An investigation into the optimization of personnel transportation to level 15 and below at Khuseleka No. 1 Shaft, Anglo Platinum

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†Paper written on project work carried out in partial fulfilment of Bsc. Eng (Mining Engineering)

Synopsis

The paper reports on a vacation work project conducted at Khuseleka No. 1 Shaft, Anglo Platinum, where there was a need to optimize the transport of personnel to level 15 and below. Approximately 900 men per hour need to travel between the shaft and the start of the current chairlift system. Time studies were used as the major indicator of the extent of the current problem, and it is recommended that a new chairlift system be installed to cover the distance from the vertical shaft station at level 15 to the chairlift decline station on level 15. A capital cost of approximately R10 million is necessary to carry out the proposed recommendation.

Khuseleka No.1 Shaft has the capacity to wind 1070 people per hour, and the current labour complement going to the level 15 shaft station stands at 1570 employees; thus at optimum efficiency the proposed chairlift system could transport the entire shift to the start of the current chairlift system in only 1 hour and 45 minutes. Reducing the distance walked at the start of the shift may also have an impact on productivity.

Keywords

optimization, fatigue, chairlifts, cost-effective, travel times.

Introduction

The practical phase of this project was undertaken during the period November 2010 to January 2011. At that time Khuseleka No. 1 Shaft (K1) was searching for ways to optimize all the sub-systems within their operation in order to realize the full profit potential of the shaft. Transportation of men and material was considered to be one of the major constraints preventing this[1]. This problem was considered most severe for levels 15 and below (level 28 was the lowest working level at the time of this study). Personnel transport and material transport were reviewed separately, although it is obvious that a change in one will affect the other. This paper focuses on the transportation of men below level 15 at K1 and, in particular, looks for a solution that will have significant impact for the remaining life of the mine.

In order to compare suggested changes in the system to obtain the optimum, a model elimination analysis was conducted. Various transport models, after being investigated, were eliminated based on the priority project objectives, with an eventual goal of decreasing walking distances and increasing effective stope times. Through implementing an optimum design, the mine should be able to realize a higher productivity.

Transport systems from the bank area to the raise transportation are regulated, which limits capacities and possible achievable speed due to safety considerations[2]. Throughout this project safety was the paramount consideration, so the respective regulations governing a transport system were first studied and used to ensure all recommendations met their requirements. Other shaft-specific limitations such as sizes, speeds, efficiencies- and availability of technology were considered in each option for the transportation of men to level 15 and below.

Mine background

The site of the project was Khuseleka No. 1 (K1) Shaft near Rustenburg. K1 is one of two shafts within the Khuseleka operation. K1 was previously known as Townlands shaft, and the other shaft, K2, as Boschfontein Shaft. Both shafts are located on the western limb of the Bushveld Complex and, are situated on the western outskirts of the Anglo American Rustenburg Platinum Mines (RPM). K1 was sunk in 1967 and commenced mining in 1971 with platinum group metals (PGMs) being mined from both the Merensky Reef and the UG2 Reef. The current life of mine is until the year 2017[2]. The main access from surface to underground for men, material, mine services, and for the removal of broken rock is a vertical shaft.

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Mining

A conventional method, namely scattered mining in the form of breast mining, is currently used to excavate the reef from level 15 to level 28. Level 28, the lowest level of the shaft, is also used to provide the services associated with a shaft bottom. Level 28 is currently being deepened, although the work was suspended at the time of the practical phase of this project. The production figures[3] for K1 for the year 2010 were 1906 kt of ore, at an average grade of 4.3g/t. K1 currently has two projects running concurrently, both of which are aimed at maximizing the excavation of the lease area, namely the Khuseleka Ore Replacement Project (KORP) and the Stay In Business (SIB) project. Currently the plans being produced by KORP will extend the life of mine to 2038[4]. The underground labour force of the shaft is 3988 employees, excluding the service departments.

Figure 1 illustrates the location of K1 relative to other shafts within the RPM lease area. The town of Rustenburg lies in southerly direction from K1. The names of the shafts in Figure 1 have been edited to reflect the names currently used by RPM.

