

Safety in Mines Research Advisory Committee

Draft 2 Project Report (Revised 2 November 2000)

Coupling systems and designs in use in the Gold and Platinum sector

**PG van der Walt - Turnberry Projects
Dr J Naude - RAU
SW Lubbe – Alexander Forbes
PJ Hutcheson – Turnberry Projects
Prof JP Meyer - RAU
KC Spencer - Turnberry Projects**

Research agency: Turnberry Projects (Pty) Ltd in association
with Alexander Forbes Risk Engineering
and the Engineering Faculty of RAU
Project number : GAP 703
Date : September 2000

Executive Summary

One of the findings of SIMRAC Project GAP 520 dated March 1999 ('Investigate safety of rail vehicles and systems operating in South African gold mines') was that about 20% of accidents involving locomotives and rolling stock were during coupling and de-coupling operations. In most cases a limb is squashed between the buffers of the units being coupled/de-coupled.

This project was a general study of the existing coupling systems and a general assessment of the coupling systems against the ergonomics requirements for safer operation or use.

The project team met with the major South African users and manufacturers of buffers, hoppers, locomotives and other rolling stock, collecting information on the types of buffers used, coupling procedures, designs of coupling systems, accidents, etc. The team also carried out intensive discussions with European manufacturers and users of coupling systems. A patent search of coupling systems was carried out in both the South African and USA Patent offices. The legislation appertaining to underground rail transportation in South Africa, the UK, the USA, Canada and Australia was investigated

Arising from the engineering assessment and risk evaluations carried out by the project team was that the gold and mining industry in South Africa is largely standardised on a link and pin type coupling system for underground rolling stock.

Where underground transport is carried out in an environment with

- Good quality trackwork
- Standardised rolling stock
- Well maintained rolling stock and buffers
- Skilled and well trained operators
- Effective and reliable communication between driver and guard
- A culture of safe working practices

then the system of links and pins as used by the industry for many decades would probably be adequate.

It would appear that finger and hand accidents are largely caused during coupling with very few accidents occurring during uncoupling. The drooping of buffers and sagging of the links appears to be the biggest single contributor to accidents - but is a symptom of the problem rather than the root cause. The operator has to, in the very confined area between the cars or hoppers, exert significant mechanical effort from an unbalanced position to wrestle the link into a position in which it will engage the mouth of the buffer. It is in this position, with the train moving that most accidents occur.

The slotted holes in the link and pin system do however result in severe backlash, which leads to high impact loading, which results in:

- Distortion of the chassis and loosening of the bolts attaching the buffer to the chassis;
- Plastic deformation of the buffer mouth and pin locating hole, the link and it's slots and the pins
- Premature failure of the resilient rubbers

The conclusions of this study were:

- The use of dedicated well-trained tramming teams should significantly reduce accidents.
- Coupling designs should be modified or alternatively new couplings developed that minimise backlash and that can withstand the resultant impact forces experienced

- without plastic deformation. Some conceptual alternative designs were developed.
- Systems used should allow for coupling and un-coupling to take place such that the guard can stand outside of the line of the vehicles whilst they are in motion.

Acknowledgements

The assistance of the participating mines manufactures and members of SIMRAC committees and SIMROS staff is acknowledged.

Table of contents

	Page
Executive summary	2
Acknowledgements	3
List of figures	8
List of tables	10
Glossary of abbreviations, symbols and terms	11
1. Introduction.....	12
1.1 Research problem statement.....	12
1.2 Objectives and aims of this study.....	12
1.2.1 Main objectives.....	12
1.2.2 Additional outputs.....	13
1.2.3 Project Structure.....	13
2. Problem Definition and Data Collection.....	14
2.1 Accident data.....	14
2.2 Local data.....	14
2.3 International practice.....	14
2.4 Patent searches.....	14
2.5 Legislation.....	15
3. Assessment of Data and Design.....	16
3.1 Estimate of number of units.....	16
3.2 Evaluation of existing and proposed couplings.....	16
3.2.1 Simplicity.....	16
3.2.2 Robust.....	16
3.2.3 Inherently safe as a coupling.....	17
3.2.4 Low maintenance.....	17
3.2.5 Ergonomically suitable/safe for coupling and uncoupling.....	17
3.2.6 Price.....	17
3.2.7 Compatible with existing coupling systems.....	17
3.2.8 Performance in a derailment situation.....	17
3.2.9 Minimise shock/impact loads.....	17
3.3 Training and specialisation.....	18
3.3.1 Specialisation.....	18
3.3.2 Training.....	18
3.4 Impact loads.....	18
3.5 Clearance between cars.....	19
3.6 Risk assessment	19
3.6.1 Operational recommendations.....	20
3.6.2 Training.....	20
3.6.3 Conclusion of risk assessment.....	21

	Page
4. Discussion.....	22
4.1 Primary Outputs	22
4.1.1 Provide technical specification for the best design for couplings for safety.....	22
4.1.2 Best practice in coupling/de-coupling procedure.....	22
4.1.3 A practical strategy for the improvement of the ergonomic aspects of the current coupling systems in use in the Gold and Platinum Sector.....	23
4.1.4 A report identifying critical areas associated with the design, maintenance and safe operation of coupling systems underground along with recommendations.....	24
4.2 How Used?.....	24
5. Conclusions.....	26
5.1 Couplings.....	26
5.2 Impact loading and safety factors.....	26
5.3 Training and specialisation.....	26
6. Recommendations.....	27
6.1 For industry.....	27
6.2 Future research work.....	27
References.....	28
Appendix 1 Data Collection.....	30
Appendix 2 International Practice.....	33
Appendix 3 Patents and Patent Searches.....	40
Appendix 4 International Legislation.....	41
Appendix 5 Meetings with interested and affected parties.....	47
Appendix 6 Risk Assessment on Link and Pin Coupling on Rolling Stock	50
Appendix 7 Estimate of the number of units on the gold and platinum mines.....	72
Appendix 8 Clearances between cars.....	74
Appendix 9 Discussion on Links and Pins	82
Appendix 10 Impact loading and Resilience	84
Appendix 11 New Concepts.....	96
Appendix 12 Evaluation of existing and proposed couplings.....	113
Appendix 13 Synopsis of Coupling Related Aspects of GAP 520	116

Appendix 14

**Proposed regulations and codes
of practice..... 120**

List of Figures

	Page
Appendix 2	
Figure 1: Typical couplings unit with Hook and Link.....	33
Figure 2: Typical non-articulating head type coupler with swivelled 'D' coupling Link.....	34
Figure 3: Typical non-articulating head type coupler with shackle and hook Couplings.....	35
Figure 1.1: Typical semi-automatic 'dolly' type coupler operated from either side by gear mounted on both ends of the car.....	36
Figure 2.1: Willison Coupler.....	37
Figure 3.1: The Hudson Hook and Link coupler.....	38
Appendix 6	
Figure 5.1: Severity Profile.....	53
Figure 5.2: Probability Profile.....	52
Figure 5.3: Risk Profile.....	55
Appendix 8	
Figure 1: Tramming speed versus radius of curve.....	76
Figure 2: On scale Hoppers on minimum curve.....	77
Figure 3: Schematic of Hoppers on curve.....	78
Figure 4: Force diagram of Hopper and link.....	78
Figure 5: Resultant force, RF, effect on Hopper.....	80
Figure 6: Link locking position.....	81
Appendix 10	
Figure 4.2.1: Simulation 1 results.....	90
Figure 4.2.2: Simulation 2 results.....	91
Figure 4.2.3: Simulation 3 results.....	91
Figure 4.3.1: FEM analysis mesh.....	92
Figure 4.3.2: Forces and restraints on 3D model.....	93
Figure 4.3.3 a: Stress results (side view).....	93
Figure 4.3.3 b: Stress results (front view).....	94

Figure 4.4.1: Link slot dimensions.....	95
---	----

Appendix 11

Figure 1.1.1: Linked closed.....	97
Figure 1.1.2: Pin unlocked.....	97
Figure 1.1.3: Pin removed.....	98
Figure 1.1.4: Link disengaged.....	98
Figure 1.1.5: Link parts.....	99
Figure 2.1.1 a: Link open.....	101
Figure 2.1.1 b: Link open.....	101
Figure 2.1.2: Link closing.....	102
Figure 2.1.3 a: Link closed.....	102
Figure 2.1.3 b: Link closed.....	103
Figure 3.1.1: Uncoupled link.....	105
Figure 3.1.2 a: Engaging Link.....	105
Figure 3.1.2 b: Engaging Link.....	106
Figure 3.1.3: Coupled Link.....	106
Figure 4.1.1: Open Screw Link.....	107
Figure 4.1.2 a: Engaging Screw Link.....	108
Figure 4.1.2 b: Engaging Screw Link.....	108
Figure 4.1.3 a: Coupled Screw Link.....	109
Figure 4.1.3 b: Coupled Screw Link.....	110
Figure 5.1.1: Modified Standard Link.....	112
Figure 5.1.2: Cut away of Modified standard Link.....	112

List of tables

Appendix 6

Table A.....	70
Table B.....	70
Table C.....	71

Appendix 8

Table 1.1 Hopper specification.....	75
-------------------------------------	----

Appendix 10

Table 4.1.1 Hopper information.....	85
Table 4.1.2 Loco information.....	86
Table 4.1.3 Linking information.....	86
Table 4.1.4 Column A to H of simulation.....	87
Table 4.1.5 Column I to N of simulation.....	88
Table 4.1.6 Column O to R of simulation.....	88
Table 4.1.7 Column S to Y of simulation.....	89
Table 4.2.1 Simulation Inputs.....	90

Glossary of abbreviations, symbols and terms

Abbreviations

S A mines reportable accident statistics system	SAMRASS
Gold and Platinum mines	GAP
Estimated Maximum Loss	EML

Terminology

“**Buffer**” means the unit permanently attached to either side of the rolling stock chassis, which allows for the coupling between rolling stock, and movement when pushed or pulled

“**Car**” means the same as rolling stock

“**Coupling**” means a device or set of devices specifically designed to couple two vehicles, and includes the buffers, connecting link and locking pins

“**Hopper**” means rolling stock specifically used for the transport of rock

“**Locomotive**” or “**Loco**” means a railbound vehicle, which is self-propelled, requires a driver and is used for the purpose of tramping operations in or on a mine.

“**Man car**” means a car for the transport of men

“**Material car**” means a car used for the transport of material

“**Rolling stock**” means any item of equipment that is designed to run on a track system but is not self-propelled

“**Train**” means a locomotive with rolling stock attached to and pulled or pushed by it

“**Tramming**” means the pushing or pulling of a train

1. Introduction

1.1 Research problem statement

One of the findings of SIMRAC Project GAP 520 dated March 1999 ('Investigate safety of rail vehicles and systems operating in South African gold mines') was that about 20% of accidents involving locomotives and rolling stock were during coupling and de-coupling operations. In most cases a limb is squashed between the buffers of the units being coupled/de-coupled.

1.2 Objectives and aims of this study

It was proposed by SIMRAC that the percentage of accidents could be reduced if these operations could be either automated, or a safer coupling procedure could be adapted. There are a variety of coupling systems in use in the mines, some of them safe and others relatively unsafe. This project was aimed to investigate all coupling designs and procedures, and to recommend a safer coupling system for the industry.

