
1.6	Wait for cage	0:02:00									
2.1	Cage on bank/Open gates, doors	0:00:29									
2.1.1	Offload all decks	0:01:17									
2.2	Travel through turnstile	0:00:04									
2.2.1	Close and open gates	0:00:29									
2.3	Load cage	0:04:18									
2.3.1	Close door and gates	0:00:17									
2.4	Signal (ring away)	0:00:20									
2.4.1	Cage departs	0:00:40									

2.5	Lower to level	0:05:00
2.6	Apply Levelok	0:00:40
2.7	Levelok clamping	0:01:22
2.8	Signal offload	0:00:02
2.9	Open shaft and cage doors	0:00:12
2.10	Offload all decks	0:02:17
3.1	Walk to man carriage	0:02:00
3.2	Wait for man carriage	0:38:00
3.3	Drivers deboard train	0:00:35
3.4	Open carriage doors	0:00:15
3.5	Load carriage	0:06:15
3.6	Close carriage doors	0:00:15
3.7	Drivers board train	0:00:40
3.8	Travel to Three West	0:13:00
3.9	Drivers deboard train	0:00:35
3.10	Open carriage doors	0:00:15
3.11	Offload carriage	0:02:00
3.12	Drivers board train	0:00:40
3.13	Travel to Two West	0:02:00
3.14	Driver deboard train	0:00:35
3.15	Open carriage doors	0:00:15
3.16	Offload carriages	0:02:00
4.1	Walk to waiting place	0:18:40
4.1.1	Wait for crew	0:18:50
4.2	Safety meeting	0:10:00
4.3	Planning meeting	0:10:00
4.4	General discussions	0:19:00
5.1	Walk to face	0:26:00
5.2	Arrive at face/work	4:43:25
5.3	Travel to waiting place	0:09:00
5.4	Collect clock card	0:12:00
6.1	Walk to station	0:20:10
7.1	Clock in at station turnstile	0:00:08
7.2	Walk into aisle way	0:00:30
7.3	Wait in aisle way	0:01:00
7.4	Cage arrival on station	0:00:05
7.5	Unlock counting turnstile	0:00:09
7.6	Apply Levelok	0:00:40
7.7	Levelok clamping	0:01:22
7.8	Load Signal/Open Gates/Doors	0:00:12
7.9	Travel through turnstile	0:00:04
7.10	Load cage	0:07:49
7.11	Close gates, doors	0:00:15
7.12	Release Levelok	0:01:03

7.13	Ring away to bank	0:00:27									
7.13.1	Cage departs	0:00:32									
7.14	Travel to bank	0:05:00									
7.15	Signal/Open doors, gates	0:00:29									
7.16	Offload on bank	0:02:17									
8.1	Walk to lamp room	0:02:00									
8.2	Clock out at turnstile (security search)	0:02:00									
Total time		**9:30:00**									
Time			4:43:25	1:28:25			1:09:28			1:23:38	0:45:04
% of time			49.7	15.5	0	0	12.2	0	0	14.7	7.91

The table below demonstrates the time value analysis in considering the personnel logistics cycle only, excluding actual working time. In other words, had the personnel logistics process itself been the core business of the mine, certain process steps/activities would have been considered fully VA. As indicated in process step code numbers 2.5, 3.8, 3.13, 7.14, these process steps involve pure linear travel/transport, and although in pure Lean thinking terms would definitely be considered waste (*muda*), the logistics process is imperative as, without it, employees would be unable to perform VA activities. Both customers, the employer and employee, would certainly be concerned in the event that personnel could not be transported, and would definitely pay for these steps, as these add value in the overall process of the mine.

The overall cycle time of the personnel logistics process was determined to be 4h46min (4:46:35 exactly), where VA time, VE time, and NVA time were expressed as a percentage of the total cycle time. The magnitudes of the VA time, VE time, and NVA time were determined, and the NVA time was then further sub-categorised into the seven forms of waste (DIMTOWN). Defects, excess inventory, excess transport, and over-production were not considered. The main NVA activities fell into the waste sub-categories of excess motion, waiting/queueing, and NVA processing. Optimisation efforts could now be focussed on these activities.

VE activities were defined and allocated according to the criteria previously stipulated; these are either mandatory under mining legislation or in place to ensure conformance to mine standard operating procedures and codes of practice developed in line with the mine risk management processes. An example is process step Code 2.8, Signal and offload cage. The signalling arrangements in all South African mine shafts where winders are in use are governed and legislated by the Mine Health and Safety Act 29 of 1996. The Minerals Act 50 of 1991, in force in terms of Item 4 of Schedule 4, regulates signalling between winding engine drivers, onsetters, and banksmen, as well as the signals being rung. Therefore, this process step is compulsory.

This further highlights the importance of involving the persons directly involved with a particular process in applying the DMAIC Model. Identifying VA-, VE-, and NVA-time steps in a process could be conducted incorrectly, and critical VA and VE steps could be removed in an attempt to optimise or remove steps misunderstood to be a form of waste, with catastrophic consequences for the customer.

Table 6.8: Twin Shaft personnel logistics — time value analysis (personnel logistics)

Process step code	Process step name	Time	VA	VE	Non-value-adding						
					D	I	M	T	O	W	N
1.1	Clock in: Zone 1	0:00:04									■
1.2	Mustering Room	0:15:00									■
1.3	Clock in: Zone 2	0:00:04		■							
1.4	Collect meal	0:11:00									■
1.5	Walk to shaft	0:02:00					■				
1.6	Wait for cage	0:02:00								■	
2.1	Cage on bank/Open gates, doors	0:00:29		■							
2.1.1	Offload all decks	0:01:17								■	
2.2	Travel through turnstile	0:00:04					■				
2.2.1	Close and open gates	0:00:29								■	
2.3	Load cage	0:04:18								■	
2.3.1	Close door and gates	0:00:17		■							
2.4	Signal (ring away)	0:00:20								■	
2.4.1	Cage departs	0:00:40		■							
2.5	Lower to level	0:05:00	■								
2.6	Apply Levelok	0:00:40								■	
2.7	Levelok clamping	0:01:22								■	
2.8	Signal offload	0:00:02		■							
2.9	Open shaft and cage doors	0:00:12		■							
2.10	Offload all decks	0:02:17		■							
3.1	Walk to man carriage	0:02:00					■				
3.2	Wait for man carriage	0:38:00								■	
3.3	Drivers deboard train	0:00:35		■							
3.4	Open carriage doors	0:00:15		■							
3.5	Load carriage	0:06:15		■							
3.6	Close carriage doors	0:00:15		■							
3.7	Drivers board train	0:00:40		■							
3.8	Travel to Three West	0:13:00	■								
3.9	Drivers deboard train	0:00:35								■	

3.10	Open carriage doors	0:00:15									
3.11	Offload carriage	0:02:00									
3.12	Drivers board train	0:00:40									
3.13	Travel to Two West	0:02:00									
3.14	Driver deboard train	0:00:35									
3.15	Open carriage doors	0:00:15									
3.16	Offload carriages	0:02:00									
4.1	Walk to waiting place	0:18:40									
4.1.1	Wait for crew	0:18:50									
4.2	Safety meeting	0:10:00									
4.3	Planning meeting	0:10:00									
4.4	General discussions	0:19:00									
5.1	Walk to face	0:26:00									
5.2	Arrive at face (Milestone No. duration)	0:00:00									
5.3	Travel to waiting place	0:09:00									
5.4	Collect clock card	0:12:00									
6.1	Walk to station	0:20:10									
7.1	Clock in at station turnstile	0:00:08									
7.2	Walk into aisle way	0:00:30									
7.3	Wait in aisle way	0:01:00									
7.4	Cage arrival on station	0:00:05									
7.5	Unlock counting turnstile	0:00:09									
7.6	Apply Levelok	0:00:40									
7.7	Levelok clamping	0:01:22									
7.8	Load signal/Open gates, doors	0:00:12									
7.9	Travel through turnstile	0:00:04									
7.10	Load cage	0:07:49									
7.11	Close gates, doors	0:00:15									
7.12	Release Levelok	0:01:03									
7.13	Ring away to bank	0:00:27									
7.13.1	Cage departs	0:00:32									
7.14	Travel to bank	0:05:00									
7.15	Signal/Open doors, gates	0:00:29									
7.16	Offload on bank	0:02:17									
8.1	Walk to Lamp Room	0:02:00									
8.2	Clock out at turnstile (security search)	0:02:00									
Total time		**4:46:35**									
Time			0:25:00	1:03:25			1:09:28			1:23:38	0:45:04
% of time			**8.72**	**22.1**			**24.2**			**29.2**	**15.7**

As shown in Table 6.8, above, the VA, VE, and NVA time percentages of total time were 8.72%, 22.1%, and 69.15% respectively. It was therefore clear that the personnel logistics process was highly inefficient and urgently required optimisation in order to maximise face time. The table below lists all the NVA activities that required process simplification during the *Analyse* phase of the DMAIC process, which was the next phase.

Table 6.9: Total shift duration vs logistics cycle only (NVA time)

<table>
<tr><th>Process step code</th><th colspan="4">Non-value-adding steps</th><th colspan="2">Time</th></tr>
<tr><td>1.1</td><td colspan="4">Clock in: Zone 1</td><td colspan="2">0:00:04</td></tr>
<tr><td>1.2</td><td colspan="4">Mustering Room</td><td colspan="2">0:15:00</td></tr>
<tr><td>1.4</td><td colspan="4">Collect meal</td><td colspan="2">0:11:00</td></tr>
<tr><td>1.5</td><td colspan="4">Walk to shaft</td><td colspan="2">0:02:00</td></tr>
<tr><td>1.6</td><td colspan="4">Wait for cage</td><td colspan="2">0:02:00</td></tr>
<tr><td>2.1.1</td><td colspan="4">Offload all decks</td><td colspan="2">0:01:17</td></tr>
<tr><td>2.2</td><td colspan="4">Travel through turnstile</td><td colspan="2">0:00:04</td></tr>
<tr><td>2.2.1</td><td colspan="4">Close and open gates</td><td colspan="2">0:00:29</td></tr>
<tr><td>2.3</td><td colspan="4">Load cage</td><td colspan="2">0:04:18</td></tr>
<tr><td>2.4</td><td colspan="4">Signal (ring away)</td><td colspan="2">0:00:20</td></tr>
<tr><td>2.6</td><td colspan="4">Apply Levelok</td><td colspan="2">0:00:40</td></tr>
<tr><td>2.7</td><td colspan="4">Levelok clamping</td><td colspan="2">0:01:22</td></tr>
<tr><td>3.1</td><td colspan="4">Walk to man carriage</td><td colspan="2">0:02:00</td></tr>
<tr><td>3.2</td><td colspan="4">Wait for man carriage</td><td colspan="2">0:38:00</td></tr>
<tr><td>3.9</td><td colspan="4">Drivers deboard train</td><td colspan="2">0:00:35</td></tr>
<tr><td>3.10</td><td colspan="4">Open carriage doors</td><td colspan="2">0:00:15</td></tr>
<tr><td>3.11</td><td colspan="4">Offload carriage</td><td colspan="2">0:02:00</td></tr>
<tr><td>3.12</td><td colspan="4">Drivers board train</td><td colspan="2">0:00:40</td></tr>
<tr><td>4.1</td><td colspan="4">Walk to waiting place</td><td colspan="2">0:18:40</td></tr>
<tr><td>4.1.1</td><td colspan="4">Wait for crew</td><td colspan="2">0:18:50</td></tr>
<tr><td>4.4</td><td colspan="4">General discussions</td><td colspan="2">0:19:00</td></tr>
<tr><td>5.1</td><td colspan="4">Walk to face</td><td colspan="2">0:26:00</td></tr>
<tr><td>6.1</td><td colspan="4">Walk to station</td><td colspan="2">0:20:10</td></tr>
<tr><td>7.2</td><td colspan="4">Walk into aisle way</td><td colspan="2">0:00:30</td></tr>
<tr><td>7.3</td><td colspan="4">Wait in aisle way</td><td colspan="2">0:01:00</td></tr>
<tr><td>7.6</td><td colspan="4">Apply Levelok</td><td colspan="2">0:00:40</td></tr>
<tr><td>7.7</td><td colspan="4">Levelok clamping</td><td colspan="2">0:01:22</td></tr>
<tr><td>7.9</td><td colspan="4">Travel through turnstile</td><td colspan="2">0:00:04</td></tr>
<tr><td>7.10</td><td colspan="4">Load cage</td><td colspan="2">0:07:49</td></tr>
<tr><td>7.12</td><td colspan="4">Release Levelok</td><td colspan="2">0:01:03</td></tr>
<tr><td>7.13</td><td colspan="4">Ring away to bank</td><td colspan="2">0:00:27</td></tr>
<tr><td>7.13.1</td><td colspan="4">Cage departs</td><td colspan="2">0:00:32</td></tr>
<tr><td>Total shift duration</td><td rowspan="2">Total time</td><td>9h30min</td><td rowspan="2">NVA time</td><td>3h18min</td><td rowspan="2">% Total time</td><td>34.77%</td></tr>
<tr><td>Logistics cycle only</td><td>4h46min</td><td>3h18min</td><td>69.15%</td></tr>
</table>

6.1.4.1.3 Total lead time and process cycle efficiency

In order to determine the efficiency of the personnel logistics process, the total lead time of the process had to be known. To achieve this, Little's Law (Little, 2011:536) for queuing systems was applied, where:

> *…the average number of items in a queuing system, denoted L, equals the average arrival rate of items to the system, λ, multiplied by the average waiting time of an item in the system, W. Thus, L= λ W.*

The criteria that must be in place in order to utilise this theorem is that the system must be stable, and the system must not be in the initial start-up phase or in the shutdown phase. Through the analysis of the personnel logistics process, all criteria were met and the theorem was used to calculate total lead time (TLT) as follows:

$$TLT = \frac{WIP}{Ave.\ Rate}$$

where

- TLT: total lead time (total time to meeting the customer demand, as defined by the supplier);
- WIP: work in progress (units partially completed/through the process); and
- Ave. rate: average rate of completion (number of units passing through the process per unit time).

In the case of the personnel logistics process flow diagram (Figure 6.15), the second cage trip down was considered, and the cycle depicts the movement of a single person in the second cage, going down. The total number of persons passing through the process flow diagram within the defined period of time (cycle time) was approximately 180 persons, based on the capacity of the cage (conveyance), as illustrated in Figure 6.3. Therefore, the total number of persons passing through a single cycle of the process was 180 persons with a set shift duration of 9h30min. The total cycle time of the logistics end-to-end process was indicated in Table 6.6 as approximately 4h46min, which was 50.2% of the total shift duration. The work in progress (WIP) was therefore equal to 180 persons within a single process cycle (end to end) at any one time. The average completion rate was 180 persons through the end-to-end process in a total cycle time of 4h46 minutes (286min35 sec, exactly), which amounted to 0.628 persons per minute:

$$TLT = \frac{WIP}{Ave.\ Rate}$$

$$TLT = \frac{180}{0.628}$$

$$\underline{TLT = 286.5\ minutes}$$

The TLT of the process was 286.5min or 4h46 min to get the entire work in progress (persons) through one defined end-to-end personnel logistics process. When determining PCE for the purpose of finalising the process of establishing baseline performance per the DMAIC Model's Step 9, the TLT and VA time are required.

Process cycle efficiency (PCE)

The purpose of calculating the personnel logistics PCE is to determine the baseline performance of the current-state process. In the *Analyse* and *Improve* phases of the DMAIC process, a benchmark value of the original process is imperative in quantifying the magnitude of overall success after improvements. The PCE is described by Sye (2009:118) as a measure of the overall health of a process, determined by calculation. The calculation yields a percentage efficiency value based on a ratio of two factors, namely VA and TLT, expressed as follows:

$$PCE = VA/TLT$$

where

- PCE: process cycle efficiency (a measure of overall process health);
- TLT: total lead time (total time to meet the customer demand, as defined by the supplier); and
- VA: value-adding time (from the customer's viewpoint).

The PCE of the personnel logistics end-to-end process shown in Figure 6.15 was calculated as follows:

$$PCE = \frac{VA}{TLT}$$

$$PCE = \frac{25}{286.5}$$

$$PCE = 0.0873\ as\ a\ factor$$

$PCE = 0.0873 \, x \, 100$

$PCE = 8.73\% \, as \, a \, percentage$

Sye (2009:18) postulates that PCE values in excess of 25% are considered world-class processes. The Twin Shaft personnel logistics process had a PCE of approximately 9%. Clearly, improving the PCE of this process would increase profitability. This would require greater average face time and decreased average travelling times (waste). The formula for improving PCE is therefore:

$$PCE \propto VA \infty \frac{1}{TLT}$$

As PCE is directly proportional to VA time and inversely proportional to TLT, the strategic approach in the *Analyse* and *Improve* phases to follow would be to increase VA time and/or to reduce TLT in the process. Table 6.9 indicates the strategies implemented to eliminate or mitigate waste. If Twin Shaft's personnel logistics process could be increased to over 25%, it would, in industry norms, be considered a lean process.

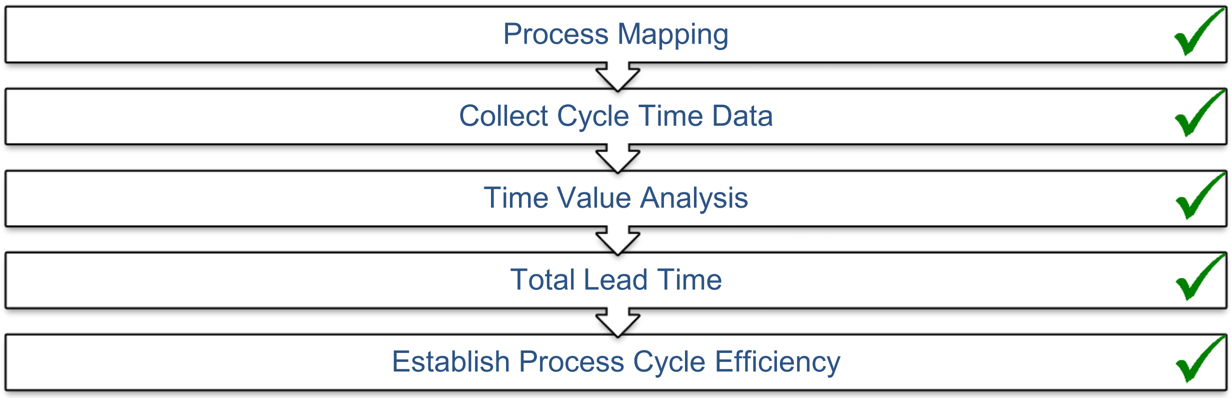


Figure 6.17: *Measure* phase — establishing baseline performance — complete

6.1.5 *Analyse* — Maximising face time (Quantification section)

6.1.5.1 Analysis of process flow chart

Figure 6.18, below, represents the complete cross-functional process flow diagram, including analysis of activities with regard to value add and PCE. The colour scheme demonstrates which activities were deemed VA (green), VE (yellow), and NVA (red). This visual representation of the process provided immediate insight into the process with regard to waste and inefficiencies, guiding decision-making with regard to optimisation efforts.

The PCE is indicated on the flow chart, along with the other critical cycle metric, TLT. It is of primary concern that the TLT of the logistics process itself be reduced as much as possible, thereby automatically converting the time reduced into additional face time, with the intention of maximising the primary metric of the first research objective, the face time efficiency factor.

Potential face time savings initially estimated during the formulation of the Research Charter (Figure 6.13) were determined by the difference between current and target lead times for each macro-level process. The current and target lead times are tabulated below; target time can be considered the customer's demand/requirement. Table 6.10 indicates the current and estimated target lead times set while developing the Research Charter.

Table 6.10: Current and target macro-level process lead times

Process	Current estimated time (min)	Estimated target time (min)
Shaft access	30	10
Vertical transport	21.5	15.91
Horizontal transport	67	23
Waiting place/Meeting	48	20.16
On-reef transport	26	12
On-reef transport (return)	12	12
Horizontal transport (return)	23	23
Vertical transport (return)	18	15.91
Shaft egress (return)	5	5

NVA activities must be minimised or eliminated. In order to prioritise these waste activities for selection during the *Improve* phase of the DMAIC Model, the following selection criteria were decided upon:

- Ease of solution implementation; and
- Impact on face time improvement.

This is discussed in more detail in the discussion on identifying the greatest opportunities for efficiency improvement in Section 6.1.5.3. However, prior to improvement, it is imperative that any potential process constraints such as bottlenecks time traps be identified, in order to correctly focus optimisation efforts during the *Improve* phase of the DMAIC Model.

6.1.5.2 Analyse process performance and identify bottleneck and/or time traps

At this point, the process was analysed by means of Takt time charting, a constraints analysis methodology, which entailed plotting the time rates taken to complete each process step and then comparing these time rates to the actual rate of production necessary to meet customer demand.

The Takt time formula used to determine the customer demand time per unit was:

$$Takt\ time = \frac{Net\ operating\ time\ per\ cycle}{Customer\ demand\ per\ cycle}$$

The cumulative potential time savings estimated during the development of the Research Charter was a 90min reduction of the logistics process's TLT. The actual cycle time data, as indicated at the bottom of Table 6.8, shows that the overall logistics cycle was completed in 4h46 minutes (286.5min). This was actual TLT, not the customer demand time. Customer demand time is the difference between the current TLT of the process and the cumulative face time saving as stipulated in the Research Charter.

Therefore:

Customer demand time (minutes) = TLT – Cumulative face time saving

= 286.5 – 90

<u>= 196.5 minutes</u>

The estimated cumulative face time saving can be confirmed by comparing the TLT of the logistics process with the overall NVA time (waste) in the process shown in Table 6.9.

The overall NVA time of the process amounted to 3h18 minutes (198min). This NVA time was approximately 69% of the overall logistics process. A reduction of 90min from the 198 min was therefore deemed possible. It would, however, not be possible to completely eliminate NVA time in this particular process, and the majority of the NVA activities would only be mitigated with the intent on maximising face time.

Takt time could now be determined, as the desired variables have been clarified and selected for input and computation:

- Net operating time per cycle (customer demand time): 196.5 min
- Customer demand per cycle (number of persons): 180

Takt time = Net operating time per cycle / Customer demand per cycle

= 196.5 / 180

= 1.091

<u>= 1.1 minutes per person</u>

Through the achievement of this Takt time, all primary target metrics as defined in the Research Charter would be realised.

It was now possible to plot and analyse the Takt time chart. The chart is illustrated by Figure 6.19, below. It is clear from the figure that there were numerous process constraints (bottlenecks), as indicated by the bars on the chart exceeding the Takt time line (red line). Any sub-process or activity that takes longer than Takt time essentially constrains the process. The single process step that takes the longest and is also in excess of the Takt time is referred to as the *time trap*, which, in the case of the personnel logistics process, was the step *Wait for man carriage*, as shown in the figure.

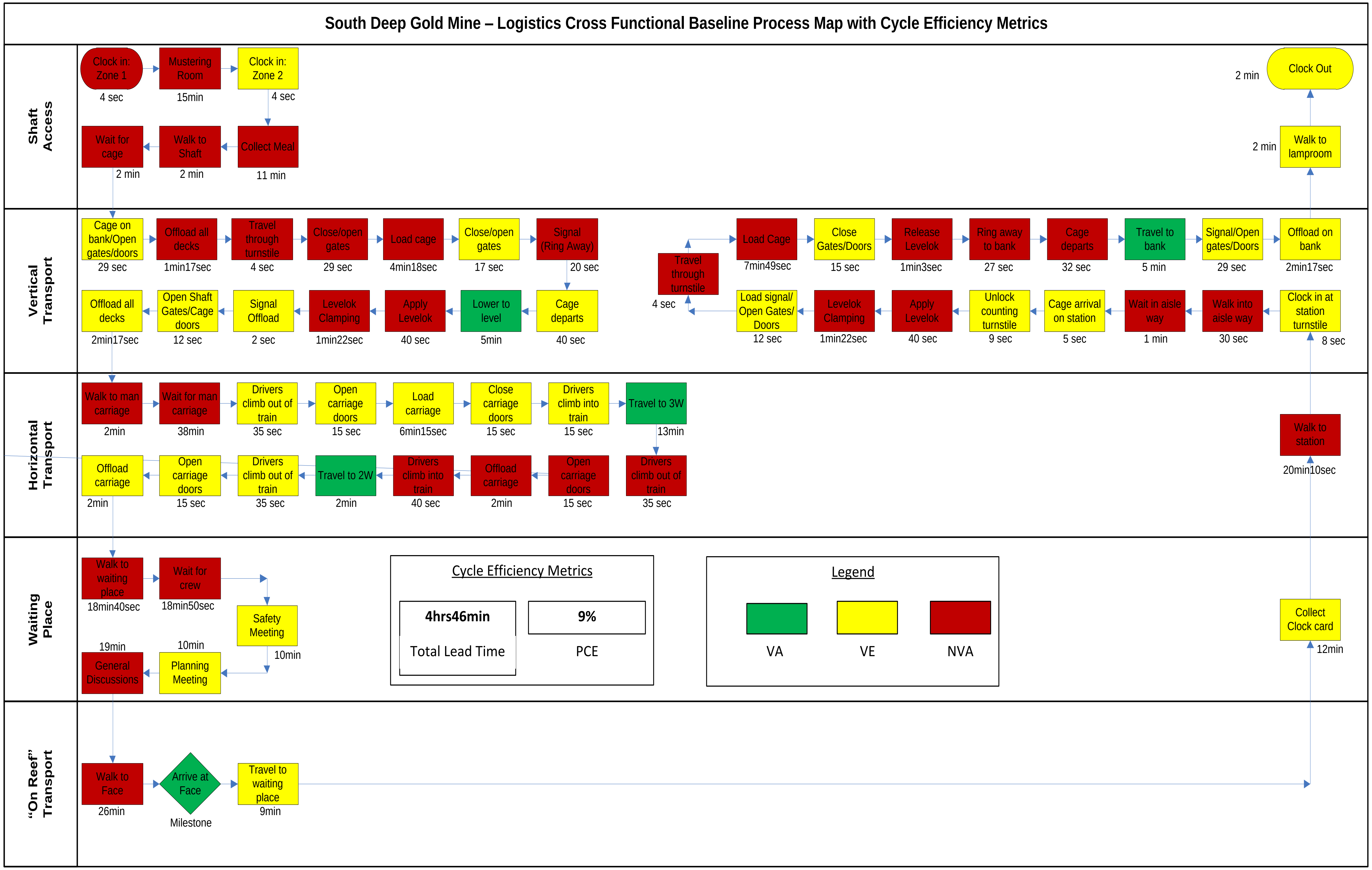


Figure 6.18: Baseline/Current-state cross-functional process flow diagram with cycle efficiency metrics

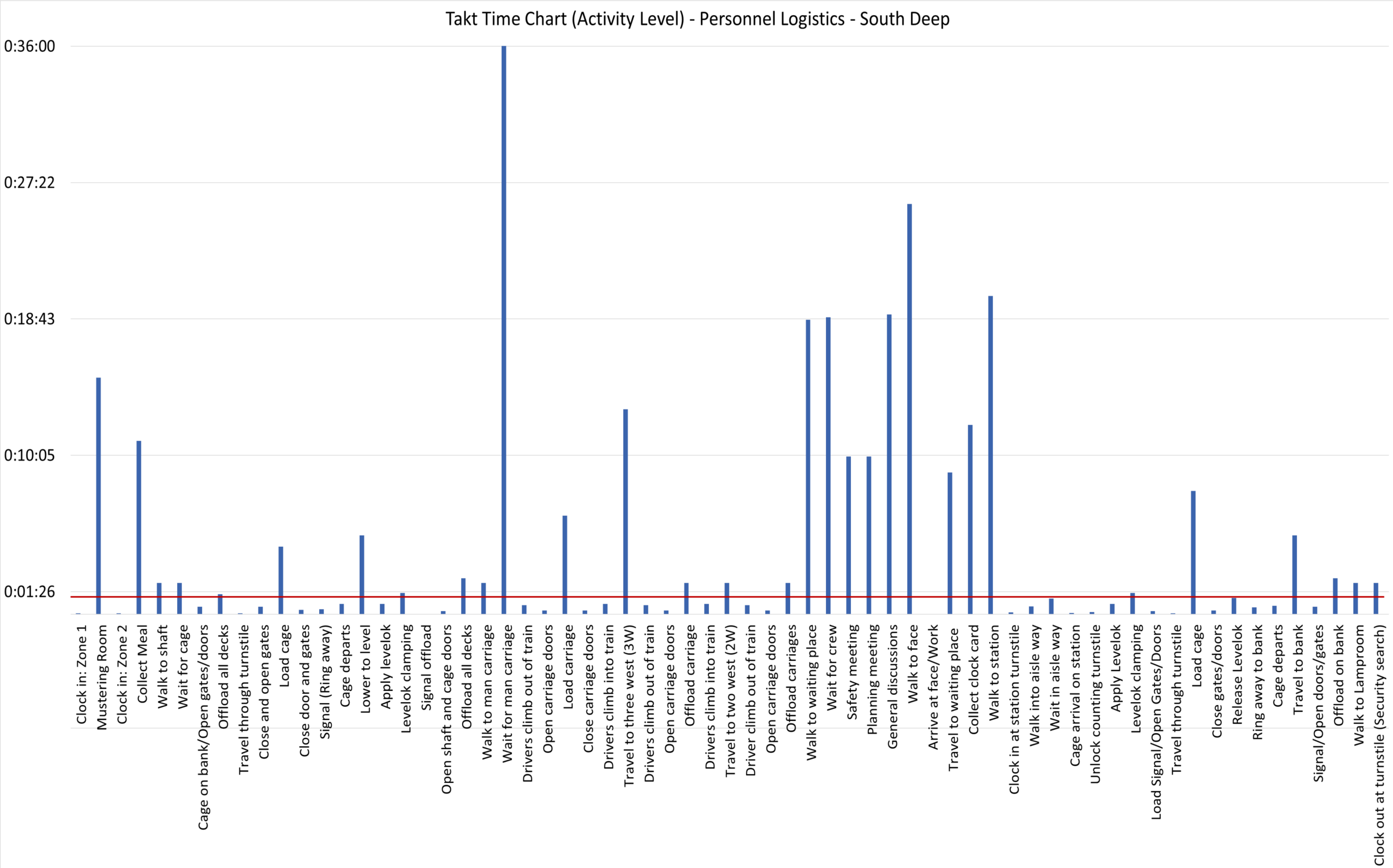


Figure 6-19: Takt time chart for personnel logistics process at Twin Shaft

6.1.5.3 Identify where the greatest opportunities for efficiency improvement exist

Efficiency improvement lies within the reduction of waste or NVA. As stated above, prioritising which waste activities to treat, and in which order, was a function of:

- Ease of solution implementation (probability of success); and
- Impact on face time improvement (impact of implementation).

Ease of solution implementation refers to the expected difficulty or complexity involved in executing predetermined waste mitigation measures. *Impact on face time improvement* refers to the effect on overall face time that may be realised through the mitigation of waste. A qualitative opportunity assessment approach to ranking the NVA activities was taken. Finally, to determine where waste mitigation efforts should be focused, the Pareto theorem was employed.

The Pareto principle or theorem, as described by Sye (2009:396), is derived from the principle of unequal distribution, and holds that 80% of problems are caused by 20% of the contributors.

Figure 6.20, below, illustrates the framework developed for the *Analyse* phase of the DMAIC Model, which involved the integration between qualitative opportunity assessment techniques and Pareto theorem for the purpose of ultimately streamlining waste mitigation efforts using Lean principles.