Project background

When this work was undertaken Khuseleka was in a phase of optimizing systems in order to maximize the profitability of both shafts. The project described in this paper was a small part of the K1 programme and was aimed at establishing the optimum method of personnel transportation to level 15 and then to the lower levels.

Defining the problem

The long distances from the shaft area to the working stopes had already been identified by the mine as one of the contributing factors to the lower productivity experienced by the shaft. The underground labour complement going to level 15 and below is 1570 employees. The lowest level for the vertical shaft is level 15, which is 598 m below collar elevation. Levels from level 15 to level 28 are serviced by two chairlift declines in series, which are interlinked at level 23. The first chairlift sub-decline is from level 15 to level 23. The second chairlift sub-decline shaft is from level 23 to level 28. There are three haulages running the distance between the vertical shaft station and the first leg chairlift station at level 15. The first haulage contains the broken rock conveyor belt, which services the lower levels and has a travelling way on the side to allow men to walk alongside the belt. The second haulage is used for rail bound transportation which includes material cars and the man carriage. The third haulage is referred to as the 'old haulage' and is currently not utilized.

The best solution when considering the twin problems of fatigue and travelling times is installing a transport system at each level to efficiently transport men to their respective working places. However, a new transporting system at each level will have exceedingly high capital outlay and operational costs, and will significantly increase the mining costs. A man carriage system is currently (at the time of the project) in operation between the vertical shaft station and the first leg chairlift station on level 15. Below level 15, men walk the rest of the distances from the chairlift station on their respective working levels to their working places. The man carriage was intended to decrease the effective walking

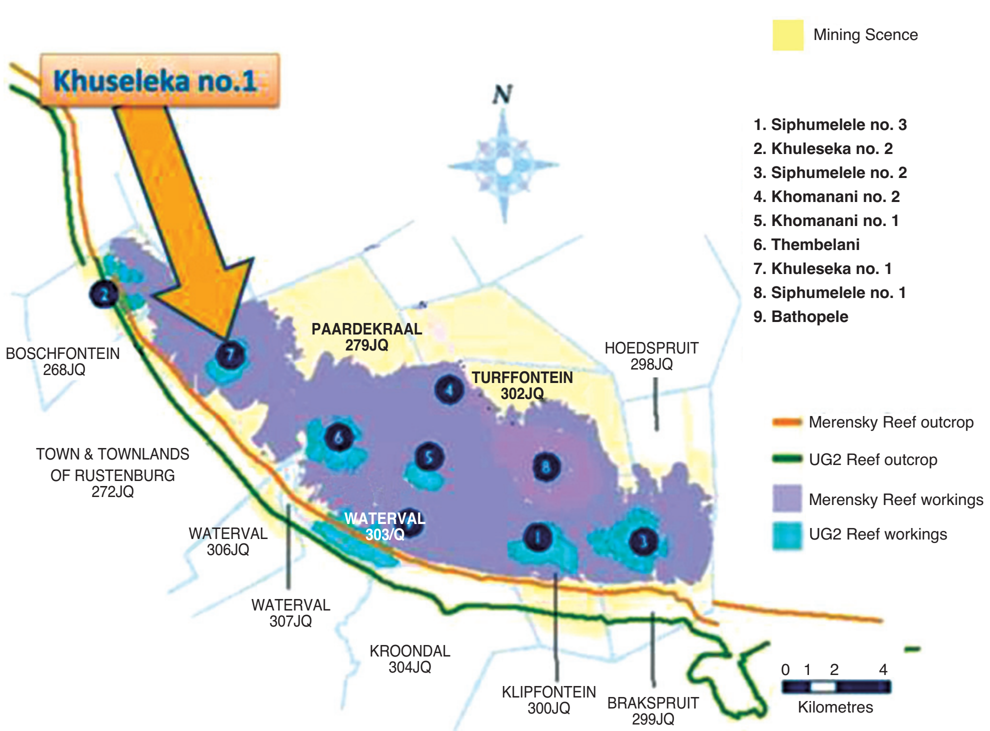

Figure 1—The Rustenburg Platinum Mines (RPM) lease area showing location of Khuselek No. 1 Shaft[5]

distances of mine personnel working at level 15 and lower levels[6] in order to increase the effective stoping time and thereby increase the blasting frequency. According to a study conducted by Ukhozi Project Management for Impala Platinum, the blasting frequency of panels increases if most work is concentrated towards the start of the shift[7]. Therefore one of the criteria used in this project was, in addition to increasing stoping time, the need to get the workforce to the stope as early as possible in the shift.