This project was intended as a dispassionate study of the existing coupling systems and an assessment of the coupling systems against the ergonomics requirements for safer operation or use.

Included in the scope of work were the following actions:

- Assessment of coupling systems design for safety, i.e. visibility, operator position in relation to the whole train, and ease of use;
- Conduction of an international survey and compare the designs used elsewhere with local designs;
- Evaluate above and give a concise and practical recommendation on best design for safety;
- Liaison with major manufacturers; and
- Liaison with mines from all the major groups.

The objective of the project was to address the issues in a holistic, comprehensive and systematic manner, taking into account the conditions underground with regard to the environment, typical conditions and the availability of skilled personnel.

1.2.1 Main objectives

The main objectives of the project were to provide:

- a technical specification for the best design for couplings for safety;
- a best practice in coupling/de-coupling procedure;
- a practical strategy for the improvement of the ergonomic aspects of the current coupling systems in use in the Gold and Platinum Sector; and
- a report identifying critical areas associated with the design, maintenance and safe operation of coupling systems underground along with recommendations.

Both local and international experience and opinion were to be considered in the study. The project report was to give the results of :

- data collection analysis;
- engineering analysis;
- risk assessment;
- identification of areas; and
- Recommendations.

1.2.2 Additional outputs

It was envisaged that the work would result in the following additional outputs:

- greater understanding of the ergonomic aspects of coupling systems;
- insight into international experience and viewpoint;
- increased awareness of the problem and associated risks on participating mines;
- information for use in developing risk assessments;
- increased awareness of the risk assessment process;
- identification of the other hazards related to underground tramming practice;
- the possibility of an alternative solution to the issue emerging;
- recommendations for mine operation procedures; and
- guidelines for mine training courses, if appropriate.

1.2.3 Project Structure

The project was structured in two phases i.e.:

- Problem Definition and Data Collection; and
- Assessment of Data and Ergonomic Assessment and Design.

2. Problem Definition and Data Collection

During this phase the project team carried out the following work:

- Review of past accidents and incidents (as per GAP 520), collection of data and designs of existing coupling systems;
- visit collaborating mines & manufacturers;
- discussions with interested and affected parties;
- collect and review local standards and practices; and
- collect and review international standards and experience.

2.1 Accident data

The accident data as contained in GAP 520 was analysed by the project team with reference to its relevance to coupling accidents. This synopsis is contained in Appendix 13.

2.2 Local data

The project team met with the major South African users and manufacturers of buffers, hoppers, locomotives and other rolling stock, collecting information on the types of buffers used, coupling procedures, designs of coupling systems, accident, etc. The project team carried out two underground visits. Details are as contained in Appendices 1 and 5.

2.3 International practice

The team carried out intensive discussions with European manufacturers and users of coupling systems. It was apparent that direct comparisons can not be drawn. The type and layout of most mines require far less tramming with larger locomotives generally being used. Of relevance are:

- the use of skilled operators;
- the use of more complex buffers (Willison, Allen) that minimise backlash;
- a tendency to systems that allow the operator to stand clear whilst the train is in motion; and
- rail systems in relatively good condition.

Details are as contained in Appendix 2.

2.4 Patent Searches

A patent search of coupling systems was carried out in both the South African and USA Patent offices as detailed in Appendix 3. In the United States, most of the patents found during the search related to developments of the "Willison" type coupling. Other developments related to adapting the conventional link and pin type systems to a system that allows for:

- The draw pin to be safely retained in an upper non-engaging position while vehicles are moved together or apart during coupling and uncoupling;
- The draw pin to be remotely/automatically engaged/disengaged while the vehicles are stationary during coupled or uncoupled.

The patents that were found in both South Africa and the USA were either:

- Already in commercial production;
- Had been in commercial production but had failed; and
- Were obviously impractical.

2.5 Legislation

The legislation appertaining to underground rail transportation in South Africa, the UK, the USA, Canada and Australia were investigated. Generally, very little emphasis is placed on coupling systems in the legislation of these countries. The more relevant clauses are as specified in Appendix 4.

3. Assessment of Data and Design

In this second stage of the project the project team completed the following work:

- the study of current coupling systems and the assessment of each;
- observations and risk assessments at collaborating mines;
- ergonomic assessment of options;
- engineering assessment of options;
- risk assessment of options;
- compilation of engineering and performance specifications;
- design recommendations for retrofits; and
- proposed front end design for new coupling systems;

3.1 Estimate of number of units

Total number of locomotives:	5 000 - 5 500
Number of hoppers:	30 000 - 33 000
Number of material cars, etc.:	45 000 - 49 500
Total units of rolling stock:	80 000 - 88 000

Number of locomotive drivers:	10 000
Number of guards :	10 000

The back up to this estimate is as contained in Appendix 7.

3.2 Evaluation of existing and proposed couplings

The existing coupling systems in use in the industry, as well as alternatives proposed in this project, were evaluated against the criteria as specified below. Not one coupling satisfied all these criteria. Details of the evaluation are as contained in Appendix 12.

Coupling criteria:

- Simplicity
- Robust
- Inherently safe as a coupling
- Low maintenance
- Ergonomically suitable/safe for coupling and uncoupling
- Price
- Compatible with existing coupling systems
- Performance in a derailment situation
- Minimise shock/impact loads

3.2.1 Simplicity

With the conditions underground and the level of skills of the operating staff, couplings used should be as simple as practical.

3.2.2 Robust

The environment underground in the gold and platinum mines is hot and humid. The couplings are also exposed to mud and spillage from stope boxes. The operation of the rolling stock and design of tipping mechanisms result in high impact loading, this is exacerbated by the conditions as described in Appendix 10.

3.2.3 Inherently safe as a coupling

The primary function of the coupling is to keep the span of vehicles coupled. Once coupled, vehicles should not uncouple accidentally under any circumstances.

3.2.4 Low maintenance

As estimated in Appendix 7, there are some 80 000 to 90 000 rail bound vehicles operating underground on the gold and platinum mines, i.e. 160 000 to 180 000 buffers and pins, 80 000 to 90 000 links. The sheer volume of these items makes a low maintenance type coupling desirable.

In the operating environment, high maintenance items tend not to be maintained and deteriorating condition impact on productivity and safety. Equipment that is subject to plastic deformation is not maintainable.

3.2.5 Ergonomically suitable/safe for coupling and uncoupling

The high percentage of rail related accidents attributable to couplings are largely due to the ergonomic deficiencies of the couplings in use.

3.2.6 Price

If the industry were to, say, convert to a Willison type coupling overnight, to the estimated 90 000 rail bound vehicles the cost implications would be:

Supply of 90 000 sets @ R1 650/set:	R148.5 million
Installation of 90 000 sets @ R100/set (say):	<u>R 9.0 million</u>
Total cost:	R157.5 million

3.2.7 Compatible with existing coupling systems

As discussed above, the cost of changing all the couplings in the industry is prohibitive. The logistics of manufacturing and fitting such a coupling would also be prohibitive. A system that is compatible with existing systems would lend itself to phasing in programs.

3.2.8 Performance in a derailment situation

As discussed in section 2.1, in the current operating environment underground, frequent derailments are a fact of life. Until this is resolved, it is critical that the coupling system can be fairly readily uncoupled after a derailment.

3.2.9 Minimise shock/impact loads

The operating conditions result in severe impact or shock loading, particularly for hoppers. Couplings that minimise and/or absorb shock loads are advantageous. The backlash due to the slotted holes in the links currently used results in gross impact loading. The consequential collapse of the resilient rubbers and plastic deformation of coupling components further increases the backlash, so compounding the problem.

3.3 Training and specialisation

3.3.1 Specialisation

Ore transport should be allocated to dedicated locomotives. Each such locomotive should be allocated to a driver and guard, along with a span of hoppers. The driver and guard should be trained in the coupling of hoppers, loading of hoppers and tipping of hoppers. In this way, a degree of ownership and specialisation can be fostered. For reef tramming, such an arrangement results in minimal coupling being required, with the span being permanently coupled to the dedicated locomotive.

Where possible, transport of material cars should be undertaken by specially allocated gangs. These gangs should be trained on material handling aspects of their job.

3.3.2 Training

If the order of magnitude estimate of the total numbers of locomotive drivers and guards can be accepted, in an industry employing some 350 000 people.

From the findings of GAP 520 (as summarised in Appendix 13) we know:

Members of the train teams were victims in 49 percent of the accidents.

Members of the train teams were victims in 72 percent of the fatal accidents.

Therefore based on the estimate of number of drivers and guards as per section 3.1, this implies that five percent of the workforce was involved in 49 percent of all rail accidents and 72 percent of all fatal accidents.

This would suggest that by giving the locomotive drivers and guards focussed training on underground transport (including coupling of cars, re-railing of equipment, etc., that a large percent of possible accident victims could be trained by training a relatively small proportion of the workforce. This training should be incorporated into the standard training program after returning from leave.

Aside from reducing accidents, such structured training should pay dividends in terms of improved performance and productivity. Empirical evidence gathered on mine visits supports this view.

3.4 Impact Loads

Most design and testwork appears to be based on static loading conditions. The impact of:

- Excessive play between the slotted holes on the link and the pin
- Impact through the tipping arrangements
- Poor track conditions
- Poor conditions of wheels

is, we believe, significant resulting in severe impact loading being experienced. This results in plastic deformation of the load bearing areas of the coupling. The premature failure of the resilient buffers is also probably attributable to this factor.

The number of buffer designs that, on failure or loss of the resilient rubbers, lead to drooping of the buffer head also contribute significantly to the difficulties associated with coupling.

Analysis were therefore carried out by the project team to:

- estimate the size of the impact loads being experienced;
- quantify the minimum load bearing areas required to ensure plastic deformation is minimised.

The conclusions of the analyses were:

- The most important parameter in the above simulations is the Max Impulse Time. This parameter refers to the time duration in which the newly coupled hopper accelerates from zero velocity to the velocity of the train after the backlash in the links has been taken up. The value of 10 ms was used in all the calculations. This value was estimated, but can be determined by, for example, attaching accelerometers to the hoppers.
- In the case of zero backlash the maximum force on the buffer would be equal to the maximum pulling force of the Loco thus 40 kN or 4 ton.
- If Figures 4.2.1 to 4.2.3 in Appendix 10, are examined, the Impulse increases as backlash increases up to a maximum of 38 ton. In this case backlash of 100 mm was used. This present a factor of 9.5 over the zero backlash case.
- If the absorption/elastic material within the buffer configuration is worn or has fallen out, the backlash is further increased. Loose bolts, which attach the buffer to, the hopper phenomenon also adds to the backlash.
- Figure 4.3.3 a and b in Appendix 10, presents the results of the FEM analysis. From this follows that the area around the pin hole experiences a stress of 557 MPa. This stress is higher than the yield stress of cast iron of about 250 MPa. It is thus concluded that permanent deformation in this area would occur and thus the reason for the wear on the pin holes of buffers.
- It is recommended that a linking system that presents as little as possible backlash be implemented.
- It is also recommended that the load bearing area of the pin on the buffer be increased to bring the impact load stress at least below the yield stress.