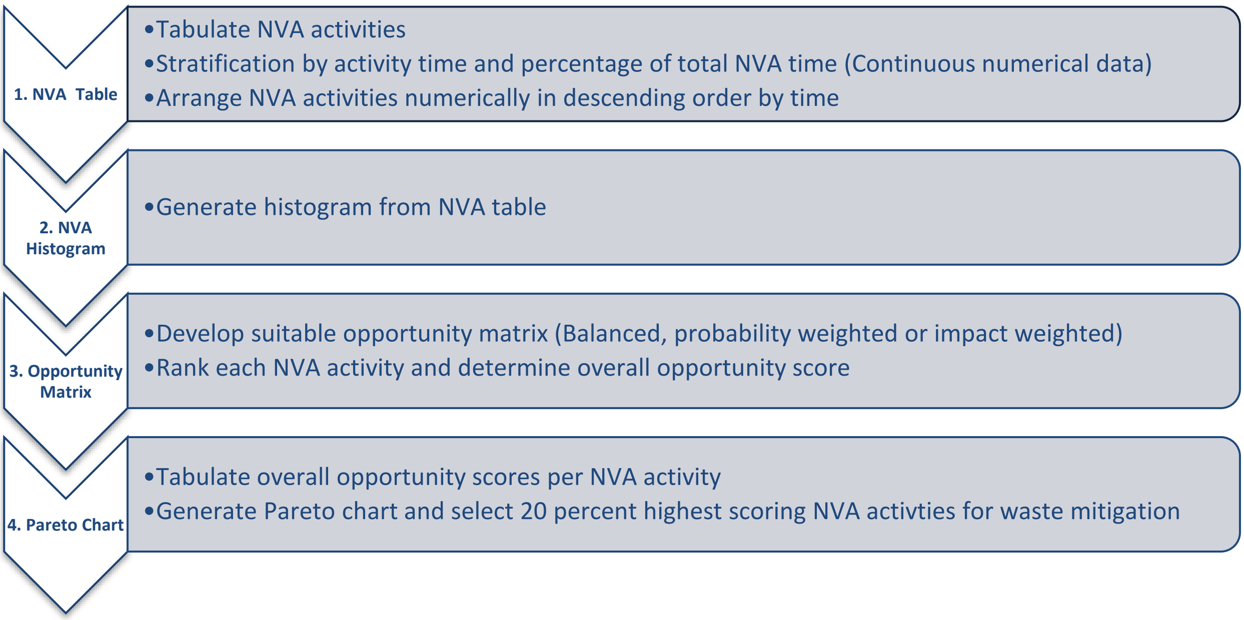


Figure 6.20: Opportunity-Pareto assessment model for prioritising waste mitigation efforts

The model illustrated by Figure 6.20 describes four overall process steps taken in selecting which NVA activities to carry through to the *Improve* phase of the DMAIC Model. As previously stated, the intention of the model was to streamline waste mitigation efforts in dealing with lean improvement problems, thereby ensuring that the *Improve* phase was both efficient and economical, as resources could be correctly focused and utilised. The results of implementing this model in practice to address the Twin Shaft personnel logistics problem are presented in Table 6.11, which indicates the outcome of Step 1 in the Opportunity-Pareto assessment model (in Figure 6.20, above).

Table 6.11: Numerically arranged NVA

Non-value-adding activities	Activity time	% of NVA time
Wait for man carriage	0:38:00	19.18%
Walk to face	0:26:00	13.12%
Walk to station	0:20:10	10.18%
General discussions	0:19:00	9.59%
Wait for crew	0:18:50	9.50%
Walk to waiting place	0:18:40	9.42%
Mustering Room	0:15:00	7.57%
Collect meal	0:11:00	5.55%
Load cage	0:07:49	3.94%
Load cage	0:04:18	2.17%
Walk to shaft	0:02:00	1.01%
Wait for cage	0:02:00	1.01%
Walk to man carriage	0:02:00	1.01%
Offload carriage	0:02:00	1.01%
Levelok clamping	0:01:22	0.69%
Levelok clamping	0:01:22	0.69%
Offload all decks	0:01:17	0.64%
Release Levelok	0:01:03	0.53%
Wait in aisle way	00:01:00	0.50%
Apply Levelok	0:00:40	0.34%
Drivers board train	0:00:40	0.34%
Apply Levelok	00:00:40	0.34%
Drivers deboard train	0:00:35	0.29%
Cage departs	0:00:32	0.27%
Walk into aisle way	00:00:30	0.25%
Close and open gates	0:00:29	0.25%
Ring away to bank	0:00:27	0.23%
Signal (ring away)	0:00:20	0.17%
Open carriage doors	0:00:15	0.13%
Clock in: Zone 1	0:00:04	0.03%
Travel through turnstile	0:00:04	0.03%
Travel through turnstile	0:00:04	0.03%
Total NVA time	**3:18:10**	
Percentage of total NVA time	**100%**	

Figure 6.21, below, depicts the NVA histogram as an outcome of Step 2 of the model in Figure 6.20, above.

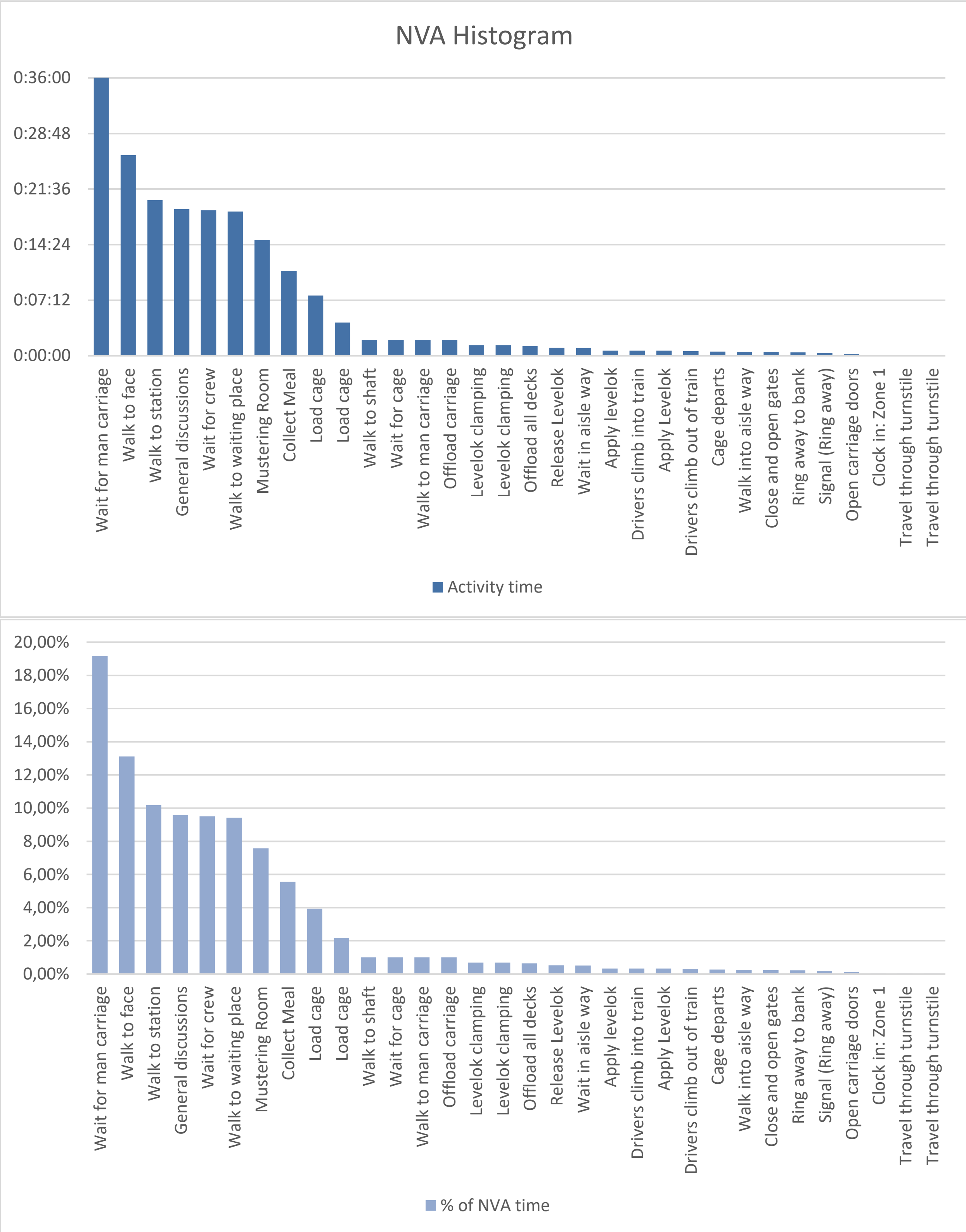


Figure 6.21: NVA histogram representing activity time and percentage of total NVA time

Figure 6.22 and 6.23, below, are results of the opportunity assessment process step of the aforementioned model.

Opportunity Matrix						
0-5 = Poor Opportunity		Impact (Solution implementation)				
6-10 = Moderate Opportunity		1	2	3	4	5
11-15 = Good Opportunity 16-25 = Great Opportunity		0 - 2% (NVA Time)	3 - 5% (NVA Time)	6 - 10% (NVA Time)	7 - 12% (NVA Time)	13 - 25% (NVA Time)
Probability (Solution implementation)	5 Almost certain	5	10	15	20	25
	4 Likely	4	8	12	16	20
	3 Possible	3	6	9	12	15
	2 Unlikely	2	4	6	8	10
	1 Highly unlikely	1	2	3	4	5

Figure 6.22: Balanced opportunity matrix and associated legend

The opportunity matrix above consists of two main components namely, impact and probability, or, as highlighted in Section 6.1.5.3, impact on face time improvement (impact of implementation) and ease of solution implementation (probability of success) respectively. The matrix was balanced equally; hence, there was no difference in weighting between probability and impact. An assessment where the probability of success is deemed of greater importance than the impact would result in a probability-weighted matrix, and vice versa if the impact were deemed more vital. In the case of the logistics process, probability and impact were weighted equally, evidenced by the linear proportional matrix with a simple five-by-five matrix structure.

The probability scale values ranged from *1* (*Highly unlikely*) to *5* (*Almost certain*). The impact scale also ranged from *1* to *5*, where the percentage NVA time increased from zero to 25% in five increments of 5. As designed by the researcher, any NVA activity that consumes 13% to 25% of the overall NVA time is considered a major waste contributor in terms of the above model, and this range was set accordingly in the present study with an impact of five. In essence, the matrix, although balanced, was slightly focused around impact, especially with regard to the major NVA time consumers, as this is where large face time improvement opportunities lie. Even large-impact NVA activities that are excessively complex to implement received a very low probability of success score; hence the overall opportunity assessment rating would render them unattractive in the Pareto chart when compared to others.

As can be seen in Figure 6.23, below, when each NVA activity was qualitatively assessed according to probability and impact, the product of the two figures yielded and overall opportunity rating for each activity. These opportunity ratings were utilised in the Pareto chart (Figure 6.24).

Opportunity Assessment					
Non-value-adding activities	**Activity time**	**% of NVA time**	**Probability rating**	**Impact rating**	**Opportunity rating**
Wait for man carriage	0:38:00	19.18%	5	5	25
Wait for crew	0:18:50	9.50%	5	4	20
Walk to waiting place	0:18:40	9.42%	5	4	20
Mustering Room	0:15:00	7.57%	5	4	20
Walk to station	0:20:10	10.18%	4	4	16
Collect meal	0:11:00	5.55%	5	3	15
General discussions	0:19:00	9.59%	3	4	12
Load cage underground	0:07:49	3.94%	5	2	10
Levelok clamping	0:02:44	1.38%	5	2	10
Apply Levelok	0:01:20	0.67%	5	2	10
Load cage	0:04:18	2.17%	5	1	5
Walk to shaft	0:02:00	1.01%	5	1	5
Release Levelok	0:01:03	0.53%	5	1	5
Ring away to bank	0:00:27	0.23%	5	1	5
Signal (ring away)	0:00:20	0.17%	5	1	5
Clock in: Zone 1	0:00:04	0.03%	5	1	5
Travel through turnstile ug	0:00:04	0.03%	5	1	5
Travel through turnstile	0:00:04	0.03%	5	1	5
Walk to face	0:26:00	13.12%	1	5	5
Walk into aisle way	0:00:30	0.25%	3	1	3
Wait for cage	0:02:00	1.01%	2	1	2
Walk to man carriage	0:02:00	1.01%	2	1	2
Offload carriage	0:02:00	1.01%	2	1	2
Cage departs	0:00:32	0.27%	2	1	2
Offload all decks	0:01:17	0.64%	1	1	1
Wait in aisle way	0:01:00	0.50%	1	1	1
Drivers board train	0:00:40	0.34%	1	1	1
Drivers deboard train	0:00:35	0.29%	1	1	1
Close and open gates	0:00:29	0.25%	1	1	1
Open carriage doors	0:00:15	0.13%	1	1	1

Figure 6.23: Opportunity assessment of potential for waste removal

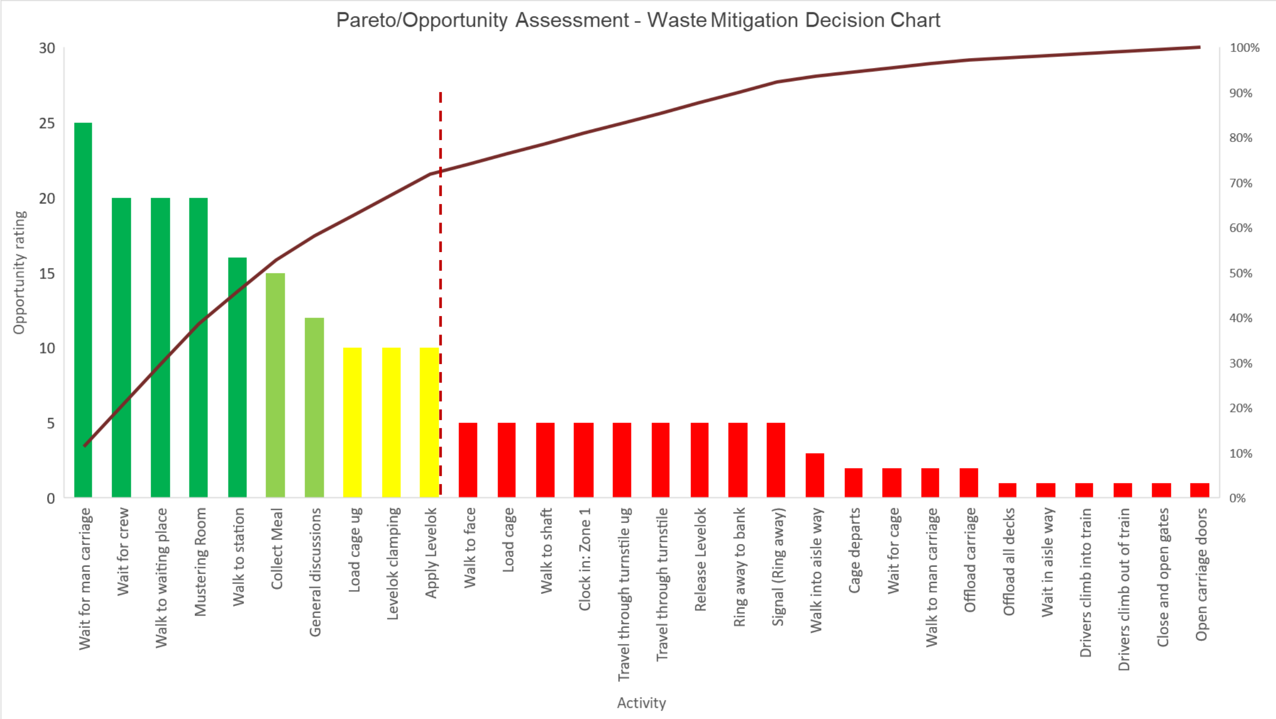


Figure 6.24: Pareto chart of opportunity rating results

The Pareto chart in the figure above indicates the opportunity ratings for waste removal, ranging from greatest (on the left) to least (on the right), colour-coded in accordance with the opportunity matrix in Figure 6.22, above. The activities relating to Levelok clamping and application occur on more than one occasion and were automatically grouped when generating the Pareto chart. In determining which NVA activities to analyse further prior to progression into the *Improve* phase of the DMAIC Model, the Pareto principle below was considered:

Total count of NVA activities = 30

20% of total count = 0.2 x 30

= 6 activities

The first six activities were selected for further analysis. At this point, a comparison between the customer demand time saving and the time saving from the aforementioned six activities was performed. The customer demand face time saving had been established during the formulation of the Research Charter at 90min. The six activities selected through Pareto analysis amounted to a total of 61.40% or 121min40 sec, which would suffice to achieve the 90min face time saving. An additional four activities were included, thereby bringing the total NVA activities for further analysis to ten out of the total 30. The potential face time saving was thereby increased to 76.98% or 152min33sec (152min).

The cut-off point is indicated on the Pareto chart by means of the vertical red dashed line at the point that intersects the cumulative percentage curve. All activities to the left were carried through (see table below) for further analysis and considered for mitigation in the *Improve* phase. All activities to the right-hand side of the cut-off point would not be considered yet, unless:

- through mitigation efforts of the selected NVA activities, the primary metric targets for face time improvement were not fully achieved; or
- customer demand increases in future.

Table 6.12, below, is the final NVA list, in order of opportunity rating, selected through the Opportunity-Pareto assessment model (Figure 6.20). Further analysis was then undertaken where required. Where improvements could already be effected, it was critical that these be done, as a key principle of lean improvement 'early wins.'

Table 6.12: Waste mitigation decision table

Waste mitigation decision table				
Code	**NVA activities**	**Activity time**	**% of NVA time**	**Opportunity rating**
NVA-1	Wait for man carriage	0:38:00	19.18%	25
NVA-2	Wait for crew	0:18:50	9.50%	20
NVA-3	Walk to waiting place	0:18:40	9.42%	20
NVA-4	Mustering Room	0:15:00	7.57%	20
NVA-5	Walk to station	0:20:10	10.8%	16
NVA-6	Collect meal	0:11:00	5.55%	15
NVA-7	General discussions	0:19:00	9.59%	12
NVA-8	Load cage underground	0:07:49	3.94%	10
NVA-9	Levelok clamping	0:02:44	1.38%	10
NVA-10	Apply Levelok	0:01:20	0.67%	10

All activities selected for waste mitigation efforts in the *Improve* phase were allocated codes. NVA-1 through 10 were tabulated in order of priority, from highest to lowest rating. The final step of the *Analyse* phase was initiated, in which the selected NVA activities were analysed further, unless the source of waste could be addressed immediately (mitigation or elimination) though conventional problem-solving techniques.

6.1.5.4 Detailed analysis of identified sources of waste

6.1.5.4.1 NVA-1: *Wait for man carriage*

Background and problem:

Man carriages consist of specially designed rail-bound carts or wagons, referred to as *carriages*, which by design are intended and approved in mining legislation for the transportation of persons by means of conventional underground rail track or railway. These carriages are coupled to locomotives, which then provide the driving force for the propulsion, as well as the braking force required for the carriages, which are coupled in series. The combined set of machinery, equipment, and rolling stock, commonly referred to as *a train*, consists of a locomotive at the driving end and a specified number of man carriages (set design capacity based on number of persons), all coupled together by means of coupling pins and drawbars.

Trains are operated on the main production level (95 level), and are positioned near the shaft area at the start of shift. The areas were the trains are parked are called *loading/offloading bays*, and are designed and constructed for the purpose of loading or offloading passengers, similar to a normal passenger train station. The employees travel down the shaft, arrive at the shaft station, and then walk to the loading bay near the shaft. At this point, the employees board the train and travel to their respective offloading stations, near their waiting places. Each working area has an offloading bay, namely Two West and Three West Offloading Bay. From the offloading bay, the employees walk to their respective waiting places, meetings are conducted, and employees thereafter proceed to their working places inside the stoping, development, and destress workings of the mine.

Figure 6.24 illustrates the shaft station area, including the position of the train loading/offloading bay. Label 1 on the figure indicates the position of the main shaft barrel where employees are offloaded on the shaft station area. Label 2 is the position of the loading/offloading bay, Label 3 is the main intake haulage, commonly referred to as the *MIH*, Label 4 is the return airway haulage, commonly referred to as the *RAW*, and Label 5 is the haulage cross-section as well as dimensions, clearances, and positioning of rail-bound equipment (RBE) and services (compressed air, water, drainage, and electrical reticulation, as well as rail-track dimensional specifications). The trains depart into the MIH and return by means of the RAW, in a continuous loop after having offloaded employees at their respective offloading bays.

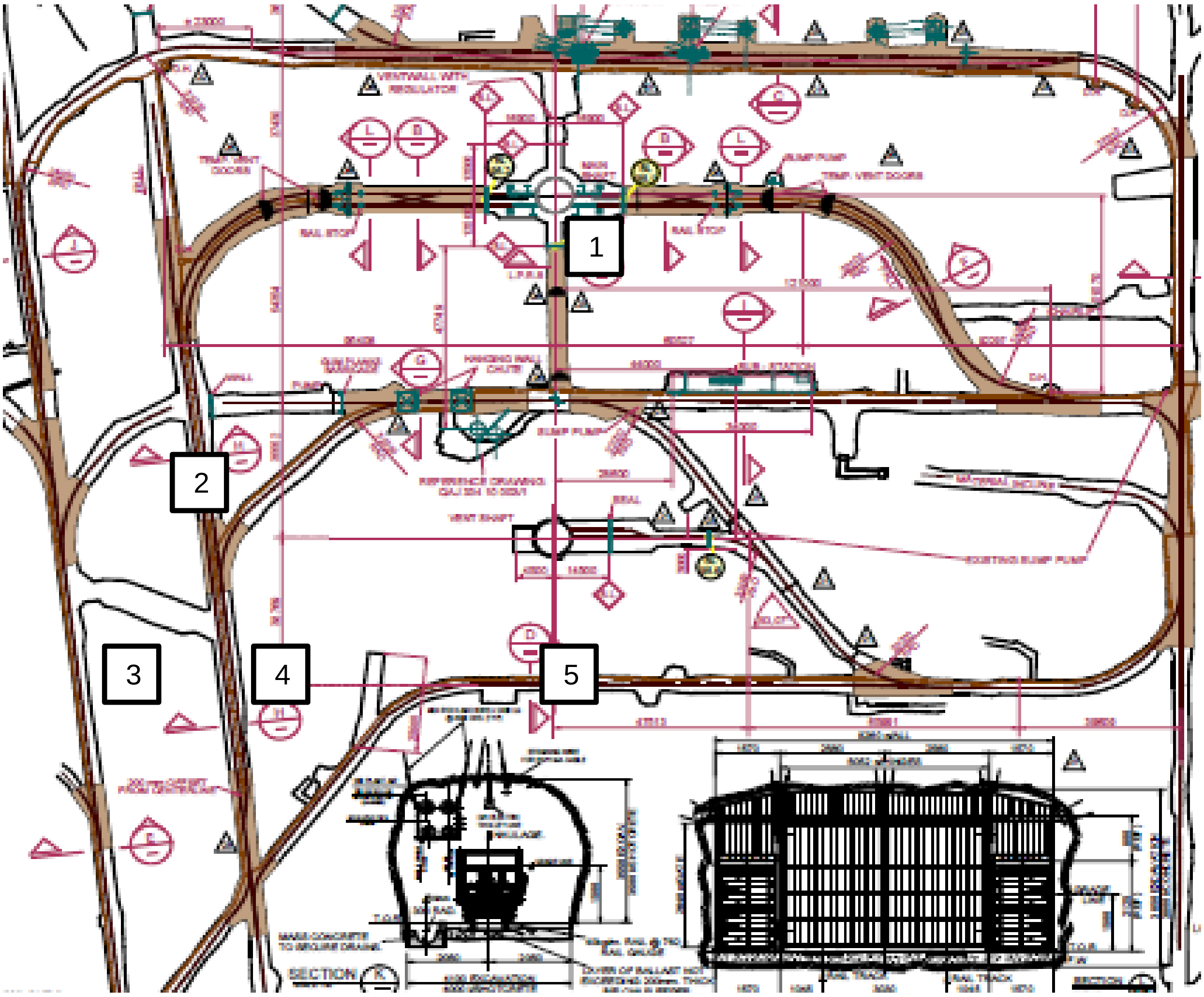


Figure 6.25: Opportunity assessment of potential for waste removal

As described by the name given to this NVA activity — *Wait for man carriage*, employees, for some reason, wait, or perhaps queue, for a man carriage upon arrival on the shaft station after vertical transport has been completed. The total time waiting amounted to approximately 38min, on average, according to the data collected in the time–motion studies during the *Measure* phase of the DMAIC Model. This particular source of waste falls within the category of *Waiting* when considering the seven forms of waste specified in Lean theory. The question then is, why?

For this particular problem, a suitable Lean tool or technique to implement is the 5 What Cause–Effect Chain (Sye, 2009: 464). The technique had been adapted from Toyota Motor Corporation's technique called the *5 Why methodology*. As described by Sye (2009), the technique allows for rapid identification of probable root cause, and is highly effective for event-based problems or simple variation in a process. As this particular NVA activity was event based, the 5 What Cause–Effect Chain method was implemented by the improvement team. The result is shown in Figure 6.25, below.

The 5 What Cause–Effect Chain method: NVA-1

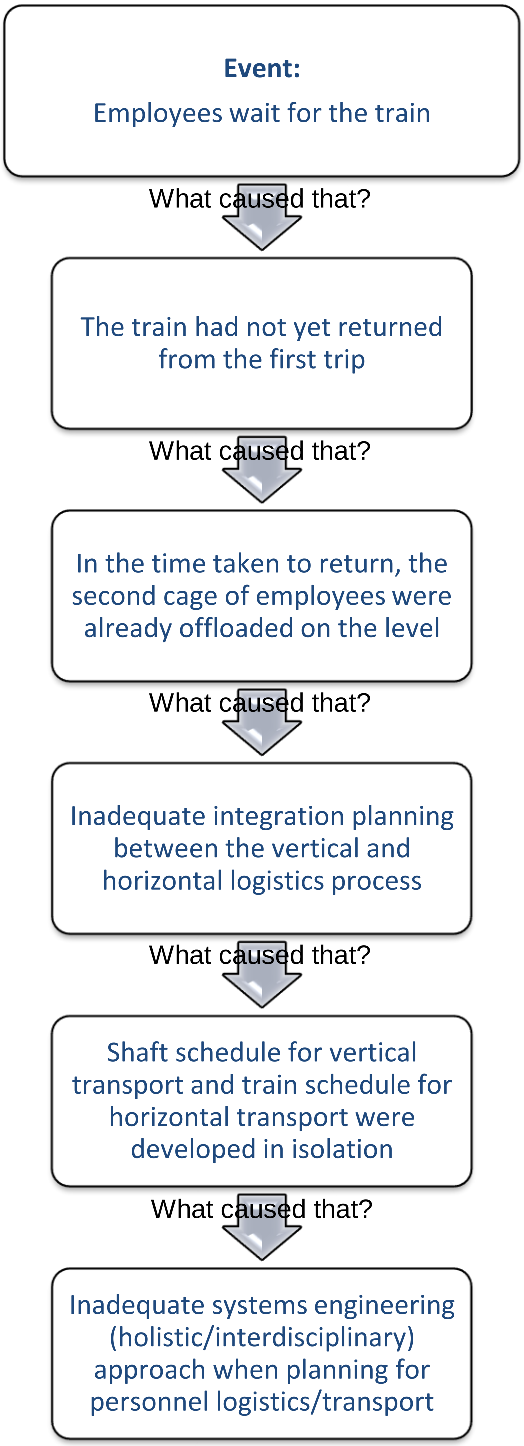


Figure 6.26: The 5 What Cause–Effect Chain (NVA-01: *Waiting for man carriage/train*)

When conducting the cause-and-effect (C–E) analysis depicted above, it was imperative that operational personnel involved in this particular process be included, in order to uncover the actual or most probable root cause. Employees with first-hand knowledge of the process, preferably those employed for the process/function, are key.

With regard to the findings of the analysis of the NVA activity of employees waiting at the loading bay for a train to collect them, it was uncovered that the first train departs, at full capacity, shortly after the first cage arrived on the shaft station. The second cage then arrives on the shaft station, and these employees then wait for the man carriage to return.

It was clarified that the Horizontal Logistics Department had planned for only one train with a capacity of 120 people (three man carriages coupled in the train, each seating 40 persons). The cage capacity, as indicated in Figure 6.3, is 180 persons. Per Figure 6.7, the amended shaft schedule developed in 2017 allows for the first cage down to 95 level for employees working at Two West (2W in table) corridor (working place), and the second cage down for employees working at Three West (3W) corridor. The analysis uncovered a significant planning misalignment between the Vertical Shaft Logistics Department and the Horizontal Logistics Department, due to inadequate application of a holistic/interdisciplinary systems approach by management when conducting vertical and horizontal personnel logistics/transportation planning. As a result, the shaft schedule and train schedules and capacities were misaligned. This finding is validated in the table below, based on the data gathered in the time–motion studies conducted in the *Measure* phase.

Table 6.13: Validation of CE analysis findings

NVA-01: Validation of CE analysis findings			
Aspect	Train	Cage 1 (95 2W)	Cage 2 (95 3W)
Capacity (persons)	120	180	180
Cage departure time from surface	N/A	05:05	05:20
Cage arrival time on station	N/A	05:10	05:25
Train departure time to working place	05:20	N/A	
Train arrival time back at loading/offloading bay	06:03		
NVA times = 06:03 and 05:25	**38 minutes**		

As shown in the above table, three main issues existed due to inadequate personnel logistics planning between the Vertical and Horizontal Logistics Departments, namely:

- Train capacity and cage capacities differ; therefore, the train will depart full, while employees remain behind waiting for the train to return (cage capacity is 180; train capacity is 120).
- There is only one train planned for horizontal transport of personnel to both Two West and Three West working places. The train transports a portion of the Two West employees, and then does not return at the same time as the cage for transportation of the Three West employees. Hence, unnecessary waiting occurs.
- There is no formal train schedule that is correctly aligned with the shaft schedule to ensure zero waiting time.

In conclusion, during the *Improve* phase, it was desirable to completely eliminate the waiting time by addressing the aforementioned three issues. The elimination of these three issues would translate to an additional 38min of face time (of the target of 90min).

6.1.5.4.2 NVA-2: *Wait for crew*

Background and problem:

The NVA activity identified as *Wait for crew* refers to the form of waste termed *waiting*, from Lean principles' seven forms of waste. The crew referred to is the operational/mining crew members employed on 95 level in Two West and Three West working places. Industry best practice is that the standard operating procedure (SOP) involves conducting safety and planning briefing sessions at the waiting place prior to performing the production work requirements for that particular shift. These briefing sessions are conducted by the legally appointed ganger or miner, of the working place. The sessions are conducted as soon as the entire crew arrives at the waiting place. This briefing session is called the *waiting place meeting*.

Whilst conducting physical time–motion studies during the *Define* and *Measure* phases, it was identified that there was an average waiting period of just over 20min when the crew waited for the waiting place meeting to be initiated. The primary reason for this unnecessary time spent waiting was that the meeting could only be initiated when the entire crew was present at the waiting place. A portion of the crew in each waiting place spent this time waiting for the remainder of that crew to arrive and be seated.