Project scope

The area of interest for the project was from the bank area to level 28, which is the lowest level on the shaft. The longest distance from the level 28 chairlift station to the furthest stope was, for modelling purposes, taken to be 2.5 km, although there are some work areas that exceed the chosen conceptual distance. In modelling the progress of an employee clocking-in into the bank area, a person will first queue up at the bank area before they enter the cage. The 'case study person' was modelled as they traversed each transport element until they reached their working place. The identified peak time for the transportation of men to level 15 and levels below was used as a guideline for optimizing the transportation of men on the levels.

Shifts

The shaft has two main shifts, which are the morning shift and the night shift. An afternoon shift is also available, although it is limited to the level 15 logistics crew, which consists of approximately 25 employees. The allocated time as shown by the shaft schedule for the morning shift and the nightshift is 8 hour and 50 minutes, which includes the travelling time[8]. The shaft has allocated a total of 1 hour and 30 minutes for travelling to the working place and returning. Maintenance times are scheduled so they do not interfere with the transportation of personnel underground. In order to have maximum impact the project concentrated on the mine's peak time (from 4:20 am to 6:20 am). This helped to limit the project scope.

Problem statement

The mine has identified a constraint leading to a loss in productivity, i.e. the transportation of personnel underground to their respective working places, particularly at level 15 and levels below. The main objective is to minimize this constraint in the most cost-effective manner, with the aim of increasing productivity of the affected levels by efficiently transporting mine personnel. The end product of the project was to conceptualize a system allowing a person to move from surface to their respective working areas without experiencing delays, to decrease the effective travelling time for each individual, and to also decrease the overall travel times of underground crews. The project also aimed to weigh the various tradeoffs to eliminate the necessity of the man carriage if at all possible.

Project objectives

- ➤ To understand the significance of the transportation problem within the project scope area
- ➤ To decrease the effective walking distances for employees and thus decrease fatigue in order for employees to arrive at their workplace in a fit state to begin work immediately and to concentrate most of their effective work at the beginning of the shift
- ➤ To decrease travelling times and thus increase the overall time for stoping activities within the shift
- ➤ To synchronize the transport system as far as practicably possible considering the change from a discrete transportation element (the shaft) to a continuous transportation element (chairlifts)
- ➤ To minimize queuing within the system and thus decrease the overall 'idling' time for employees during the shift.

Methodology

The methods used to conduct the project are summarized in Table I and are as follows:

- ➤ Measurement and observation
- ➤ Personal communication
- ➤ Literature research.

Results

The model analysis assumes a 100 per cent availability of transport elements during the shift peak time, which begins after 4 am and lasts until just before 7 am. The results consider travelling time distributions and overall walking distances, as these are the highlighted factors in optimizing the transport system.

Table I

Methodology

1. Measurement and observation	a. Define project scope area, constraints, peak time b. Time studies c. Interaction of the transport elements, loading, queuing
2. Personal communication	a. Consult relevant mine personnel b. Consulting with the supervisor at Wits
3. Literature research	a. Related projects previously done b. Data documents from the mine c. Further reading on parameters which affect the project outcome

Fixed parameters

The following parameters, according to the preliminary results of the project, were to remain unchanged. The parameters include:

- The cage capacity and winding cycle times (i.e. the shaft capacity): this is a major factor in determining the number of employees that go below level 15 in a morning shift. The cage has a higher capacity than any other element within the transport system, and thus by matching other transport elements to the shaft capacity, optimized of personnel transportation can be achieved.
- The current first leg and second leg chairlift systems: both the chairlift systems are moving at the maximum allowable speed for a chairlift of their configuration[9] which is 1.5 m/s.

