AN ASSESSMENT OF THE EFFECTIVENESS OF SAFETY INTERVENTIONS IN THE FIELD OF BULK MATERIALS HANDLING

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1. INTRODUCTION

Since the widespread adoption of large scale, bulk mining operations after the Second World War, conveyors have become essential equipment to efficiently move material. During this same period, mine safety has become progressively more important, initially in developed countries, but recently even in undeveloped countries, and as a result, in most countries where accurate records are maintained, fatality rates associated with mining have gradually declined. South Africa for instance, has reduced the total number of mine fatalities from 309 in 1999 to 128 in 2010 [1]. In order to continually improve safety, especially to reduce major accidents and prevent fatalities, it is currently accepted that it is necessary to be constantly aware of, and manage major workplace hazards, as well as to encourage a culture of responsibility and safe behaviour to eliminate injuries and fatalities that result from unsafe work practices [2].

In the mining environment, conveyors and material handling systems present a significant hazard as a result of the associated large amounts of installed power, stored energy and inertia. Despite their widespread use, and the significant associated hazard, conveyors account for a relatively small proportion of mining fatalities. During the time period from 1989 to 2006, in Australia [3], only six conveyor-related fatalities have been recorded, compared to a total of 310 mining fatalities (or 1.8%). In South Africa over a similar period there were 131 conveyor related fatalities which account for an estimated 3% of mining fatalities. (Based on an estimated average of 200 fatalities a year). The figures for the USA are somewhat different with 49 conveyor related fatalities out of 533 (or 9.2%) occurring in the period 1995-2007 [4]. The purpose of this paper is to review available conveyor related accident data, to determine if conveyor safety has improved over recent time, to attempt to understand why the safety has improved, and get an understanding of where the major risks are, and what can be done to mitigate these risks.

2. OBJECTIVES

This paper has the following objectives:

- Based on a review of available safety statistics, to determine whether conveyor systems have become safer over the last thirty years
- To attempt to identify possible reasons for the improved safety
- Based on the review of the statistics, to identify high risk activities
- To determine if there is any specific equipment, or parts of the conveyor that represent an elevated safety risk
- To make appropriate recommendations with respect to improving belt conveyor safety.

3. REVIEW OF DATA AVAILABLE

A search was done for safety data in a number of countries where mining is a significant industry. Data from the USA, Australia and South Africa was assessed. The quality, ease of access and reliability of this data differed greatly as follows:

USA

In the USA, the Department of Labor, on its website [5] has a complete database of all fatal accident reports from 1995. The database is searchable through the equipment involved, and therefore conveyor related fatalities can be easily extracted. A total of 50 fatal incident reports are available from 1995 to 2007. In addition, a complete database of all mining safety statistics from 1983 is available on the National Institute for Occupational Health and Safety website [7] but conveyor related incidents cannot be easily extracted, and the database lacks narrative information to provide context.

Australia

Australian mine safety statistics are collected on a state by state basis, which results in the data being somewhat fragmented. For all states however, there is a publicly available safety alert for every serious safety incident since the early 1990's. The information supplied in the bulletin is sufficiently complete to determine the details of the event, the activities that were being performed, the location of the activities and the seriousness of the outcome. A brief summary of the safety alerts for New South Wales, Queensland and Western Australia is presented in Table 1. It should be noted that the information in Table 1 is for three states only and not Australia as a whole.

State	First Alert Issued	No. of Alerts	No. Conveyor Related	Conveyor Fatalities
NSW [6]	1998	210	1	0
Queensland [7]	1999	76	0	0
Western Australia [8]	1989	170	2	1

Table 1. Summary of Australian safety alert

South Africa

The only data that could be found on the Department of Minerals and Resources website [10] is limited to a summary of mine fatalities by month from February 2009 up to January 2011 (although a number of months are missing). The summary includes only very basic details of the fatalities. It was, however, possible to extract that of the 162 fatalities detailed, only two (1.2%) were as a result of conveyors, whist another two were due to inundation by bulk material. In addition, a database of all mining reportable incidents between 1990 and 2009 was obtained from the DMR [11]. This database had no narrative information, but did include the number of fatalities and injuries, the mine at which the incident occurred, as well as a code which indicates the type of equipment involved and the nature of the incident. Conveyor incidents were characterised as one of seven categories, head pulley, snub pulley, tail pulley, idler, tension carriage, and feeder breaker.