The 5 What Cause–Effect Chain method: NVA-2

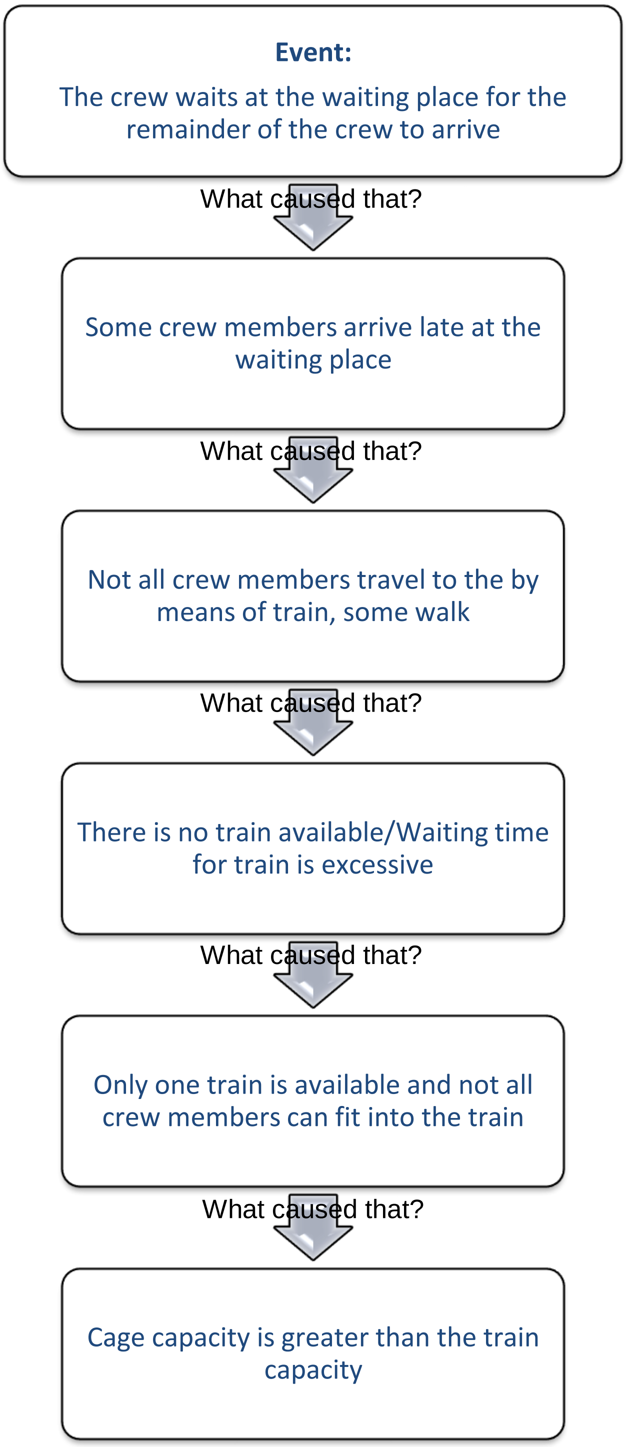


Figure 6.27: The 5 What Cause–Effect Chain (NVA-02: Wait for crew)

From the above C–E analysis, the main issue was found to be that, as the train capacity is 120 versus a cage capacity of 180, some crew members were left behind at the loading/offloading bay and decided to walk instead. Another issue was that, as the second cage of Three West, employees knew they would need to wait, on average, 38min for the train to return from the first trip, and some of these crew members decided to walk inside. The result of this was that crew members arrived at the waiting places for the meetings very erratically, and even the crew members who arrived on time, those who were able to use the train, ended up having to wait for the remainder of their crew to arrive in order that the waiting place meeting could be held. It was also discovered in further analysis of this issue that some crew members preferred to walk inside, despite the train being available.

The three main issues to be addressed here were:

- Train capacity versus cage capacity;
- Crew members walking inside by choice, despite the availability of trains; and
- Horizontal transport misaligned with shaft schedule; hence, not all employees utilise the trains. Due to a portion of the crew walking, all crew members did not arrive simultaneously, and the waiting place meeting was delayed until all crew members were present.

6.1.5.4.3 NVA-3: *Walk to waiting place*

Background and problem:

As earlier described in the analysis of NVA-1, the personnel trains depart from the loading bay on the shaft station area to the offloading bays near the respective worming places at Two West or Three West, and vice versa. On average, employees spend nearly 19min walking from the respective offloading bay at either Two West or Three West to the waiting place for their section. This commute involves walking from the offloading bay, along the walkway side of the rail-bound haulage, into the trackless mechanised mining section, and then arrival at the waiting place. Once all employees have arrived at the waiting place, normal briefing sessions are initiated.

Figure 6.25, below, is a level plan indicating the positioning of loading/offloading bays in proximity to the waiting place positions for Two West and Three West. Label 1 indicates Three West's offloading bay, Label 2 indicates the Two West offloading bay, Label 3 indicates the approximate position of Three West's waiting place, and Label 4 the approximate position of Two West's waiting place. Label 5 indicates the positioning of the loading bay at the shaft station area. The actual walking distances are also indicated in the figure, as well as the routes taken from the offloading bays to the waiting places.

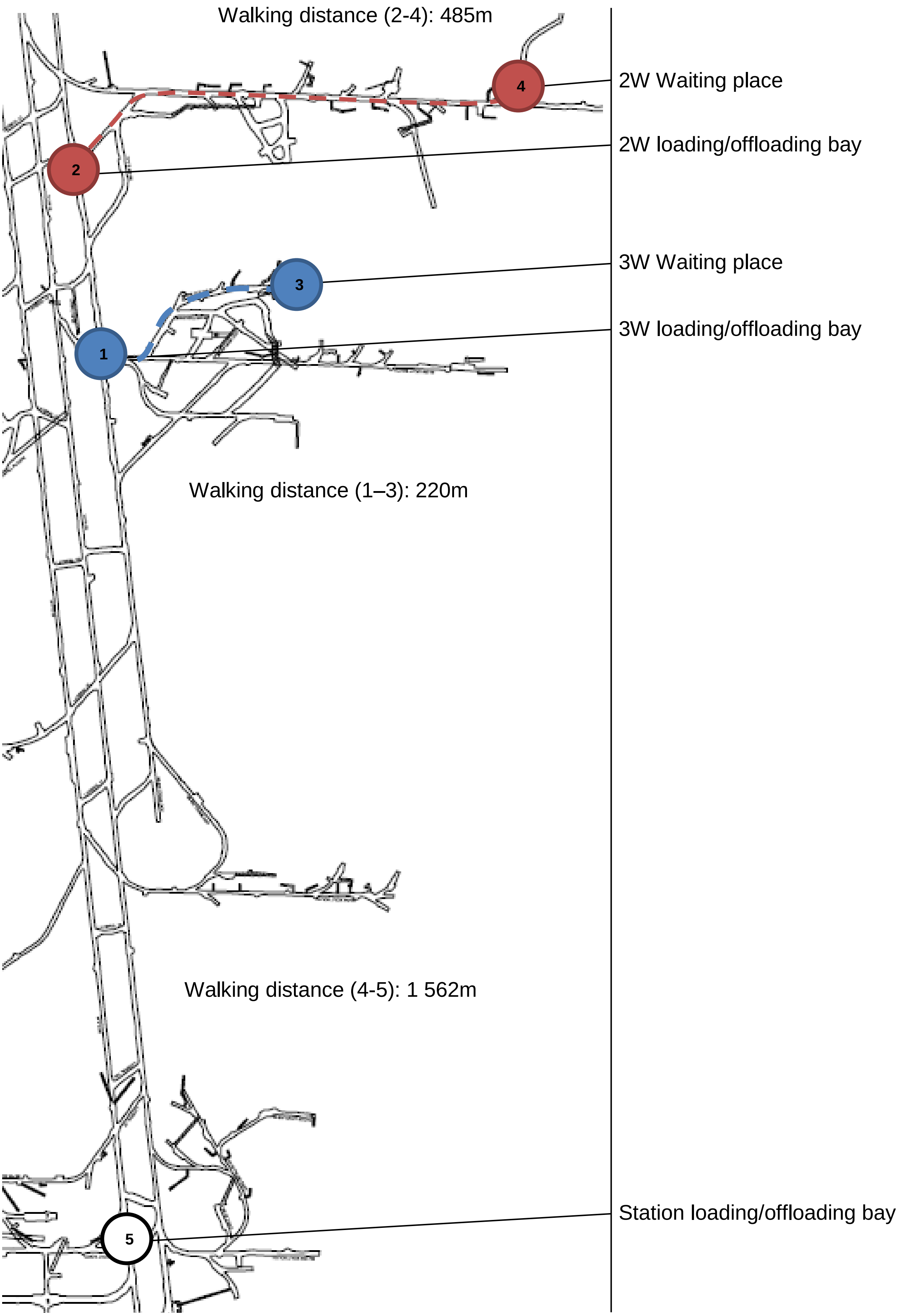


Figure 6.28: Level plan (95 level) indicating personnel walking routes. Courtesy of Gold Fields

Per Figure 6.26, above, the walking distance for Two West personnel travelling from the loading/offloading bay to the waiting place is excessive, and numerous personnel walked due to the unavailability of adequate man carriage/train capacity. The main issue to be addressed was the physical walking distance between loading/offloading bays and the waiting places, especially where Two West was concerned.

6.1.5.4.4 NVA-4: *Mustering Room*

Background and problem:

The Mustering Room is a meeting room on the surface, situated directly next to the Lamp Room. Figure 6.27, below, is a plan view of the shaft access area, including the Lamp Room, Mustering Room, meal-collection bay, shaft access tunnel (sky walk), and shaft bank area.

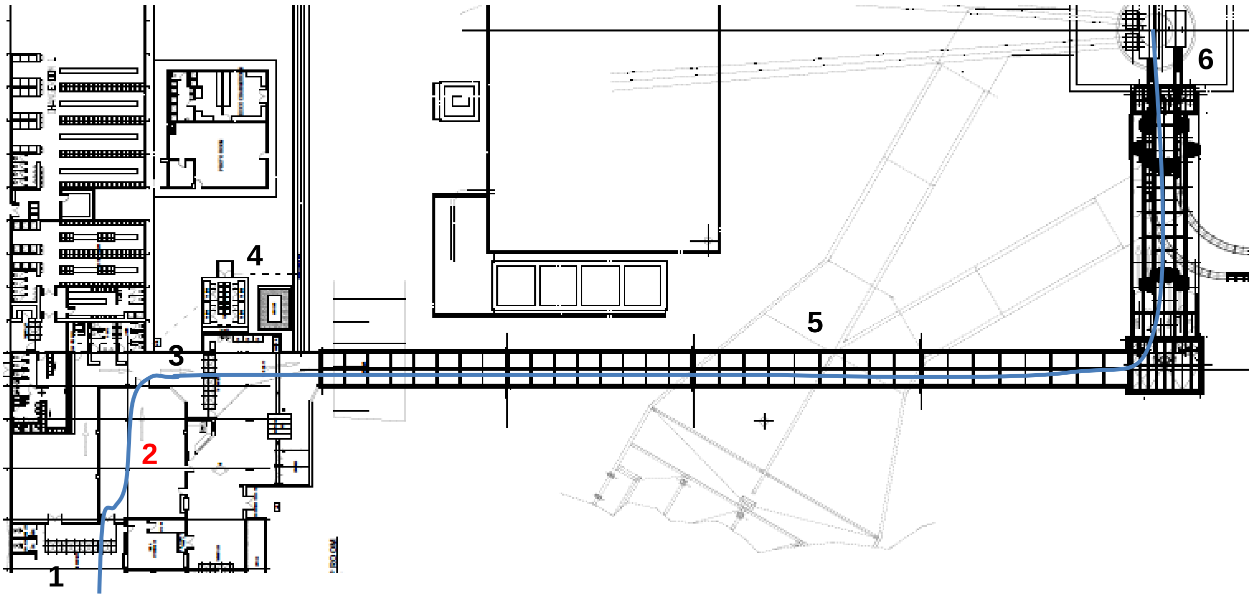


Figure 6.29: Shaft access layout including walking route. Courtesy of Gold Fields

Legend:

1: Turnstiles (Zone 1)
2: Mustering Room
3: Turnstiles (Zone 2)
4: Mid-shift meal collection bay
5: Tunnel (Sky walk)
6: Shaft bank

Personnel going underground collect inside the Mustering Room for a safety communication meeting on a daily basis, prior to proceeding underground. These meetings are scheduled to last 15min, and are for the sole purpose of discussing safety and other general issues raised by employees. The meeting is generally chaired by senior supervisory staff, in conjunction with the

Safety Department. The Mustering Room meeting results in a 15-min reduction in face time. Employees clock in for work at access Zone 1; thereafter, the Mustering Room safety meeting is held for each scheduled cage being lowered down the mine, per the shaft schedule. Figure 6.30, below, is an extract from the shaft schedule, indicating the allotted time for the Mustering Room meeting (in red border).

Shaft Schedule -

Mustering Meeting Starts	Zone Opens	Zone Closes	Cage Departs	MONDAY	TUESDAY	WE
04:35	04:50	05:00	05:05	93, 94 & 95 Level 2W 4x4 Day Shift Down	93, 94 & 95 Level 2W 4x4 Day Shift Down	93 4
05:05	05:20	05:30	05:35	95 Level 3W, 100 Level 4x4 Day Shift Down	95 Level 3W, 100 Level 4x4 Day Shift Down	95 4
05:30	05:45	05:55	06:00	Daily Examination (Reg 16.74) Banskman Clean Cages	South Shaft ESF Day Shift Down	D Bar
06:00	06:15	06:25	06:30	93, 94 & 95 Level ESF Day Shift Down	93, 94 & 95 Level ESF Day Shift Down	E
06:30	06:45	06:55	07:00	100, 105 & 110A Level ESF 110A Level 4x4 Day Shift Down	100, 105 & 110A Level ESF 110A Level 4x4 Day Shift Down	100,
			07:30	Officials Down Last Cage	Officials Down Last Cage	

Figure 6.30: Extract from Shaft Schedule — Twin Shaft (Courtesy of Gold Fields)

As shown above, every cage scheduled to be lowered at the start of the morning shift has an individual Mustering Room meeting, scheduled before the zone (access turnstile) opens for each cage. The main issue to be addressed was the necessity of the Mustering Room meeting, with consideration of legislative requirements and operational risk.

6.1.5.4.5 NVA-5: *Walk to station*

Background and problem:

At the end of shift, personnel were observed leaving their working places and going back to the waiting place to collect their access cards, which are submitted at the start of shift to their supervisor as part of the waiting place procedure for roll call. Thereafter, these employees did not walk to the train loading/offloading bay to board the train back to the station. Instead, all employees working on 95 level simply walked back to the shaft station area, which is an approximate 1.6km walk. This physical walking time could be reduced from an average of 20min to an average of 15min travelling time if they used a train. Another identified disadvantage of walking was that employees became fatigued, and there was a lack of control of actual departure time from working places, as personnel could start walking back at their own discretion. Through the time–motion studies conducted in the development of the process flow diagrams for the personnel logistics process, the NVA activity of walking to the station at the end of shift was discovered. The decision to categorise the activity of walking back to the station as NVA was based on the seven forms of waste, specifically *unnecessary motion*.

The 5 What Cause–Effect Chain Method: NVA-5

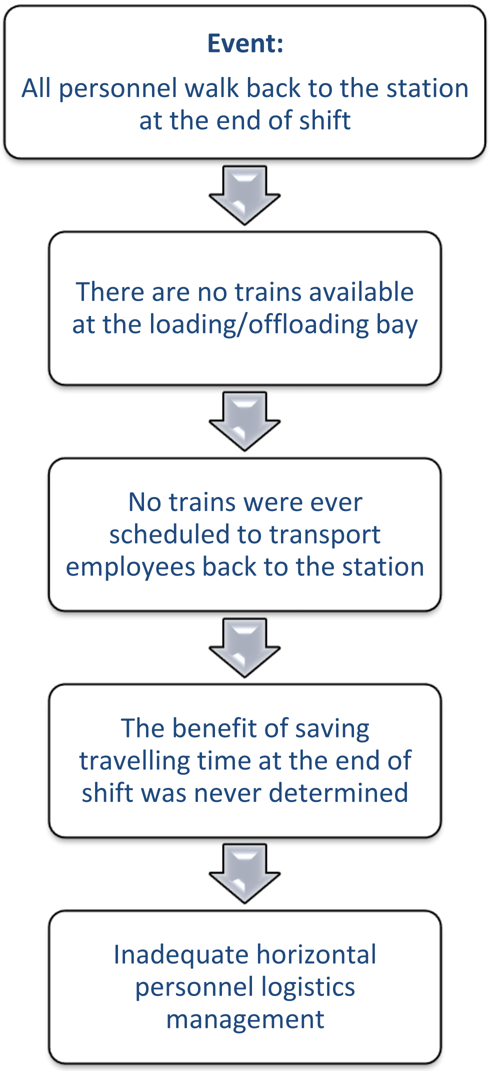


Figure 6.31: The 5 What Cause–Effect Chain (NVA-05: Walk to station)

The main issues to be addressed in order to realise a future face time saving through the mitigation of this NVA were:

- The fact that no trains were ever scheduled for the collection of personnel at the end of their shift.

- The lack of integration between Vertical and Horizontal Logistics and mining operational departments with regard to personnel transport planning (inadequate systems engineering and lack of a holistic/interdisciplinary approach)

6.1.5.4.6 NVA-6: *Collect meal*

Background and problem:

All underground personnel at the mine receive a complimentary mid-shift meal as part of the mine's health and safety management system, in this case, fatigue management. The meal-collection point is positioned behind the Mustering Room. Personnel wait in a queue where the mid-shift meal is issued, after the employees' access cards have been swiped. The figure below indicates the position of the meal-issuing bay in relation to the shaft and Mustering Room, as well as underground access turnstiles.

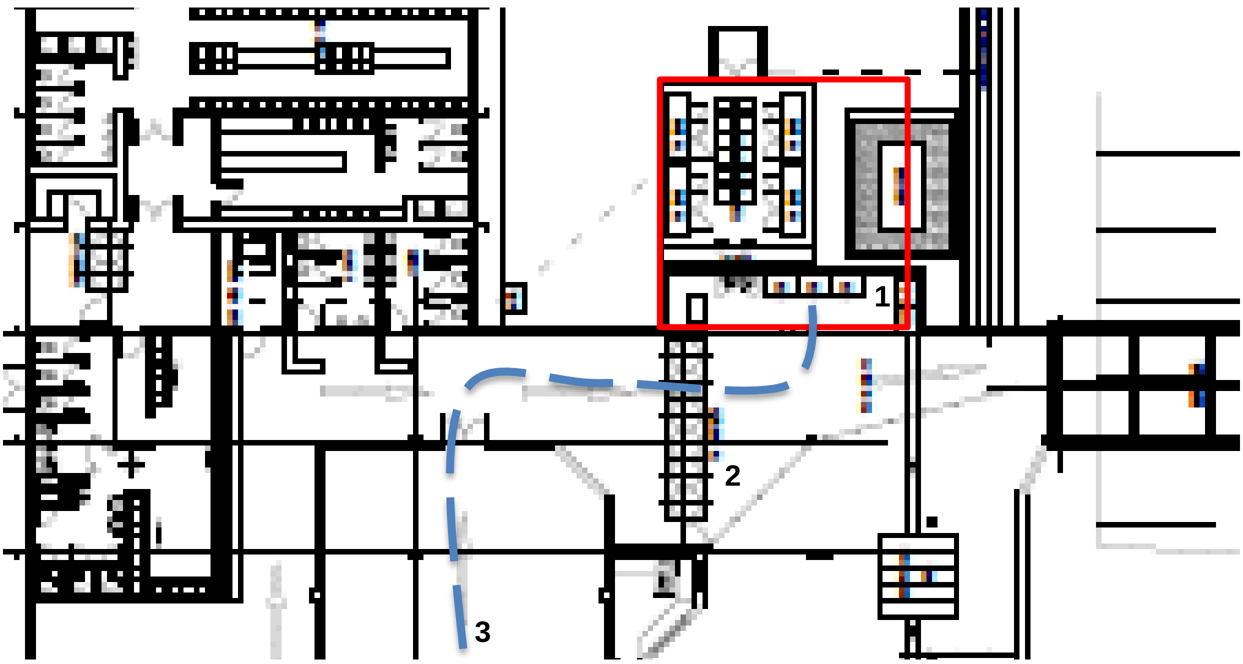


Figure 6.32: Shaft access layout indicating meal collection bay. Courtesy of Gold Fields

Highlighted in the figure above is the collection bay (1). Personnel clock-in for work at the turnstile (2), at which point their shift duration time is initiated.

Through the time–motion studies and careful observation of this process, it was noted that the average time spent queuing for meal collection amounted to 11min. It was observed that the meal-collection bay's service hatch has only two access card swipe points. Personnel may only be served two at a time; however, there were no queuing facilities in place to ensure personnel arrived at the service hatch in single file or double file. As a result, personnel crowded in front of the service hatch. The overcrowded service hatch and only two access card swiping points created a delay in serving personnel, and the meal-issuing staff needed to select which person from the crowd to attend to next. A schematic representation of the process is provided in Figure 6.33, below.

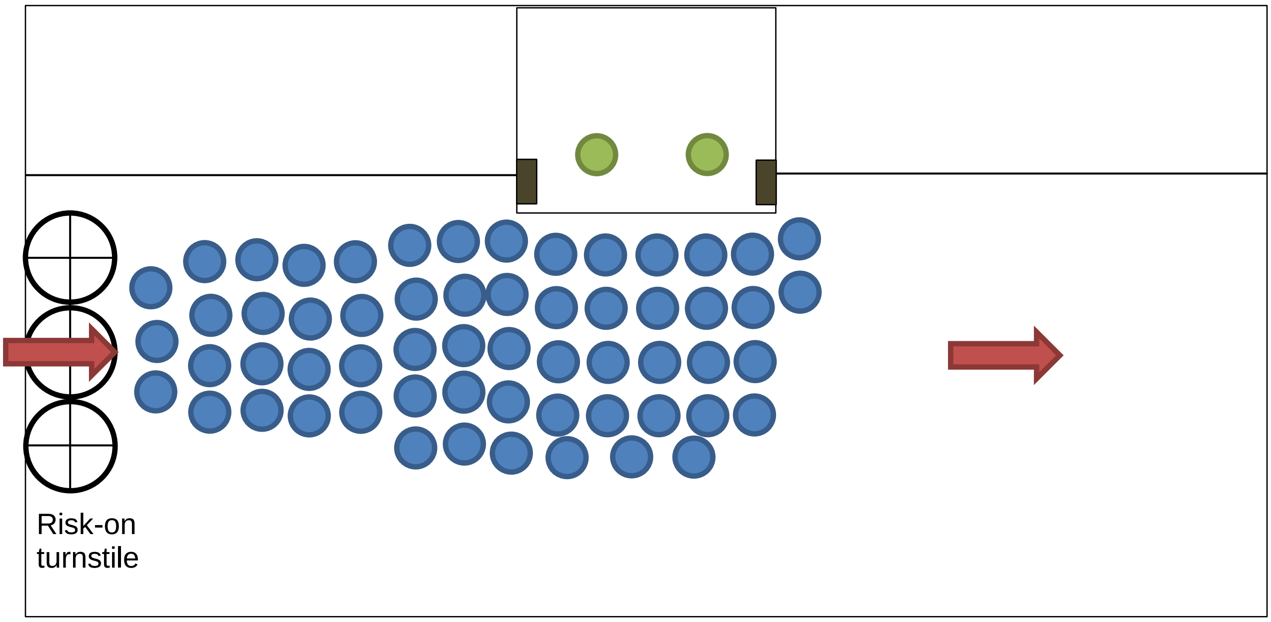


Figure 6.33: Schematic representation of meal collection bay congestion

Personnel, illustrated as blue dots, are congested around the service hatch of the meal collection bay. The two green dots represent the meal-issuing personnel inside the issuing bay. The two rectangular brown blocks represent the card readers to be accessed by each person being issued a meal, for permission. The arrow on the left represents the flow direction of personnel coming from the Mustering Room to the meal-collection bay. The arrow to the right indicates the flow direction toward the shaft bank area, where personnel are loaded to go underground by means of vertical transport. Congestion clearly caused a delay.

6.1.5.4.7 NVA-7: *General discussions*

Background and problem:

Personnel arriving at the waiting place attend the planned waiting place meeting. It was observed that general discussions during or after the planned safety meeting took, on average, approximately 19min. In some instances, the waiting place meeting duration exceeded 1h30min. The general discussions undertaken at the waiting place, by observation, involved work-related issues such as bonuses, training, overtime, and various other issues, which are not part of the scope of the waiting place planning and safety meeting. It was evident that there were no rules or standards around the agenda or the allotted time for these meetings, hence the variability.

The 5 What Cause–Effect Chain method: NVA-7

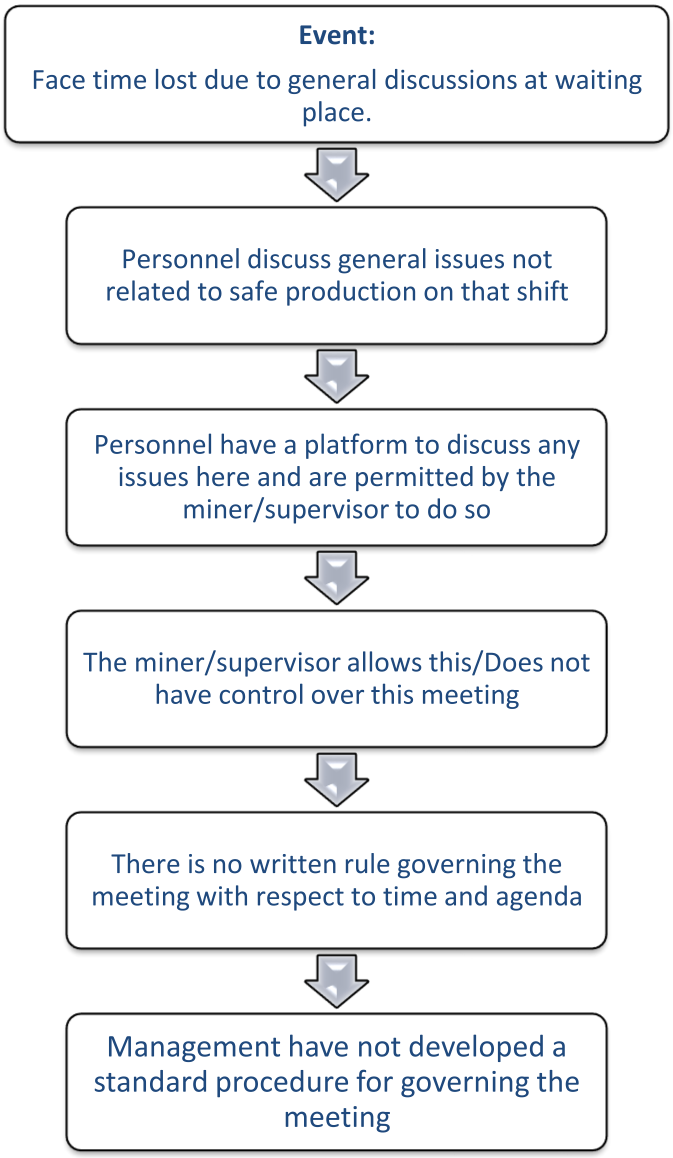


Figure 6.34: The 5 What Cause–Effect Chain (NVA-07: General discussions)

6.1.5.4.8 NVA-8: *Underground cage loading*

Background and problem:

At the end of shift, personnel arrive back at the shaft station area to be raised to surface in the vertical transport system. The figure below indicates the shaft station area as well as the directions of personnel flow.

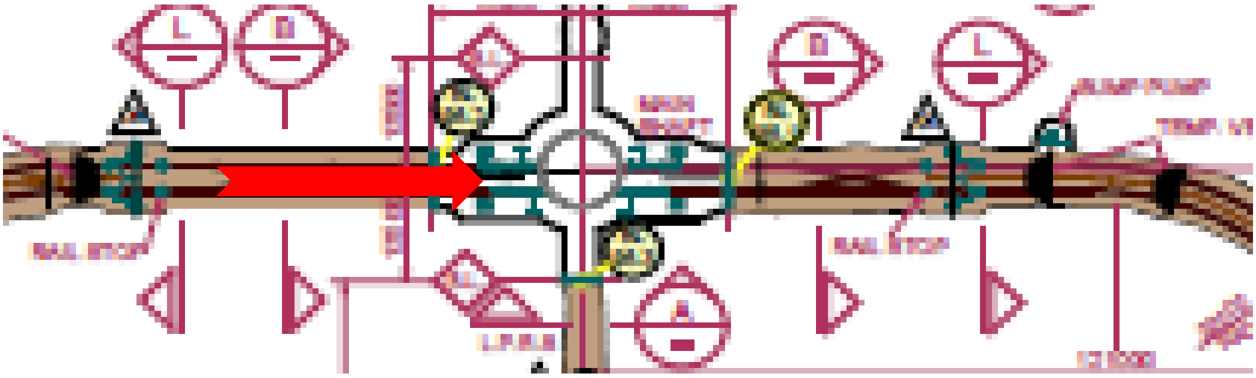


Figure 6.35: Shaft station area and flow direction at end of shift. Courtesy of Gold Fields

Personnel travel to the shaft station at the end of their shift, and then use their access cards to gain entry through the turnstile into the aisle way or queuing area to wait for the cage to arrive. Once the cage arrives, the personnel move through a second turnstile, which counts the number of persons being loaded per cage deck. This prevents overloading.

Approximately 4% of the overall NVA time could be attributed to loading the cage underground. There are three main levels where underground loading takes place, namely 93, 95, and 100 level. This loading results in approximately 22min of available time in the shaft being lost to loading personnel on these levels. Figure 6.36, below, is a schematic representation of the underground cage loading process. The process is demonstrated and then analysed by means of a modified spaghetti diagram, which was used to uncover potential waste in the process and identify improvements.

The figure above is a plan view of the shaft station area, including turnstiles and 2-deck cage in position inside the shaft barrel. Below is the side view of the cage being loaded, indicated by colour-coded arrows, where the top deck is indicated by green and bottom deck by maroon. The final figure below is a modified spaghetti diagram indicating a series sequence where 90 persons are first loaded onto the bottom deck and thereafter another 90 persons are loaded onto the top deck. Therefore, the turnstiles (1 and 2), together, pass 180 persons through.

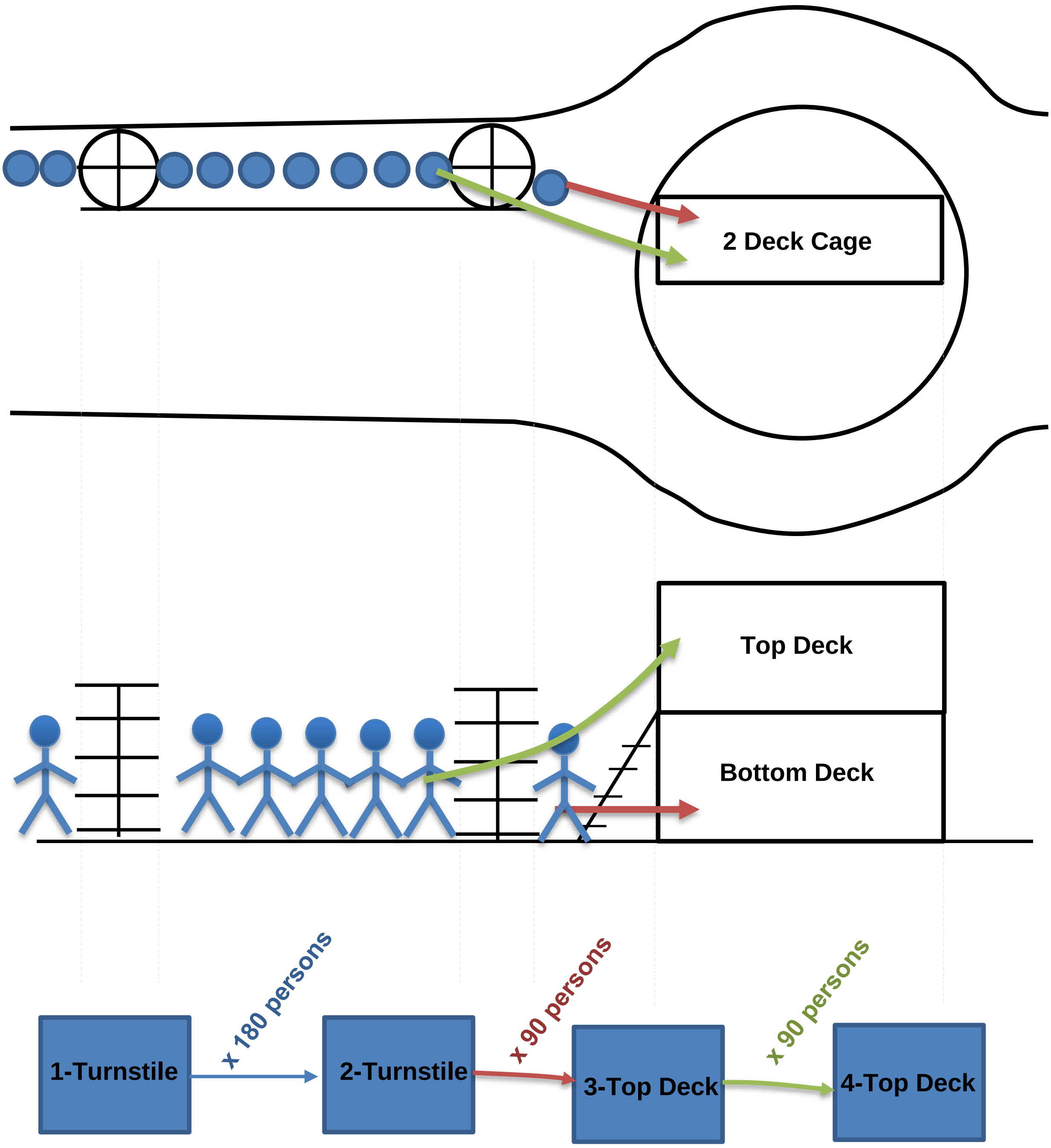


Figure 6.36: Current-state spaghetti diagram — underground cage loading process (NVA-8)

It is clear from the above modified spaghetti diagram that 180 persons are loaded in single file into the cage, which has two separate loading points, a top and bottom deck. The loading time per person when travelling from Turnstile 2 to the cage can therefore be multiplied by 180, which then generates the total of approximately 7.5 minutes to load the cage (2.6sec per person). It was considered highly desirable to reduce this loading time in the *Improve* phase, and the loading configuration would perhaps also be considered.