The detailed analysis of these impact loads is contained in Appendix 10.

3.5 Clearance between cars

A number of the crushing accidents are attributable to the limited clearance between two cars. This restricted clearance also makes coupling ergonomically awkward.

The geometrical aspects of buffer and link length in relation to rail gauge, wheel base and track radius were modelled (as specified in Appendix 8).

This analysis indicated that extending the link to a length of one meter should have no effect on the dynamics of the train around curves. The above will ensure enough space for an operator to conduct de/coupling operations which should result in safer de/coupling.

3.6 Risk assessment

A comprehensive risk assessment exercise was carried out in a participating mine as detailed in Appendix 6. Information obtained from the risk assessment worksheets was utilised to make recommendations to eliminate or reduce the high potential risk areas.

3.6.1 Operational recommendations

Recommendations are listed on the worksheets in Appendix 6 with each deviation / hazard identified and should be regarded as the minimum requirements to reduce risk levels.

- No changes to the original buffer should be made without a proper risk assessment.
- No attachments should be made to the link or pin without a proper risk assessment.
- Mine specific standards should address all types of links and pins in use with the correct application as assessed by the supplier, manufacturer and the mine.
- Standardisation of the critical components on a specific mine is essential. This would inter alia include the following:
 - Buffer heights.
 - Type and size of pins and links.
 - Types of handles fitted to pins.
 - Method of fitting buffers to hoppers.

3.6.2 Training

The risk assessment exercise indicated that training of users of the coupling system; their supervisor's etc. remains the most important aspect in the prevention of accidents involving this type of coupling.

- The mine procedural training manuals should take cognisance of the findings and recommendations of the risk assessments carried out on the type of coupling (including any alterations) used by the mine.
- Ensure training is evaluated against actual practices underground and on surface.
- Emergency situations should form part of the training process for new, transferred and refresher programmes.
- Personnel involved with the assessment process should address deficiencies in the content of training manuals.
- Supervisors should be trained and equipped with the necessary knowledge to provide on the job training of hazard awareness to their employees.
- Person moving to a new area that uses different couplings should be retrained on the use of the coupling system in his new work environment, regardless of the insignificance of the alteration to the coupling system.
- Training should include the various conditions and scenarios under which coupling of hoppers are being carried out. Most training manuals address only the obvious situation i.e. when the coupling is carried out under ideal conditions.

3.6.3 Conclusion of risk assessment

The risk assessment revealed that a great amount of onus is placed on the operator to perform the coupling and uncoupling operations in a safe manner. He is the person who has to work closely to the danger zone between the rolling stock, to assess the immediate conditions and ensure correct actions are taken.

There is a general opinion that training is not comprehensive enough and could be improved considerably. Operators should also carry out a risk assessment as part of his training syllabus.

Standardisation of equipment and related conditions are essential. Manufacturers and suppliers and mines should work closely together to find a real solution to the problem.

4. Discussion

The gold and mining industry in South Africa is largely standardised on a link and pin type coupling system for underground rolling stock.

4.1 Primary Outputs

The primary outputs of this project (GAP 703) were, at commencement, envisaged as being:

- Provide technical specification for the best design for couplings for safety
- Best practice in coupling/de-coupling procedure
- A practical strategy for the improvement of the ergonomic aspects of the current coupling systems, in use in the Gold and Platinum Sector.
- A report identifying critical areas associated with the design, maintenance and safe operation of coupling systems underground along with recommendations.

On completion of this project the progress towards attaining the primary outputs originally envisaged is as described below:

4.1.1 Provide technical specification for the best design for couplings for safety

As discussed in this report in section 3.2 and Appendix 12, it emerged from this project that the best design of a coupling for safety would be a coupling system that is:

- Simple
- Robust
- Inherently safe as a coupling
- Low maintenance
- Ergonomically suitable/safe for coupling and uncoupling
- Reasonably priced
- Compatible with existing coupling systems
- Can be readily uncoupled in a derailment situation
- Minimise shock/impact loads

None of the coupling systems in general use in the South African mining industry even come close to satisfying all these criteria. It is the opinion of the project team that none of the systems in use in this country are inherently safe.

In terms of this project, modifications to existing couplings as well as some proposed new conceptual designs are presented (as detailed in Appendix 11). These proposals go, we believe, some way toward satisfying most if not all the above criteria. The brief of this project was general and required the generation of “front end designs”. We believe there is scope to carry out the detailed engineering, produce prototypes and test in a subsequent phase to this work.

4.1.2 Best practice in coupling/de-coupling procedure

As discussed in Appendix 9, the project team feels that the following elements should be incorporated into a best practise in coupling/de-coupling procedures:

The guard should roughly align the link while the locomotive and cars are

both separate and stationary. He should then be able to stand clear of the span and give, while within the line of sight of the driver, both audible and visual signals to the driver for the locomotive to move to engage the link in the mouth of the buffer. This “hands free” engagement of the link is strongly advocated.

Once the link has been engaged in the buffer mouth, it should be possible for the guard to stop the movement of the train and to insert the locking pin through the slot in the link with both the car and locomotive stationary.

No coupling or de-coupling should be done while cars and or locomotives are in motion. No coupling should be done with the guard standing on the inside radius on a curve.

It is not practically possible to achieve this with any of the coupling systems in general use in the South African mining industry.

The concept of “pre-setting” or “auto coupling” used in conjunction with the flared or bell mouth buffer mouth would be a refinement, in that it would eliminate the need for the guard to go between the vehicles to set the pin. Such mechanisms should, however, be intrinsically “fail-safe”, a requirement that is not fully met by some of the products currently available in the market.

From the evidence gathered and investigations, it appears that there is no big need for remote uncoupling. In the operating environment, any remote uncoupling system is reliant on some sort of system using levers and linkages. This results in greater complexity, higher maintenance requirements and more that can go wrong.

4.1.3 A practical strategy for the improvement of the ergonomic aspects of the current coupling systems in use in the Gold and Platinum Sector.

As discussed in Appendices 1, 5, 6 and 14, the project team feel that the following elements should result in an improvement of the ergonomic aspects of the current coupling systems in use in the Gold and Platinum Sector.

It should be mandatory that all rolling stock in a span should have the same buffer height above rail.

The use of a flared or bell mouthed buffer mouth or slot to pick up a sagging link and guide it into position has merit. This buffer mouth should be sufficiently deep to readily accommodate the link as well as wide enough for the car to traverse the tightest radius curve on the rail system. There are a number of variants available from local manufacturers that go a long way towards meeting this requirement. The design of the buffer mouth and link to minimise the sagging effect is also recommended.

4.1.4 A report identifying critical areas associated with the design, maintenance and safe operation of coupling systems underground along with recommendations.

As discussed in section 3.4 and Appendix 10, the coupling systems in general use in the South African mining industry all appear to generate impact loads above the plastic yield point of the buffers, links and pins. It is thus not possible to maintain these coupling in the generally accepted sense of engineering maintenance. The current systems used have a built in tendency to self-destruct. This impact results in:

- distortion of the chassis
- loosening of the bolts attaching the buffer to the chassis
- plastic deformation of the buffer mouth and pin locating hole
- plastic deformation of the link and it's slots
- plastic deformation of the pins
- premature failure of the resilient rubbers

As the buffer heads, links and pins wear, the backlash in the system increases, so resulting in increased impact loads. The consequential failure of the rubber doughnuts and the attachment of the buffer to the chassis also exacerbate the problem.

Until the excessive impact loads are engineered out of the couplings, or alternatively the couplings are designed to withstand the impact loads without plastic deformation then the couplings are effectively not maintainable.

Based on the data collected the following aspects of the pins should be addressed:

- Pins should be robust;
- Pins should only be used as pins, should not be used as hammer, sprag, crowbar, etc. This should reduce the chance of the pin being bent, scored or otherwise damaged so as to make it difficult to insert or withdraw;
- Pins should be secured to the buffer by chain or some other means – long enough to be easily used, short enough so that the loose pin will not drag on the ground or foul wheels etc.;
- The buffer housing should have a holder to store the pin safely when not in use;
- It should be mandatory that only the correct pin be used. From evidence and comment it would appear that the use of non-standard items in lieu of pins is a contributor to accidents; and
- Pins should have taper to ensure location in buffer head or link.

4.2 How Used?

At the commencement of the project it was envisaged that the outputs of the project could be used as described below:

This project will highlight the ergonomic deficiencies of current coupling systems that contribute to accidents underground, in particular the squashing of limbs. It will provide recommendations for improving the design of existing models as well as recommendations for a new unit that would incorporate the desirable features arising from the study.

Arising from the study it became apparent from the data collected and discussions

with interested parties (including operators and equipment manufacturers) as per Appendix 1, 5, 9 and 10, that finger and hand accidents are largely caused during coupling with very few accidents occurring during uncoupling.

The drooping of buffers and sagging of the links appears to be the biggest single contributor to accidents. This is compounded when buffers heights are not standardised.

The operator has to, in the very confined area between the cars or hoppers, exert significant mechanical effort from an unbalanced position to wrestle the link into a position in which it will engage the mouth of the buffer.

The operator has to lean forward between the cars, hold up the link, and signal the driver by whistle to back the locomotive up while he is in this position. To exert the necessary lift on the link he is inclined to support his body with his other hand – this hand often being in a crush or nip position. During this time he is out of the sight of the loco driver. To ensure location of the pin in the link he often inserts his fingers into the buffer head.

This situation cannot be improved unless:

- the excessive impact loads are engineered out of the couplings, or alternatively the couplings are designed to withstand the impact loads without plastic deformation;
- all rolling stock in a span should have the same buffer height above rail;
- buffers have flared or bell mouthed mouth or slot to pick up a sagging link and guide it into position;
- the design of the buffer mouth and link are changed to minimise the sagging effect;
- that procedures are put in place to ensure “hands free” engagement of the link;
- that operators are properly trained in the use of the equipment.

The project team believes it will not be possible to effect these improvements unless the changes as described are incorporated into existing or new coupling systems.

5. Conclusions

5.1 Couplings

Ideally couplings should be such that the guard can stand outside of the line of the vehicles whilst they are in motion. This would imply:

Coupling:

- Train stationary - guard goes between vehicles and aligns link;
- Guard steps away from vehicles and signals driver to back up so as to engage the link;
- Guard stops train;
- Train stationary - guard goes between vehicles and inserts pin; and
- Guard steps away from vehicles and signals driver to move the train.

Un-coupling :

- Train stationary - guard goes between vehicles and removes pin; and
- Guard steps away from vehicles and signals driver to move the train.

5.2 Impact loading and safety factors

The design of coupling systems should be such so as to minimise the backlash, and in so doing to minimise the impact loading. The current systems in use in the industry experience impact loading above the plastic yield point of the materials of construction.

The links, pins and buffers should be designed to a safety factor of at least 15 of the static load. The current practice is to use a safety factor of 10. As indicated in Appendix 10 this factor is insufficient to cater for impact loads. Furthermore, all load-bearing surfaces should be sized with sufficient area to ensure that they do not experience plastic distortion or wear even under impact loading conditions. A safety factor of 1.5 times the impact load is recommended.