4. METHODOLOGY

In order to gain an understanding of the nature of conveyor related fatalities, fatality reports involving conveyors from the USA, as well as safety incident reports from Australia were analysed. Additional fatality data was extracted from The International Mining Fatality Review, available from the New South Wales Department of Primary Industries website [3]. This review is an extensive database of mining related fatalities; including a comprehensive listing of fatalities from Canada, USA, UK, Australia, and New Zealand.

Associated with the hazards, there are a number of activities (related to conveyor belt operation and maintenance) that could result in a safety incident. The most common of these are:

- Cleaning of spillage
- Cleaning of chutes
- Cleaning of material from (moving) mechanical equipment
- Riding on the belt
- Crossing the moving belt
- Unexpected movement of belt during maintenance
- Unexpected movement of take-up during maintenance.

These activities can be further classified as those that occur during operation, start-up conditions or during maintenance.

By matching (where possible) conveyor related fatalities extracted from the review, with narrative information from fatality or incident reports, the fatalities were categorised as to:

- The year that the incident occurred
- The country where the fatality occurred
- The state of the plant at the time of the activity for instance, was the plant in operation, or was it undergoing (routine) maintenance. A third category of fatalities was identified as those that occurred during installation or during non-routine major maintenance
- Where on the conveyor the incident occurred
- The nature of the hazard that caused the fatality. On first examination, the hazards associated with a conveyor can be identified as:

  i. The nip points, where the belt passes over a rotating element (pulley or idler)
  ii. The stored energy associated with the take-up counterweight
  iii. The stored energy associated with belt stretch
  iv. The kinetic and potential energy associated with the material, either as large lumps, or as a material stream
  v. The movement of the belt past fixed structures (in particular the risk to anyone riding on the belt posed by structural steel and chute work)
  vi. As with any elevated building, the risk of falling from heights
  vii. The risk of equipment and material dropping from heights (including return idlers)
  viii. Risk of electrical shock
  ix. Fire
  x. The collapse of supporting structures due to overloading, which in turn could be due to misuse or improper design.

  Some of the above hazards are particular to conveyor belt installations and material handling systems, whilst others are common to most industrial plants - all industrial plants have electrical reticulations systems, and there is a risk of falling from heights in any industrial building. In order to limit the scope of this paper, the focus will be on hazards that are particular to conveyors. Although the other hazards are as important, they would be more properly addressed as part of a plant-wide safety program.

- The activity that resulted in the fatality. This was recorded by means of a brief description, so that they could be categorised in terms of related activities such as:

  i. Cleaning
  ii. Working near unguarded rotating equipment
  iii. Equipment not locked out
  iv. Working in guarded area.

- Finally, where sufficient information relating to the fatality existed, the major causes were listed, noting that there may be more than one contributing cause.

5. ANALYSIS AND DISCUSSION

5.1 Are Conveyors Getting Safer?

The first objective is to determine if conveyors are getting any safer. There is significant data that indicate that mining operations, especially in developed countries, are getting safer. Figure 1 shows the annual number of fatalities in Australian mines from 1989 to 2007 as published by the Minerals Council of Australia [2] indicating an overall downward trend (although both measures seem to have flattened out since 1998). The improvement in safety statistics can, in the author's opinion, be attributed to improvements in mine safety legislation, an improved understanding of the causes of unsafe behaviour and a greater corporate focus on safety.