Travelling sequence

Figure 2 illustrates the sequence through which people travel in order to get to their working places. The chart displays how each transport element within the overall transport system feeds men onto the next transportation element.

The distances travelled by mine personnel from the vertical shaft station at level 15 to their respective level, excluding the chairlift distances and the distance covered after dismounting the chairlifts, are as follows:

- Level 15 vertical shaft station to man carriage loading point: 982 m
- Man carriage unloading point to the first leg chairlift station at level 15: 182 m
- From the first leg chairlift station at level 23 to the second leg chairlift station at level 23: 125 m.

Motion path of mine personnel to level 15 and levels below

Figure 3 shows the motion path of mine personnel from the bank area to the end of the first leg chairlift station at level 23.

The path in Figure 3 includes travelling with the man carriage and excludes the path of walking from the vertical shaft station to the chairlift decline station on level 15. The average times taken by each transport element are shown with the distances of travel. The accumulative time of travel is also displayed to show the average time spent in travelling to the working place.

From the time studies, the following average speeds were observed:

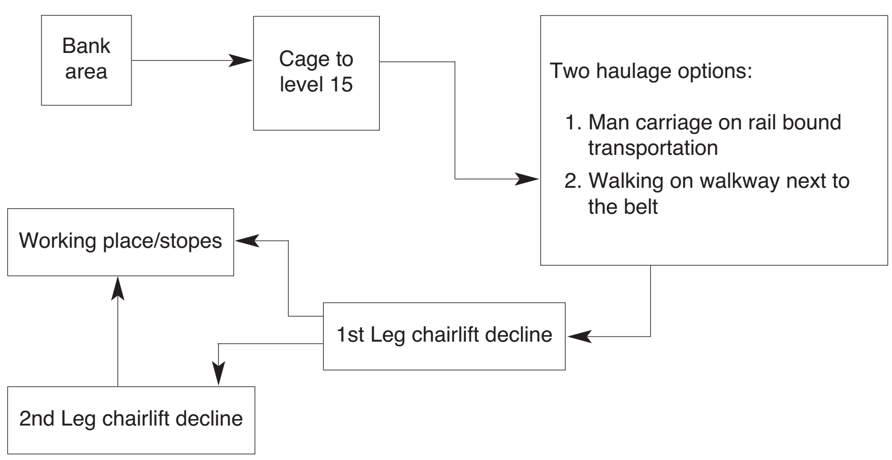

Figure 2–Travelling sequence from the bank area to working places on level 15 and levels below

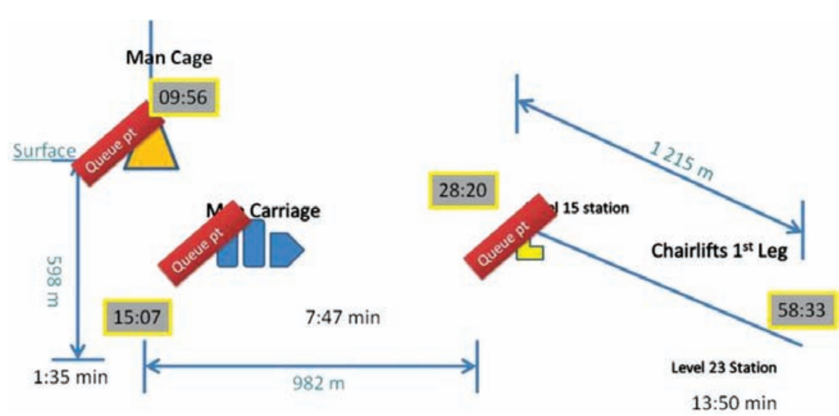

Figure 3—Annotated diagram of travelling sequences from bank area to first leg chairlift decline