Such a design should ensure that insertion and removal of links and pins could be readily executed during the serviceable life of the buffer.

From the analysis done by the project team, one was able to quantify the impact loading due to backlash for a typical coupling type and so to quantify minimum dimension to prevent plastic deformation of load bearing surfaces.

5.3 Training and specialisation

By having dedicated tramming teams, and by giving the locomotive drivers and guards focussed training on underground transport (including coupling of cars, re-railing of equipment, etc.), a large percent of possible accident victims could be trained by training a relatively small proportion of the workforce. The analysis as discussed in section 3.3.2 indicates that by training only five percent of the workforce a significant reduction in the number of rail related accidents could be achieved.

Aside from reducing accidents, such structured training should also pay dividends in terms of improved performance and productivity.

6. Recommendations

6.1 For industry

The following recommendations are made for adoption in the industry:

- Dedicated well-trained tramming teams should be used;
- Systems used should allow for coupling and de-coupling to take place such that the guard can stand outside of the line of the vehicles whilst they are in motion; and
- Coupling designs should be modified or alternatively new couplings developed that minimise the backlash and that can withstand the impact forces experienced without plastic deformation. Some possible new designs are proposed in Appendix 11.

6.2 Future research work

Arising from the general findings of GAP 703, there is scope for further research work on coupling design. This work would include:

- Installing strain gauges on a typical coupling and measuring impact forces during normal operation to confirm the simulation results;
- Developing industrial prototypes of :
 - A modified conventional link and pin type system;
 - A modified Willison type coupling; and
 - The conceptual alternative couplings proposed in GAP 703.
- Installing these prototypes on a train and using strain gauges to measure performance under load, to verify reductions in impact load; and
- Designing impact absorption systems suitable for the residual impacts loads.

7. References

- Betton, D. 2000** Personal communication on the coupling systems for underground rolling stock. Northam Platinum Ltd
- Bullen, G. 2000** Personal communication on the coupling systems for underground rolling stock. Kloof Gold Mining Co. Ltd
- Crause, C. 2000** Personal communication on the coupling systems for underground rolling stock. DME, Pelser Building, Voortrekker Road, Klerksdorp
- Crause, C. 2000** Personal communication on the coupling systems for underground rolling stock. Seran Engineering, PO Box 290, Potchefstroom
- Greyling, A. 2000** Personal communication on the coupling systems for underground rolling stock. AngloGold Ltd, 11 Diagonal Street, Johannesburg, 2001
- MacRae, R. 2000** Personal communication on the coupling systems for underground rolling stock. Galison Manufacturing, Block 1A, Constantia Park, Roodepoort, 3177
- Mylon, G. 2000** Personal communication on the coupling systems for underground rolling stock. Allan Maskew, Industries Road, Isando
- Page T, Morton G, Vermaak P. 1999** Investigation of Safety of Rail Vehicles and Systems Operating in South African Gold Mines. *SIMRAC Draft Final Project Report GAP 520*. Pretoria: Department of Minerals and Energy.
- Page T, Vermaak P, et al. 2000** Performance requirements for locomotive braking systems. *SIMRAC Draft Final Project Report GAP 635*. Pretoria: Department of Minerals and Energy.
- Republic of South Africa. Department of Minerals and Energy, Mine Health and Safety Inspectorate. 2000.** Guideline for the compilation of a mandatory code of practice for underground railbound transport equipment. Pretoria (*MRAC Circular No.:73/2000 - draft*)
- Robinson, B. 2000** Personal communication on the coupling systems for underground rolling stock. AngloGold Ltd, 11 Diagonal Street, Johannesburg, 2001
- SABS 0339: 199x.** Code of Practice – Design, construction, maintenance and safe use of permanent underground rail trackwork in mines (draft). Pretoria. South African Bureau of Standards.
- Snashall, T. 2000** Personal communication on the coupling systems for underground rolling stock. Gopro, 8 Harry Street, Robertsham, 2019
- Steele, R. 2000** Personal communication on the coupling systems for underground rolling stock. Bateman Trident, Peddie Street, Wadeville ext 6, Germiston
- Taylor, N. 2000** Personal communication on the coupling systems for underground rolling stock. Dorbyl RSD, Victor Street Industrial Sites, Boksburg East

Van Heeswijk, C. 2000 Personal communication on the coupling systems for underground rolling stock. Gold Fields Ltd, 23 Girton Road, Parktown, Johannesburg, 2000

1964. Underground Rail Practice, Investigations Committee Report No. 1.06, GOLD FIELDS OF SOUTH AFRICA LIMITED, p 3-5.

Appendix 1

Data Collection

Companies Visited

The project team visited the major South African manufacturers of buffers, hoppers, other rolling stock and locomotives, these companies holding in excess of 80 percent of the South African market share. Discussions were held with senior personnel from these companies and design data of their various products were collected. These companies included:

- Company A – Hopper and buffer manufacturer
- Company B – Buffer manufacturer
- Company C – Locomotive manufacturer
- Company D – Locomotive and buffer manufacturer
- Company E – Hopper and buffer manufacturer

Company A – Hopper and buffer manufacturer

Company A are the largest manufacturer of hoppers in South Africa with probably 80 percent of the market share. They claim:

“By far the largest number of accidents associated with tramming underground can be attributed to coupling and, to a far lesser degree, uncoupling of hoppers and other rolling stock. This is particularly true in development ends where hoppers are being coupled and uncoupled on an on-going basis in a high-speed production environment where time is of the essence.”

The coupling systems used in almost all South African mines ... consist of a link and pin system, which had to be installed by hand. This involves the operator, very often unsighted to the driver, having to get between the stationary hopper and the moving train in order to guide the link into the mouth of the buffer. This results in innumerable hand injuries, occasional serious body injuries and when hopper with overlapped ends are used fatal accidents are a very real possibility.”

They have developed the “Auto Lock Safety Buffer”. This buffer, they claim:

- Is 100 percent compatible with conventional buffers;
- Couples automatically;
- Replaces the link pin, which is often lost, with a latch (permanently hinged inside the buffer);
- Uses a patented cruciform link (the cruciform nature also assists in minimising the sag of the link);
- An additional safety lock has been added to prevent the latch from opening inadvertently;
- Options of spillage covers are available; and
- Options of linkage systems for remote uncoupling are available.

Castings to BS 3100 A2 in the normalised condition.

Links – 25mm mild steel (30mm used for heavy-duty applications).

Latches – profiled from VRN360 (Roqtuf). Designed to withstand 150kN.

Rubbers – three off rectangular resilient buffers.

They estimate that there are some 32 000 hoppers in the SA mining industry.

They feel at least 90 percent of accidents occur during coupling. Most fatalities are when heads are crushed while coupling on the inside radius of a curve or where the design of the hopper does not give sufficient clearance.

They feel the biggest problem is the misalignment of the links. This is exacerbated by the use of the incorrect pins.

80 percent of the industry uses the Kudu buffer or a variant thereof, on hoppers (resilient buffer). Most material cars have rigid (non-resilient buffers); there are many types on the market as well as many mine specific standards.

Company B – Buffer manufacturer

Company B is the largest producer of buffers in South Africa, with probably 60 percent of the market share. They manufacture a wide range of buffers, all of which are variations of the old Alrub Major (now sold as the Buffalo) and Alrub Minor (now sold as the Duiker) buffers:

- The most common buffer is the Kudu buffer;
- The Springbok buffer is used for material cars. It can accommodate a drawbar, and so is suitable for use on inclines;
- The Eland buffer, with extended buffer head was developed to create more clearance when hoppers with extended lips were used; and
- The Elephant buffer is a heavy-duty buffer for 25-ton hoppers.

Most of the buffers are resilient type buffers, which rely on rubber doughnuts in compression or rings in shear to absorb the impact.

The earlier buffers (including the RC Power “Enilo” buffer and “Losena” buffer) put the rubber under compression, allegedly resulting in premature failure of the rubber. This results in a drooping buffer and so a sagging link that results in many of the difficulties experienced in coupling and uncoupling.

They feel that many accidents occur whilst the guard is trying to get the link lined up to the buffer mouth, exacerbated by trying to insert the incorrect pin.

They estimate that there is population of Goodman battery locomotives in the industry of 3350 units. They claim to be developing an automatic coupling system, but would not divulge details. Buffers are cast from BS 3100 A2, SG60 mild steel.

A number of problems are due to poor initial fitting of the buffers to the cars. Over time, bolts come loose, bolt holes wear, all resulting in drooping buffers.

While the manufacturer has control over the design and manufacture of the buffers, the following items are generally out of their control:

- the links used underground;
- the pins used underground;
- the fitting of the buffers to the cars; and
- the maintenance of the buffers.

Company C – Locomotive manufacturer

Company C is a manufacturer of battery locomotives, claiming to be the largest manufacturer of locomotives in South Africa.

A multi slot plate buffer, used with a pin is supplied as a standard with the locomotives. This allows compatibility with a wide range of rolling stock using links and pins, as well as being able to handle a fair range of buffer heights. The buffer is also supplied with a safety chain. They have seen a wide variance in buffer heights. The use of stepped links to overcome this is dangerous.

They estimate that there are some 30 000 to 50 000 units of rolling stock on the mines.

Company D – Locomotive and buffer manufacturer

Company D manufactures the Funkey diesel locomotive and the Willison Coupler under license for use underground. Whilst they are the biggest manufacturer of diesel locomotives for underground in the country, this market is now relatively small and their core business is surface rolling stock and coupling systems.

They comment that while they used to sell some Willison couplings for use on major tramming lines underground, this market has virtually dried up and they hardly sell any units at present.

The Willison coupling is a unit that couples automatically, with manual uncoupling. The unit can be supplied with a linkage to allow remote decoupling.

Company E – Hopper and buffer manufacturer

Company E is a small manufacturer of hoppers and buffers. They claim that:

“Many accidents and hand injuries occur in the mining industry during the connection of the buffers of rolling stock.

One of the reasons is that the shock absorbing rubbers in the buffers which are used underground flatten and sometimes even fall out of the buffer housings. This is due to the small area of rubber expected to absorb the tremendously high shock loads exerted. The result is that the buffers have no shock absorbing ability and the buffer heads are hanging down.

In an attempt to connect buffers with heads hanging down, the heads have to be lifted before the link and pin can be fitted. One has not enough hands to carry out the above duties safely, with the result that workers hands get trapped between the buffers.”

They claim that their new coupling, which is derived from a link and pin type coupling:

- Is designed to be maintenance free. It has large rubber pads in compression only, they claim the distributed loads are too small to cause deterioration of the rubber pads;
- Is designed so that the link never sags;
- Have a pre-set mechanism so that the pin is pre-set whilst the vehicle is stationary. The operator can then stand clear while the car is moved to get “automatic “coupling;
- Have a bell mouthed buffer slot to pick up a sagging link and guide it into position;
- Have tolerance inside the buffer to hold the link in a reasonably horizontal position;
- Can be used interchangeably with existing manual link and pin systems;
- Has a robust pin, which is secured by a chain to the buffer to prevent it from being used for other purposes, lost, etc.;
- The pin bearing area has been increased to prevent excessive wear; and
- Has a hole or seat in the buffer to store the pin when not in use.