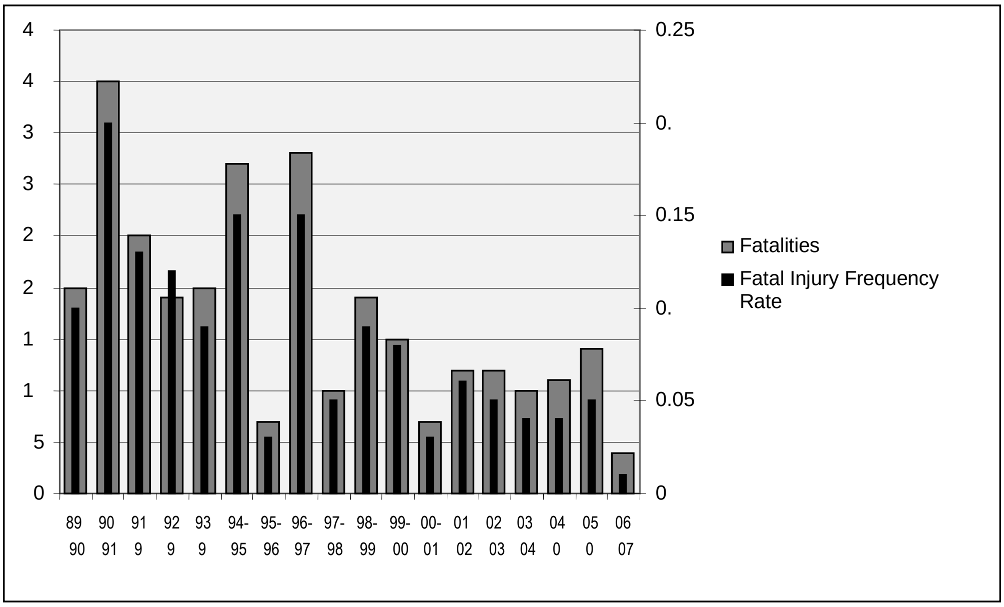

Figure 1. Australian mining fatalities 1990-2007 [2]

In Australia, the Australian Standard - Conveyor Safety Requirements - was revised to AS 1755-1986 in 1986 and again to AS1755-2000 in 2000. This standard sets minimum requirements for guarding, access, control, isolation, lighting, fire protection and operation of conveyors. In practice, there is plenty of anecdotal evidence that the interpretation of the standard by users is becoming ever stricter, with (for instance) guarded convex curves on long overland conveyors, now not uncommon in Australia. As these conveyors, designed in accordance with the revised standard are coming into service, and older conveyors go out of service (assuming that the standards have been improved), conveyor safety should improve.

Figure shows the number of conveyor related fatalities that occurred in Australia per year from 1972. The following observations are worth noting. Firstly, there are relatively few fatalities that result from conveyor incidents (the maximum being three that occurred in 1972), and in many years there are no incidents. This makes statistical analysis based on annual data difficult. Secondly, there are two significant periods where no incidents occurred at all, between 1980 and 1986, and then from 1998 until 2005. There is sufficient evidence that the data for the period 1998-2005 is accurate, as all safety alerts for the major mining states have been reviewed for this time period with no record of a conveyor-related incident. There is, however, some uncertainty about the first period as the only source of data is the 'International Mining Fatality Review' [3], however, as the review lists 42 other mining fatalities in Australia during this period, it is unlikely that conveyor-related fatalities have been missed.

Figure 2. Number of conveyor related fatalities in Australia per year

In order to try and get a sense of whether there is a downward trend, Figure shows the total conveyor related fatalities over a ten year period (that ends in the year noted). By analysing the data in this way, a downward trend in the number of fatalities does emerge, and supports the view that conveyors (in Australia at least) are 'safer'.