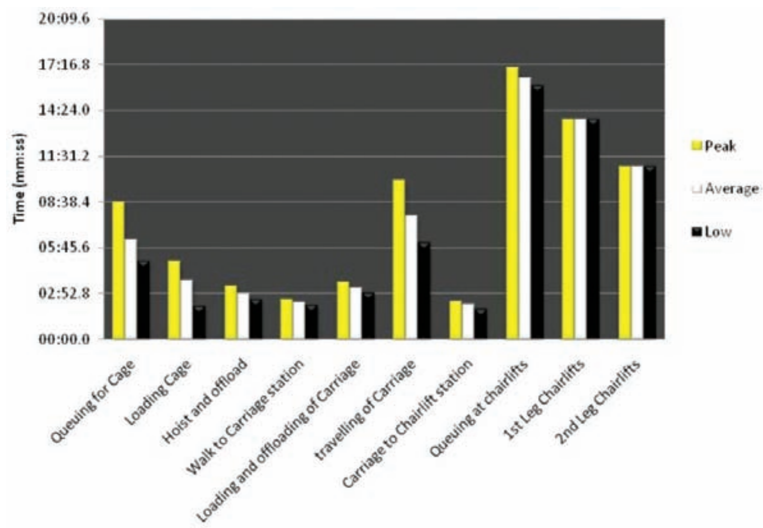

Figure 4—Time distribution for mine personnel using the man carriage

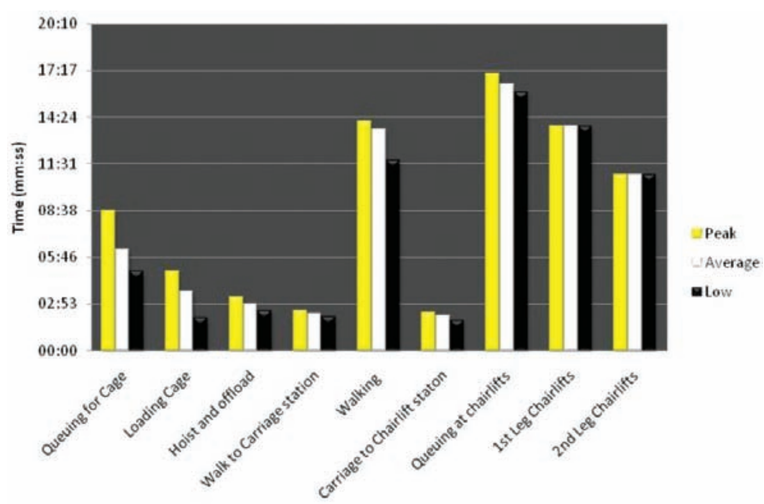

Figure 5—Time distribution for mine personnel walking in the conveyor belt haulage

- Cage 6.30 m/s
- Man carriage 2.10 m/s
- Walking 1.25 m/s
- Chairlift (1st and 2nd leg) 1.50 m/s.

The average speeds for both the cage and man carriage include the full cycle of travel starting from acceleration, constant speed motion and deceleration until a halt. The average speed of men walking was derived from constant observation and the time studies undertaken.

The average inter-level spacing from level 15 to level 28 is 32 m. The average inclination of the first leg and the second leg chairlifts is 10.6 degrees, which is almost the same as the dip of the reef which is an average of 9 degrees[3].

Level clocking-in

All fulltime underground mine personnel working on day shift and going to the level 15 vertical shaft station have a flexible clocking-in time from 03h47 to 05h10, as stipulated by K1's shaft schedule. This means that a person working on level 28 is able to go through the crush at 05h10 and will only arrive at the 28th level chairlift station at 06h17[8]. If the same person has to then walk the maximum distance to their workplace (estimated to be 2.5 km from the chairlift station), that person will only arrive there at 06h50.

Travelling time distribution

Figure 4 displays the time distribution for men who travel to level 28 chairlift station. The time distribution is for mine personnel who use the man carriage to travel from level 15 vertical shaft station to the chairlift station on level 15. Queuing at the first leg chairlift station takes the longest time, with 15 minutes on average being spent by each person. Fixed times are times that are deemed unchangeable for the purpose of this project, i.e. they could be changed but only as part of a more major reorganization.