6.1.5.4.9 NVA-9: *Levelok clamping time*

Background and problem:

The Levelok system locks the cage with occupants in position on the shaft steelwork (guides) upon arrival at the underground station, prior to offloading personnel. This ensures that the cage remains stationary at depths in excess of 2 500m underground during offloading or loading. The cage is fitted with a hydraulic power pack driven by a compressed air pump. The power pack delivers pressure into a system with four clamps, which, in turn, apply against the four guides in the shaft on which the cage runs. When the clamps are applied, the cage can be offloaded or loaded safely, without movement of the cage due to subsequent rope elastic deformation (rope stretch).

When reviewing the design criteria and output specifications of the Levelok system, it was evident that the clamping time required should be within the region of 20sec to 30sec; however, the installed system operating at Twin Shaft had an average clamping time of 1min22 sec. In certain instances, clamping time exceeded 3min. When raising or lowering personnel or material cars, this type of time delay accumulates for every stop on every station, resulting in major time delays over a 24-hour period. The technical staff of the original equipment manufacturers, together with the mine's electrical and mechanical maintenance teams, were subsequently invited to conduct a root cause failure analysis. The findings are provided in Table 6.14, below.

Table 6.14: Root cause failure analysis (RCFA) — 5 Why analysis including actions to prevent reoccurrences

Failure:	1 minute 22 seconds for clamps to be fully applied versus the 30-second design specification
1st Why?	Clamps take too long to approach guides with the compressed air quick-approach function
2nd Why?	Incorrect quick-approach time setting
3rd Why?	Inadequate proactive functionality testing by maintenance staff
4th Why?	Inadequate planned inspection/maintenance strategy
5th Why?	Inadequate implementation of manufacturer's maintenance manual tactics in mine's computerised maintenance management system (CMMS)
Actions to prevent a reoccurrence:	

1	Rectify quick-approach time setting
2	Review manufacturer's maintenance manual tactics
3	Include manufacturer's maintenance tactics in mine CMMS system
4	Generate daily CMMS work orders for the inspection and testing of the Levelok clamping times by mine electrician and fitter
5	Generate monthly CMMS Levelok system audit by manufacturer
6	Conduct training of operational staff (onsetters and banksmen) to identify incorrect operating times and report defects to mine control centre
7	Training by manufacturer of maintenance staff to enable the quality inspections and maintenance

6.1.5.4.10 NVA-10: *Apply Levelok*

Background and problem:

Levelok application is conducted underground, at the stations, by the onsetter, who is responsible under mining legislation for safely loading and offloading personnel and material on mine conveyances (cages). The Levelok is applied by means of a pneumatic hose coupled directly to the system, which is fixed to the cage. When the cage is stopped at the underground station, the onsetter unplugs the pneumatic (fly) hose from the park panel and then couples the hose by quick coupler to the cage supply fitting point. The compressed air available on the underground station then passes into the cage-mounted Levelok system, at which point the clamps begin their quick-approach process to the guides. Once the four clamps are secured against the guides, the hydraulic intensifier (pump) is activated by the pneumatic supply pressure, and the clamps begin exerting a force perpendicular to the guides. Once the system-designed working pressure is achieved, a green indication light is activated, indicating that it is safe to load or offload the cage.

Through observation of this process, it was identified that, on average, 1min20sec elapsed during the process of unplugging the pneumatic hose from the park panel and fastening the hose by quick coupler to the cage supply fitting/point. The spaghetti diagram below demonstrates sources of waste in the process.

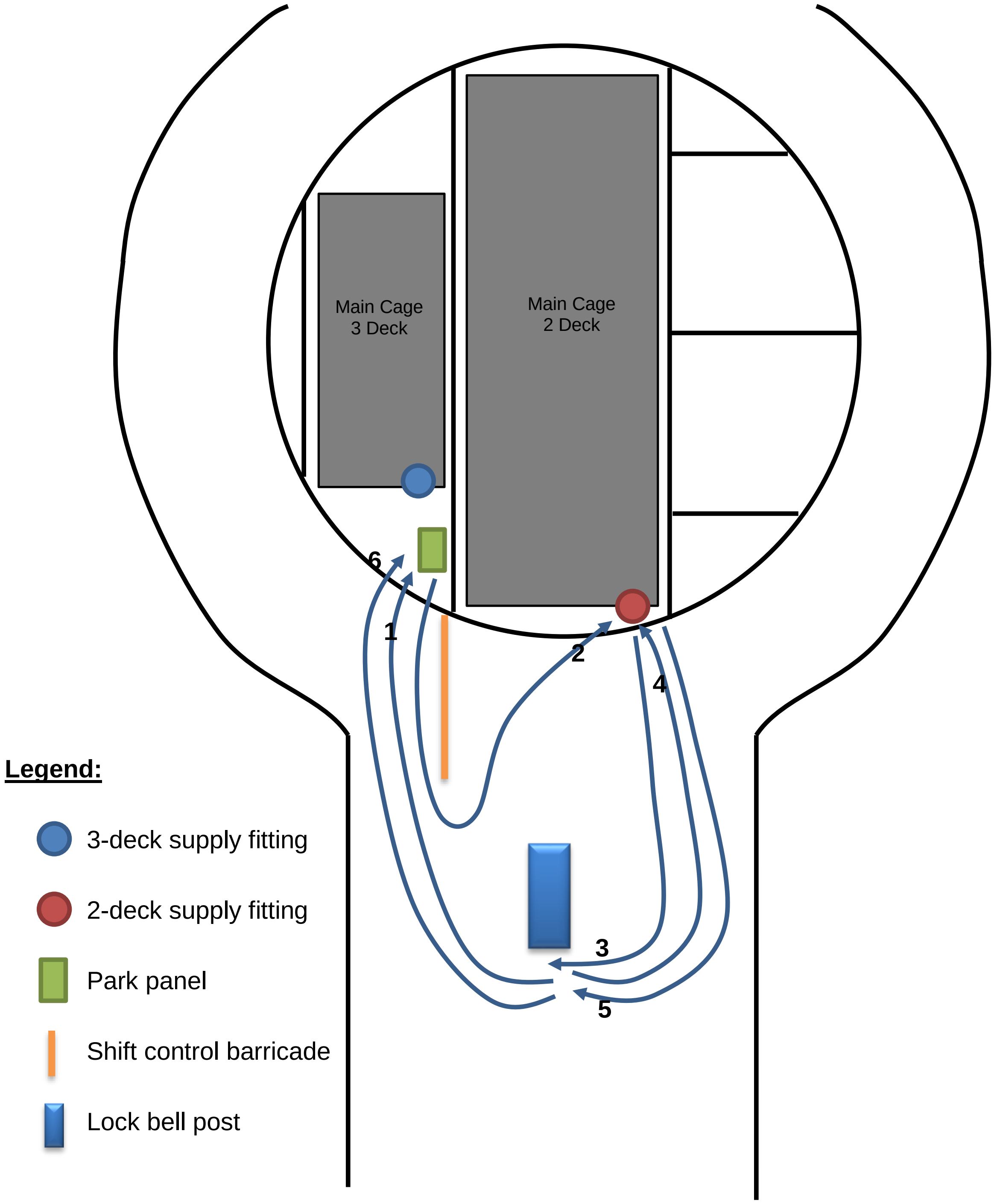


Figure 6.37: Current-state spaghetti diagram — Levelok application process onto 2-deck cage (NVA-10)

It is evident from the analysis in Figure 6.37, above, that six movements in total are made from the time the cage arrives at the station until the Leveloks are applied. In the interest of improving the application time, the following had to be performed, if possible, during the *Improve* phase of the DMAIC Model:

1. Reduce number of movements (decrease time of overall process);
2. Reduce travelling distances between movements (decrease time between movements); and
3. Change positions of components (decrease time between movements).

6.1.5.4.11 Findings: Detailed analysis of identified sources of waste

The table below provides a summary of the findings uncovered during the detailed analysis of the identified sources of waste. These findings were carried over to the *Improve* phase of the DMAIC Model, in which solution-generation and selection are pursued.

Table 6.15: Summary of findings — detailed analysis of identified sources of waste

NVA Code	**NVA Description**	**Issues outcome register**
NVA-1	*Wait for man carriage*	NVA-1.1: Train capacity and cage capacities differ; therefore, the train will depart full whilst employees remain behind waiting for the train to return (cage capacity is 180, whilst train capacity is 120).
		NVA-1.2: There is only one train planned for horizontal transport of personnel to both Two West and Three West working places. The train transports a portion of the Two West employees inside, and then does not return at the same time as the cage for the Three West employees to transport them inside. Hence unnecessary waiting occurs.
		NVA1.3: There is no formal train schedule that is properly aligned with the shaft schedule to ensure zero waiting time.
NVA-2	*Wait for crew*	NVA-2.1: Train capacity versus cage capacity (As with NVA-1.1)

		NVA-2.2: Crew members walk inside by choice, despite the availability of trains (behavioural issue).
		NVA-2.3: Horizontal transport is misaligned with shaft schedule; hence, not all employees utilise the trains. Due to a portion of the crew walking, all crew members do not arrive simultaneously. The waiting place meeting is delayed until all crew members arrive (systemic issue).
NVA-3	*Walk to waiting place*	NVA-3.1: Physical walking distance between loading/offloading bays and the waiting places, especially where Two West is concerned.
NVA-4	*Mustering Room*	NVA-4.1: Determine necessity of the Mustering Room meeting, considering legislative requirements and operational risk.
NVA-5	*Walk to station*	NVA-5.1: No trains were ever scheduled for the collection of personnel at the end of their shift.
		NVA-5.2: There is a lack of integration between vertical and horizontal logistics, as well as mining operational departments, with regard to personnel transport planning (inadequate systems engineering and a holistic/interdisciplinary approach in planning personnel logistics/transport).
NVA-6	*Meal collection*	NVA-6.1: There is congestion around meal-collection service hatch, leading to a time delay (Systemic issue)
		NVA 6.2: Personnel collecting meals is at the expense of shift duration and face time (systemic issue).

NVA-7	*General discussions at waiting place*	NVA-7.1: No approved standard procedure is in place to strictly govern the meeting agenda.
		NVA-7.2: There is a lack of control/monitoring of the duration of the waiting place meeting.
NVA-8	*Underground cage loading*	NVA-8.1: Although multiple cage decks are available, only one deck is loaded at any one time, as all personnel are controlled in single file through a single turnstile.
		NVA-8.2: There is a time delay for every person passing through a turnstile to be loaded into the cage when it is already in position.
NVA-9	*Levelok clamping*	NVA-9.1: The quick-approach time setting is incorrect. (See RCFA and solutions Table 6.13)
NVA-10	*Apply Levelok*	NVA-10.1: Levelok application process is unduly onerous.

6.1.6 *Improve* — Maximising face time (Optimisation section)

6.1.6.1 Generation and selection of appropriate solutions

Generation of ideas to resolve the issues uncovered during the *Analyse* phase of the DMAIC Model involved the utilisation of multiple variants of brainstorming techniques. Idea-generation was conducted in a team environment, and included personnel closely involved with the process being analysed. Creativity and innovation are particularly vital in this step, and, therefore team members' ideas were allowed to flow freely. The solutions selected through this facilitated team environment are discussed below.

6.1.6.1.1 NVA-1: *Wait for man carriage*

NVA-1.1: Train capacity

As the cage capacity is a maximum of 180 persons and the current train capacity is only 120, the train capacity had to be aligned with the cage capacity. As each man carriage is designed to carry 40 persons and there are three man carriages per train, the inclusion of two additional man carriages per train would result in five carriages in a train, with a total capacity of 200 persons if fully laden.

NVA-1.2: Number of trains

The first 200-seater train will depart to Two West with a full first cage (180) persons. The second full cage of Three West personnel will be loaded into a second 200-seater train. The trains will be stationed one behind the other, ready and in position at the start of the shift, and will depart directly after one another, in alignment with the first two cages of personnel being lowered down the shaft, thereby eliminating any waiting time. Trains are to be stationed at the start of shift, as illustrated in Figure 6.38.

NVA-1.3: Formal train schedule (integrated logistics schedule)

The development of an optimised shaft schedule, train schedule, waiting place schedule, and work schedule was performed later in the solutions-generation process. These schedules were developed through a holistic interdepartmental systems approach involving all relevant logistics and operational functions. The final outcome would be a model — Twin Shaft Integrated Logistics Schedule (IPLS) — which would cater for all internal personnel transportation and logistics processes, as well as their interdependencies.

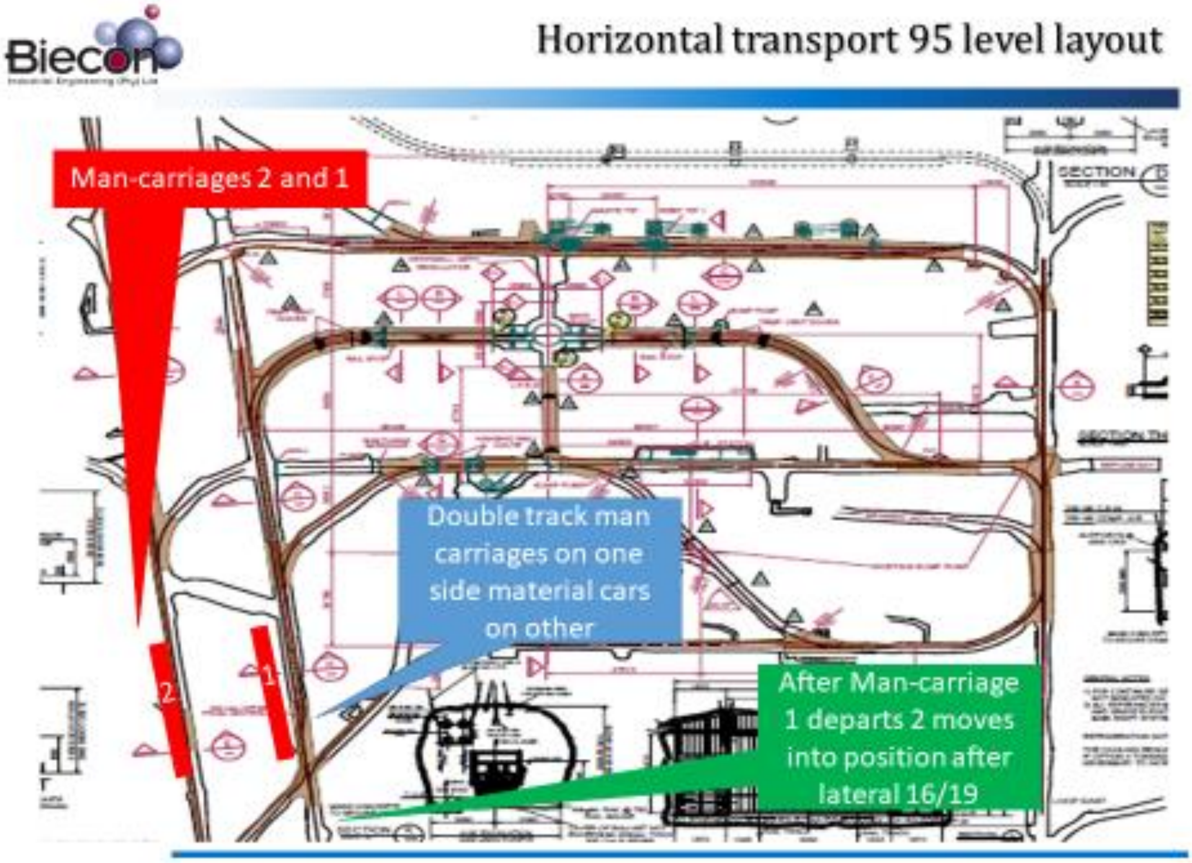


Figure 6.38: Inclusion of second 200-seater train per NVA 1.2. Courtesy of Biecon Industrial Engineering and Gold Fields (2017)

6.1.6.1.2 NVA-2: *Wait for crew*

NVA-2.1: Train capacity

The solution in this case is as per NVA-1.1 — increasing train capacity to a 200-seater from a 120-seater.

NVA-2.2: Discretionary utilisation of trains

It was observed that certain personnel decided not to use the trains at all, preferring to walk. This resulted in waiting place meetings being delayed, as persons walking and those travelling in the train arrived at different times. Through facilitated brainstorming exercises with the team, various solutions were generated, and the method illustrated by Figure 6.39, below, was selected.

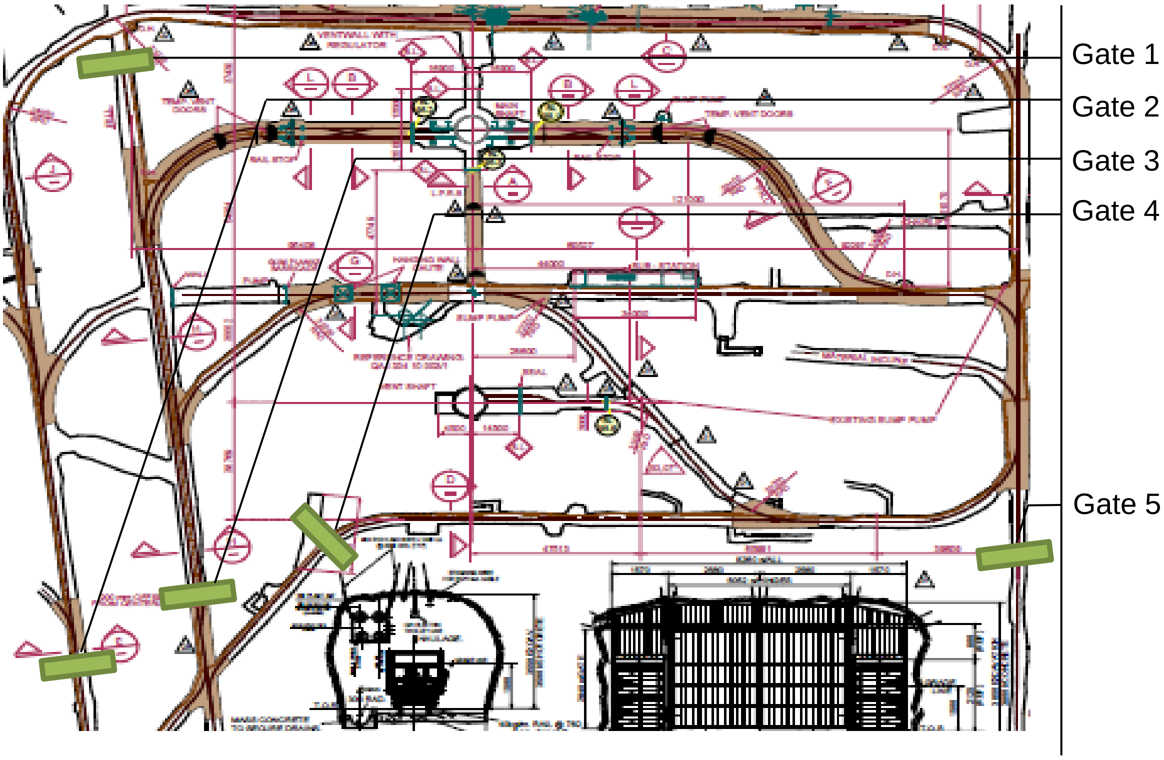


Figure 6.39: Positioning of access control gates into 95 level haulages (NVA 2-2). Courtesy of Gold Fields

As illustrated above, all accesses into 95-level working places and haulages are to be access controlled at the start of shift by means of access control gates. These gates are to be locked at the start of shift, and only opened to allow the train to pass through when full. After all personnel have been lowered in the shaft and transported inside by train, the gates will all be unlocked, to allow normal ore and material hauling/tramming activities to commence.

NVA-2.3: Shaft and train schedule misalignment

The solution in this case is as per NVA-1.3 — to develop an integrated logistics schedule (Model).

6.1.6.1.3 NVA-3: *Walk to waiting place*

NVA-3.1: Physical walking distance

The average walking distance from the train offloading bays to the respective working areas' waiting places at Two West and Three West, are 485m and 220m respectively. Through the repositioning and reconstruction of these waiting places, these walking distances could be significantly reduced. The figure on the following page illustrates the new positioning of the loading/offloading bay, relative to their waiting places.

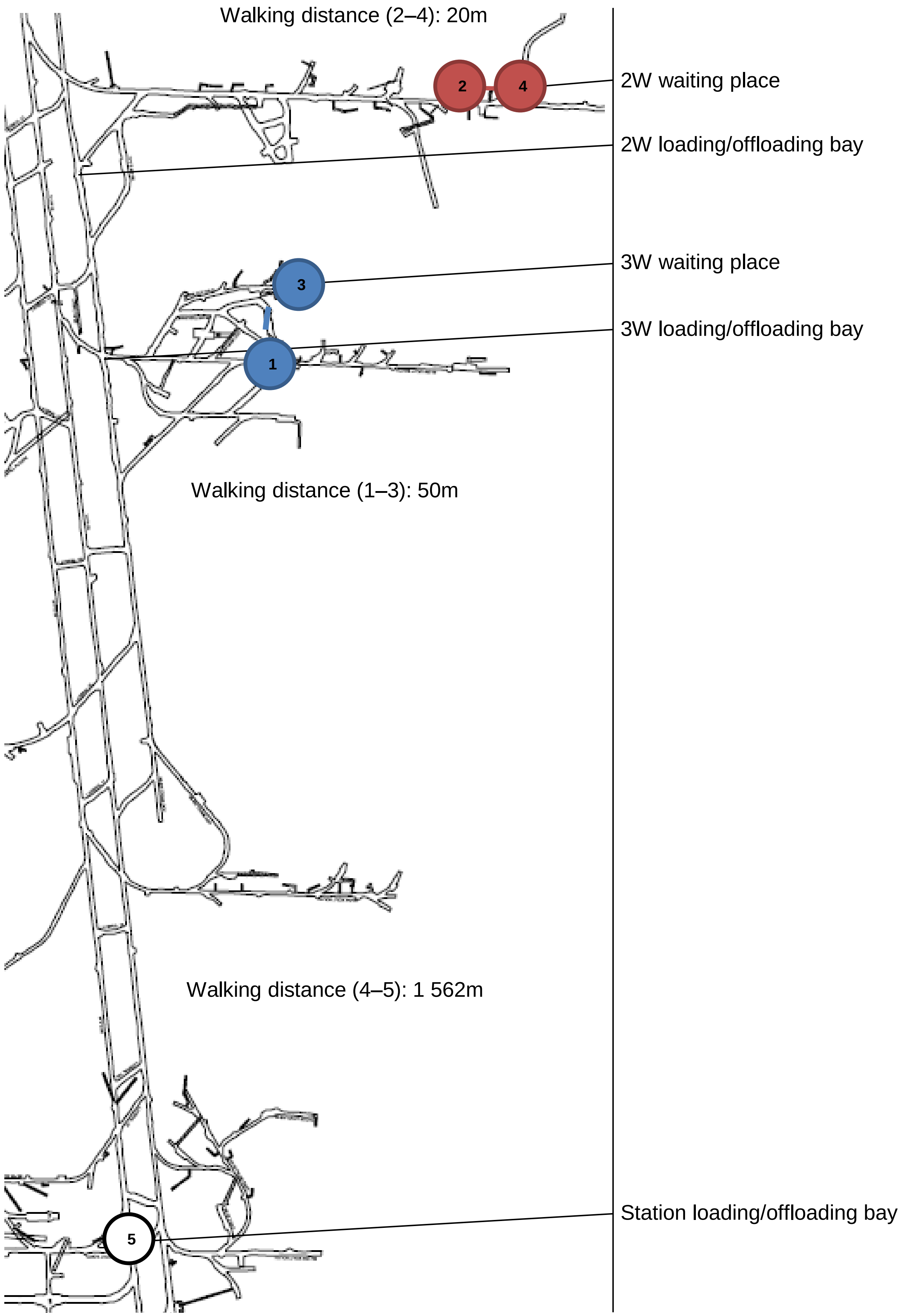


Figure 6.40: Level plan (95 level) indicating personnel new walking routes. Courtesy of Gold Fields

As can be seen in Figure 6.40, above, Two West's walking distance was reduced from 485m to 20m, and Three West's walking distance was reduced from 220m to approximately 50m. This mitigation of waste (in the form of excessive motion) resulted in a lessening of walking time by 95% and 77% for Two West and Three West respectively. The new theoretical walking times for Two West and Three West were 47sec and 4min19sec respectively. These values are rounded up to the nearest minute in the rest of discussions in this paper. Thus, Two West's new physical walking time was 1min and Three West's was 5min.

6.1.6.1.4 NVA-4: *Mustering Room*

NVA-4.1: Cancellation of Mustering Room meeting

The main issue to be addressed here was the necessity of the Mustering Room meeting, with consideration of legislative requirements and operational risk. Through the review of the Mine Health and Safety Act 29 of 1996 (MHSA) as well as the Minerals Act 50 of 1991, (MA) in force in terms of item 4 of schedule 4 of MHSA, as well as other applicable legislation, mine standards, and procedures of South Deep Gold Mine, the decision was taken to conduct a risk assessment regarding the cancellation of the scheduled Mustering Room meetings held on surface at the start of shift. The outcome of the risk assessment would indicate whether the cancellation of the meeting would result in any significant risk to the health and safety of persons.

The risk when considering the consequences and their probability with regard to cancellation of this meeting was deemed insignificant in terms of health and safety, the environment, and the company as a whole, based on the certain factors, current controls, and risk mitigation measures already in place, which included:

1. This specific meeting is not mandatory under legislation (MHSA and Minerals Act);
2. The meeting is not required by any Gold Fields standard, procedure, or code of practice;
3. Daily safety meetings are conducted between line supervisors and their teams underground; and
4. Weekly safety meetings chaired by senior management are conducted, where supervisors are briefed on all current matters related to health, safety, and the environment.

The review showed that this meeting is not specifically governed by any legislation. In terms of Section 11 of the MHSA, where the employer is required to assess and respond to risk, the issue-based risk assessment conducted indicated that the cancellation of the meeting would not generate any significant risk to the health and safety of persons, as sufficient control measures were already in place.

6.1.6.1.5 NVA-5: *Walk to station*

NVA-5.1: No trains scheduled for transport at end of shift

The main issue to be addressed here was the fact that no trains were scheduled for the collection of personnel at the end of their shift. As the loading/offloading bays had been moved closer to the waiting places and specific train schedules were to be developed, which would be aligned with the shaft schedule, the scheduling of horizontal transport out of the mine would be included.

It must be borne in mind that, when considering the optimisation of face time, the transport of personnel out of the mine at the end of their shift is as vital as transport into the mine. The personnel logistics system is cyclic in nature, and any delays in the cycle, from start to finish, will diminish the mid-cycle key metric, namely the face time efficiency factor.

NVA-5.2: Lack of integrated logistics planning by relevant functions

Logistics planning between Vertical and Horizontal Logistics, as well as mining operational departments, is notoriously inadequate in terms of following a systems engineering (holistic/interdisciplinary) approach. The solution in this case was as per NVA-1.3, where the development of an integrated personnel logistics model would be required.

6.1.6.1.6 NVA-6: *Meal collection*

NVA-6.1: Congestion/time delay around meal-collection service hatch (systemic issue)

In order to alleviate congestion, various other service hatch and queuing activities in other industries were considered and used as benchmarks. Through this process, a common linear queuing technique was adopted. Queuing techniques are known systems put in place to serve customers in a manner that is orderly, which prevents chaos and ensures individuals are served equitably. Service disciplines were considered, and the first-in-first-out (FIFO) scheduling policy was selected, also called *first-come first-served* (FCFS).

The figure below indicates the results of the timeplot analysis for this particular queue. The average service time through observation was found to be in the order of 3sec, whereas the inter-arrival time of persons at the queue was 1sec. As indicated in Figure 6.33, the meal-collection bay’s hatch has two service points. A decision was therefore taken to create to queues, each with a dedicated server. Figure 6.41, below, is a schematic representation of the new layout of the service hatch, including the queueing system.

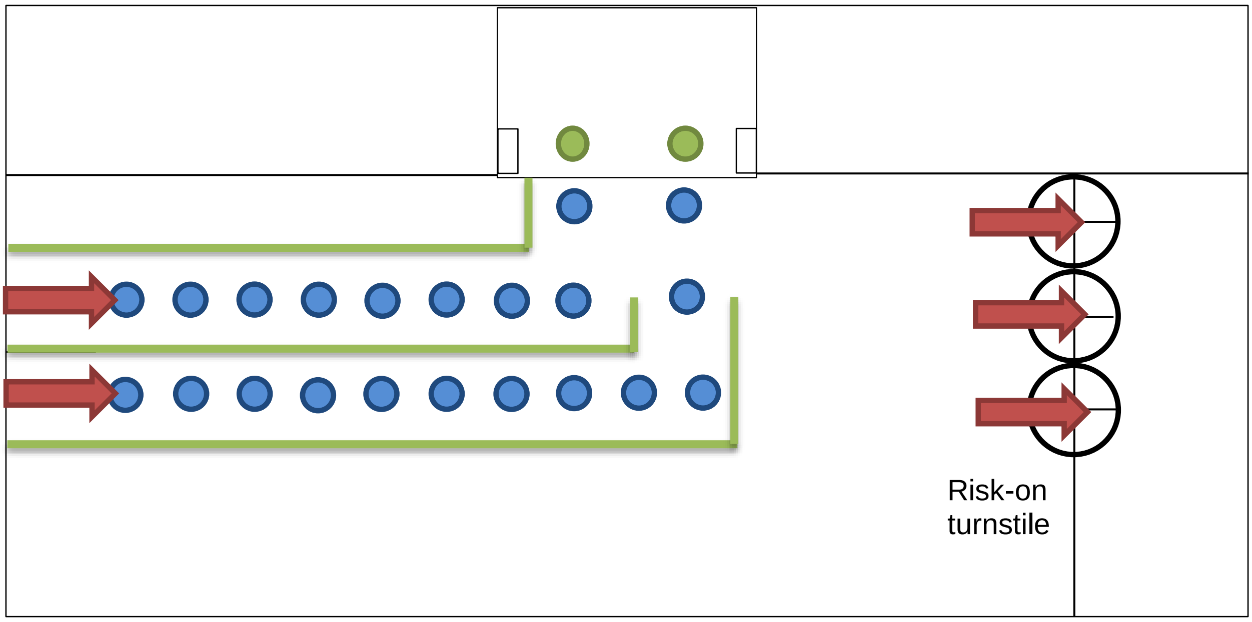


Figure 6.41: Schematic representation of layout and queuing system for meal-collection bay

The theoretical queueing system's performance was determined by means of a timeplot study, shown in Figure 6.42, below. The subsequent theoretical queue performance graphs are indicated in Figure 6.42, which indicates the service of 180 persons (one cage) in 270sec or 4.5min. The theoretical queuing system was put into practice using temporary stanchions, and examined through time–motion studies. The results showed that the average queue depletion rate was comparable to that of the theory, where the average queue depletion rate was found to be in the region of 5min. The variation was found to be as a result of the non-perfect linear inter-arrival times of persons at the queue. Fixed stanchions/handrails were thereafter installed to control the queue flow, as indicated in Figure 6.41, above.