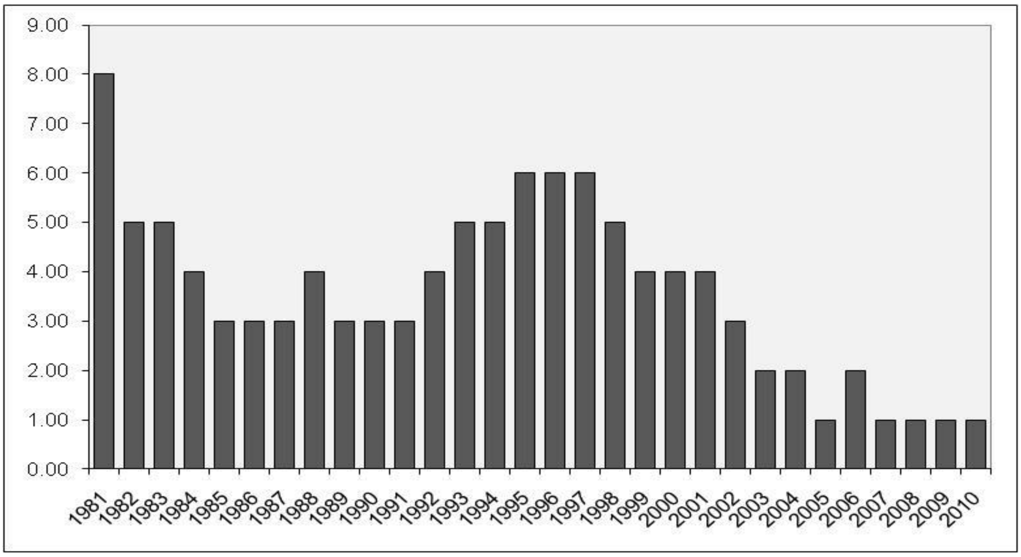

Figure 3. Total conveyor fatalities over a ten year period

In the case of the USA, there is only data available from 1995 until 2007. In Figure, the number of conveyor related fatalities are presented on an annual basis, and on the same axis, totalized for a five year period (ending in the year noted). In the case of the USA, there is little evidence that the number of fatalities has reduced. In the same period, the number of miners in the USA has increased by 6.4% from 355 496 to 378 123 [5]. It should also be noted that the proportion of fatalities due to conveyors in the USA (as previously mentioned) appears to be significantly higher than in Australia.

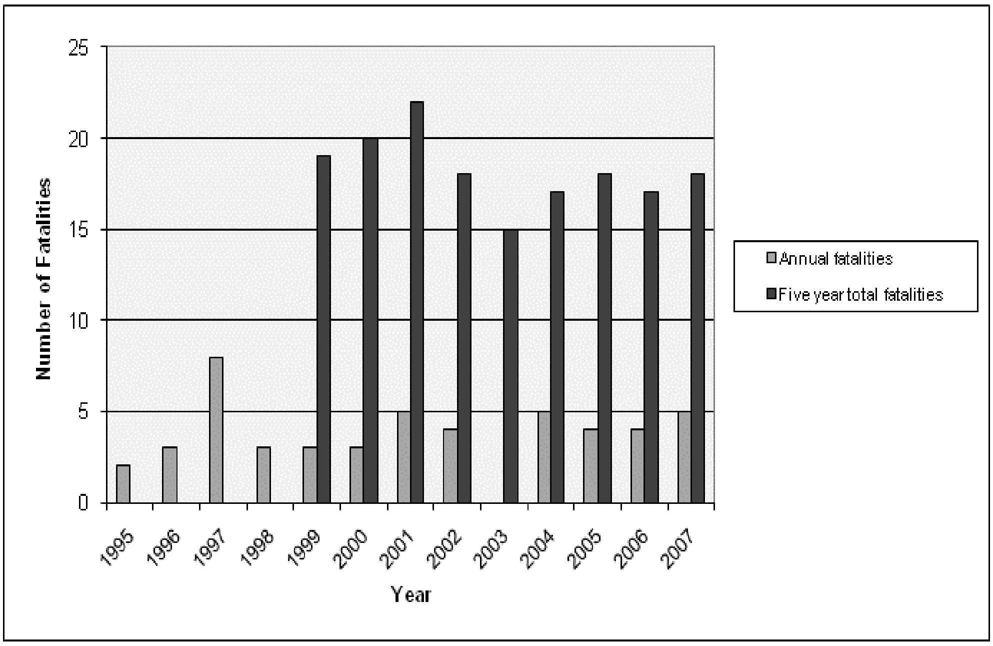

Figure 4**.** Conveyor related fatalities in the USA

In the case of South Africa, as indicated in Figure 0. , there is no indication of the number of fatalities reducing, if anything, there is a worrying upward trend if the fatalities are totalized over a five year period.