Figure 5 displays the time distribution of men who travel to level 28 chairlift station. The time distribution is for mine personnel who use the walkway adjacent to the conveyor belt from level 15 vertical shaft station to the chairlift station on level 15. Figure 5 also shows the sensitivity of each factor. Although the times for both chairlift systems are fixed, queuing is again seen to be a major time consumer within the transporting route. This reinforces the data presented in Figure 4.

Figure 6 shows the time distributions for mine personnel who use the man carriage from the vertical shaft station and the current first leg chairlift station on level 15. The data is divided into walking, loading and offloading, queuing, and fixed times. This is the analysed version of the time studies done throughout the transporting route. Although 51 per cent of the time is for activities with fixed durations for the project purposes, 33 per cent is used in queuing, which is a significant amount of 'idling time'.

Figure 7, which is similar to Figure 6, shows the time distributions for personnel walking in the conveyor belt haulage.

Walking time as shown by Figure 7 is 25 per cent of the total travelling time. The fixed time is a lesser percentage (38 per cent) than in Figure 6 due to the fact that the travelling time of the man carriage is factored in as a fixed time. The reason for factoring the man carriage travelling time as fixed is due to mine regulations on maximum speeds for carriages transporting people[10].

Comparing models

Table II illustrates two possible models that the mine can adopt. The first model is that currently used by K1, while the second proposes an alternative using an additional chairlift. The capacity of each transport element and the number of employees who need to walk if the period of travelling exceeds 1.5 hours are the main parameters to compare. The additional capacity per hour offered by the chairlift not only reduces the cumulative travelling time but also has a major effect on the number of people required to walk.

Safety and cost implications

According to the 2010 safety statistics shown in Table III, the man carriage is safer than a chairlift transport system[6]. Both transport systems are not without injuries, and it must always be remembered that there is a constant need for improvements in the safety of transport systems. However, the size of the samples is too small to make any firm conclusion on the relative safety of the two systems.

Initial cost comparisons of the two models are given in Table IV. The costs of the chairlift system include the sliping of the sidewall throughout the length of the current man carriage route, which covers a distance of 982 m. The capital cost does not include the equipping of the old haulage (currently not utilized) for material transport, and thus the total cost of changing from the current model to a new