Appendix 2 International Practice

Most of the reported information from this section was provided in interviews with: Mr John Browitt, Chief Mechanical Engineer for RJB Mining Ltd, Mr Melvin Brown, Marketing Manager for Allen's Light Rail, Mr Malcolm Simpson, Sales Manager for River Don Castings, and Mr Mark Simpson, Consultant to Clayton Mining Equipment Ltd. Request for information was also made to several manufacturers of locomotives and rolling stock for mining applications in Europe.

UK Practice

The manufacturing specifications for coupler systems for underground mine cars are covered within BS3237: 1960 for light and medium rolling stock, and BS4073: 1966 for heavy rolling stock. Both were based upon original National Coal Board standards used by British Coal. BS3237 describes very simple non-resilient coupler systems. BS4073 describes the resilient type couplers. See Figures 1, 2, 3, 1.1, 2.1, and 3.1

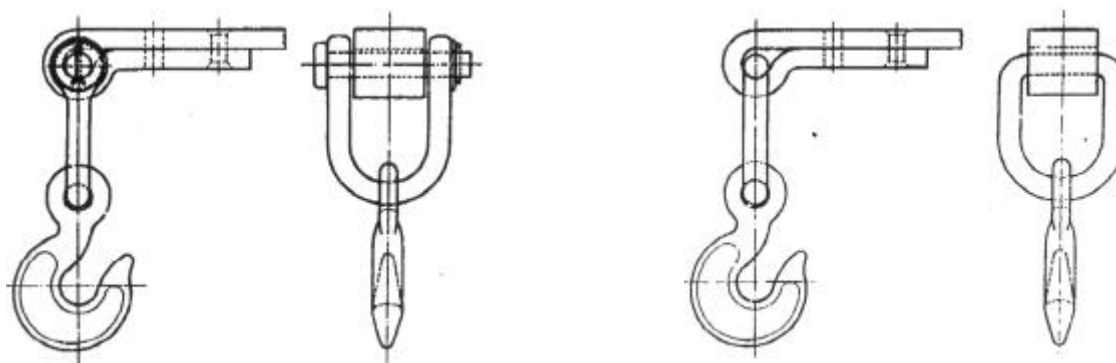


Figure 1. Typical couplings unit with Hook and Link

The key points from these standards are:

- All fully stressed cast and forged components are manufactured from 1.5 percent manganese steel manufactured to BS2772 - Iron and Steel for Colliery Haulage and Winding Equipment. The minimum tensile strength for the steel used in castings is 640 MPa (40tonf/in²), and for forged components 800 – 1280 MPa (50 – 70tonf/in²). Only non-fully stressed components can be specified in mild steel. This compares to the mild steel typically used in South African products.
- All components must be heat-treated.
- The ultimate breaking load for the coupler is a minimum of 7 times the static load for BS3237 and 8 times for BS4073. BS4073 also provides a formula for the minimum tensile breaking load of the coupler in tons (L) as:

$$L = 5 \cdot W (\sin \alpha + 0.125 \cdot \cos \alpha)$$

where

W = dead weight of train in tons

α = maximum angle of the track to the horizontal.

- Where steel resilient elements are used, stoppers must be used to prevent the resilient units being stressed beyond their capacity. Stops are not necessary for rubber

resilient elements.

- Couplers fitted with operating gear must lock in both the engaged and disengaged positions, and allow full articulation of the coupler.
- Operating gear pins, joints and fulcrums must be manufactured to avoid binding, and twisting.
- Operating gear must have provision to allow for adjustment to take up wear.
- Handles of operating gear must be at the ends of the car, and readily accessible from both sides of the track. They should be at waist height, and no more than 300-mm (12 inches) inward from the side of the car body, and positioned so as to prevent the operator from becoming trapped between the cars.
- Operating gear should have guards to prevent damage, and which can be removed for inspection.
- Shackles and pins must comply with BS3032

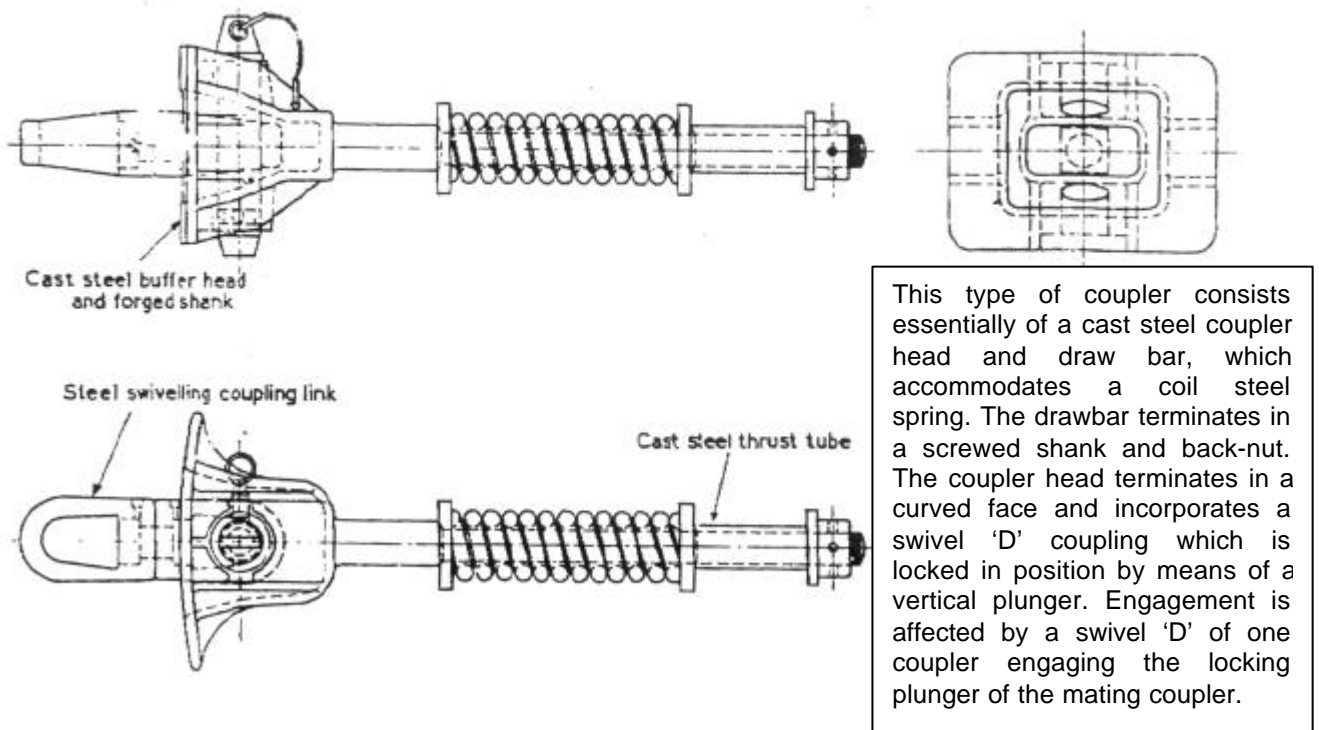
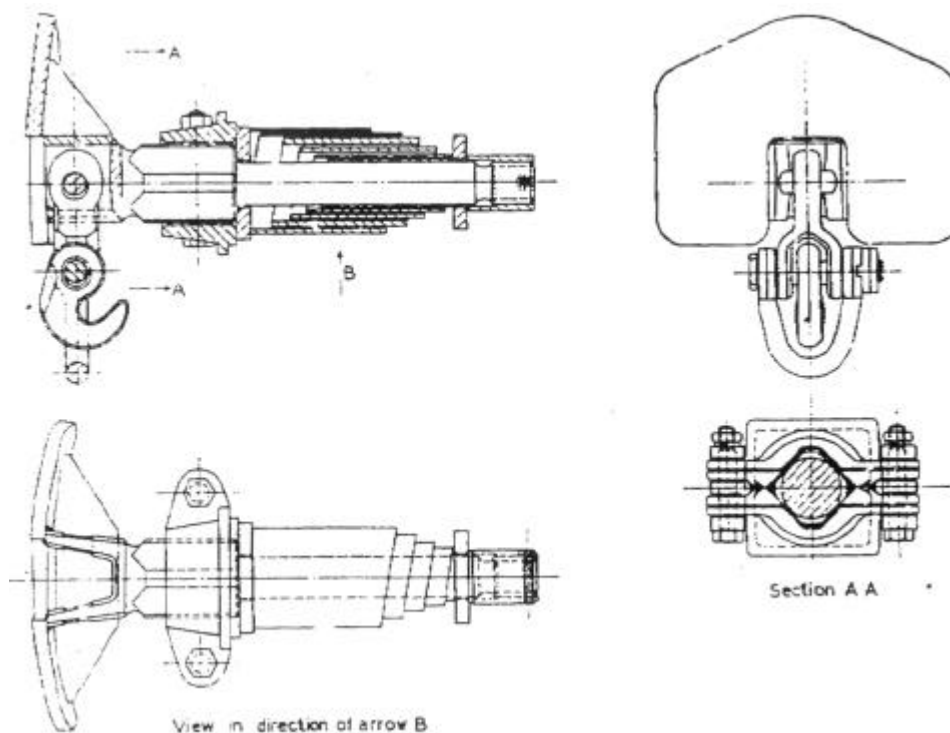


Figure 2. Typical non-articulating head type coupler with swivelled 'D' coupling link

The remaining UK collieries use three types of couplers: the Allen Universal, the Willison, and the Hudson Hook and Link. All three were reported as being rated at a breaking force of 70 ton, this strength rating being based upon an industry rule of thumb of approximately 2,5 times the mass on the driving wheels of the locomotive. The standard locomotive used is 25 ton, which is 2,5 times the mass of most units in the South African Gold and Platinum mines.

In addition, the collieries operate their rolling stock on a gradient, rather than the horizontal, so that strength and safety are key concerns in a coupler to avoid accidents caused by runaways.

RJB Mining does not have standardised wheel diameters for their rolling stock. They used to have a standard coupling height, but that has fallen away as a specific standard, although it is generally respected by manufacturers to within 30 - 40 mm.



This type of coupler consists essentially of a forged drawbar integral with a cast steel buffer head with a curved face. This drawbar terminates in a back nut split pin and incorporates two carrier plates accommodating either a helical or volute steel or rubber spring. A distance piece welded to the rear carrier plate forms the centralising medium. A coupling 'D' shackle mounted on a horizontal pin passing through the bulk head is designed to give a line of pull through the axis of the drawbar. On the shackle is a special hook with a large eye, which also accommodates a ring. The hook of one coupler engages with the ring of the mating coupler.

Figure 3. Typical non-articulating head type coupler with shackle and hook couplings

1. Allen's Universal Coupler

The coupler is illustrated in BS4073 and Figure 1.1. The coupler was developed and patented by Allens's Light Rail for hoppers rotated through up to 360 degrees during tipping. It was introduced to a large number of the old British Collieries, and has become the most common coupler on the remaining pits by default. Allen's Light Rail has been unable to supply any detailed information on their product for this study.

It is not automatic and requires the coupler faces to be square when coupling up. Its low tolerance to differences in buffer heights is increased due to drooping of the coupler head with wear and softening of the centring spring. The drooping of the heads has been known to result in accidental uncoupling.