The extract from the timeplot figure, indicated below, shows Collection Bay 1's performance on the left of the figure and Collection Bay 2's on the right. On the far right of the figure is their overall queue performance of the two-queue, two-server system. The first 13sec of the process is illustrated below.

Timeplot — FIFO Queue												
	Meal-collection Point 1 — Server 1					**Meal-collection Point 2 — Server 2**					**Combined queue performance**	
Serving time	**3 seconds**					**3 Seconds**						
Inter-arrival time	**1 Seconds**					**1 second**						
Code description:	**P = Person**	**Prefix**				**P = Person**	**Prefix**					
	Numerical value	**Suffix**				**Numerical value**	**Suffix**					
Elapsed time (seconds)	**Number of persons served**	**Code**	**Arrivals**	**Persons in queue**	**Queue length (persons)**	**Number of persons served**	**Code**	**Arrivals**	**Persons in queue**	**Queue length (persons)**	**Total number of persons served**	**Total queue length (persons)**
0	1	P1	P1		0	1	P1	P1		0	2	0
1	1		P2	P2	1	1		P2	P2	1	2	2
2	1		P3	P2, P3	2	1		P3	P2, P3	2	2	4
3	2	P2	P4	P3,P4,	2	2	P2	P4	P3, P4	2	4	4
4	2		P5	P3, P4, P5	3	2		P5	P3, P4, P5	3	4	6
5	2		P6	P3, P4, P5, P6	4	2		P6	P3, P4, P5, P6	4	4	8
6	3	P3	P7	P4, P5, P6, P7	4	3	P3	P7	P4, P5, P6, P7	4	6	8
7	3		P8	P4, P5, P6, P7, P8	5	3		P8	P4, P5, P6, P7, P8	5	6	10
8	3		P9	P4, P5, P6, P7, P8, P9	6	3		P9	P4, P5, P6, P7, P8, P9	6	6	12
9	4	P4	P10	P5, P6, P7, P8, P9, P10	6	4	P4	P10	P5, P6, P7, P8, P9, P10	6	8	12
10	4		P11	P5, P6, P7, P8, P9, P10, P11	7	4		P11	P5, P6, P7, P8, P9, P10, P11	7	8	14
11	4		P12	P5, P6, P7, P8, P9, P10, P11, P12	8	4		P12	P5, P6, P7, P8, P9, P10, P11, P12	8	8	16
12	5	P5	P13	P6, P7, P8, P9, P10, P11, P12, P13	8	5	P5	P13	P6, P7, P8, P9, P10, P11, P12, P13	8	10	16
13	5		P14		9	5		P14		9	10	18
269	90				0	90				0	180	0

Figure 6.42: FIFO two-row, two-server queueing process designed for the meal-collection bay at Twin Shaft

Figure 6.43: FIFO individual queue performance (Server 1 and 2) as well as two-row, two-server queueing system combined performance output

NVA-6.2: Personnel collecting meals at the expense of shift duration and face time (systemic issue)

As can be seen in Figure 6.39, above, the risk-on turnstile position was changed from its original position before the meal-collection bay. By positioning it after the meal-collection area, the personnel shift duration now only starts depleting once the meal-collection process is complete.

In terms of the logistics process, the meal-collection function is considered waste, as it may be categorised as an NVA activity when considering the seven forms of waste (*muda*) of Lean principles. Due to the changes mentioned, face time, which is the primary metric of this research, is now unaffected by the meal-collection process, and the 11min previously spent collecting meals were immediately converted to available face time. It is imperative to note the importance of optimising the actual queueing process (NVA-6.1), as personnel now collect meals on their own personal time; however, meal collection is still optional.

6.1.6.1.7 NVA-7: *General discussions at the waiting place*

NVA-7.1: No approved standard procedure in place that strictly governs the meeting agenda

To prevent time being wasted in general discussions held at waiting place at the start of the shift, a formal agenda has to be drafted by the Safety Department and mining operations departments, and then included in an SOP for the waiting place meeting. The agenda has to indicate a fixed allotted period for the meeting, which has to be complied with as part of the waiting place SOP.

In the event that special circumstances (safety- or production-related) delay the meeting, the section mine overseer or section manager is to be informed by the miner or shift supervisor chairing the meeting. The allocated time for the waiting place meeting may not exceed 30min. Discussions that are not part of the agenda are deemed a breach of SOP, and the relevant employee or supervisor will be dealt with in accordance with the mine’s disciplinary codes.

NVA-7.2: Lack of control/monitoring of waiting place meeting duration

Included in the SOP is the manner in which waiting place meetings are to be controlled and monitored. This control and monitoring system is illustrated in Figure 6.42, below.

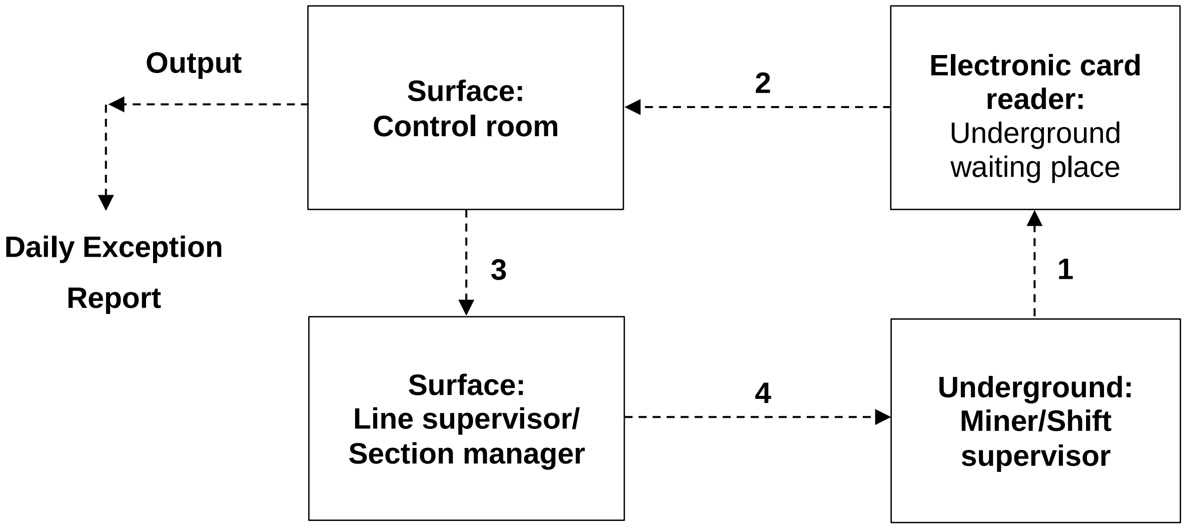


Figure 6.44: Waiting place meeting duration compliance control system

The steps in the figure above are explicated below.

1: Supervisor and crew access waiting place by electronic card reader

- The crew arrive at the waiting place and all use their personnel access cards to gain access.
- After the meeting, all personnel use their access cards to exit the waiting place, to walk to their working places.

2: Electronic card reader’s signal to central control room (surface)

- Control room operator generates a report of arrival and departure times.
- Control charts with upper and lower control limits are programmed into the report.
- The daily exception report is distributed to mine management to respond to deviations and any special cause variations.

3: Control room reports deviations (meeting exceeded 30min) to line supervisor/section manager (surface)

- Control room operator immediately reports any deviation in arrival or departure time to the responsible line supervisor/section manager, telephonically, by two-way radio communication, or electronic mail.

4: Surface: Intervention by line supervisor and/or section manager (surface)

- Line Supervisor and/or Section Manager intervenes by contacting crew underground to assist in resolving the cause of the delay.

6.1.6.1.8 NVA-8: *Underground cage-loading process*

NVA-8.1: Although multiple cage decks are available, only one deck is loaded at any one time, as all personnel are controlled in single file through a single turnstile

The future-state spaghetti diagram below shows the solution selected regarding the underground cage loading process.

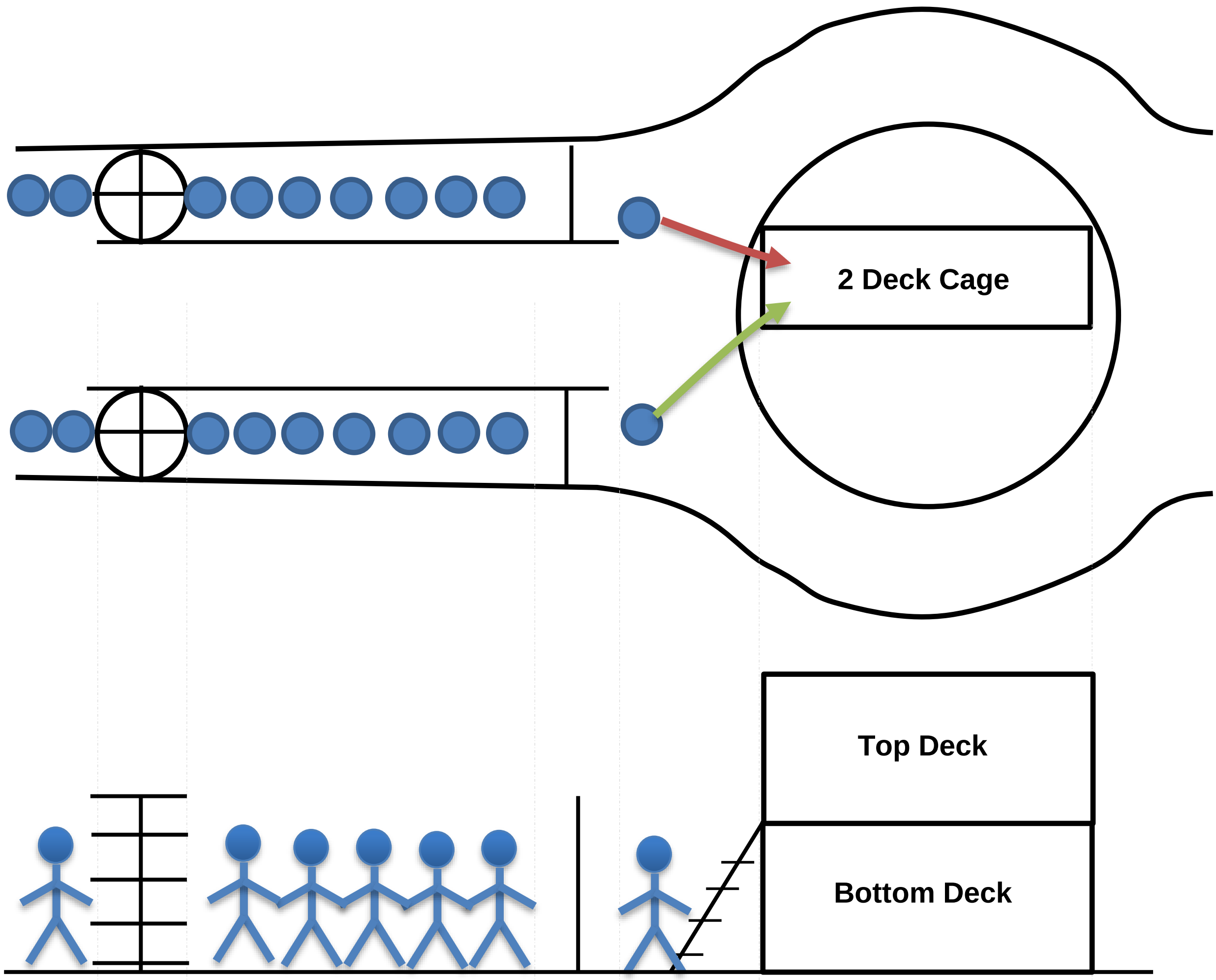


Figure 6.45: Future-state station layout — dual-stream loading

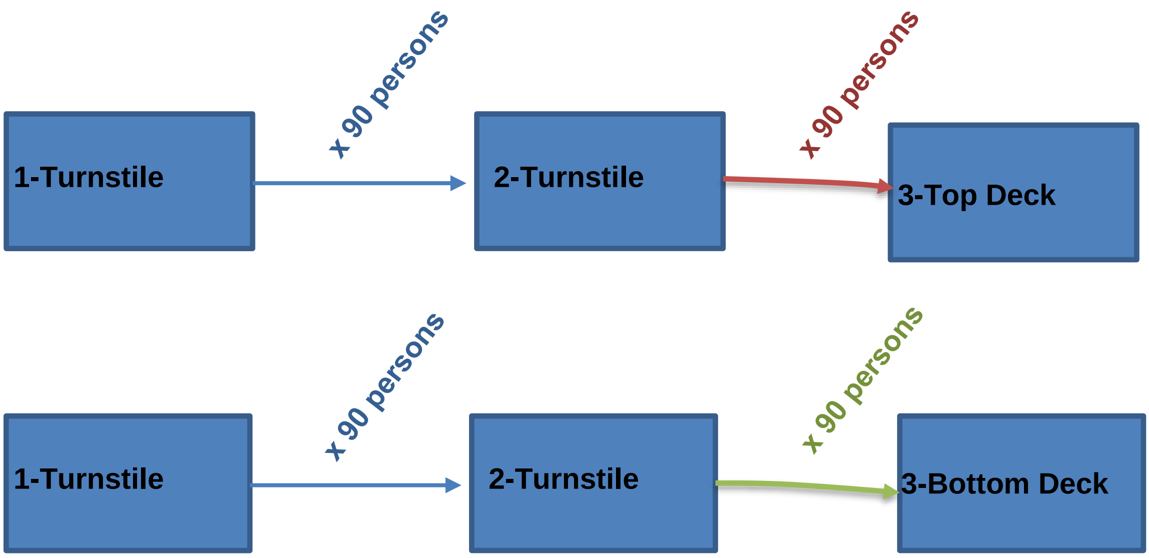


Figure 6.46: Future-state spaghetti diagram — dual-stream underground cage-loading process (NVA-8)

As can be seen when comparing Figure 6.36 (current state) with Figure 6.46 (future state), the cage loading sequence has been split into two streams. The loading time has therefore theoretically been halved. The total number of movements in the steady-state process was 180 persons in the single-stream process, loaded in sequence. The total number of movements in the future-state process is 90 persons per stream, loaded concurrently.

NVA-8.2: Time delay for every person to pass through a turnstile to be loaded into a cage already in position

As can be seen in Figure 6.45, above, the front turnstile nearest to the shaft barrel was removed and replaced with a normal lockable gate. The time taken per person passing through the turnstile is approximately 3sec, where passing through an open gate is less than 2sec. Therefore, dual-streaming and removal of the front turnstile significantly reduced the underground cage-loading time. After implementation of dual-stream loading, the NVA time reduced from 7min49sec to 3min54sec. Through the replacement of the turnstiles with regular swing gates, the time further reduced by 90sec, as 1sec was saved when travelling through the gate when compared to the turnstile (difference between 3sec and 2sec).

The new underground cage loading time is therefore approximately 2min24sec, which is an approximate 325% saving in face time.

6.1.6.1.9 NVA-9: *Underground cage-loading process*

NVA-9.1: Incorrect quick approach time setting

Through the root cause failure analysis using the 5 Why method (reported in Table 6.14), it was determined that the quick-drop setting had to be adjusted to specification. The planned maintenance approach was also enhanced, to prevent a repeat of this system fault in future. This reduced the clamping time from 1minute22sec to 15sec, which is a significant reduction in NVA time.

6.1.6.1.10 NVA-10: *Underground cage-loading process*

NVA-10: Levelok application process unduly onerous

Per the future-state spaghetti diagram below, in Figure 6.47, the number of movements remained the same (6); however, the overall distance of travel in these six movements was reduced (using a work cell optimisation study). The temporary shift-control barricade was removed and the Levelok park panel was moved to the centre of the two conveyances. As a result, the distances travelled by the onsetter during this process were reduced, realising a total saving in time of 20sec.

In conclusion, through the enhanced NVA activity analysis, improvement solutions were developed. The problems were first correctly defined, the root causes and cause–effect relationships clarified, and, through group brainstorming involving process operators and owners, applicable improvement options were designed and prepared for implementation. These results are illustrated in the figure below.

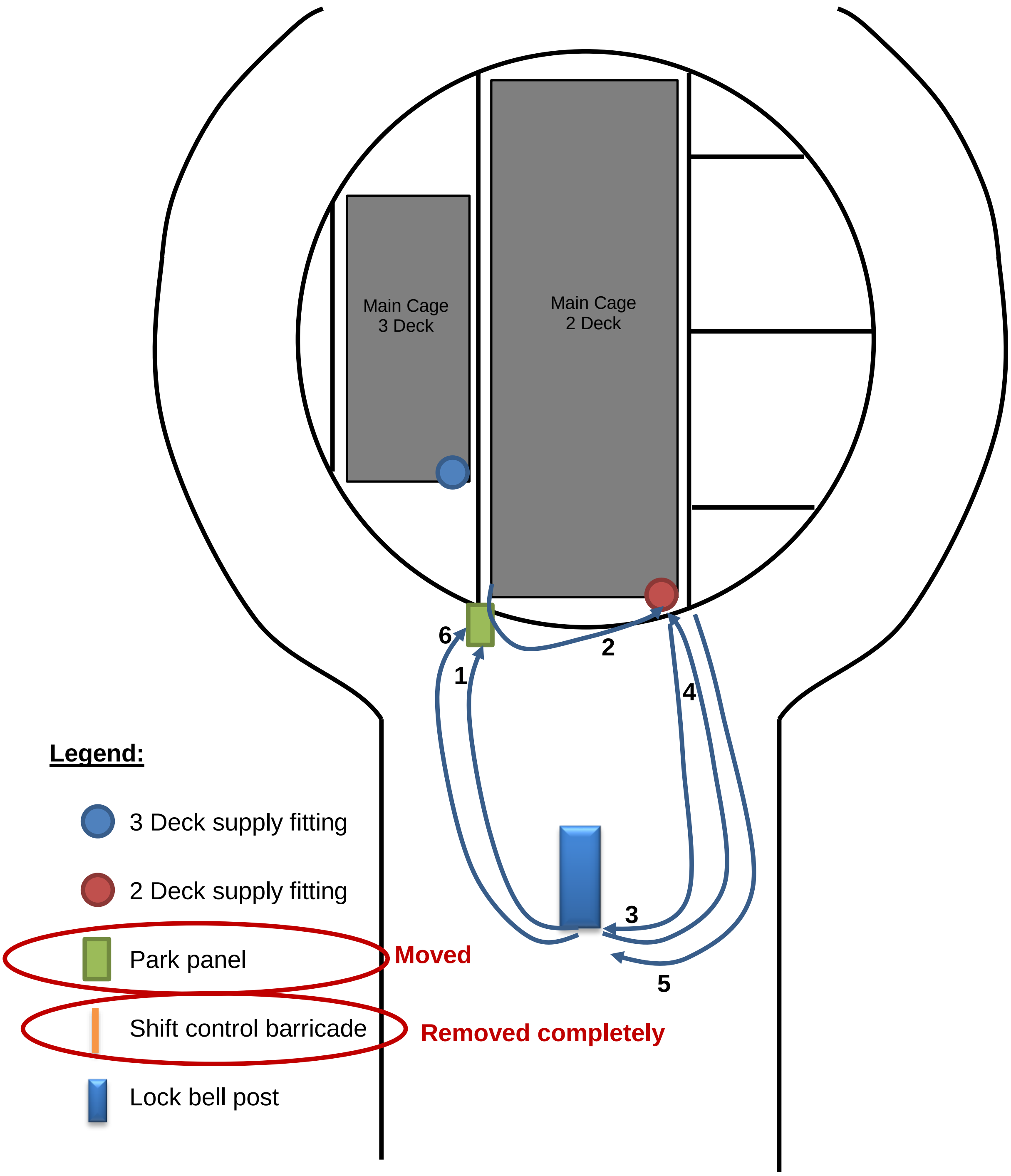


Figure 6.47: Future-state spaghetti diagram — Levelok application process onto 2-deck cage (NVA-10)

The table below includes all solutions generated and selected for each NVA activity requiring waste mitigation. The column on the far right of the table lists the items of the Solutions Register.

Table 6.16: Solutions Register for selected NVA activities

NVA code	**NVA description**	**Issues Outcome Register**	**Solutions Register**
NVA-1	*Wait for man carriage*	**NVA-1.1**: Train capacity (120) and cage capacity (180) differ; therefore, the train departs when full, and employees remain behind, waiting for the train to return	Increase capacity to five man carriages per train (200-person capacity)
		NVA-1.2: There is only one train planned for horizontal transport of personnel to both Two West and Three West working places. The train transports a portion of the Two West employees inside, and then does not return at the same time as the cage for the Three employees to transport them inside. Hence, unnecessary waiting occurs.	Inclusion of second 200-seater train to align with the shaft schedule and run directly after the first train departs, eliminating personnel waiting time.
		NVA1.3: There is no formal train schedule that is correctly aligned with the shaft schedule to ensure zero waiting time.	Develop Integrated Personnel Logistics Schedule (Model).
NVA-2	*Wait for crew*	**NVA-2.1**: Train capacity versus cage capacity	As per **NVA-1.1**: Increase to five man carriages per train (200 person capacity).
		NVA-2.2: Crew members walking inside by choice, despite the availability of trains (behavioural issue)	Installation of access control gates and mandatory utilisation of trains
		NVA-2.3: Horizontal transport misaligned with shaft schedule; hence, not all employees utilise the trains. Due to a	As per **NVA-1.3**: Develop Integrated

		portion of the crew walking, all crew members do not arrive simultaneously, and the waiting place meeting is delayed until all crew members arrive (systemic issue).	Personnel Logistics Schedule (Model).
NVA-3	*Walk to waiting place*	**NVA-3.1**: Physical walking distance between loading/offloading bays and the waiting places, especially where Two West is concerned	Reduction in walking distances by repositioning and reconstructing train loading/offloading bays
NVA-4	*Mustering Room*	**NVA-4.1**: Determine necessity of the Mustering Room meeting with consideration of legislative requirements and operational risk.	Mustering Room meeting cancelled.
NVA-5	*Walk to station*	**NVA-5.1**: The fact that no trains were ever scheduled for the collection of personnel at the end of their shift.	Include horizontal transport by train out of the mine at end of shift.
		NVA-5.2: Lack of integration between Vertical and Horizontal Logistics as well as mining operational departments with regard to personnel transport planning (inadequate systems engineering and holistic/interdisciplinary)	As per **NVA-1.3**: Develop Integrated Personnel Logistics Schedule (Model).
NVA-6	*Meal collection*	**NVA-6.1**: Congestion/time delay around meal-collection service hatch (systemic issue)	Dual-queue, dual-server system implemented
		NVA 6.2: Personnel collecting meals at the expense of shift duration, leading to loss of face time (systemic issue)	Risk-on turnstile moved to position after the meal-collection area, thereby ensuring shift duration is no longer impacted.

NVA-7	*General discussions at waiting place*	**NVA-7.1**: No approved standard procedure in place that strictly governs the meeting's agenda	SOP developed and implemented, and included in the induction training process for all mine personnel.
		NVA-7.2: Lack of control/monitoring of waiting place meeting duration	Electronic card reader system installed at waiting places, coupled with compliance exception reporting by Control Room
NVA-8	*Underground cage loading*	**NVA-8.1**: Although multiple cage decks are available, only one deck is loaded at any one time, as all personnel are controlled in single file through a single turnstile.	Implemented dual-stream loading
		NVA-8.2: Time delay for every person to pass through a turnstile to be loaded into the cage when cage is already in position	Removal of turnstile nearest to shaft barrel and replaced with gate.
NVA-9	*Levelok clamping*	**NVA-9.1**: Incorrect quick-approach time setting (See RCFA and solutions Table 6.14)	Rectified quick-approach setting and enhanced maintenance tactics
NVA-10	*Apply Levelok*	**NVA-10**: Levelok application process unduly onerous (Spaghetti diagram/ Work cell optimisation required)	Work-cell optimisation through removal of unnecessary screen and moved park panel

6.1.6.2 Mitigation of potential errors or consequences

It must be borne in mind that, through the implementation of the generated solutions, certain changes in the process environment were inevitable; therefore, the potential for the introduction of risk existed. It was imperative that these risks be identified and that mitigation or elimination measures be implemented, to prevent any consequences associated with the new solutions. In order to anticipate and address potential failures and subsequent consequences, a failure mode and effects analysis (FMEA) may be performed.

Such risks should be mitigated or eliminated through the implementation of additional control measures where necessary, although certain risks may be left untreated, based on risk priority ranking and tolerance thresholds. If the number and magnitude of risks involved in the improvements selected are considerable, a formal risk management plan may be required to ensure the successful implementation of improvements. Should the FMEA process identify significant risks that cannot be mitigated, . It may be necessary to suspend the implementation of the relevant idea generated for waste mitigation. All the NVA activities selected for solution-generation in the present study were deemed suitable for implementation after the FMEA analysis, and did not require a risk management plan.

6.1.6.3 Implementation of solutions and reviewing results

This section highlights the performance improvements after implementation of the selected solutions. The standard *Measure* and *Analyse* phase studies conducted are revised — from the current state to the future state — to demonstrate performance improvements according to primary metrics selected. The following future-state models and efficiencies are illustrated and discussed below:

- Time value analysis;
- TLT;
- PCE; and
- Cross-functional process flow diagram.

Table 6.17: Waste-mitigation results table (NVA)

The table below demonstrates the current- and future-state activity times after the implementation of the generated solutions. The table indicates whether an NVA activity was eliminated or merely mitigated.

Waste-mitigation results summary						
Code	**NVA activities**	**Current state activity time**	**Future state activity time**	**Eliminated**	**Mitigated**	**Face-time saving**
NVA-1	*Waiting for man carriage*	0:38:00	0:00:00			0:38:00
NVA-2	*Waiting for crew*	0:18:50	0:00:00	■		0:18:50
NVA-3	*Walking to waiting place*	0:18:40	0:00:47		■	0:17:53
NVA-4	*Mustering Room*	0:15:00	0:00:00	■		0:15:00
NVA-5	*Walking to station*	0:20:10	0:15:00		■	0:05:10
NVA-6	*Collect meal*	0:11:00	0:00:00	■		0:11:00
NVA-7	*General discussions*	0:19:00	0:00:00	■		0:19:00
NVA-8	*Loading cage underground*	0:07:49	0:02:24		■	0:05:25
NVA-9	*Levelok clamping*	0:02:44	0:00:30		■	0:02:14
NVA-10	*Applying Levelok*	0:01:20	0:00:40		■	0:00:40
Total face time saving						**2:13:12**

Note: NVA-9 and NVA-10 each occur twice during a full process (i.e. Levelok clamping takes 15 seconds x 2 = 30 seconds)

From the above table, the cumulative face time saving through the implementation of all solutions developed during the *Improve* phase amounted to 2h13min. The table below demonstrates the new/future-state time value analysis of the personnel logistics process.

Table 6.18: Twin Shaft personnel logistics — future-state time value analysis (personnel logistics process)

The table below illustrates the future-state personnel logistics process, after removal of NVA activities and with NVA-activity time saved through implementation of the *Improve* phase solutions. It must be noted that, as the two trains run consecutively, there is no need for an interval stop at Three West when transporting Two West employees inside; hence, additional face time of 3min30sec was saved.

Process step code	Process step name	Time (duration of activity)	VA	VE	Non-value-adding						
					D	I	M	T	O	W	N
1.1	**Clock in: Zone 1**	**0:00:04**									■
1.3	**Clock in: Zone 2**	**0:00:04**		■							
1.5	**Walk to shaft**	**0:02:00**					■				

1.6	Wait for cage	0:02:00									
2.1	Cage on bank/Open gates, doors	0:00:29									
2.1.1	Offload all decks	0:01:17									
2.2	Travel through turnstile	0:00:04									
2.2.1	Close and open gates	0:00:29									
2.3	Load cage	0:04:18									
2.3.1	Close door and gates	0:00:17									
2.4	Signal (ring away)	0:00:20									
2.4.1	Cage departs	0:00:40									
2.5	Lower to level	0:05:00									
2.6	Apply Levelok	0:00:20									
2.7	Levelok clamping	0:00:15									
2.8	Signal offload	0:00:02									
2.9	Open shaft and cage doors	0:00:12									
2.10	Offload all decks	0:02:17									
3.1	Walk to man carriage	0:02:00									
3.3	Drivers deboard train	0:00:35									
3.4	Open carriage doors	0:00:15									
3.5	Load carriage	0:06:15									
3.6	Close carriage doors	0:00:15									
3.7	Drivers board train	0:00:40									
3.13	Travel to Two West (2W)	0:15:00									
3.14	Driver deboard train	0:00:35									
3.15	Open carriage doors	0:00:15									
3.16	Offload carriages	0:02:00									
4.1	Walk to waiting place	0:00:47									
4.2	Safety meeting	0:10:00									
4.3	Planning meeting	0:10:00									
5.1	Walk to face	0:26:00									
5.2	Arrive at face (Milestone-No duration)	0:00:00									
5.3	Travel to waiting place	0:09:00									
5.4	Collect clock card	0:12:00									
6.1	Man carriage to station	0:15:00									
7.1	Clock in at station turnstile	00:00:08									
7.2	Walk into aisle way	00:00:30									
7.3	Wait in aisle way	00:01:00									
7.4	Cage arrival on station	00:00:05									
7.5	Unlock counting turnstile	00:00:09									

7.6	**Apply Levelok**	00:00:20									
7.7	**Levelok clamping**	**0:00:15**									
7.8	**Load signal/Open gates, doors**	0:00:12									
7.9	**Travel through turnstile**	0:00:04									
7.10	**Load cage**	0:02:24									
7.11	**Close gates, doors**	0:00:15									
7.12	**Release Levelok**	0:01:03									
7.13	**Ring away to bank**	0:00:27									
7.13.1	**Cage departs**	0:00:32									
7.14	**Travel to bank**	0:05:00									
7.15	**Signal/Open doors, gates**	0:00:29									
716	**Offload on bank**	0:02:17									
8.1	**Walk to Lamp Room**	0:02:00									
8.2	**Clock out at turnstile (security search)**	0:02:00									
Total time		**02:29:53**									
Time			00:40:00	01:07:46			00:30:38			00:11:25	00:00:04
% of time			**26.7**	**45.2**	**0.00**	**0.00**	**20.4**	**0.00**	**0.00**	**7.62**	**0.04**

As shown in the above table, the new personnel logistics process cycle time is approximately 2h30min. The percentage of time spent on NVA activities was approximately 28%, compared to the current state of approximately 69%. The percentage of VA time had increased from the initial approximately 8% to the new approximately 27%. The process, at this point, seemed far more efficient with regard to cycle time; however, this was calculated for validation purposes by means of the process cycle time calculations to follow.

<u>New total lead time:</u>

The average completion rate is 180 persons through the end-to-end process in a new total cycle time of 2h29min, which is 149min53sec, exactly, which equates to an average completion rate of 1.208 persons per minute.