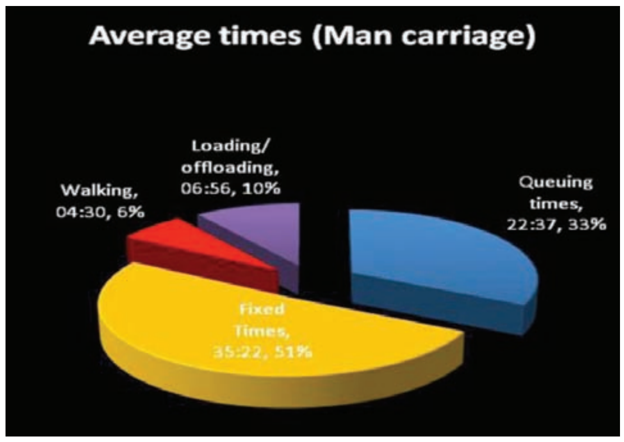

Figure 6—Analysed times for mine personnel using the man carriage

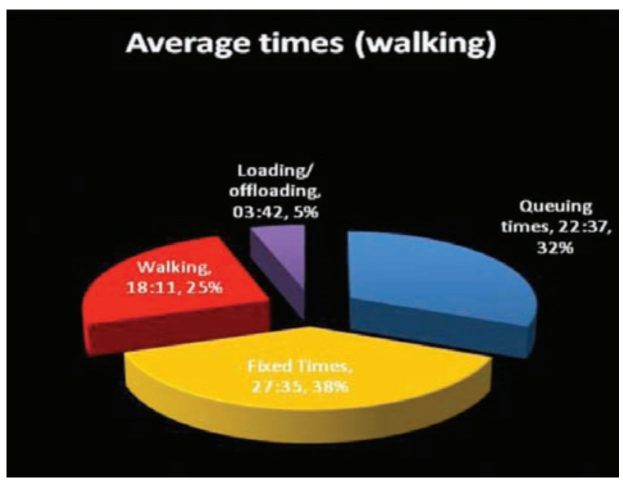

Figure 7—Analysed times for mine personnel walking in the conveyor belt haulage

Table II

Model comparison

From bank area to level 28 chairlift station	Current model 5t Locomotives, 4 MnC)	Possible model (chairlifts, 1.5 m/s)
Total travel time excluding queuing (min)	43	43
Total queuing time constant (13:34)	16	8
Capacity per hour	436 (persons)	900 (person)
Percentage using transportation element (%)	27.8%	57.4%
No. employees to walk after 2.5 hrs	1132	668
Cumulative time (min)	59	51

Table III

Safety record for the year 2010

Transport element	Fatalities	Lost time injuries
Chairlift system (1st leg and 2nd leg chairlift decline)	0	2
Man carriage (5 t locomotive)	0	1

Table IV

Cost implication per transport element[11]

Transport element	Capital cost (R/mil)	Monthly Maintenance cost (R)	Monthly labour cost (R)	Total cost (Jan'12–Dec'30)
Chairlift system	10	42 000	24 000	R13 376 000
Man carriage (5 t)	1.5	20 000	24 000	R3 751 000

Table V

Analysis of new transport system

ID	Benefits	Disadvantages
1	Decreases travelling time by 8 minutes	High capital outlay (R10 million)
2	Used by most people, thus decreases overall fatigue effects	High maintenance costs
3	Increases time for stoping activities (indirect payback)	Relatively higher safety concern
4	Better synchronization for the overall transport system	

chairlift model is understated. The capital cost quoted for the man carriage includes five individual carriages and a single 5t locomotive. The costs given in Table IV indicate that there must be significant advantages of the chairlift model over the man carriage model for it to be a feasible alternative.

Analysis of results

Table V shows the advantages and the disadvantages of installing a new chairlift system for the mine. The high capital and operational costs can be offset by the decrease in fatigue due to decreased walking distances and the addition time saved. The safety statistics comparing the man carriage and the chairlift system do not indicate a significant variation in the injury rate per person using the system; although there is a definite urgency to decrease the injury rate to zero.

Time at the workplace is a parameter which has a major impact on productivity. Any decrease of time spent travelling will increase the available time for men in their working places. The series connection of the transportation elements within the system limits the flexibility of the overall system and the impact that alterations in any discrete element can have on overall performance. Queuing is found at the start of transport elements and points where transport modes are changed; the effects are most severe when the transport mode changes from a 'batch' transport mode to a continuous transport mode. From Figures 4–7 it is evident that the man carriage and walking from the vertical shaft station to the chairlift station have a negligible time difference. Hence the major difference would be in the fatigue experienced by the workers.

Using a chairlift transport element in the level 15 haulage is more expensive than man carriages, especially since this system currently stretches most of the length from the vertical shaft station to the current first leg chairlift station. The labour costs are the same for both the transportation models, but the chairlift system is more efficient due to its higher capacity and the fact that fewer employees will be inclined to walk the 982 m to the first chairlift station.

Conclusion

The current clocking-on schedule at the mine causes inconvenience, with its severity increasing with depth below surface. According to the results, a person working 2.5 km away from the level 28 chairlift station and clocking-in on surface at 5 am will arrive at their work place only at 6:55 am. As a result, an entire crew can start their shift late due to such an occurrence. Another aspect that delays the commencing of stoping activities is the fatigue effect, where people have to rest when they arrive at their workplace before starting work. A man-riding transport system with a high capacity will result in decreases fatigue effects, indicating that mine employees should be transported by either a man carriage or a chairlift system between the vertical shaft station and the current chairlift station. From the analysis, the installation of a chairlift system is shown to be highly beneficial and gives the better solution of the two models considered. The capital cost of the chairlift system is substantial, and there is therefore a need of assurance for a return on investment. The savings in the accumulative travelling time (8 minutes per employee per shift) and less fatigued workers suggests that the mine will be in a position to improve blasting frequency and to obtain a good return on this investment.