In a derailment situation, the Allen's coupler is easiest of the systems used to uncouple because of its rotational capability.

The market for these couplers has fallen dramatically in the UK with the decline of the coal industry, and the manufacturer has moved its focus to new product areas. As a result the price of new head castings has risen to approximately £1,400, and refurbishment of heads to £350. It is understood that the patent has expired, or is due to expire very shortly.

Couplers have a long life span, and although maintenance costs were not reported by RJB Mining as excessive, the ex Manager of Allen's stated that spares consumption on

the operating gear is high.

Qualter Hall reported sales of the coupler on equipment supplied to Canada, Korea, and India. The company expressed no interest in licensing the manufacture of the coupler.

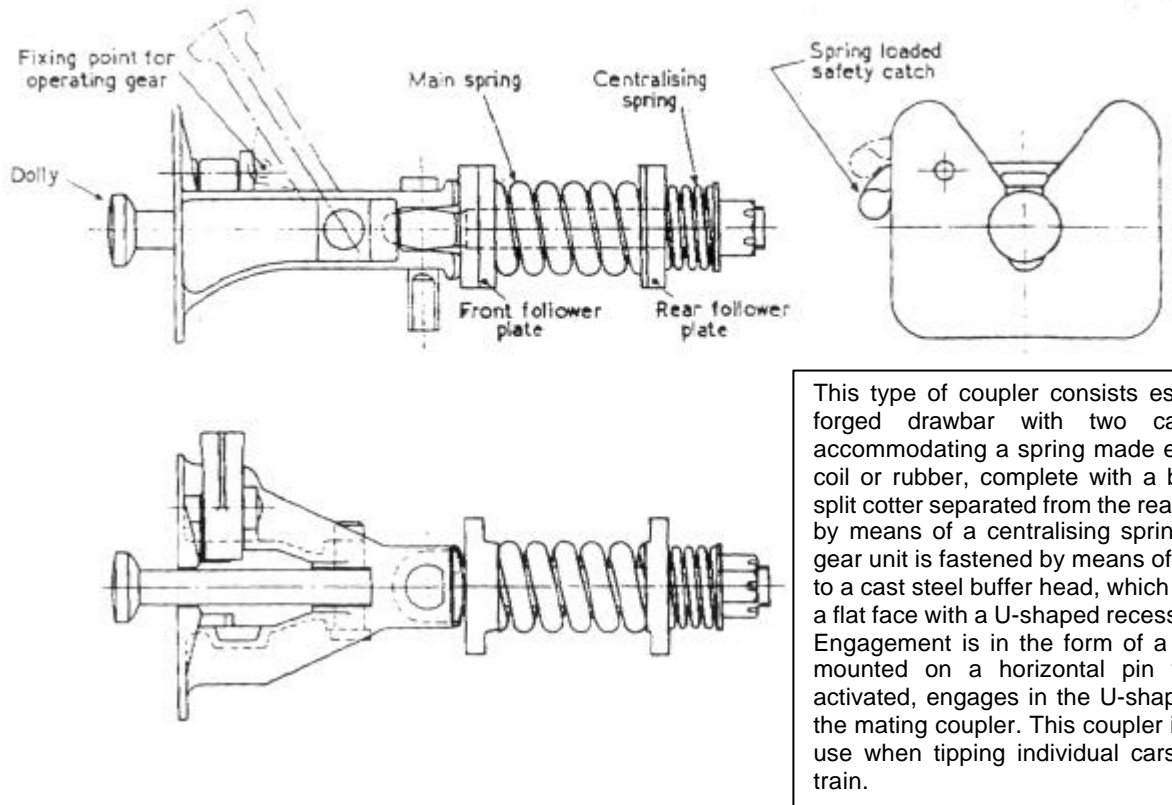


Figure 1.1 Typical semi-automatic 'dolly' type coupler operated from either side by gear mounted on both ends of the car.

2. Willison Coupler

The original Willison Coupler was a full size Industrial version for surface rolling stock, developed and patented by National Castings in the US. It is illustrated in Figure 2.1. This product was licensed for manufacture world-wide. The UK licensee is River Don Castings, part of Sheffield Forgemasters Engineering Ltd.

River Don Castings developed their own smaller (fractional) size patented designs for mining rolling stock, and now offer four sizes in the UK:

Size of Coupler	Breaking Load
$\frac{1}{2} - \frac{3}{4}$	58 tonnes
$\frac{3}{4}$	58 tonnes
Heavy Duty	86 tonnes
Mark II Heavy Duty	101 tonnes

More information is available in their brochures. Fractional sizes are also manufactured by companies in France and Italy, but the Italian product may be an inferior product.

Although slightly more complex than the Allen's coupler, this is the preferred choice of coupler for RJB Mining, although their experience with it is limited compared to the Allen's unit. Coupling is fully automatic, and it has a very good record with regard to safety and accidental uncoupling. It is robust, and with good maintenance couplers can achieved a life span in excess of 20 years.

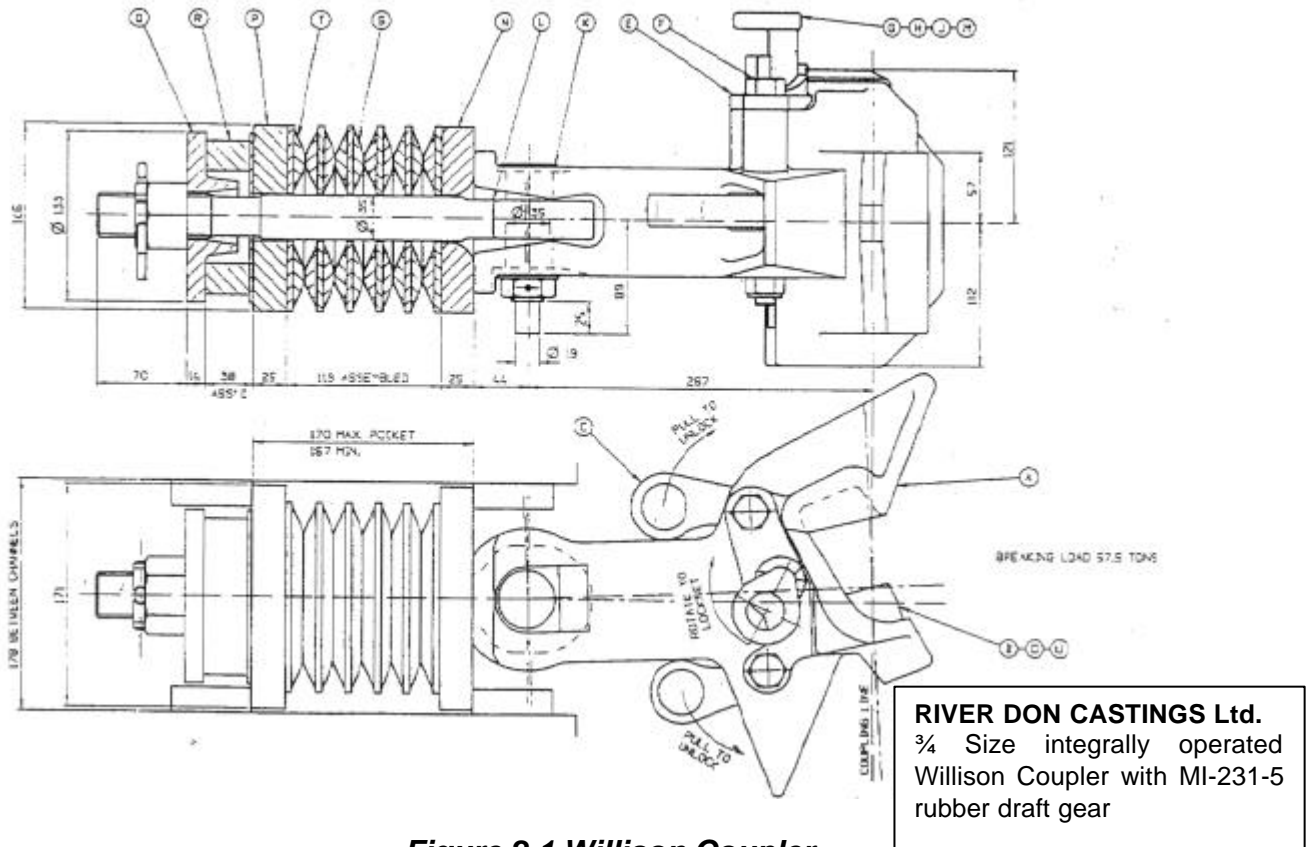


Figure 2.1 Willison Coupler

The coupler has a good tolerance for horizontal and vertical misalignment. Shock loading is absorbed by the design to increase the life of coupler and rolling stock, and although slight sagging of the coupler does occur with wear, but was not considered problematic. Maintenance costs were not reported as a concern.

In derailment, the Willison coupler tends to keep the cars upright.

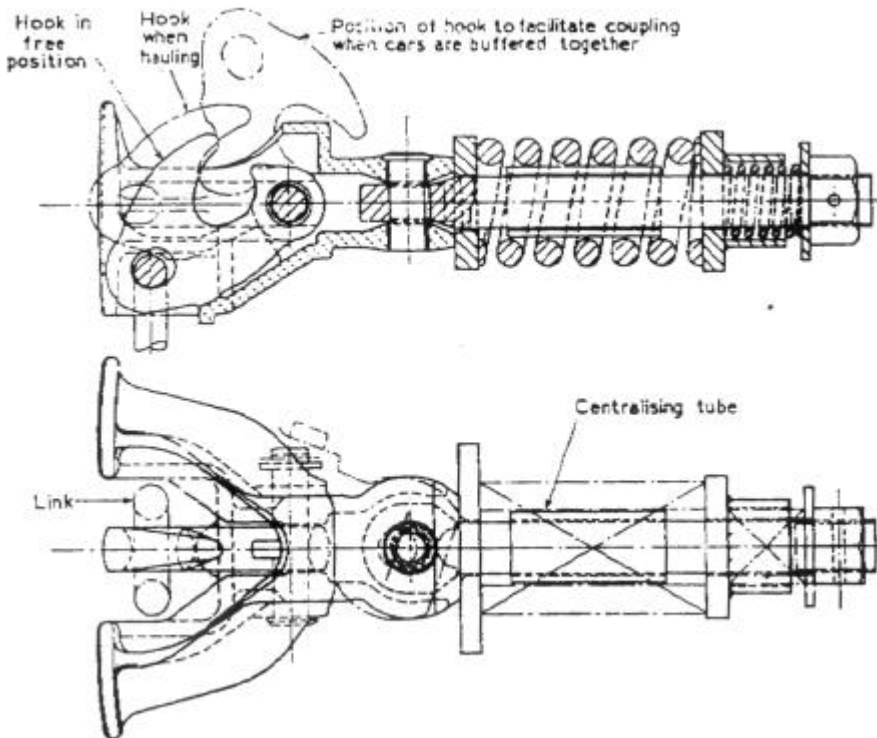
The price of a new fractional size coupler head is from the UK manufacturer is £400 - £500. Operating gear to provide for remote uncoupling can be supplied, or designed readily.