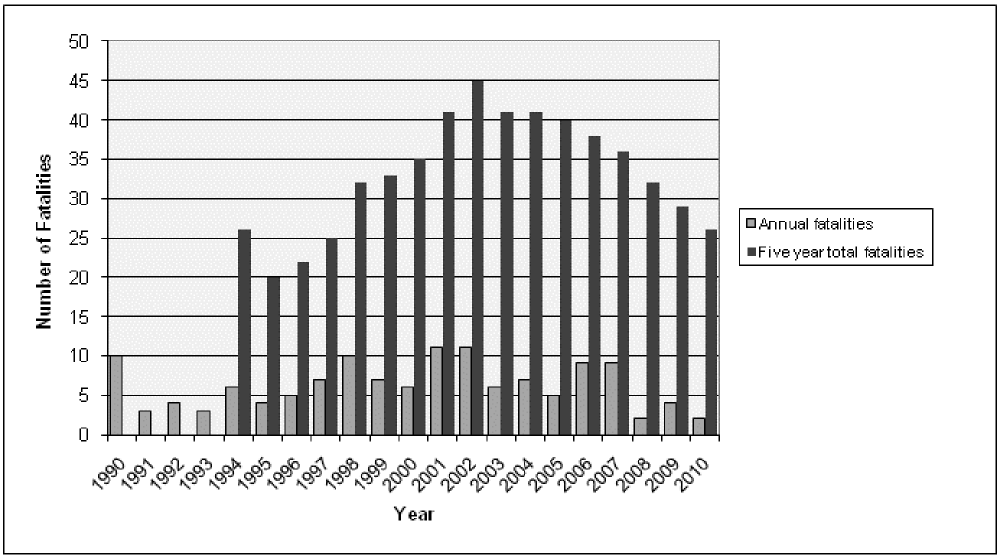

Figure 0**.** South African conveyor related fatalities 1990-2008 [11]

5.2 Possible Reasons for the Improved Safety

What are the possible reasons for the improved safety of conveyors (in the case of Australia) and why is there not an equivalent improvement in the safety of conveyors in the USA and South Africa? And why is the proportion of conveyor-related fatalities in the USA so much higher than that of Australia?

One possibility is a difference in the quality and standard of conveyor guarding. The Australian specification AS 1755-2000 Conveyors – Safety Requirements prescribes in detail the minimum requirements for the positioning and design of conveyor guards as well as minimum requirements for lighting, control of the conveyor, fire protection and signage. In the USA, CEMA 6 addresses safety and guarding, but is not prescriptive, leaving the positioning and design of guards up to a responsible and qualified engineer. For large surface mine installations, where conveyors are designed by professional engineers, the resulting guards will in all likelihood be more than adequate. In smaller sand and gravel quarry operations, which are less profitable, and where conveyors are built and modified without professional design, conveyors may well be inadequately guarded.

The data reviewed indicates that in fact, most conveyor related fatalities in USA are in sand and gravel or rock quarry plants (60%). The photos below are from the Department of Labor Fatality Reports [5]. The inadequacy of the guarding and lack of safety considerations is evident. Sand and quarry operations are characterised by low margins, small throughputs and small modular re-locatable plants. The relocation and reconfiguration is bound to have a negative impact on the integrity of the guarding systems.

Figure shows a completely unguarded tail/take-up pulley and loading area on a short conveyor in a US quarry operation. In addition to the lack of guards, there is considerable material build-up below the conveyor. Any attempt to remove the material whilst the belt is running would require working in very close proximity to the nip point.

Figure 6. Unguarded pulley [4]

Figure indicates a similar conveyor, completely unguarded, and again with considerable material build-up. In addition, in this instance, poor maintenance is clearly visible, including the poor alignment of the head pulley and resultant poor tracking of the belt. Figure shows another unguarded installation in a US operation that includes two unguarded pulleys. In this particular installation it is clear that as well as no guards being installed, there are also no nip guards. There is in fact, no evidence of nip guards in any of the other referenced installations.

Figure shows a completely unguarded idler in an elevated portion of the conveyor, where a fatality occurred. The idler is easily accessible from below the conveyor, and there is no barrier to prevent crossing underneath the conveyor.

Figure 7. Unguarded pulley and conveyor [4]

Figure 8. Another unguarded pulley and conveyor [4]

Although all of the referenced installations would not meet the criteria envisaged in CEMA 6, that a suitably qualified engineer ensure that the conveyor be properly guarded, they would all explicitly fail to meet specific prescribed requirements of the AS 1755-2000, and it is extremely unlikely that a comparable Australian operation would risk operating similarly unguarded equipment.