Recommendations

This project resulted in a number of recommendations to the mine

➤ *Re-implement level-specific clocking-in*—The present system is that level 15 and all levels below have a common window for clocking-in. Personnel working on each level need to have a specified time at which they can go through the crush into the shaft area. This will help in people getting to their working areas in time for them to be able start their stoping activities and complete their tasks within the stipulated shift time

➤ *Install a chairlift system from the vertical shaft station to current first leg chairlift system on level 15*—The chairlift system provides a better transport model and has the potential to yield a higher financial return than the current system

➤ *Equip the old haulage for transportation of material*—If a chairlift system is installed, there will be the need for material transport to be moved to another haulage, which is the 'old haulage'.

Recommendations for further work

➤ *Fatigue caused by walking long distances to working places*—In conjunction with the above project, a stope shift buffering project was undertaken by Phillis and Gumede[7]. The mine can use this to further investigate how fatigue affects productivity. The main aim is to eventually motivate underground crews to focus all their energies on the stope face to achieve a daily blast

➤ *Effective control of crew adherence to knock-off times*—Due to the fact that the clocking off time is also flexible, there is a way for mine personnel to leave their place of work early before even completing their task. The benefits of the proposed mine personnel transportation will not be achieved if this possibility is not regulated, and it is recommended that an investigation should be conducted into the regulation of the knocking off time for underground crews

➤ *Restructuring of vertical shaft station loading points*—The loading of men at level 15 station can be construed as a potential hazard, and the design of this area and the relevant procedures require revisiting to eliminate this hazard

➤ *Possibility of installing cost-effective transport systems*—Even after implementing the new chairlift system, the problem of long walking distance will remain for some underground crews. The problem of distance to the working places will become more severe as the mine gets deeper, and so a safe, fast, and cost-effective transport system for each level still needs to be considered for the future.

Acknowledgements

The following organizations and people have been instrumental in assisting with the project in many ways. The first token of appreciation goes to Anglo American Platinum for providing the project and giving permission for the results to be published. Secondly, thanks are due to Mr L. Mnisi and the K1 logistic section team for assisting with data and advice throughout the project. The assistance of the School of Mining Engineering at the University of the Witwatersrand is also gratefully acknowledged with special thanks to Professor Huw Phillips who was instrumental in producing the final version.

Most importantly I would like to give thanks the Most High Lord whom by his grace and unparalleled providence has shown his generosity and mercy throughout, though undeserved.

References

1. Mnisi, L. Personal communication. Production manager. Khuseleka No.1 Shaft, Rustenburg 18 November 2010.
2. Roodt, B. 2011 January 10. Personal communication. Human resource Manager. Khuseleka no. 1 Shaft, Rustenburg, 8 January 2011.
3. Survey office 15 level to 23 level chairlift decline plan, Khuseleka no. 1 Shaft, Rustenburg, 04 January 2011.
4. Labuschagne, A. personal communication. Shaft mine engineer. Khuseleka no. 1 Shaft, Rustenburg, 18 January 2011.
5. Rustenburg Platinum Mines, (original source unknown).
6. Naude, I. Personal communication. Logistics Mine Overseer. Khuseleka No.1 Shaft, Rustenburg, 10 January 2011.
7. Phillis, R.C.D. and Gumede, H. The Impala case study on stoping shift buffering: a critical chain project management perspective. Hard Rock Safe Safety Conference. *The Southern African Institute of Mining and Metallurgy*, Johannesburg, 2009, pp. 31–41.
8. Sinden, W. Personal communication. (shaft m/o), 8 January 2011.
9. Rustenburg Platinum Mines-Rustenburg Section, Anglo Platinum Group-Engineering Technology. Engineering Standards: Standard for Chairlift, 11 November 2002, Regulation 16.111.09, pp. 3–9.
10. Rustenburg Platinum Mines-Rustenburg Section. Undeground tramming and transport procedure Engineering Procedure. Rustenburg, 15 May 2006, pp. 3–13.
11. Phalane, L. Personal communication. Engineering Foreman. Khuseleka No. 1 Shaft, Rustenburg, 4 January 2011. ◆