Thus:

$$TLT = \frac{WIP}{Ave.\ Rate}$$

$$TLT = \frac{180}{1.208}$$

$\underline{TLT = 149\ minutes}$

The total lead time for the process is 149min to get the entire work in progress (persons) through one defined end-to-end personnel logistics process. PCE was calculated as follows:

$$PCE = \frac{VA}{TLT}$$

$$PCE = \frac{40}{149}$$

$$PCE = 0.268\ as\ a\ factor$$

$$PCE = 0.268\ x\ 100$$

$$\boldsymbol{PCE = 26.8}\%$$

As previously stated, PCE is directly proportional to VA time and inversely proportional to TLT. The strategic approach in the *Analysis* and *Improve* phases was to increase VA time in the process and/or to reduce TLT.

Twin Shaft's personnel logistics process now has a PCE above 25%, and can therefore be considered a lean process.

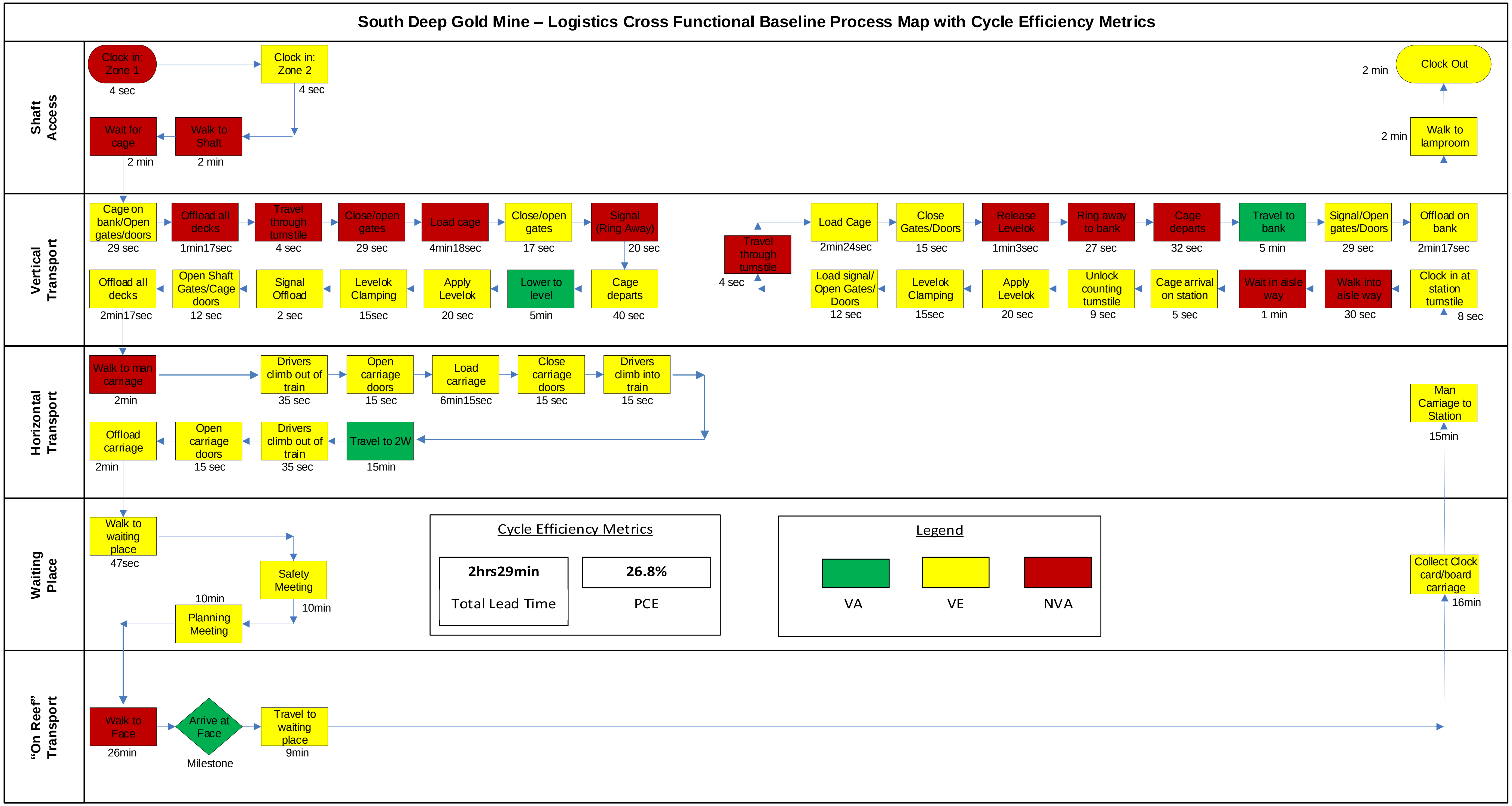


Figure 6.48: Future-state cross-functional process flow diagram with new cycle efficiency metrics

Per Figure 6.48, on the previous page, it is clear that, although similar, the process has been substantially shortened through the removal of NVA activities (waste). Certain activities previously considered to be NVA were now deemed VE, as they had been reduced to the shortest time possible and were still required for the process to be performed correctly from start to end. The result of reducing NVA time and increasing VA time whilst reducing TLT was that PCE improved.

Effective implementation:

The model outline below demonstrates the high-level strategic requirements for successful implementation of the process changes within the organisation. As can be seen from the model below, after solutions are generated and selected for implementation but before any actual implementation takes place, all unintended consequences of implementation must be identified and dealt with by means of a suitable risk management plan. The selected solutions then has to undergo a process of standardisation, initially by means of developing standard specifications and SOP documents, as and where applicable.

A training and development plan then has to be developed, focusing on aligning the required skills to the new solutions to be implemented, to prevent any gap in training or knowledge and the possible consequences thereof. Imperative to the successful implementation of changes is a formal communication plan involving all affected stakeholders, both internal and external to the process. Stakeholder engagement plans may be required after determining and analysing the level of buy-in or commitment to the proposed solutions.

Finally, a formal change response or change management plan should be introduced, focusing on the identification and monitoring of KPIs of success, as well as warning signs to be monitored for during the *Control* phase of the DMAIC Model, which will act as early indicators of performance running off track.

Figure 6.49: Solutions implementation strategy — organisational effectiveness

After the successful execution of the above strategy, solutions are more likely to be successfully adopted in the organisation. The sustainability of the implemented solutions is highly dependent on the level of support from employees who use the solutions. The support of stakeholders who may not be directly involved with the daily process but are still affected by these activities is also critical to the success of the implemented solutions.

It is imperative that performance results are monitored continuously after implementation, in order to identify early signs of deviation, to enable rapid intervention and rectification, as well as to inform performance enhancement. The aim in final phase of the DMAIC process, *Control*, is to ensure the sustainability of the implemented solutions.

6.1.7 *Control* — Maximising face time (Optimisation section)

In the final phase of the DMAIC model — *Control* — the steps applied during the research consisted of process standardisation, performance monitoring, and responding to deviations. These three steps are of vital importance in ensuring that implemented solutions/changes are engrained into the process during actual operation, on a continual basis. The execution of the process must be completed in the exact same manner by all variable process operators over an indefinite period. All process owners must understand the process, and output performance must be continuously monitored through a suitable monitoring system. Normal and abnormal levels of performance have to be clearly defined and KPIs developed. These KPIs are to be utilised for the purposes of monitoring the levels of success in process execution, as well as for the early identification of subnormal process performance and response initiation requirements. Ultimately, the desired outcome of this phase is that changes implemented are permanently embedded within the organisation, thereby establishing the new performance baseline for continuous improvement. The schematic model below outlines the strategy formulated for the *Control* phase of this research, the *Optimum face time — Process performance control plan*.

Optimum face time – Process performance control plan

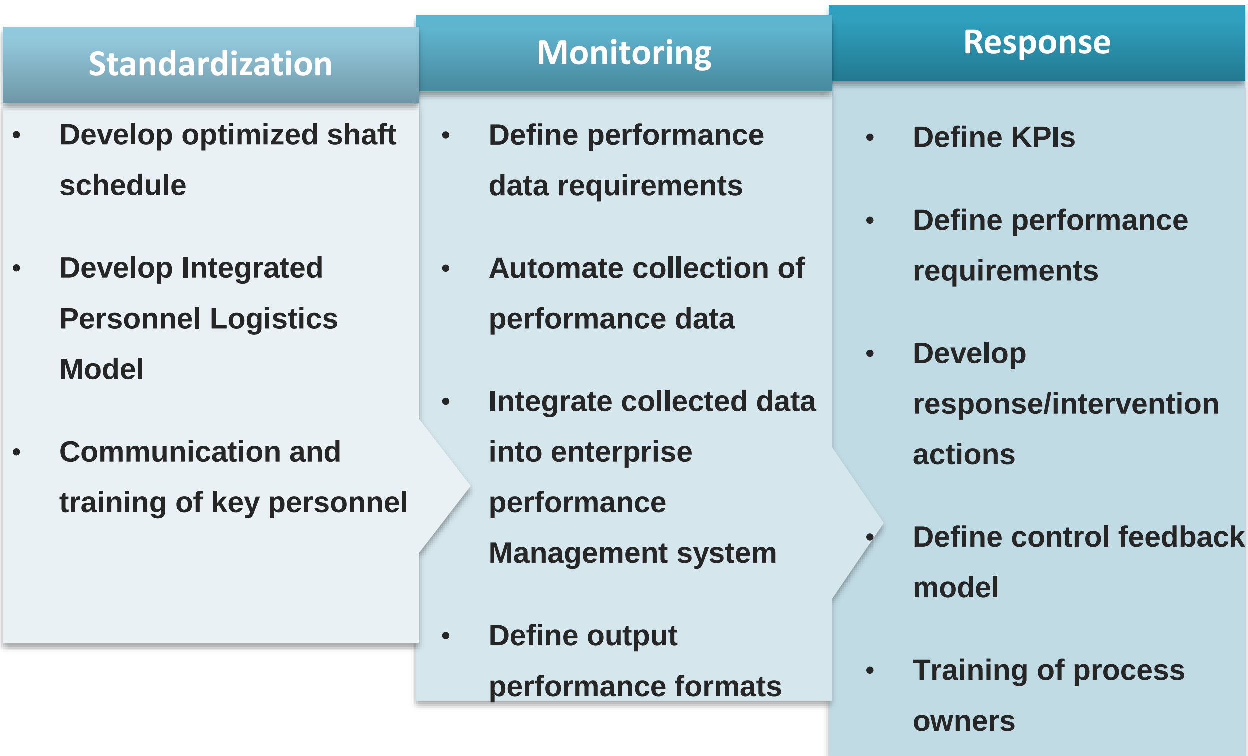


Figure 6.50: Process performance control plan

6.1.7.1 Standardisation

Standardising the process is of utmost importance in ensuring the solutions implemented during the *Improve* phase are sustainable. The key in this case consistency in performance. If no standardised method is developed for implemented solutions, the risk of process variability is introduced. A lack of process standardisation and training of process owners/operators on these standards will lead to inconsistency in output results over time. Hence, performance variability, waste-generation, and, ultimately, in this case, loss of face time will ensue. It is therefore imperative that best practice standard operating models be developed, key personnel be involved in the development process, and the process be formally documented, together with effective configuration management.

The fist deliverable in the *Standardisation* stage was the development of the optimised shaft schedule for Twin Shaft. The future-state cross-functional process flow diagram evidenced significant elimination and mitigation of process waste. It is necessary to mention again at this point that, when referring to the SIPOC analysis, the shaft access and vertical transport functions still remain at the head of the process at macro level. When considering the logistics process as a cycle, it is clear that the cycle starts with shaft access and vertical transport and also ends with shaft access vertical transport.

The development of an optimised shaft schedule as the foundation of the *Standardisation* stage was opted for, as all other activity initiation times follow on from this.

6.1.7.1.1 Optimised shaft schedule

The table below contains all the pertinent information (future-state times, post waste mitigation) required for the development of a standardised shaft schedule (vertical logistics operating model). There are numerous variables of importance, which, if unavailable, will result in difficulty in developing the schedule. These variables include bank-to-level travelling times (measured), conveyance design capacity, actual conveyance capacity considering loading factors determined through empirical data, number of designated working levels (destinations), number of personnel per working place, vertical logistics process times (time–motion data), employee shift duration, number of contractors and/or maximum potential number of ad hoc contract workers per shift.

Table 6.19: Shaft scheduling — pertinent data

Shaft Scheduling Data	
Bank-to-level travelling times:	
Bank to 90 level	3min41sec
Bank to 93 level	4min33sec
Bank to 94 level	4min36sec
Bank to 95 level	4min40sec
Bank to 100 level	4min48sec
Bank to 110A level	5min14sec
Conveyance design capacity:	

Mass per person (kg)	75 (Regulated by MHSA)
Persons per deck (2-deck cage)	89
Persons per deck (3-deck cage)	60
Persons per cage (2-deck)	178
Persons per cage (3-deck)	180
Actual conveyance capacity:	
Cage loading factor	0.85 (From empirical data)
Persons per deck (2-deck cage)	75
Persons per deck (3-deck cage)	51
Persons per cage (2-deck)	150
Persons per cage (3-deck)	153
Approximate number of permanent employees per working place per shift:	
93 level	120
95 level 2 West	140
95 Level 3 West	130
100 Level	100
110A Level	30
Approximate number of contractors per working place per shift (including potential ad hoc):	
93 level	30
95 level 2 West	90
95 Level 3 West	60
100 Level	50
110A Level	30

Vertical logistics process times (future state and in sequence):	
Clock in: Zone 1	0:00:04
Clock in: Zone 2	0:00:04
Walk to shaft	0:02:00
Wait for cage	0:02:00
Cage on bank/Open gates, doors	0:00:29
Offload all decks	0:01:17
Travel through turnstile	0:00:04
Close and open gates	0:00:29
Load cage	0:04:18
Close door and gates	0:00:17
Signal (ring away)	0:00:20
Cage departs	0:00:40
Lower to level	0:05:00
Apply Levelok	0:00:20
Levelok clamping	0:00:15
Signal offload	0:00:02
Open shaft and cage doors	0:00:12
Offload all decks	0:02:17
Unlock counting turnstile	00:00:09
Apply Levelok	00:00:20
Levelok clamping	0:00:15
Load signal/Open gates, doors	0:00:12

Travel through turnstile	0:00:04
Load cage	0:02:24
Close gates/doors	0:00:15
Release Levelok	0:01:03
Ring away to bank	0:00:27
Cage departs	0:00:32
Travel to bank	0:05:00
Signal/Open doors, gates	0:00:29
Offload on bank	0:02:17
Employee shifts details and duration:	
Day shift	9 hours 30 minutes
Night shift	9 hours 30 minutes

From the information above, the following shaft scheduling procedure was applied to develop the shaft schedule, with every decision based on the Lean thinking principle of eliminating waste.

Table 6.20: Shaft scheduling procedure

The table below highlights the procedure followed for the development of the optimised shaft schedule using future-state vertical logistics process times and pertinent data from Table 6.18, above.

Procedure:	
Step	**Description**
1	The total number of trips required, which must be kept to a minimum in order to maximise the shaft time available for shaft and winder maintenance, as well as for the raising and lowering of material for the mining process underground
2	The sequence in which the levels will be served in lowering all personnel at the start of day shift

3	The sequence in which the levels will be served in raising personnel at the end of day shift
4	The sequence in which the levels will be served in lowering all personnel at the start of night shift
5	The sequence in which the levels will be served in raising personnel at the end of night shift.
6	The actual departure times from surface to underground of all trips at the start of shift
7	The actual arrival times on the levels for all trips lowered at the start of shift
8	The actual departure times at the end of shift from the levels underground to surface, at the end of shift
9	The actual arrival times on surface for all trips raised, at the end of shift
10	The scheduling of all mandatory examinations and inspections of the shafts and winding plants as enforced by South African mining legislation
11	The scheduling of all time slots for the raising and lowering of material to and from underground, which must be maximised to ensure shaft availability to meet material logistics requirements (to supply mining and maintenance materials for underground operations)

Note: See Annexure C for details on shaft scheduling calculations.

Optimised shaft schedule for Gold Fields Twin Shaft operations

<table>
<tr><th colspan="16">Shaft Schedule - Twin Shaft Operations</th></tr>
<tr><th>Zone open</th><th>Zone close</th><th>Cage</th><th>Depart</th><th>Arrive</th><th>Duration</th><th>Destination/ Function</th><th>Shift</th><th>Direction</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th><th>Saturday</th><th>Sunday</th></tr>
<tr><td>05:45</td><td>05:55</td><td>3 Deck</td><td>06:00</td><td>06:06</td><td rowspan="7"></td><td>110A Level</td><td rowspan="7">Dayshift</td><td rowspan="7">Down</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>06:11</td><td>06:21</td><td>2 Deck</td><td>06:26</td><td>06:31</td><td>100 Level</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>06:35</td><td>06:45</td><td>3 Deck</td><td>06:50</td><td>06:55</td><td>93 Level</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>06:57</td><td>07:07</td><td>2 Deck</td><td>07:12</td><td>07:17</td><td>95 Level</td><td colspan="7">All Contractors only</td></tr>
<tr><td>07:15</td><td>07:25</td><td>3 Deck</td><td>07:30</td><td>07:35</td><td>95 Level</td><td colspan="7">95 2W Employees only</td></tr>
<tr><td>07:33</td><td>07:43</td><td>2 Deck</td><td>07:48</td><td>07:55</td><td>95 Level</td><td colspan="7">95 3W Employees only</td></tr>
<tr><td>07:52</td><td>08:02</td><td>3 Deck</td><td>08:07</td><td>08:12</td><td>95, 100 and 93 level</td><td colspan="7">Supervisors/Management only</td></tr>
<tr><td></td><td>Start:</td><td>08:30</td><td>End:</td><td>09:30</td><td>01:00</td><td rowspan="2">Statutory</td><td colspan="2"></td><td>Daily winder exam</td><td>Daily winder exam</td><td>Daily winder exam</td><td>Daily winder exam</td><td>Daily winder exam</td><td>Daily winder exam</td><td>Daily winder exam</td></tr>
<tr><td></td><td>Start:</td><td>09:30</td><td>End:</td><td>14:00</td><td>04:30</td><td colspan="2"></td><td>Shaft exam</td><td>Material cars</td><td>Winder maintenance</td><td>Material cars</td><td>Shaft exam</td><td>Material cars</td><td>Shaft maintenance</td></tr>
<tr><td>13:52</td><td>14:02</td><td>3 Deck</td><td>14:07</td><td>14:13</td><td>06:06</td><td>95, 100 and 93 level</td><td rowspan="8">Dayshift</td><td rowspan="8">Up</td><td colspan="7">Supervisors/Management only</td></tr>
<tr><td>15:00</td><td>15:10</td><td>2 Deck</td><td>15:15</td><td>15:21</td><td>09:21</td><td>110A Level</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>15:26</td><td>15:36</td><td>3 Deck</td><td>15:41</td><td>15:46</td><td>09:20</td><td>100 Level</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>15:50</td><td>16:00</td><td>2 Deck</td><td>16:05</td><td>16:10</td><td>09:20</td><td>93 Level</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>16:12</td><td>16:22</td><td>3 Deck</td><td>16:27</td><td>16:32</td><td>09:20</td><td>95 Level</td><td colspan="7">All Contractors only</td></tr>
<tr><td>16:30</td><td>16:40</td><td>2 Deck</td><td>16:45</td><td>16:50</td><td>09:20</td><td>95 Level</td><td colspan="7">95 2W Employees only</td></tr>
<tr><td>16:48</td><td>16:58</td><td>3 Deck</td><td>17:03</td><td>17:08</td><td>09:20</td><td>95 Level</td><td colspan="7">95 3W Employees only</td></tr>
<tr><td></td><td>Start:</td><td>17:30</td><td>End:</td><td>18:00</td><td>00:30</td><td>Clean/Inspect</td><td colspan="7">Clean cages and prepare for nightshift down</td></tr>
<tr><td colspan="16">Shaft clearance - Centralised Blast Initiation at 17:30</td></tr>
<tr><td>17:45</td><td>17:55</td><td>3 Deck</td><td>18:00</td><td>18:06</td><td rowspan="6"></td><td>110A Level</td><td rowspan="6">Nightshift</td><td rowspan="6">Down</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>18:11</td><td>18:21</td><td>2 Deck</td><td>18:26</td><td>18:31</td><td>100 Level</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>18:35</td><td>18:45</td><td>3 Deck</td><td>18:50</td><td>18:55</td><td>93 Level</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>18:57</td><td>19:07</td><td>2 Deck</td><td>19:12</td><td>19:17</td><td>95 Level</td><td colspan="7">All Contractors only</td></tr>
<tr><td>19:15</td><td>19:25</td><td>3 Deck</td><td>19:30</td><td>19:35</td><td>95 Level</td><td colspan="7">95 2W Employees only down</td></tr>
<tr><td>19:33</td><td>19:43</td><td>2 Deck</td><td>19:48</td><td>19:55</td><td>95 Level</td><td colspan="7">95 3W Employees only down</td></tr>
<tr><td></td><td>Start:</td><td>20:30</td><td>End:</td><td>03:00</td><td>06:30</td><td>Material logistics</td><td colspan="2"></td><td colspan="7">Material cars</td></tr>
<tr><td>03:00</td><td>03:10</td><td>3 Deck</td><td>03:15</td><td>03:21</td><td>09:21</td><td>110A Level</td><td rowspan="7">Nightshift</td><td rowspan="7">Up</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>03:26</td><td>03:36</td><td>2 Deck</td><td>03:41</td><td>03:46</td><td>09:20</td><td>100 Level</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>03:50</td><td>04:00</td><td>3 Deck</td><td>04:05</td><td>04:10</td><td>09:20</td><td>93 Level</td><td colspan="7">All Employees & Contractors</td></tr>
<tr><td>04:12</td><td>04:22</td><td>2 Deck</td><td>04:27</td><td>04:32</td><td>09:20</td><td>95 Level</td><td colspan="7">All Contractors only</td></tr>
<tr><td>04:30</td><td>04:40</td><td>3 Deck</td><td>04:45</td><td>04:50</td><td>09:20</td><td>95 Level</td><td colspan="7">95 2W Employees only down</td></tr>
<tr><td>04:48</td><td>04:58</td><td>2 Deck</td><td>05:03</td><td>05:08</td><td>09:20</td><td>95 Level</td><td colspan="7">95 3W Employees only down</td></tr>
<tr><td></td><td>Start:</td><td>05:30</td><td>End:</td><td>06:00</td><td>00:30</td><td>Clean/Inspect</td><td colspan="7">Clean cages and prepare for dayshift down</td></tr>
<tr><td colspan="16">Shaft clearance - Centralised Blast Initiation at 05:30</td></tr>
</table>

Figure 6.51: Optimised shaft schedule developed through the inclusion of future-state process cycle-time data

6.1.7.1.2 Integrated personnel logistics model

When referring back to the research objectives, as well as the *Improve* phase (generation and selection of appropriate solutions), the solution number NVA-1.3 regarding the development of an integrated personnel logistics model was defined (IPLS). The aim in developing this model was to ameliorate the current shortcomings in terms of a holistic systems engineering approach. The desired final outcome was the resolving of the cross-functional interdependency issues between Vertical, Horizontal, and mining operations departments with regard to personnel logistics.

Figure 6.52, below, is the optimised and integrated personnel logistics model for the primary production level. All calculations involved in the development of the model are provided in Annexure E. To ensure process standardisation, the integrated logistics model is shown in the form of a schedule, which can be integrated into the training and communication plan prior to implementation. All process personnel, including process owners, operators, and end users must be adequately trained with regard to the process and the measures to be taken in the event of any deviations.

Integrated personnel logistics schedule for Twin Shaft operations

Integrated Personnel Logistics Schedule																			
Shift	Personnel	Vertical logistics (down)				Horizontal logistics (In)		Mining operations (In)			Mining operations (Out)			Horizontal logistics (Out)		Vertical logistics (Up)		Face Time	Face Time Factor
		Zone open	Zone close	Cage departure from surface	Cage arrival on station	Man carriage Departure to waiting place	Man carriage arrival at waiting place	Personnel arrive at waiting place	Personnel depart from waiting place	Start Work	End Work	Personnel depart to waiting place	Personnel arrive at waiting place	Man carriage departure to station	Man carriage arrival at station	Cage departure to surface	Cage arrival on surface		
Dayshift	All Contractors 2 and 3 West	06:57	07:07	07:12	07:17	07:27	07:47	07:55	08:25	08:51	15:31	15:31	15:57	16:01	16:22	16:27	16:32	06:39	70,17%
	95 2W Employees only	07:15	07:25	07:30	07:35	07:45	08:02	08:06	08:36	09:02	15:55	15:55	16:21	16:22	16:40	16:45	16:50	06:53	72,49%
	95 3W Employees only	07:33	07:43	07:48	07:55	08:05	08:20	08:28	08:58	09:24	16:12	16:12	16:38	16:42	16:58	17:03	17:08	06:48	71,61%
	Supervisors/Management only	07:52	08:02	08:07	08:12	08:22	08:42	08:50	09:20	09:46	12:54	12:54	13:20	13:41	14:02	14:07	14:13	03:08	N/A
Nightshift	All Contractors 2 and 3 West	18:57	19:07	19:12	19:17	19:27	19:47	19:55	20:25	20:51	03:31	03:31	03:57	04:01	04:22	04:27	04:32	06:39	70,17%
	95 2W Employees only down	19:15	19:25	19:30	19:35	19:45	20:02	20:06	20:36	21:02	03:55	03:55	04:21	04:22	04:40	04:45	04:50	06:53	72,49%
	95 3W Employees only down	19:33	19:43	19:48	19:55	20:05	20:20	20:28	20:58	21:24	04:12	04:12	04:38	04:42	04:58	05:03	05:08	06:48	71,61%

Figure 6.52: Integrated personnel logistics schedule including future state primary metric face time factors

6.1.7.2 Monitoring

6.1.7.2.1 Define performance data requirements

In order to effectively monitor performance, certain data must be readily available at all times for analysis and decision-making purposes. With regard to the personnel logistics process, thousands of potential data variables could be monitored; however, data collected should be important in terms of process performance management, and not collected for the sake of collecting data. The data must be pertinent to understanding performance on a real-time basis, in order to enable process control and intervention where necessary, to prevent deviation from set targets.

In Six Sigma theory (Sye, 2012), the second principle of Six Sigma, where the process output (*y*) is a function of a multitude of inputs and process variables (x), was considered in optimising the personnel transportation process. Sye (2012: 17) stated that, as "y is a function of multiple x's, rapid improvement occurs when you focus on the key x's," expressed as:

$$y = f(x_1, x_2, x_3, \dots x_n)$$

The key output variable (*y*) is also the primary metric of the study, namely face time factor. The variables (*x*'s), which would impact on the output in the case of the personnel logistics process, are found when reviewing the integrated personnel logistics schedule (IPLS). It must be borne in mind that any sub-process delay in the IPLS would result in extended time spent completing the personnel logistics end-to-end process. In this case, the primary metric of face time factor would immediately be reduced in direct correlation to the time delay. In simple terms, any time wasted on personnel transport would immediately be deducted from available face time. The data requirements are defined in Table 6.21, below, and are deemed the *x* variables to be monitored (the *Control* phase of the DMAIC process) to ensure maximum face time is achieved. From the Research Charter, the total travelling time, face time, and face time factor are all primary metrics to be monitored and are located in the *y* column (*Output performance*), whereas the IPLS times are located in the *x* column (*Input variables*)

Table 6.21: Performance data requirements

.

Performance data requirements	
y	**x**
Output performance	**Input variables (actual times)**
Vertical logistics process time	Cage departure from surface
Horizontal logistics process time	Cage arrival on station
Waiting place process time	Man carriage departure to waiting place
Actual shift durations	Man carriage arrival at waiting place
Face time factor	Personnel arrive at waiting place
	Personnel depart from waiting place
	Start of work time
	End of work time
	Personnel depart to waiting place
	Personnel arrive at waiting place
	Man carriage departure to station
	Man carriage arrival at station
	Cage departure to surface
	Cage arrival on surface
	Waiting place total duration
	Cage loading factor
	Train loading factor

The input variable times defined above are actual time data of the IPLS once implemented. This input data must be physically measured, collected, and communicated on a continuous basis, in real time, in order for useful data monitoring to commence. The following section deals with the methodology and strategic rationale behind the automation of input data collection.

6.1.7.2.2 Automate performance data collection

In order to eliminate the risk of human error and the subsequent negative effect on the quality and usefulness of the gathered data, performance data should be collected by automated means.

The schematic illustration in Figure 6.53, below, depicts the concept design behind automated performance data collection in the personnel logistics process that was followed in the present study. The primary means of performance time data collection was through electrical/electronic components, instrumentation, and radio frequency identification (RFID) technology.

With regard to the vertical logistics, magnetic switches were installed just below the surface bank level, as well as on all operational levels underground. A fixed magnet unit is installed on the cages (conveyances), which then interacts with the magnetic switches inside the shaft barrel at selected locations. These magnetic switches latch when the cage comes into position at a new location at a specific time. This electronic information is received into the SCADA system and thereafter converted through programming into useful information for the mine's enterprise performance management (EMP) software.

The automated data collection methodology applied in the horizontal logistics process involves the tracking of man carriages or trains as they arrive at and depart form set destinations according to the IPLS. The inherently installed proximity detection systems (PDS), which indicate proximity between personnel and trackless mobile machinery, as required by Chapter 8 of the MHSA Machinery Regulations, allowed for adaptation of the system to enable tracking of train locations and times. An RFID tag is installed on the train itself, and a receiver is mounted at the loading/offloading bays (transmitter-receiver). This data is then also fed into the mine's EPM software via SCADA systems. When a train departs from the station and arrives at the waiting place offloading bay, the departure and arrival times are electronically measured through the PDS system.

In terms of human resources, access control, and payroll management software, the surface turnstiles for accessing the mine and vertical transport areas (shaft) are well controlled and electronic reporting systems are established. Access control card readers using the same technology are installed in each waiting place. All employees electronically access their waiting places underground to signal the initiation of the waiting place meetings, and swipe their cards upon departing from their waiting places to their working areas. In this manner, arrival and departure times are monitored electronically and in real time.

Finally, through the underground wireless network, all trackless mobile machinery is fitted with a machinery management system that allows for real-time information access (on surface) of machine condition, position, and activity. The actual time that personnel begin to work, which is the start of face time, can be monitored in real time through this system. The moment a machine is positioned at the rock face and the drilling process (percussion) is initiated, the actual personnel face time can be monitored.

Figure 6.53, above, illustrates the six key data collection points whose functions were explained above.