Figure 9. Unguarded return idler [4]

Figure 10. shows an installation in a sand and gravel operation where a fatality occurred due to a large rock falling off the conveyor onto a person below the belt. Despite the steepness of the conveyor, it is clear that no effort has been made to prevent access to the danger area underneath, or to provide a safe underpass where required.

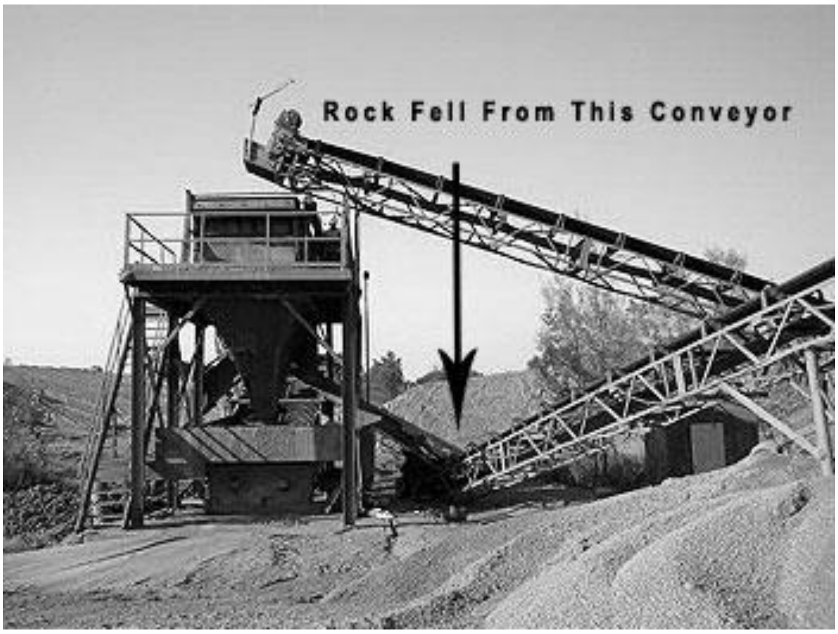

Figure 10. No safe crossing below the belt [4]

5.3 Causes of Conveyor Fatalities

The results of the analysis are summarised in Table2 below. In total there were 76 fatal incidents where there was sufficient information to assign the main causes. A maximum of three causes were assigned for each incident. For analysis purposes, where possible the description of the causes was kept generic. The classification of causes is of course open to interpretation, for instance 'guarding removed' could have been grouped with 'unsafe behaviour', but has been included separately as a cause in its own right. In all the 'guarding removed' cases, 'unsafe behaviour' would also have been listed as a cause. The first three causes in Table2 all relate to unsafe work practices, but differ as follows:

Unsafe work procedures relate to events that occurred as a result of following a standard work procedure that is itself inherently unsafe. There is only one such occurrence, where a sample of material was drawn by standing on the material heap in a bin.

No safe work procedure relates to incidents that have resulted where no safe work procedure was in effect and if there had been a safe work procedure, the incident may have been prevented.

Unsafe behaviour relates to incidents where the behaviour at the time was inherently unsafe. Unsafe behaviour may occur as a result of: system gaps or organisational failures (lack of training for example) where the individual is in no way at fault; of 'slips' or lapses, which are unintentional failures by an individual; or finally, as a result of violations (which are deliberate contraventions of systems or procedures).

Cause	No of occurrences
Unsafe work procedure	1
No safe work procedure	9
Unsafe behaviour	41
No risk assessment	8
Structural failure	2
Inadequate rigging	1
Poor access	1
No safe crossing	3
Inadequate guarding	27
Guards removed	4
Maintenance while operating	2
No start alarm	6
Not locked out	11
No holdback	1
Design	2
Inadequate planning	3

Table 2. Summary of main causes of conveyor accidents

From Table2, it can be seen the most significant cause is 'unsafe behaviour', followed by 'inadequate guarding' (27 times).