It is unclear if the fractional size couplers are available in South Africa. River Don Castings reported exporting the device to Australia, Cyprus, France, Germany, Ghana, Peru, Scandinavia, Switzerland, Turkey, Yugoslavia, Zambia, and Zimbabwe, but expressed a preference against licensing their designs outside the UK.

3. The Hudson Hook and Link Coupler

The coupler is illustrated in Figure 3.1. Originally developed by Hudson's (now part of Clayton Equipment Ltd), this coupler is used on at least one UK colliery. RJB Mining had little to report on the coupler. The key points raised were that it did not appear to be as secure as the Willison with regard to accidental uncoupling, and did not have a high degree of tolerance on differences in buffer height.

No information has been provided by Clayton Equipment to date on this coupler. However, it would appear that this design has been largely superseded in South Africa by some newer Galison coupler systems.



This coupler consists essentially of a forged drawbar terminating in a back nut and split cotter. The drawbar has two carrier plates accommodating a helical coil spring in which is fitted a centralising tube. The back nut is separated from the rear carrier plate by means of a centralising spring surrounded by a distance tube welded to the carrier plate. The drawbar is attached, by means of a vertical pin, to a cast steel head with a curved front face and a U-shaped aperture. Engagement is effected by means of a case of forged hook in the centre of the U-shaped recess mounted on a horizontal pivot pin carrying a link, which engages in the hook of the mating coupler.

Figure 3.1 The Hudson Hook and Link Coupler

The remaining two types of resilient coupler described in BS4703 are more basic designs, similar to the pin and link designs common in the South African mining industry, but no longer widely used in the UK.

4. European and North American Practice

No extensive study was carried out of couplers used in these regions. Unlike the South African operations, mining methods in these regions are more geared to large excavations and bulk material handling systems. Where rolling stock is used it is typically larger than the units used in the gold and platinum mines, demanding larger and more sophisticated couplers. Safety is another key issue in the more advanced economies, which again supports the use of highly specified equipment.

Anecdotal evidence suggests that the Willison coupler is the most widely used device in both Europe and North America, with an estimated 75 – 80 percent of North American mining operations using this unit. GIA Industrier of Sweden, a locomotive and rolling stock manufacturer, confirmed the Willison coupler to be commonly specified by their clients.

Qualter Hall of the UK stated that equipment supplied to European countries was often fitted with couplers from local manufacturers that were very similar to the Willison, Allen's or Hudson units.

Requests to DIEMA and Muehlhauser of Germany for information on their proprietary coupler systems did not receive any response.

Appendix 3

Patents and Patent Searches

The project team carried out Patent Searches of the South African Patent Office and the United States Patent Office.

In South Africa, some 43 patents appertaining to rail couplings underground were found, with copies being made of the 16 more relevant patents. The patent numbers are:

89/6677; 92/4737; 89/5037; 89/9313; 89/8984; 89/8891; 87/0607; 95/2054; 87/7413; 87/7205; 90/6265; 95/8849; 87/0061; 87/9200; 87/7025; 98/2186.

These included:

- Automatic coupling using a link and a hinged pin;
- “Willison” type automatic couplings;
- A link and pin coupling for articulated bogies;
- A disc and pin type coupling;
- A link and pin coupling with a spring and pivot mechanism for automatic coupling;
- A linkage for remote decoupling by raising the locking pin;
- A spherical ball joint;
- A link with a cruciform handle;
- A coupling pin with a flexible handle;
- A chain and fixed pin coupling;
- A spring loaded double hook coupling; and
- Automatic coupling using a wedge shaped link and a vertically acting pin.

In the United States, most of the patents found during the search related to developments of the “Willison” type coupling. Other developments related to adapting the conventional link and pin type systems to a system that allows for:

- The draw pin to be safely retained in an upper non-engaging position while vehicles are moved together or apart during coupling and uncoupling; and
- The draw pin to be remotely/automatically engaged/disengaged while the vehicles are stationary during coupled or uncoupled.

The patents that were found were either:

- Already in commercial production;
- Had been in commercial production but had failed; and
- Were obviously impractical.

Appendix 4 International Legislation

The legislation appertaining to underground rail transportation in South Africa, the UK, the USA, Canada and Australia were investigated. Generally, very little emphasis is placed on coupling systems in the legislation of these countries. The more relevant clauses are as specified below. The UK legislation is as discussed in Appendix 2. The South African legislation is fully discussed in GAP 520.

USA

Federal Mine Safety & Health Act of 1977, Public Law 91-173, as amended by Public Law 95-164*:

“(f) All haulage equipment acquired by an operator of a coal mine on or after one year after the operative date of this title shall be equipped with automatic couplers which couple by impact and uncouple without the necessity of persons going between the ends of such equipment. All haulage equipment without automatic couplers in use in a mine on the operative date of this title shall also be so equipped within four years after the operative date of this title.”

30 CFR § 57.14161
Makeshift couplings.

Couplings used on underground rail equipment shall be designed for that equipment, except that makeshift couplings may be used to move disabled rail equipment for repairs if no hazard to persons is created.

30 CFR § 57.14200
Warnings prior to starting or moving equipment.

SAFETY PRACTICES AND OPERATIONAL PROCEDURES

Before starting crushers or moving self-propelled mobile equipment, equipment operators shall sound a warning that is audible above the surrounding noise level or use other effective means to warn all persons who could be exposed to a hazard from the equipment.

30 CFR § 57.14215
Coupling or uncoupling cars.

Prior to coupling or uncoupling cars manually, trains shall be brought to a complete stop, and then moved at minimum tram speed until the coupling or uncoupling activity is completed. Coupling or uncoupling shall not be attempted from the inside of curves unless the railroad and cars are designed to eliminate hazards to persons.

30 CFR § 57.9318
Getting on or off moving equipment.

Persons shall not get on or off moving mobile equipment. This provision does not apply to trainmen, brakemen, and car droppers who are required to get on or off slowly moving trains in the performance of their work duties.

30 CFR § 57.9319

Going over, under, or between railcars.

Persons shall not go over, under, or between railcars unless--

(a) The train is stopped; and

(b) The train operator, when present, is notified and the notice acknowledged.

30 CFR § 75.1405

Automatic couplers.

[STATUTORY PROVISIONS]

All haulage equipment acquired by an operator of a coal mine on or after March 30, 1971, shall be equipped with automatic couplers which couple by impact and uncouple without the necessity of persons going between the ends of such equipment. All haulage equipment without automatic couplers in use in a mine on March 30, 1970, shall also be so equipped within 4 years after March 30, 1970.

30 CFR § 75.1405-1

Automatic couplers, haulage equipment.

The requirement of §75.1405 with respect to automatic couplers applies only to track haulage cars, which are regularly coupled and uncoupled.

Exemptions - USA

Note - These dockets relate to applications for exemptions from regulations and are posted on the Internet as a part of the process.

[Docket No. M-97-22-C]

Brookside Coal Company, General Delivery, Spring Glen, Pennsylvania 17978 has filed a petition to modify the application of 30 CFR 75.1405 (automatic couplers) to its Diamond Vein Slope Mine (I.D. No. 36-08456) located in Schuylkill County, Pennsylvania. The petitioner requests a modification of the standard to permit the use of bar and pin or link and pin.

Docket No.: M-97-022-C.

FR Notice: 62 FR 23797.

Petitioner: Brookside Coal Company.

Reg Affected: 30 CFR 75.1405.

Summary of Findings: Petitioner's proposal to use bar and pin or link and pin couplers on its underground haulage equipment considered acceptable alternative method. Granted for the Diamond Vein Slope Mine with conditions.

Rustler Coal Company [Docket No. M-98-58-C]

Rustler Coal Company, 66 South Tremont Street, Zerby, Pennsylvania 17981 has filed a petition to modify the application of 30 CFR 75.1405 (automatic couplers) to its Orchard Slope (I.D. No.36-08346) located in Schuylkill County, Pennsylvania. The petitioner requests a modification of the standard to allow the use of bar and pin, or link and pin couplers on underground haulage equipment. The petitioner asserts that the proposed alternative method would provide at least the same measure of protection, as would the mandatory standard.

Docket No.: M-98-058-C.

FR Notice: 63 FR 44291.

Petitioner: Rustler Coal Company.

Regulation Affected: 30 CFR 75.1405.

Summary of Findings: Petitioner's proposal to use bar and pin, or link and pin couplers on underground haulage equipment considered acceptable alternative method. Granted for the Archard Slope Mine with conditions.

E & E Fuels [Docket No. M-97-23-C]

E & E Fuels, P.O. Box 265, Tremont, Pennsylvania 17981 has filed a petition to modify the

application of 30 CFR 75.1405 (automatic couplers) to its Orchard Slope Mine (I.D. No. 36-08346) located in Schuylkill County, Pennsylvania. The petitioner requests a modification of the standard to permit the use of bar and pin or link and pin couplers on its underground haulage equipment. The petitioner asserts that the proposed alternative method would provide at least the same measure of protection as would the mandatory standard.

Docket No.: M-93-080-C. FR Notice: 58 FR 39235.

Petitioner: Synder Coal Company.

Reg Affected: 30 CFR 75.1405

Summary of Findings: Petitioner's proposal to use bar and pin or link and pin couplers on underground haulage equipment instead of automatic couplers considered acceptable.

Canada

COAL MINES (CBDC) OCCUPATIONAL SAFETY AND HEALTH REGULATIONS

PART III

UNDERGROUND TRANSPORTATION AND HOISTING

Underground Transportation

59. (1) The mine manager shall prepare in writing and implement safe procedures for the operation of cages, trips and mobile equipment underground.

Cage and Mine Car Construction

81. Every mine car shall be so constructed that any coupling, shackle pin or safety chain is visible for inspection.

82. Effective on October 1, 1993, every mine car shall have a name-plate that indicates

- (a) the manufacturer's name and address;
- (b) the tare weight of the fitted mine car;
- (c) the maximum load for which the mine car is designed, expressed
 - (i) in the case of a material car, in tonnes, and
 - (ii) in the case of a man car, in number of persons, calculated on the basis of 81.7 kg per person;
- (d) the maximum speed for which the mine car is designed, expressed in metres per second; and
- (e) the month and year of manufacture.

Man Cars

83.

(3) The first man car of a trip shall be secured by a primary fastening arrangement that is

(c) in the case of a locomotive system, a coupling.

84. (1) Where a man car is used on a gradient exceeding 4 per cent, it shall, for the purpose of coupling it with other mine cars, be equipped with

- (a) three continuous draw-bars made of steel; or
- (b) a single draw-bar composite of rolled steel sections and rolled steel plate.

(2) The continuous draw-bars referred to in paragraph (1)(a) shall be

- (a) extended the full length of the man car;
- (b) securely bolted to the floor and base sills of the man car; and
- (c) visible for inspection.

85. (1) Where man cars that are equipped with three continuous draw-bars are adjacent in a trip, they shall be connected to each other by

- (a) couplings at the centre draw-bar; and
- (b) safety chains at the two side draw-bars.

(2) Where man cars that are equipped with a single draw-bar are adjacent in a trip, they shall be connected to each other by

- (a) couplings at each end of the draw-bars; and
- (b) safety chains at two attachments on the chassis of each adjacent man car.