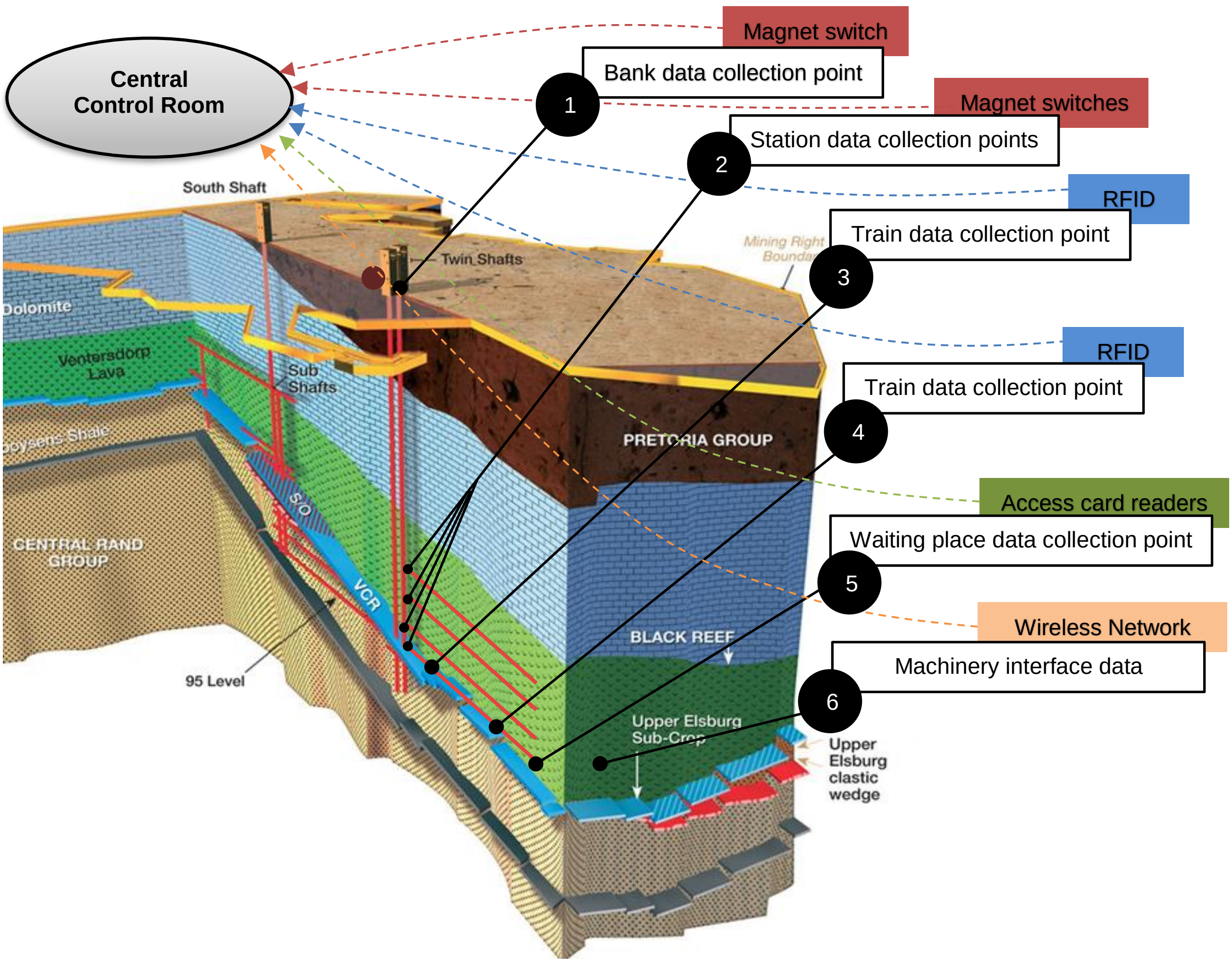


Figure 6.53: Conceptual design, schematic illustration — Automated data collection. Image courtesy of Gold Fields International

In the figure above, Point 1 is the data collection point on the surface bank, which records the time of cage departure from and arrival on surface. Similar collection points are established on each station, fulfilling the same function (Point 2). Data collection Points 3 and 4 are the horizontal logistics nodes, which receive data regarding departure and arrival times of trains at the station, as well as the loading/offloading bays near the waiting places. Point 5 indicates the position of the access card reader system to be activated at the start and end of each waiting place meeting. Finally, Point 6 is situated on each machine being operated. The on-board machine interface technology allows for wireless communication between machine and the Control Room (surface). This interface allows all machinery movements to be monitored, including the initiation of drilling Start of face time.

All data collection instruments, components, and technologies transmit information up the vertical shaft to the surface Control Room via the fibre optic backbone installed within the shaft barrel. Information received in the Control Room is deciphered into various different data bases, and, thereafter, through programming methodologies, the information is fed, in the correct format, to the mine's EPM system for monitoring and report generation, practically in real time. Once the data have been integrated and collated into the EPM system, the information is readily available for the monitoring of output performance of the personnel logistics process.

6.1.7.2.3 Define output performance information format

As the personnel logistics process has a defined primary metric measure that is time-based, all performance output information is generated in time format.

The following graphical representations and report formats of output performance are generated using the time data received from the EPM system:

- KPI Dashboards;
- Actual schedule performance;
- Exception reporting;
- Control charts; and
- General graphical representation (histograms, charts, etc.).

6.1.7.3 Response

6.1.7.3.1 Define performance requirements and set KPIs

Performance requirements for the personnel logistics process must ensure that the primary metric of face time factor is met at all times. Additional performance monitoring should also be undertaken to identify performance issues in specified areas, namely vertical, horizontal, and mining functions. When developing KPIs for monitoring and reporting on process performance, the indicators selected should be easily understood by process operators, process owners, and management alike. In order for process operators to continuously improve, it is imperative that these performance results are available to them at all times, so that they may enabled to manage themselves. All personnel involved in the process must be thoroughly trained on the KPIs and the desired performance targets.

The following key performance indicators will form part of the process performance management and response plan:

- Actual face time achieved;
- Actual logistics process time (travelling time);
- Cage departure times;
- Cage arrival times;
- Man train departure times;
- Man train arrival times;
- Waiting place arrival times;
- Waiting place departure times; and
- Start and end of work times.

The table below indicates the key performance indicator as well as the performance metric outputs expected (baseline performance, target, and stretch target performance).

The specific KPI is listed in the first column, with the baseline, target, and stretch target performance metrics listed in the columns thereafter. The baseline performance measure is the absolute minimum requirement to prevent any losses in production, and any performance below baseline will require immediate intervention. The target performance is per the IPLS, and the stretch target is set at a 3% improvement over the IPLS or target measure. In the event that a stretch target is achieved, a full investigation into the manner in which this was achieved must be initiated. It is imperative that operational personnel do not conduct any activities in a substandard manner with the aim of improving performance times. Through the training and communication plans, the emphasis on adhering to standard operating procedures is key. Ensuring health and safety in all aspects of the personnel logistics process execution is of primary concern. When prioritising process decisions, health and safety will always take preference over time-saving.

Table 6.22: Finalised KPI measures

Personnel Logistics Process: KPIs and target performance measures				
KPI	**Code**	**Baseline (Intervention)**	**Target**	**Stretch**
Face time factor (%)	η_f	68%	71%	74%
Actual face time achieved (hh:mm)	AFT	Primary activity time (06:30)	IPLS time	IPLS time + 3%
Actual logistics process time (Total lead time) (hh:mm)	TLT	3 hours	IPLS time	IPLS time – 3%
Cage departure times (hh:mm)	CD	IPLS time + 5 min	IPLS time	IPLS time – 3%
Cage arrival times (hh:mm)	CA	IPLS time + 5 min	IPLS time	IPLS time – 3%
Man train departure times (hh:mm)	MD	IPLS time + 5 min	IPLS time	IPLS time – 3%
Man train arrival times (hh:mm)	MA	IPLS time + 5 min	IPLS time	IPLS time – 3%
Waiting place arrival times (hh:mm)	WD	IPLS time + 5 min	IPLS time	IPLS time – 3%
Waiting place departure times (hh:mm)	WA	IPLS time + 5 min	IPLS time	IPLS time – 3%
Start of work times (hh:mm)	SOW	IPLS time + 5 min	IPLS time	IPLS time – 3%
End of work (hh:mm)	EOW	IPLS time + 5 min	IPLS time	IPLS time – 3%
Sub-process durations	VLD, HLD, WPD	IPLS time + 5 min	IPLS time	IPLS time – 3%

The table above contains 14 KPIs to be monitored and electronically measured, as described in Figure 6.53. The primary metric is face time factor (η), as it is an efficiency measurement of the utilisation of total employee shift duration (9 hours 30 minutes). The Research Charter highlighted the primary production activity (supporting and drilling) taking 6 hours and 30 minutes on average. Therefore, the bare minimum face time factor was calculated at approximately 68%.

$$Face\ time\ factor = \eta = \frac{Actual\ face\ time}{Total\ shift\ duration}\ x\ 100$$

$$Face\ time\ factor = \eta = \frac{6.5}{9.5}\ x\ 100$$

$$Face\ time\ factor = \eta = 68\%$$

The face time target is 71%, which equates to approximately 6 hours and 45 minutes, which is in line with the primary metric target set in the Research Charter. Performance at 74% is the stretch target, and is based on the primary metric target plus 3%, which would provide an actual face time of approximately seven (7) hours.

The actual face time has been allocated the code *AFT*, and the actual logistics process time, also termed *total lead time*, is given the code *TLT* for reporting purposes. In terms of AFT, a bare minimum time for the primary production process, as previously described, is 6 hours and 30 minutes; hence, this has been set as the baseline performance or intervention point, as anything less will result in production losses being incurred. The AFT target is set per the IPLS time as shown in Figure 6.53, above, with the stretch target being IPLS time plus 3%. In actual terms, this means that, for the Two West production section, the AFT target as per the IPLS is 6 hours 53 minutes, and, hence, stretch target achievement equates to approximately 7 hours 5 minutes. In terms of TLT, the same principle being applied results in a bare minimum logistics process time of 3 hours, as this would generate the 6 hour 30 minute AFT required to complete the primary production activity (supporting and drilling). If the TLT exceeds 3 hours, production losses will be incurred, hence this being the process owner intervention point. In terms of TLT target and stretch, the same principle has been applied as with AFT; however, in this case, interest is in IPLS minus 3%.

The following naming convention has been implemented for all other time data collection point information:

- Prefix: First letter of function (i.e. Cage is capital letter *C*);

- Suffix: Arrival or Departure (Arrival is *A*, departure is *D*).

For example, cage departure time would be *CD*. The performance targets are set out in the same manner for all time data collection points in the overall process. If any data point reading is electronically measured five minutes later than what is indicated by the IPLS, this would be considered a process-owner intervention point (baseline measure), in other words, IPLS plus 5 minutes. The target performance is aligned with the final IPLS, and the stretch target is IPLS minus 3%. This system applies to the following six KPIs:

- Cage departure times;
- Cage arrival times;
- Man train departure times;
- Man train arrival times;
- Waiting-place arrival times; and
- Waiting-place departure times.

The two KPIs Start of work (SOW) and End of work (EOW) are, in fact, process milestones, and the difference between these two measures provide a measure of actual face time. These two measures are taken from the on-board machinery interface, when the drill rig starts and ends with the function of drilling as measured by the on-board machinery management system. Therefore, EOW minus SOW equals AFT. In practice, the sum of machinery transmission and percussion hours will be measured and equated to AFT.

Finally, the remaining three KPIs are sub-process durations, and are simply the actual duration of each macro-level process per the value stream analysis. These include vertical logistics, horizontal logistics, and waiting place times. As the overall personnel logistics process has been defined as being cyclic in nature, the duration times into the mine and out of the mine are to be measured, reported, and performance-managed in the *Control* phase. These KPIs include vertical logistics duration (VLD), horizontal logistics duration (HLD), and waiting place duration (WPD). All three KPIs can be measured with personnel coming into and leaving work. Performance metrics in this case are IPLS late by five minutes as baseline or intervention point measure, IPLS as the target, and IPLS minus 3% as the stretch target performance metrics.

The KPIs defined in the above table are to be delivered at the correct organisational level and at appropriate intervals for optimal process performance control. The suitability of certain KPIs must be considered at different organisational levels, depending on employee influence and control over these KPIs. The table below defines the monitoring and reporting plan for these process KPIs in order to yield optimal process output control.

Table 6.23: Monitoring and reporting plan

As previously highlighted, certain process employees require certain KPI information at specific intervals in order for optimal process control to be achieved. It is logical that a high-level process owner such as the executive vice president of the mine does not require the cage arrival- or departure times on a daily basis, or perhaps at all. The banksman in direct control over the cage departure- and arrival times as the process operator does, however, require this information as frequently as possible; in fact, live data reporting for this employee would prove useful in early intervention if required. The table/matrix below describes the strategy for KPI monitoring and reporting.

Personnel logistics process: KPI monitoring and reporting plan							
KPI	**Code**	**Control room**	**Process operator**	**Line supervisor**	**Section Manager**	**Senior management**	**Executive Committee**
Face time factor (%)	η	Live data	No	No	Daily	Monthly	Quarterly statistics
Actual face time achieved (hh:mm)	AFT	Live data	No	Every shift	Daily	Monthly	No
Actual logistics process time (Total lead time) (hh:mm)	TLT	Live data	No	Every shift	Daily	Monthly	No
Cage departure times (hh:mm)	CD	Live data	Live data	Live data	Daily	Quarterly statistics	No
Cage arrival times (hh:mm)	CA	Live data	Live data	Live data	Daily	Quarterly statistics	No
Man-train departure	MD	Live data	Live data	Live data	Daily	Quarterly statistics	No

times (hh:mm)							
Man-train arrival times (hh:mm)	MA	Live data	Live data	Live data	Daily	Quarterly statistics	No
Waiting-place arrival times (hh:mm)	WD	Live data	Live data	Live data	Live data	Weekly statistics	No
Waiting-place departure times (hh:mm)	WA	Live data	Live data	Live data	Live data	Weekly statistics	No
Start of work times (hh:mm)	SOW	Live data	No	Live data	Daily	Weekly statistics	No
End of work times (hh:mm)	EOW	Live data	No	Live data	Daily	Weekly statistics	No
Sub-process durations	VLD, HLD, WPD	Live data	Every shift	Every shift	Every shift	Weekly statistics	No

Process controllers/operators require live performance data from SCADA systems to ensure optimal operation of their specific sub-process. An example of this is the miner in charge of his gang/crew arriving at the waiting place. He/she is aware, through training, that the meeting should not exceed 30min in duration; therefore, the meeting's start (WA) and end (WD) times are to be displayed electronically on monitor screens at each waiting place. This data are then considered live, as it can be measured and reported on immediately, in order for immediate intervention to take place if required.

Certain processes with known high levels of non-conformance require live data reporting to line managers and even section managers, to enable them to monitor the process operator of, e.g., the waiting place meeting. Other KPIs require reporting at different intervals higher up the organisational hierarchy. Intervals range from live data reporting to quarterly dashboard statistical reporting. A common theme throughout the development of the above plan is that the reporting interval, as well as the level of detail in the raw data, is directly proportional the organisational hierarchy, where lower time interval reporting is inversely proportional to organisational seniority level. Raw data detail reporting is also inversely proportional to organisational seniority. The crux is that detailed close-interval control is to be executed by operational teams such as process controllers/operators and their immediate line supervisors. Strategic KPI information is to be addressed by section and senior management at higher time intervals, when monitoring control chart trends, outliers, special causes, and common cause variations.

Management intervention should not be executed on a daily or ongoing basis, as process operator and supervisor accountability must be encouraged and developed for continuous process improvement. Strategic initiatives are to be implemented by management to address trends, common cause (Six Sigma) and special cause variation (problem-solving techniques, root cause analysis and defect elimination). Executive level management requires statistical reporting on the face time factor on a quarterly basis for performance management of senior personnel, as well as formal reporting to the board and public forums, as well as interim- and annual reports.

6.1.7.3.2 Intervention and control feedback model

Immediate process control

In terms of intervention by process operators and owners, the intervention points are based on baseline the KPI not being achieved. Intervention by process operators who control the output performance of each sub-process occurs on a continual basis as they monitor live data. The following personnel are responsible to monitor, intervene, and control the sub-processes, namely cages, trains, waiting place meetings, and drill rig operators’ start and end of work times:

1. Banksman: Cage departure and arrival (from surface)
   — Line Supervisor: Shaft foreman
2. Onsetter: Cage departure and arrival (from underground levels)
   — Line Supervisor: Banksman
3. Tramming miner: Train departure and arrival (start and end of shift)
   — Line Supervisor: Tramming Shift Boss
4. Miner: Waiting place arrival and departure (end of shift and start of shift respectively)

— Line Supervisor: Section Shift Boss

5. Miner: Drill Rig Operator (start and end of work)
   — Line Supervisor: Section Shift Boss

The above list of personnel include process operators and their immediate line supervisors responsible for the execution of the IPLS. Intervention by these teams is based upon live data feed of respective KPIs. Inter-functional/departmental communication between vertical, horizontal, and mining teams is imperative for a quick response to logistical delays. The importance of this communication is to be highlighted during training. Another critical aspect is each process operator and his or her line supervision understanding the knock-on effects of inadequate performance in his or her own sub-process. As the IPLS is series in nature, any delay in predecessor activity will result in direct delays in the activity occurring next. Each process operator and line supervisor should also be fully conversant with the end-to-end IPLS, including sub-processes before and after their own. Any delays that result in deviation from baseline performance is to be telephonically reported to the respective logistics process section manager via the Control Room.

The control room operators receive all live data through the EPM and mine SCADA systems. They are also responsible for receiving information from process operators and/or line supervision, and notifying the responsible section managers when baseline performance deviations occur. The Control Room itself serves as process control redundancy in the event that deviations go unreported or unnoticed by process operators and/or line supervision.

Short interval process control (SIC)

The IPLS is divided into two intervals of 12 hours or shifts. The day shift and night shift mining processes are duplicated, and the full mining cycle occurs twice in a 24-hour period. After each shift, line supervisors conduct SIC meetings with process operators and review the performance data collected. Small-scale repairs and process corrections are discussed and implemented on an ongoing basis. The sum of these small collective actions result in significant improvements over time.

SIC is executed by line supervisors and their process operators. The SIC system is then driven by the section manager of each logistics sub-process. SIC meetings are conducted at the end of each shift by the process operator and line supervisors, and outcomes are reported to the section manager. The SIC meeting model below is implemented at shift handover between day shift and night shift.

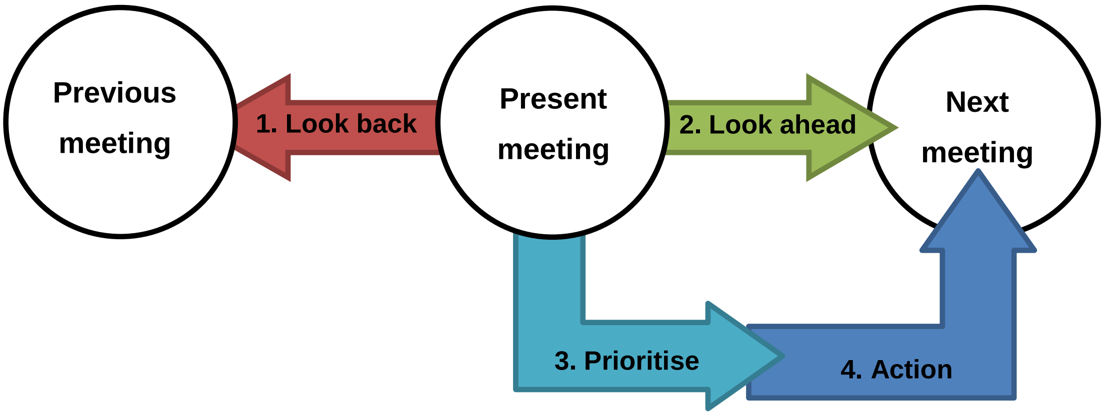


Figure 6.54: Short-interval control meeting model. Concept courtesy of Vorne Manufacturing

Per the model above, the SIC meeting is executed as follows:

1. Review previous interval performance (*Look back*)
    - Identify KPIs that were below baseline performance and require intervention.
    - List all inadequate performance points in the process on that shift.
    - Brainstorm and select countermeasures to prevent a repeat in the next interval.
2. Discuss next interval/shift performance (*Look forward*)
    - Identify any potential delays or risks to the shift in question.
    - Discuss mitigation measures to be implemented.
    - List proactive measures considered.
3. Prioritise improvement measures
    - Select the bare minimum number of actions required to stabilise or normalise performance.
    - Select any improvement measures if capacity is available to implement these.
    - Actions that cannot be implemented during the next shift or may require further resources such as personnel, time, or funding are to be elevated to section manager for decision.
4. Action
    - Implement selected measures during the next shift and log performance.
    - Any actions that are longer-term or require approval by the section manager are registered in an improvement log for later discussion and approval.

The short-interval control meeting is conducted according to the table below, at shift handover between process operators and line supervisors in each sub-process. An SIC meeting is held in the vertical logistics, horizontal logistics and mining functions at shift change, and is scheduled to last no longer than 10min.

Table 6.24: SIC meeting sheet — shift-change meeting

SIC Sheet				
Section: *Vertical logistics*	Shift: *Day shift*	Date: *10/10/17*	Supervisor: *Foreman X*	Operator/s: ~~*Banksman X*~~ *Onsetter X*
Step 1: Review previous shift logistics performance	Sub-baseline KPI performance areas:	Face time lost: (hh:min)	Possible prevention measures:	Escalate?
	CD Plan 07:30; Actual: 07:40 Due to turnstile supply fault – (Supply circuit breaker replaced)	*0:10*	*Install UPS*	*Yes*
			Bypass key	*Yes*
			Manual access	*No*
Step 2: Next shift logistics performance	Potential risks or expected delays:	Expected face time loss:	Possible prevention measures:	
	Delay due to manual turnstile	*0:05*	*Additional supervision*	
	access – Repeat fault			
Step 3: Prioritise measures	Selected actions from possible measures:		Responsible	
	Manual access		*H.R Supt.*	
	Additional supervision		*Foreman X*	
Step 4: Action feedback (for next meeting)	Action achieved?	Outcome (Success/Fail):	Comments:	
	No power supply fault repeat	*Success*	*(Root cause addressed with*	
	Manual access		*circuit breaker replacement)*	
			UPS Installation: Approved	

The actions listed in the control sheet below are conducted twice in a 24-hour period, and all actions, including those for further approval, are reviewed in a weekly strategy meeting of section managers with the aim of logistics optimisation.

A typical example is a delay of 10min occurring in cage departure time from surface (CD), resulting in an equal loss in overall face time. The SIC sheet above is completed during shift handover between day shift and night shift.

<u>Shift performance dashboard (12-hourly)</u>

The dashboard in Figure 6.55, below, is collated from KPI data derived from the mine's EPM system. The shift performance dashboard is automatically drafted and distributed via electronic mail at the end of shift to all process operators, line supervisors, and section management. This particular dashboard is utilised by line supervisors and section management during SIC meetings and management's 24-hour performance review meetings respectively.

Each logistics function, namely vertical, horizontal, waiting place, and mining, has a separate dashboard indicating the previous shift's performance. This information is used in the SIC meeting during shift change between day and night shift. Compliance with the shaft schedule is monitored and reported. In the example below, the third cage's departure was delayed by 6min, which is above the allowable defined IPLS plus 5min baseline/intervention point. The legend in the figure indicates the colour scheme for sub-baseline, target, and stretch performance for simple reference by process operators and line supervisors.

Shift performance review dashboard							
Section: Vertical logistics							
Date:	XYZ	Shift:	Day	Direction:	Down	Banksman:	X
						Onsetter:	Y
Shaft Schedule compliance							
Cage Number	**Description**	**KPI**					
		CD		**CA**		**VLD**	
		Plan	**Actual**	**Plan**	**Actual**	**Plan**	**Actual**
1	110A Level	06:00	06:00	06:06	06:06	02:12	**02:18**
2	100 Level	06:26	06:26	06:31	06:31		
3	93 Level	06:50	06:56	06:55	07:01	**Legend**	
4	95 Level Contract	07:12	07:18	07:17	07:23		
5	95 Level 2W	07:30	07:36	07:35	07:41	Sub-baseline	**Intervene**
6	95 Level 3W	07:48	07:54	07:55	08:01	Target	
7	95, 100 and 93 level	08:07	08:13	08:12	08:18	Stretch	**Investigate**

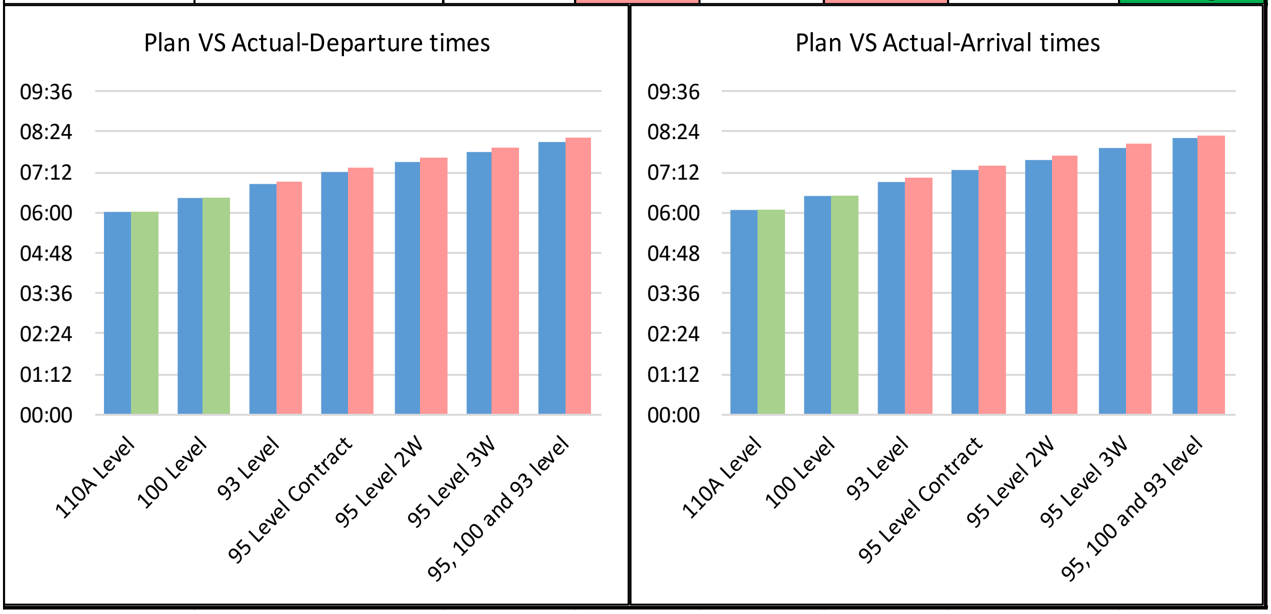


Figure 6.55: Shift Performance Dashboard — vertical logistics

As seen in the figure above, the first intervention point occurred at Cage 3, where the cage departed late by 6min. This delay resulted in a knock-on delay that is carried through the remaining schedule. The VLD is therefore also exceeded by 6min. As this is outside the allowable IPLS plus 5min, it is immediately flagged on the system as an intervention point. When the vertical logistics team conducts the SIC meeting at shift change, the delay can immediately be investigated to prevent a reoccurrence during the following shift.

<u>Management logistics strategy session (Weekly)</u>

It is imperative that section management as the process owners remain close to the logistics process. Supervisory-level personnel require management leadership, guidance, reassurance, and support on an ongoing basis for the success of any continuous improvement work. Short-interval control processes and a monthly progressive logistics performance dashboard should be included in the normal management normal routine, as indicated by the model in Figure 6.56, below.

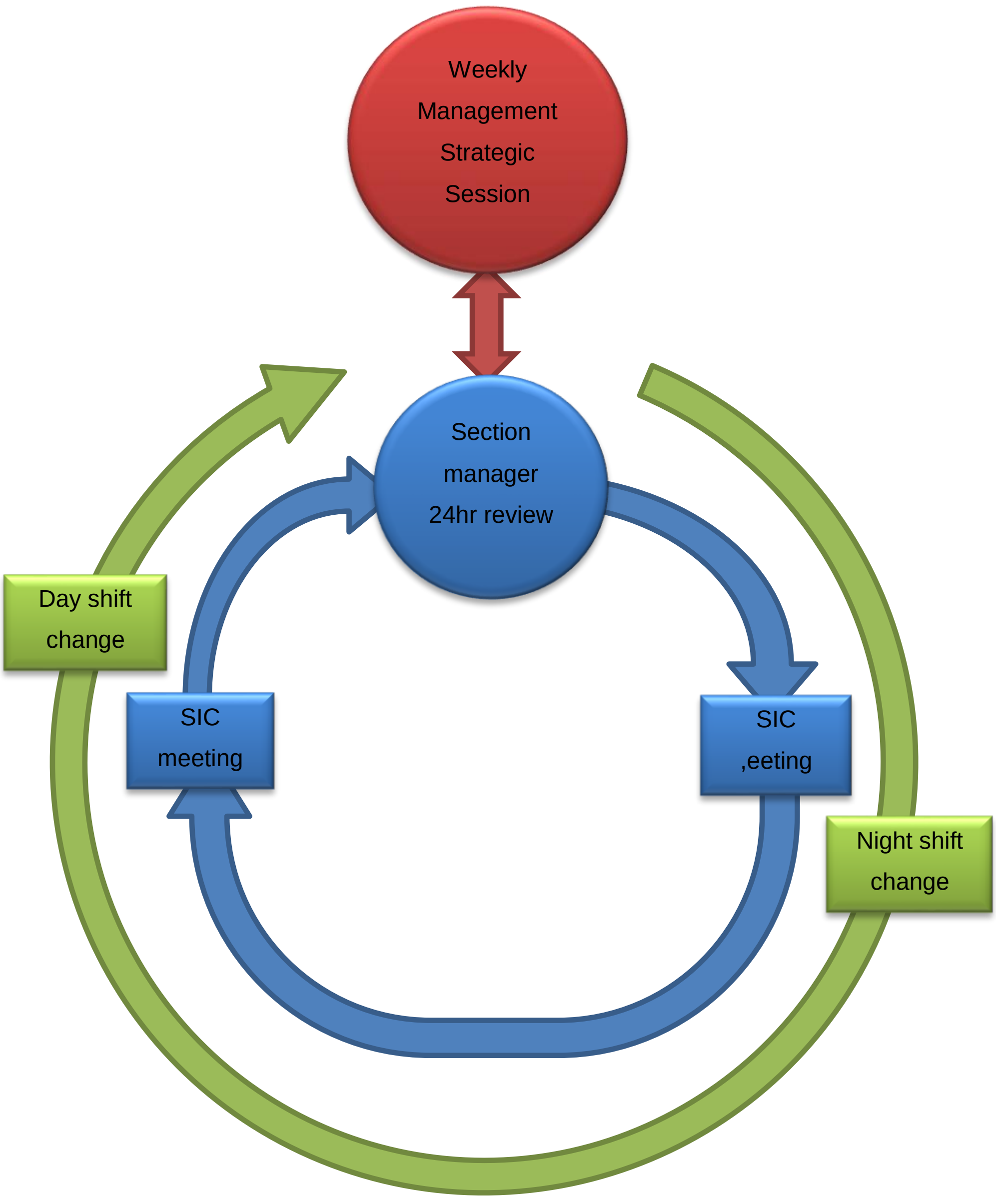


Figure 6.56: SIC integration into management logistics strategy

The model above illustrates the manner in which SIC meetings and decisions taken are reviewed on a 24-hour basis by the section manager of the specific logistics function.

On a weekly basis, sections managers from all logistics functions and departments convene for a strategic session, to review the overall weekly logistics progressive performance. Items elevated from SIC to section manager for approval are discussed, problem-solving methodologies are employed, and minor improvement projects are undertaken through this session. The aim of the session is continuous improvement of the overall personnel logistics process, in the interest of further improvements in face time.