An analysis of the frequency of the causes of fatalities in Australia over time shows a significant decrease in the proportion of fatalities that are the result of 'inadequate guarding', and a related increase in the proportion of fatalities that resulted from 'unsafe behaviour'. This strongly suggests that the more stringent guarding requirements have reduced the number of fatalities, and that the key to further reducing conveyor fatalities is now to minimise the 'unsafe behaviour' including deliberate violations such as working within guarded areas, and not following safe work procedures. This same trend was not obviously evident in the USA data. This may also suggest the underlying reason for the lack of improvement in the South African fatality figures relating to conveyors (Figure 0.). South African conveyors since the early 1980's have been guarded in accordance with the recommendations included in a memorandum issued by the Government Mining Engineer in 1982 and subsequently reiterated by the Regional Director, Eastern Transvaal Region, c1995, and conveyors in mines have typically been well guarded for some time.

	Aus <1979	Aus 1979-	USA
No fatalities	17	8	51
Insufficient guarding	8 (47%)	1 (12.5%)	16 (31%)
No safe work procedures	5 (29%)	2 (25%)	10 (20%)
Unsafe behaviour	3 (17%)	5 (62.5%)	22 (43%0
Not locked out	0 (0%)	2 (25%)	4 (8%)

Table 3. Main causes of conveyor incidents (Australia vs. USA)

5.4 Future of Fatalities

In order to establish which components of conveyors are the most dangerous, all the fatalities where narrative information was available were reviewed to determine the mechanism or the mechanical component involved, as well as the location along the conveyor where the incident occurred. The results of the analysis are summarised in Table4. As can be seen, by far the majority of the incidents are caused by entrapment in the nip point between the belt and the pulley. As has been discussed above, this is often a result of inadequate guarding (or in some instances removal of guarding). The second most common mechanism is being caught between the idler and the belt.

The location at which most incidents occurred is at the tail.

Mechanism		Location	
Pulley	35	Tail	18
Idler	11	Take-up	8
Chute	6	Transfer	4
Bin	3	Bin	3
Counterweight	0	Head	5
Drive unit	2	Drive unit	2
Carry	0	Carry	7
Fall	4	Drive	3
Falling object	3	Elevated	3
Falling rock	1	Under conveyor	2
Structure	8	Tripper	1
Structural failure	2	Run	6
Rigging	4	Bend	1
Other	2		

Table 4. Nature of fatal incidents

From the South African data, an analysis was done on all accidents (fatalities, injuries and incidents), against the location as categorised by the DMR, and summarised in Table 5.

	Head Pulley	Snub Pulley	Tail Pulley	All Pulleys	Idler	Take-up	Chute	Feeder-breaker	Total
Fatalities	7	9	56	72	13	5	27	14	131
Injuries	14	17	110	141	25	10	51	25	252
Incidents	28	34	218	280	50	20	102	49	501

Table 5. South African incidents by categorization (1990-2010)

Once again it can be clearly seen that the tail pulley is associated with more incidents in all three categories than any other part of the conveyor. This is not altogether surprising, as the tail area is often confined, requires cleaning of material from the loading point and belt plough, and is guarded only by removable (and therefore not always in place) guards.

6. CONCLUSION AND RECOMMENDATION

Although conveyors are intrinsically hazardous by virtue of the significant stored energies, they are essential to the economically efficient operation of any mining operation. The risks can however, be managed to a large extent by better design and guarding, and conveyors are by comparison to other mining operations relatively safe, in that they are associated with only a small percentage of total fatalities.

Although effective guarding has contributed significantly to safe operation of conveyors, guarding alone can only go so far in eliminating fatalities and injuries. To improve conveyor safety still further, the improvements made by better guarding must be maintained (and improved), and a renewed focus needs to be placed on eliminating unsafe practices and behaviour in the workplace. There is of course currently a strong focus on eliminating unsafe behaviour by most of the internationally listed miners. This focus applies to all aspects of mine operation, not only to conveyors.

This paper also highlights the importance of the quality and availability of data related to safety incidents. The availability of good data allows for the measurement of improvement, and identification of trends. In the Australian and USA cases, there is easily available data with respect to fatalities. Data with respect to serious incidents is more difficult to find, but in both cases is still available. For fatalities there is good narrative data, detailing the results of the preliminary investigation, including a description of the people involved, what they were doing, and the condition of the plant at the time. Trends can be identified, providing useful insight as to where best spend resources to improve safety. In the South African case, although good detail was available of where the incident happened, it would be very useful for information relating to the nature of the activity and the cause of the incident to be recorded as well.

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