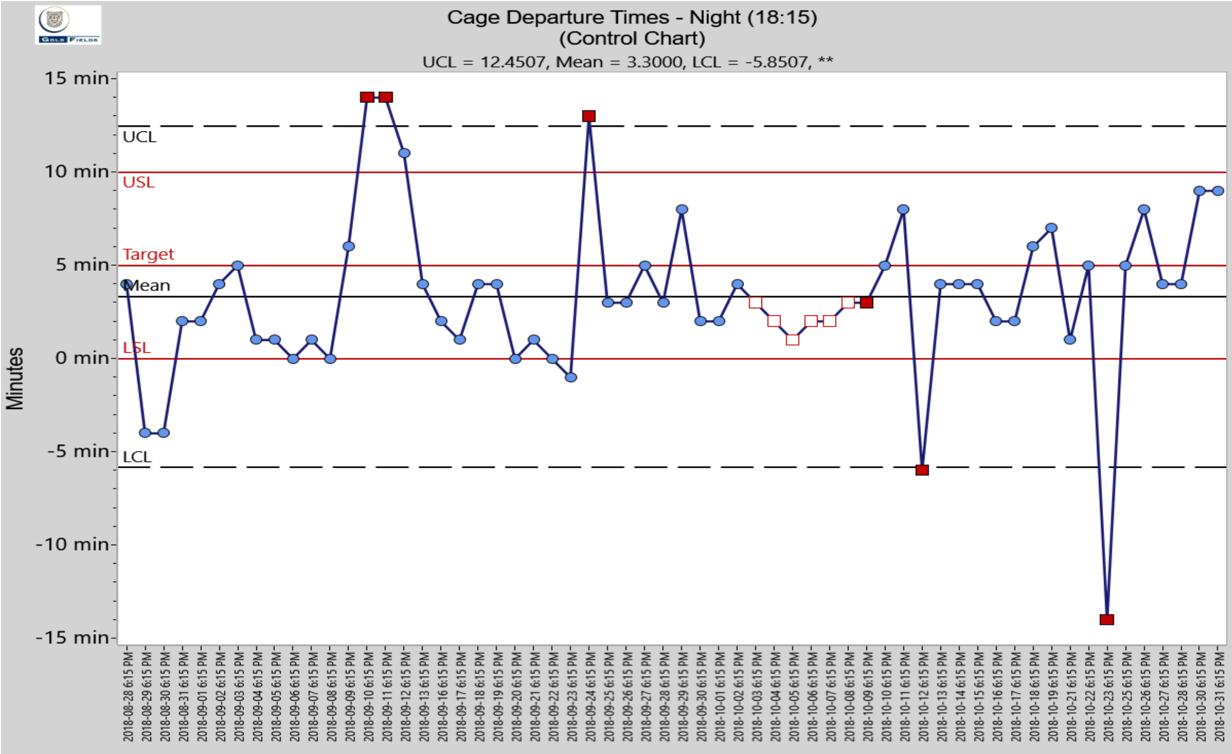
Management logistics performance tracker (Dashboard)

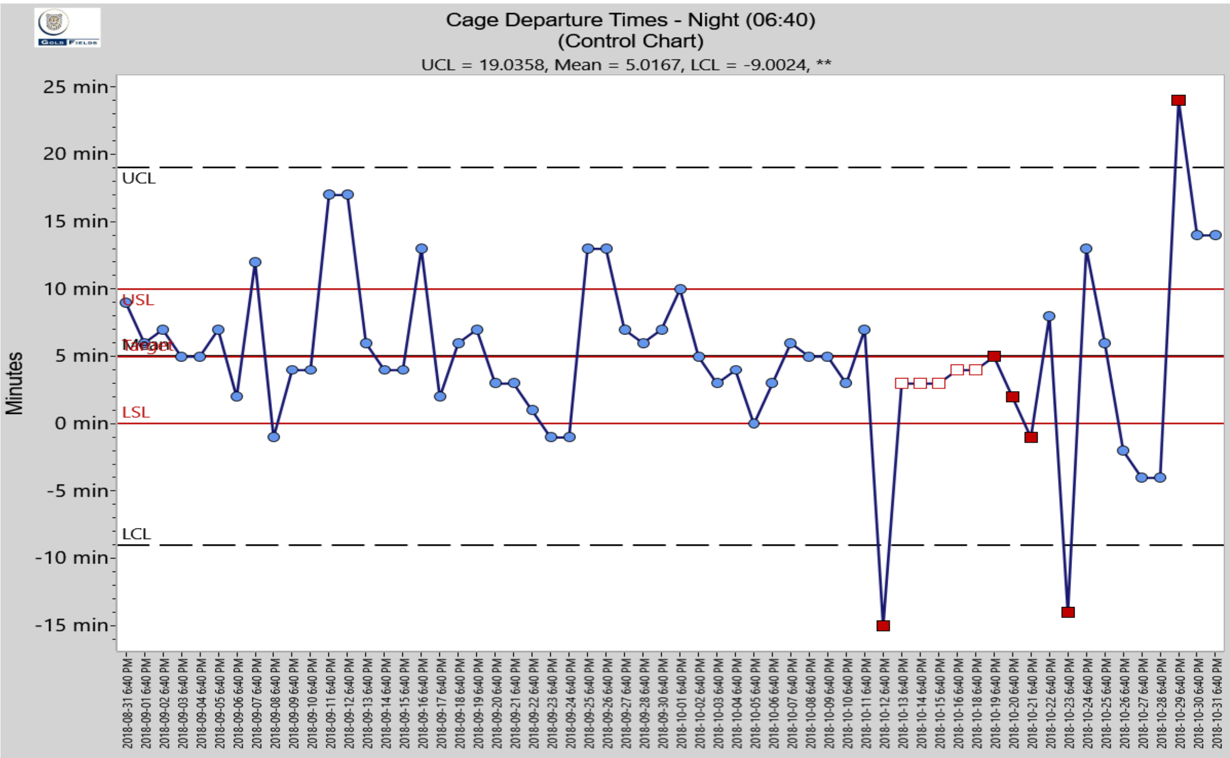
The performance tracker used by the section manager (process owner) is progressive in nature, with monthly output-reporting intervals. The dashboard data are updated on a daily basis and reviewed within the section managers' 24-hour review meeting. SIC meeting information, as well as data retrieved from the EPM system, is included in the dashboard report. The section manager utilises the report to monitor and control process performance by monitoring the output data, which is represented graphically, in the form of control charts. Each functional process, vertical, horizontal, and mining, has its own area in the dashboard report. Dashboard reporting includes the following graphical representation techniques:

- Line and bar graphs;
- Histograms; and
- Control charts.

These are accessible by mobile device to all line supervisors, section managers, and senior managers, through software applications and electronic mail. This graphical data are collated in a dashboard report and published in the company at the required level on a daily basis, prior to the 24-hour section manager's review with his/her team. Actual examples of the vertical logistics process control charts (Cage departure times (CD)) from Twin Shaft, extracted from the mine's EPM system, are provided in Figure 6.57.

The control charts indicates the cage departure times and the comparison of daily performance versus upper control limits (UCL), lower control limit (LCL), as well as upper- and lower specification limits (USL and LSL respectively). The section manager typically uses the data on a daily basis to analyse trends, outliers for special cause variation, and continuous variability perhaps as a result of common cause variation. Special cause variation requires problem-solving techniques to rectify, whereas special cause variation requires further statistical analysis and perhaps even the initiation of a minor Lean Six Sigma project to address the prominent variables affecting the output performance.


Cage Departure Times - Night (18:15)
(Control Chart)
UCL = 12.4507, Mean = 3.3000, LCL = -5.8507, **
Minutes
UCL
USL
Target
Mean
LSL
LCL
15 min
10 min
5 min
0 min
-5 min
-10 min
-15 min


Cage Departure Times - Night (06:40)
(Control Chart)
UCL = 19.0358, Mean = 5.0167, LCL = -9.0024, **
Minutes
UCL
USL
Mean
LSL
LCL
25 min
20 min
15 min
10 min
5 min
0 min
-5 min
-10 min
-15 min

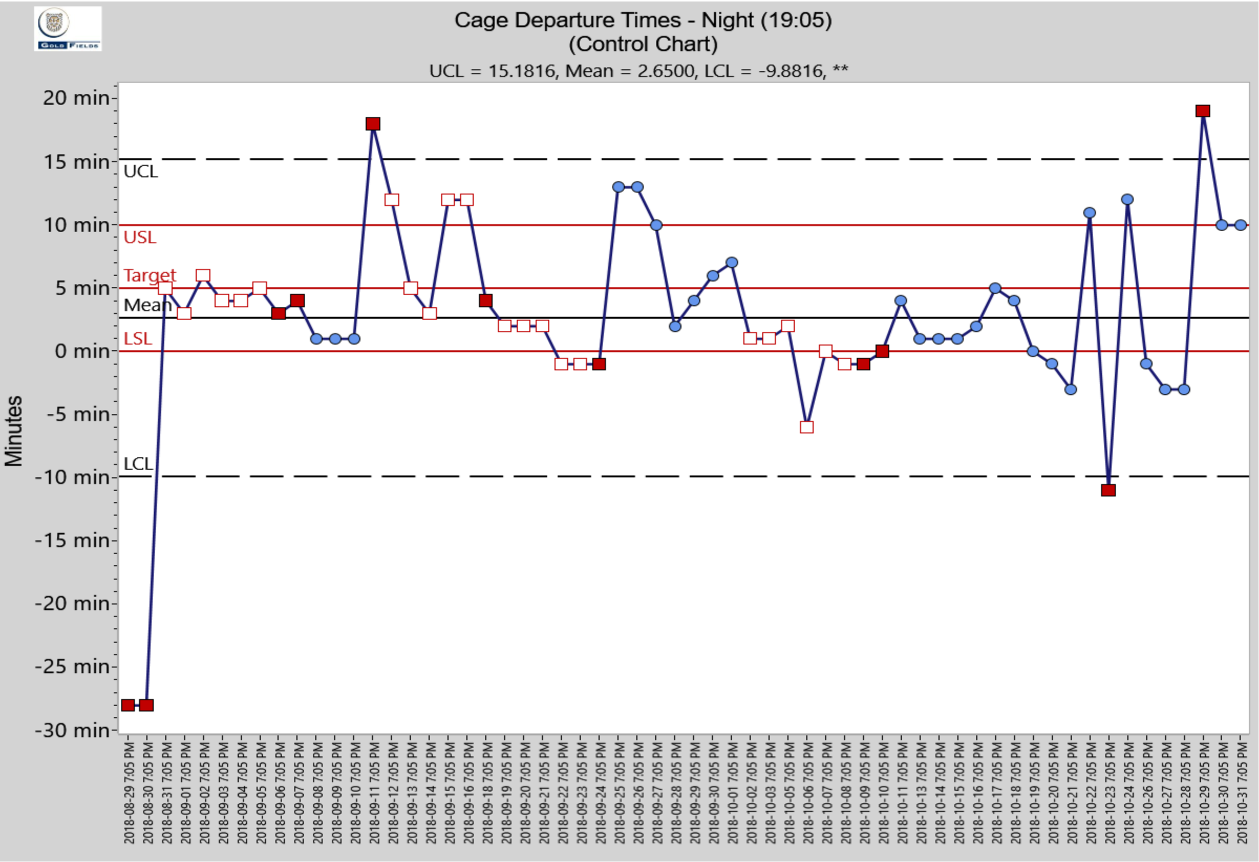


Figure 6.55: Actual CD time control charts. Courtesy of Gold Fields International

As can be seen in the control charts above, the first image represents the first cage's departure, the second image is the second cage, and the third image is the third cage. These control charts represent the actual night shift cage departure (CD) times. The UCL and LCL are set at the CD of *15min late* and *10min early*. There are two outliers on the UCL in this period and one outlier in the LCL, which all represent special cause variation, which requires root cause analysis, investigation, and conventional problem-solving techniques. The USL and LSL are set at *10min late* and *On time*, as it is not a desired specification for the cage to depart early. Any late departure exceeding 10min is grounds for investigation, as it well exceeds the plus 5min over IPLS time.

The target or baseline/intervention point is when a trend of departure times exceeds the baseline/intervention point set at 5min. The mean departure time of the last cage (third cage) is 2.6min late, which is well within the baseline of plus 5min IPLS. These control charts are run for each of the defined KPIs and monitored daily by the line supervisor and section manager of that particular logistics function. On a quarterly basis, these dashboard reports are utilised to develop performance statistics, which are reported to the senior and executive management teams. Most importantly, the primary metric of face time is also monitored daily in this manner and reported on accordingly. The next chapter reports on the achievement of the research objectives, and discusses future research in this area.

CHAPTER 7: CONCLUSION

The quantification and optimisation of logistics processes is achievable through implementation of conventional Lean Six Sigma methodologies in ultra-deep mining. The present research provides ultra-deep mines with the ability to accurately quantify the performance of their personnel logistics process. From the quantification of this baseline performance, mines can then set their required performance parameters and initiate the optimisation process. With the face time efficiency factor developed through this research, mines could benchmark their performance against one another. Face time efficiency factor as the primary metric in the quantification of personnel logistics performance is a unique contribution to the body of knowledge on ultra-deep mining.

7.1 Research objectives

Achievement of the present study's research objectives is summarised below.

Research Objective 1: Maximise face time at South Deep Twin Shaft gold mine.

> *Research Sub-objective 1.1: Quantify baseline personnel logistics performance.*
> The *Define*, *Measure*, and *Analyse* phases of the DMAIC Model were successfully implemented for the purpose of accurately quantifying personnel logistics performance. The Face time efficiency factor for South Deep Twin Shaft was found to be at a dismally low level of around 50%.
>
> *Research Sub-objective 1.2: Optimise personnel logistics performance.*
> Through the *Improve* phases, Twin Shaft's personnel logistics process was increased to approximately 72%. In the control phase, personnel logistics movements were standardised and measures put in place to sustain these.

Research Objective 2: Develop an integrated personnel logistics model.

From the *Control* phase of systematically standardising and sustaining the personnel logistics, an integrated personnel logistics model, the IPLS, was developed. This model involves all logistics departments during development and the integration of all logistics functions, and ensures the flow of the overall personnel transportation system. Through the continuous flow achieved by integration of all functions, all waste is mitigated as far as possible, and face time in all working areas was maximised.

7.2 Recommendations for practice

It is recommended that this methodology of quantification and optimisation of personnel transportation and logistics processes in ultra-deep mines be adopted in Gold Fields South Deep Gold Mine. This research should be shared with local mining houses, especially within the Witwatersrand Basin, as well as the UDMN of Canada, for review and potential implementation. It is in the view of the present researcher that this research could fundamentally change the manner in with ultra-deep mines are designed and constructed, so that personnel logistics performance is considered throughout these two phases of green fields mining projects.

7.3 Recommendations for future research

As previously described, to fully quantify the overall logistics performance of any ultra- deep mine, the supply chain and ore-handling logistics performance must also be quantified. Research should be conducted on the supply chain logistics performance of ultra-deep mines. The supply chain performance could be quantified using the supply chain efficiency factor proposed in the present study. Then, using the product of supply chain and face time efficiency factors, overall logistics performance of any mine could be quantified. The overall logistics efficiency factor could then be used in reporting to the mine's stakeholders, investors, board members. This factor is a simple yet powerful predictor of mine productivity.

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ANNEXURES

Annexure A: Main Shaft Hoisting Diagrams

Annexure B: South Deep Gold Mine - Logistics optimisation – Maximising face time

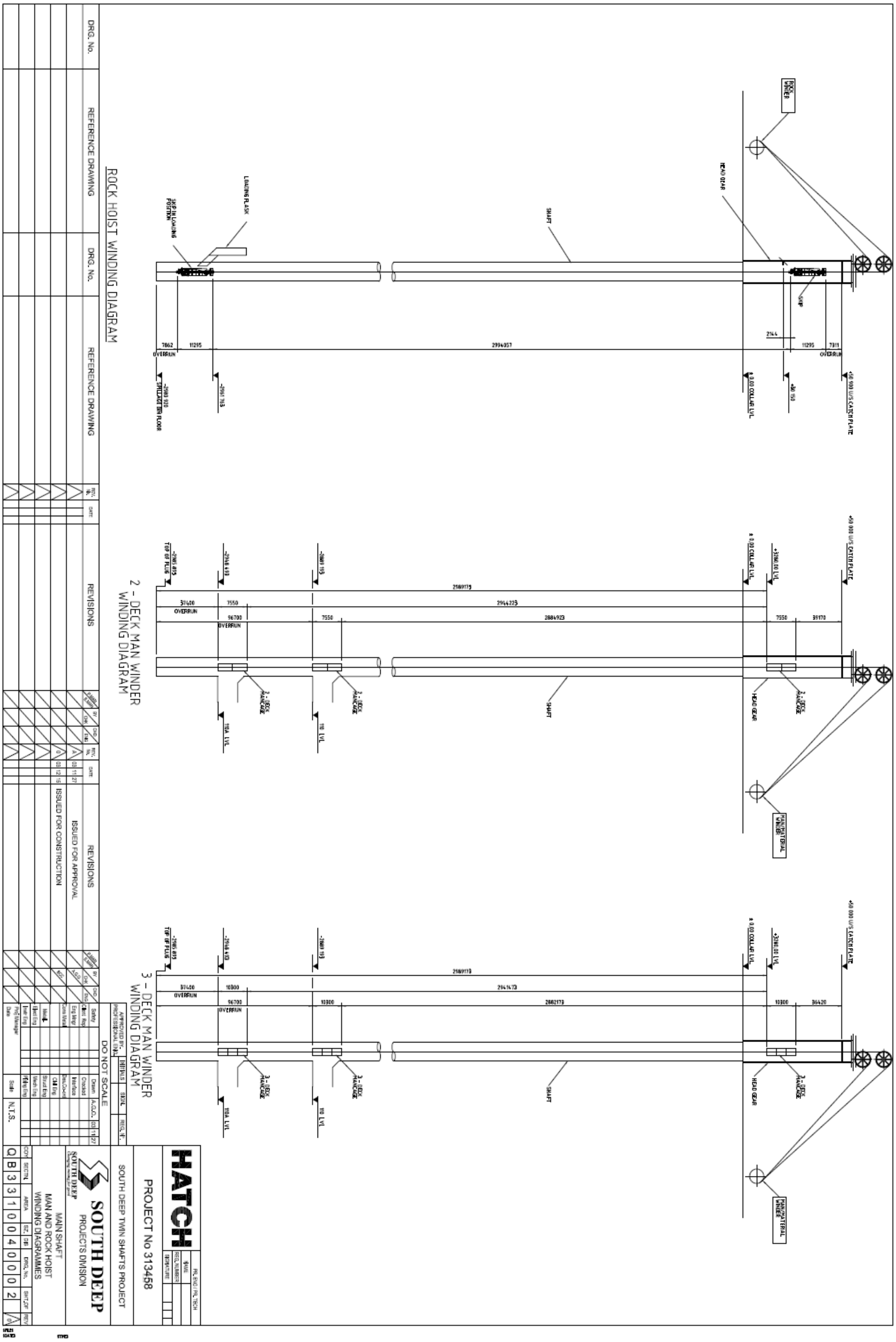
Annexure C: Shaft scheduling methodology and calculations sheets

Annexure D: Integrated Personnel Logistics Model (IPLS) methodology and calculations

Annexure E: Optimisation of the Twin shaft personnel and material handling & horizontal personnel transport – "Full document available upon request"

Annexure F: Control and instrumentation high level technical report – Control philosophy for electronic data collection

Annexure A: Main Shaft Hoisting Diagrams



Annexure B: South Deep Gold Mine - Logistics optimisation – Maximising face time

“Full document available on request”

Annexure C: Shaft scheduling methodology and calculations sheets

Calculation 1:	**Minimum number of trips**	
Actual conveyance capacity:		
Cage loading factor:	0.85 (From empirical data)	
Persons per deck (2 Deck cage):	75	
Persons per deck (3 Deck cage):	51	
Persons per cage (2 Deck):	150	
Persons per cage (3 Deck):	153	
Approximate number of permanent employees per working place		
93 level	120	
95 level 2 West	140	
95 Level 3 West	130	
100 Level	100	
110A Level	30	
Approximate number of contractors per working place per shift		
93 level	30	
95 level 2 West	90	
95 Level 3 West	60	
100 Level	50	
110A Level	30	

Trip description	**Number of personnel**	**Number of trips**
95 level 2 West Employees	140	**6**
95 Level 3 West Employees	130	
95 level All Contractors (2W+3W)	150	
93 level Employees + Contractors	150	
100 Level Employees + Contractors	150	
110A Level Employees + Contractors	60	
Total per shift	**780**	

Information:

Vertical logistics process times (Future state and in sequence):	
Clock in: Zone 1	00:00:04
Clock in: Zone 2	00:00:04
Walk to shaft	00:02:00
Wait for cage	00:02:00
Cage on bank/Open gates/doors	00:00:29
Offload all decks	00:01:17
Travel through turnstile	00:00:04
Close and open gates	00:00:29
Load cage	00:04:18
Close door and gates	00:00:17
Signal (Ring away)	00:00:20
Cage departs	00:00:40
Lower to level	00:05:00
Apply Levelok	00:00:20
Levelok clamping	00:00:15
Signal offload	00:00:02
Open shaft and cage doors	00:00:12
Offload all decks	00:02:17
Unlock counting turnstile	00:00:09
Apply Levelok	00:00:20
Levelok clamping	00:00:15
Load Signal/Open Gates/Doors	00:00:12
Travel through turnstile	00:00:04
Load cage	00:02:24
Close gates/doors	00:00:15
Release Levelok	00:01:03
Ring away to bank	00:00:27
Cage departs	00:00:32
Travel to bank	00:05:00
Signal/Open doors/gates	00:00:29
Offload on bank	00:02:17
Employee shifts details and durations:	
Dayshift:	09:30:00
Nightshift:	09:30:00

Bank to level travelling times:	
Bank to 90 level	00:03:41
Bank to 93 level	00:04:33
Bank to 94 level	00:04:36
Bank to 95 level	00:04:40
Bank to 100 level	00:04:48
Bank to 110A level	00:05:14

Inter-level travelling times:	
90-93	00:00:53
90-95	00:01:17
93-94	00:01:26
93-95	00:01:22
93-110a	00:01:56
95-100	00:01:11
95-110a	00:02:01
100-105	00:01:13
100-110a	00:02:08
105-110a	00:01:39

Calculations:

Shaft schedule sequencing		
Calculated shaft schedule times (Round up to nearest minute)		
Calculated		**Final**
110A Cage:	**3 Deck**	
Dayshift departure:	06:00:00	**06:00:00**
Trip time:	00:05:14	
Arrival on station:	06:05:14	**06:06:00**
Offload time:	00:02:31	
Send onsetter to 100 Level:	00:04:36	
Send 2 Deck to Surface:	00:05:57	
2 Deck cage arrives on bank:	06:19:04	**06:19:00**
100 Cage:	**2 Deck**	
Load cage:	00:06:37	
Dayshift departure:	06:25:37	**06:26:00**
Trip time:	00:04:48	
Arrival on station:	06:30:25	**06:31:00**
Offload time:	00:03:06	
Send onsetter to 93 Level:	00:04:00	
Send 3 Deck to Surface:	00:04:33	
3 Deck cage arrives on bank:	06:42:04	**06:43:00**
93 Cage:	**3 Deck**	
Load cage:	00:06:37	
Dayshift departure:	06:49:37	**06:50:00**
Trip time:	00:04:33	
Arrival on station:	06:54:10	**06:55:00**
Offload time:	00:03:06	
Send onsetter to 95 Level:	00:02:25	
Send 2 Deck to Surface:	00:04:40	
2 Deck cage arrives on bank:	07:04:21	**07:05:00**
95 All Contractors Cage:	**2 Deck**	
Load cage:	00:06:37	
Dayshift departure:	07:11:37	**07:12:00**
Trip time:	00:04:40	
Arrival on station:	07:16:17	**07:17:00**
Offload time:	00:03:06	
3 Deck cage arrives on bank:	07:22:23	**07:23:00**
95 2W Cage:	**3 Deck**	
Load cage:	00:06:37	
Dayshift departure:	07:29:37	**07:30:00**
Trip time:	00:04:40	
Arrival on station:	07:34:17	**07:35:00**
Offload time:	00:03:06	
2 Deck cage arrives on bank:	07:40:23	**07:41:00**
95 3W Cage:	**2 Deck**	
Load cage:	00:06:37	
Dayshift departure:	07:47:37	**07:48:00**
Trip time:	00:04:40	
Arrival on station:	07:52:17	**07:55:00**
Offload time:	00:03:06	
3 Deck cage arrives on bank:	08:00:23	**08:00:00**
Supervisors/Management Cage:	**3 Deck**	
Load cage:	00:06:37	
Dayshift departure:	08:06:37	**08:07:00**
Trip time:	00:04:40	
Arrival on station 95:	08:11:17	**08:12:00**
Offload time:	00:03:06	
Release Levelok/Load onsetter:	00:02:02	
Travel to 100:	00:01:11	
Arrival on station 100:	**08:18:19**	**08:19:00**
Offload time:	00:03:06	
Release Levelok/Load onsetter:	00:02:46	
Travel to 93:	00:01:30	
Arrival on station 93:	08:26:22	**08:27:00**
Start Daily examination	08:30:41	**08:30**

Annexure D: Integrated Personnel Logistics Model (IPLS) methodology and calculations

Integrated Personnel Logistics Schedule

Shift	Personnel	Vertical logistics (down)				Horizontal logistics (In)		Mining operations (In)			Mining operations (Out)			Horizontal logistics (Out)		Vertical logistics (Up)		Face Time	Face Time Factor
		Zone open	Zone close	Cage departure from surface	Cage arrival on station	Man carriage Departure to waiting place	Man carriage arrival at waiting place	Personnel arrive at waiting place	Personnel depart from waiting place	Start Work	End Work	Personnel depart to waiting place	Personnel arrive at waiting place	Man carriage departure to station	Man carriage arrival at station	Cage departure to surface	Cage arrival on surface		
Dayshift	All Contractors 2 and 3 West	06:57	07:07	07:12	07:17	07:27	07:47	07:55	08:25	08:51	15:31	15:31	15:57	16:01	16:22	16:27	16:32	**06:39**	**70,17%**
	95 2W Employees only	07:15	07:25	07:30	07:35	07:45	08:02	08:06	08:36	09:02	15:55	15:55	16:21	16:22	16:40	16:45	16:50	**06:53**	**72,49%**
	95 3W Employees only	07:33	07:43	07:48	07:55	08:05	08:20	08:28	08:58	09:24	16:12	16:12	16:38	16:42	16:58	17:03	17:08	**06:48**	**71,61%**
	Supervisors/Management only	07:52	08:02	08:07	08:12	08:22	08:42	08:50	09:20	09:46	12:54	12:54	13:20	13:41	14:02	14:07	14:13	**03:08**	**N/A**
Nightshift	All Contractors 2 and 3 West	18:57	19:07	19:12	19:17	19:27	19:47	19:55	20:25	20:51	03:31	03:31	03:57	04:01	04:22	04:27	04:32	**06:39**	**70,17%**
	95 2W Employees only down	19:15	19:25	19:30	19:35	19:45	20:02	20:06	20:36	21:02	03:55	03:55	04:21	04:22	04:40	04:45	04:50	**06:53**	**72,49%**
	95 3W Employees only down	19:33	19:43	19:48	19:55	20:05	20:20	20:28	20:58	21:24	04:12	04:12	04:38	04:42	04:58	05:03	05:08	**06:48**	**71,61%**

Set times from data inputs	Time
Cage arrival to carriage departure	00:10:00
Carriage departure to arrival at 3W	00:15:50
Carriage departure to arrival at 2W (No stop)	00:17:50
Carriage departure to arrival at 2W (Stop at 3W) en rou	00:20:55
Carriage to waiting place 3W	00:07:24
Carriage to waiting place 2W	00:03:52
Waiting place meeting	00:30:00
Travel to working place and start work	00:26:00
Work to waiting place	00:26:00
Waiting place to man carriage 2W	00:00:47
Waiting place to man carriage 3W	00:04:19
Man carriage to station from 2W	00:17:50
Man carriage to station from 3W	00:15:50
Man carriage at station until load into cage	00:04:28
Shift duration	09:30:00

Annexure E: Optimisation of the Twin shaft personnel and material handling & horizontal personnel transport – "Full document available upon request"

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Optimisation of the Twin shaft personnel and material handling & horizontal personnel transport

South Deep Mine

12 November 2017
BIECON 2017/12 Revision 1.0
Derek Botha & Gideon van Zyl
Project Manager – Michael Olivier

INFORMED DECISIONMAKING

Company Registration number: 2001/018192/07
Directors: DO Botha, NJ Grey and GAJ van Zyl

Synopsis

This report is published by BIECON Industrial Engineering (Pty) Ltd for South Deep mine South Africa, on behalf of the South Deep management. BIECON is the owner of the intellectual property which is being used to originate the results in this report.

Disclaimer

Rev	Description	Author	Reviewer	Date
0.0	Draft	DO Botha	GAJ van Zyl	01 November 2017
0.0	Internal Review	DO Botha	GAJ van Zyl	3 November 2017
1.0	Issue to Client	DO Botha	Michael Olivier	12 November 2017

Project Background and Management

This project is a result of the shaft problems identified by Mr. Michael Oliver - Unit Manager Engineering, whose was also responsible for the following aspects of this project:

- The identification of the outside consultants used i.e. Biecon Industrial Engineering.
- The co-ordination of all the project work and project teams.
- The analysis and interpretation of the time and motion study data.
- As well as solution generation to overcome identified constraints
- Is also the project champion for implementation of all the final accepted recommendations.

Annexure F: Control and instrumentation high level technical report – Control philosophy for electronic data collection

Optimisation of Face Time

Monitoring and control philosophy

Shaft:

Optimization of shaft time is monitored via PAC (Process Automation Controller). Discrete signals from 2 Proximity Switches are inputs to PAC. One from the Conveyance on Bank and other is shaft gates Opened. This information is used to define which conveyance is at the bank, Underlay or Overlay. The Shaft gate switch will indicate if shift was loaded from Skybank.

The data is sent via Ethernet to SQL through a Date acquisition (HSSQX) which is written into a table at a certain time. This time is determined by the Shaft schedule.

The data is Time/date stamped. A query is used to extract the data to a SSRS report that is generated automatically after day and night shift. Report gets mailed automatically to relevant persons responsible.

Man carriage tracking:

RF technology is used to track the man carriage. RF readers are placed in specific locations. Locos and carriage is tagged with a passive RFid tag. When the passive tags enters the field generated by the RF reader (5M), it readers the unique ID of the tag. This information is sent via the Ethernet network to a collector and data written into SQL database. . A query is used to extract the data from the tables in the database to a SSRS report and GUI for visual presentation.

Clocking points at Waiting Places and work Shops:

Clocking system make use of an RFid system, reader and passive tag. When the passive tags enters the field generated by the RF reader, it readers the unique ID of the tag. This information is collected on the Maxxess T&A system via the Ethernet network. Whole T&A network is time synced through NTP server linked to the internet. All data is captured in a SQL database where it is Time/Date stamped. Raw data is linked to personnel and clocking times captured for the individuals. A view table is created from the data in the database. This view is used to generate reports of time personnel clocks at waiting place or Workshops.

Newtrax:

Newtrax develops wireless devices for people, machines and sensors that can connect to any network available in the mine including leaky feeder, Wi-Fi and LTE.

The positioning of mobile terminals on underground mine maps is achieved by leveraging any tracking information provided by the networks, plus any dedicated EPC RFID tracking system.

To solve network connectivity challenges in fringe areas of the mine where wires are unreliable such as development headings, cut-and-fill stopes, Alimak raises, undercut in block caves, as well as during post-accident rescue operations, Newtrax provides a battery-powered wireless network called MineHop.

The combination of heavy mobile equipment and the very tight nature of the operating space in an underground mine means that any hard wired communication system is inherently subject to damage by equipment, causing significant and ongoing maintenance issues. With advancements in both battery technology, as well as ultra-low power radio frequency (RF) microchips, the idea of a battery-powered wireless sensor network for use in extremely rugged environments such as underground mining, has been realised. The small nature of the batteries, enclosures and antennae, allows the equipment to be mounted in areas that pose very little risk of damage by heavy equipment. Since the batteries used are of a high capacity, and the power consumption of the equipment is so low, years of battery life can be achieved while maintaining real time monitoring.

The central server acts as the central point for the MineHop Network by providing TCP/IP connectivity to all the MineHop gateways of the system. The web console allows users to view and manage the Machine data coming from the MineHop wireless network and the associated sensors. It also provides real time information about the status of the MineHop infrastructure network, allowing for easier maintenance and repair.

The Ethernet gateway provides the communication pathway between the central server and the MineHop RF network. A gateway is commonly installed at each level of the mine. Its purpose is to relay the packets of data received from the MineHop RF network across the mine's Ethernet infrastructure back to the central server. It forwards the packets received on the RS-232 port from the wireless network to the Ethernet port that communicates with the central server. There are four ports on the Ethernet gateway an Ethernet port, an RS-232 serial port, a power port (120 or 240VAC), and an RS-422 port.

The information is the send to a SQL database where information can be looked at in real-time and reports can be generated.

Information collected from Machine includes:

Positioning
Machine health
Payload