(3) The safety chains referred to in paragraphs (1)(b) and (2)(b) shall be slack during normal operation.

Material Cars

87. Effective on October 1, 1993, where material cars of a trip are used on a gradient exceeding 4 per cent,

(a) material cars that are adjacent in the trip shall be connected by

- (i) in the case of a material car that is equipped with three continuous draw-bars, safety chains at the two side draw-bars, and
- (ii) in the case of a material car that is equipped with a single draw-bar composite, safety chains at two attachments on the chassis of each adjacent mine car;

Tackling Equipment

88. (1) No single-link chain, other than a coupling attached to a cage or mine car, shall be installed on any equipment that is used for transporting persons.

(2) Subject to subsection 89(2), the couplings of a cage or mine car shall be used only in conjunction with safety chains or safety ropes that are of sufficient strength to hold the maximum load for which the cage or mine car is designed in the event that the coupling chain breaks.

(3) Every draw-bar of a three-draw-bar man car and every coupling, pin, safety chain, rope clamp and other tackling equipment that is used on a cage or mine car shall be made of steel.

(4) The steel referred to in subsection (3) shall be

(a) certified by its manufacturer not to require heat treatment to remove stresses that are due to cold working; or

(b) heat treated at least once every six months in accordance with the

recommendations of the manufacturer.

(5) The employer shall keep a record of the heat treatment referred to in paragraph (4)(b) at the coal mine in which the equipment that is heat treated is used.

(6) No draw-bar, coupling, pin, safety chain, rope clamp or other tackling equipment shall be used on a cage or mine car unless

(a) its design has been tested by the manufacturer to withstand a proof load of 40 per cent of its breaking strength without any permanent set;

(b) a certificate of the test referred to in paragraph (a) has been provided to the employer by the manufacturer; and

(c) the equipment has been legibly and permanently marked to identify it with the manufacturer's certificate.

89. (1) Couplings, pins and rope clamps shall be designed with a factor of safety of not less than six.

(2) Safety chains and safety ropes shall be designed with a factor of safety of not less than two.

(3) Draw-bars that are manufactured from steel that is certified by the manufacturer not to require heat treatment to remove stresses that are due to cold working shall be designed with a factor of safety of not less than six.

(4) Draw-bars that are manufactured from steel that requires heat treatment every six months to remove stresses that are due to cold working and draw-bars that are made of rolled steel sections and plates shall be designed with a factor of safety of not less than 10.

(5) Subsections (1) to (4) apply on and after October 1, 1993.

Operation and Inspection of Mine Cars

90. (1) Every trip shall be under the supervision of a qualified person who shall

(a) verify that all couplings and safety chains are secured to the mine cars;

(2) No person shall get into or out of a trip while it is in motion.

(3) Before a mine car is detached from its rope or locomotive and is parked on an incline, its wheels shall be sampsoned and braked or shall be spragged.

91. (1) At least once every day of operation of a coal mine, a qualified person shall inspect the couplings, pins, safety chains, draw-gear, rope clamps and safety brakes of all mine cars in use on gradients exceeding four per cent.

98. (1) A cage or mine car that is used for transporting persons shall be in the charge of a qualified person.

(2) Subject to subsection (3), no person shall be transported underground at a speed greater than 6 m/s unless

(b) where rail tracks are used, the rail track is ballasted, graded and fish-plated and is designed for mine cars travelling at speeds greater than 6 m/s.

(3) No person shall be transported underground at a speed greater than the speed for which the cage or mine car is designed.

Western Australia

“Rail haulage plan”

10.44. (1) If rail mounted locomotive haulages are used or are to be used in an underground mine, the manager of the mine must ensure that a plan is prepared in accordance with subregulation (2) to ensure that the operation and maintenance of that haulage system is made as safe as is reasonably practicable.

(2) The plan must -

(a) be prepared before the haulage system is used at the mine; and

(b) include details of -

(i) operating and maintenance procedures;

(ii) haulage specifications and layout; and

(iii) safety precautions to be observed.

(3) The manager of an underground mine must ensure that as soon as is practicable after a plan is prepared under subregulation (1), a copy of the plan is submitted to the district inspector.

(4) If in the district inspector's opinion a plan is inadequate in any respect, the district inspector may direct that the plan be amended in a specified way and re-submitted to the district inspector.

(5) A direction may be given under subregulation (4) as often as the district inspector thinks necessary.”

Appendix 5

Meetings with interested and affected parties

Meetings were held with both head office staff and operating personnel of most of the major producers. The results of the more pertinent discussions are as contained below:

Mr A – Logistics Manager – Main Shaft – Mine A

They only use manual type link and pin coupling systems.

Material cars – buffer height 360mm above rail

Hoppers – buffer height 450mm above rail

They have recently standardised buffer heights (to 10mm tolerance), increased buffer slot width to allow sharp radii on bends (were causing derailments), widened gap of slot to facilitate link fitting into slot. They have had no accidents on material cars for 4 months. Track conditions are generally poor. There historically was little standardisation on wheel diameters.

They have introduced dedicated material gangs on material cars at Main Shaft – they have drawn up a training program and standard procedures. They have a standard procedure that no coupling is allowed on the inside radius of a curve.

They have had no coupling accidents on hoppers for two years.

On stopping they have dedicated a span of hoppers to a locomotive on each level, on permanent rock hauling duties – so minimising coupling and uncoupling required. Guard and driver are trained on surface and underground.

On development they have dedicated a span of hoppers to a loco on each level, on permanent rock hauling duties – but still have regular coupling and uncoupling. Guard and driver are trained on surface and underground.

Previously, every Mine Overseer was allocated a locomotive – which was used for multiple tasks – rock, material, etc. so necessitating frequent coupling and uncoupling. Drivers were only trained to drive a loco, there was no formal training on coupling procedures, guards were not formally trained.

Main Shaft has a population of 650 material cars and approximately 350 hoppers.

They are currently carrying out a trial using a remote control unit (“garage opener” type) for the guard to give both an audible and LED signal to the Driver. This is to replace the current system of using a pea-whistle for signalling.

Mr B – Chief Inspector of Machinery

They have frequent coupling accidents in their area, virtually every week. He feels that the main reason for finger and hand accidents is wrestling with sagging links during coupling. He is not aware of accidents occurring during uncoupling.

Fatalities – significant number of head injuries. Coupling on the inside radius of a curve results in crushing injuries. Difficult to standardise on buffer heights unless the mine standardises on wheel diameters.

Underground Visit- 7 June 2000 - Mine A

The visit was to a major cross tram of some 4000 metres, with an internal orepass system on the 61 line, tramming back to the sub vertical shaft.

By industry standards the condition of the rolling stock, the trackwork and the organisation of the tramming was among the best the project team have seen.

They use five off 10 ton five cylinder diesel locomotives each pulling a span of up to ten off five ton hoppers (nominal load 3,5 ton). The haulage has 30 kg rails (the normal mine standard is 22 kg rails). They pull some 440 hoppers per day, averaging some 35 000 tons of reef per month.

They seldom uncouple the hoppers in the span; the hoppers are dedicated to the span. The loop is uncoupled, and driven round a loop to hitch up the span. Their standard modus operandi is to pull the hoppers, propelling is not encouraged.

The mine standard instructions require them to couple on the straight where possible. When coupling or uncoupling is done on a curved section of track, the guard is required to work on the outside radius of the curve.

They have drivers and guards allocated to a dedicated locomotive, complete with span of hoppers.

The material transport is done by dedicated gangs. Their standard modus operandi is to move material cars by hand when coupling.

The tramming is controlled by a dedicated horizontal transport management structure, with a horizontal transport manager (engineer), horizontal transport mine overseer and horizontal transport shift bosses.

They are using resilient type buffers (Duiker type) on their hoppers and rigid buffers on their material cars. They use a 25 mm thick, 100 mm wide link, with two slotted holes (50 mm x 80 mm) and a 30 mm round bar as a handle. They use a 30-mm pin, 210 mm long with a rounded handle that doubles up as the sprag.

They have upgraded all their material cars by:

- Modifying all buffers to be at the same level;
- Widening the slot; and
- Increasing the depth of the slot to 60 mm.

They have had very few coupling accidents on their hoppers over the last two years, and have not had a coupling accident on the material cars since they upgraded the buffers (approximately four months).

The team observed that a number of problems exist with the type of buffer being used on the hoppers. The buffers are bolted onto the hopper chassis – most of the bolts were loose, so resulting in the buffer drooping. The mine is busy with replacing the bolts with huckbolts, which seems to largely solve the problem.

Many of the buffers seen were missing their rubber “doughnuts”. The design of the buffer is such that once the doughnuts start collapsing, or fall out, the buffer head droops severely.

The relatively short throat of the buffer, together with the relatively large slot in the link (50

mm x 80 mm) and the relatively small pin (30 mm) leads to excessive play, so resulting in sagging of the link.

The combination of the above three factors i.e. loose buffers, missing or damaged doughnuts, and excessive play between link and pin results in excessive link sag. Coupling of the hoppers, as seen during the visit, could only be achieved by the guard standing between the hoppers. This was necessary to support the sagging link in a horizontal position and to guide the link into the mouth of the buffer whilst the hopper is moved by the locomotive.

When the locomotive starts from a stationary position, the play between the slotted holes and the pin results in significant impact loading on the hoppers and couplings. The pulling of hoppers through the tip arrangements also results in severe impact loads. Also obvious was excessive plastic deformation of the load bearing surfaces of:

- The buffer head (at the pin load bearing areas);
- The slots in the links; and
- The pins.

All of this over time makes the sagging effect worse and coupling and uncoupling more difficult.

Appendix 6

Risk Assessment on Link and Pin Coupling on Rolling Stock

A comprehensive evaluation to determine the hazards and risks involved with the link and pin system used for coupling and uncoupling of rolling stock as set out in this assessment, which may affect the health and safety of workers. This was done as part of the Simrac Gap 703 project.

1. Introduction and background:

This Risk Assessment report was compiled to the requirements of the Mine Health and Safety Act, 29 of 1996.

The investigation into the different coupling systems in use at mines revealed a vast number of hazards and risks involved with the coupling and uncoupling operations of rolling stock. The link and pin system is common to most mines, each having their own perspective on the use and manufacturing thereof.

The link consist of a flat bar with slotted holes on both ends. Variations include the additions of different types of handles, all designed with the objective to reduce the number and severity of injuries.

The pins are made of round bar and differ in diameter at some of the mines. Again additions are made with the same objective as for the links.

With all these different systems and alterations in use on the mines, the type and extend of injuries remain more or less the same. Risk assessments on the Link & Pin coupling are not as common as originally believed since it is generally not considered to be a major problem. This perception however also varies considerably depending on whom the problem is discussed with. Generally speaking it does present a safety problem hence the many variations from the original model.

During visits to the mines and suppliers it appears that common hazards and risks prevail where the coupling is used. The general consensus is that most accidents occur during the coupling process.

The objective of this risk assessment is to evaluate the hazards and risks involved with the coupling and uncoupling of rolling stock with the emphasis on the coupling process.

2. Participants in the Assessment

The risk assessment was carried out on a gold mine in the Free State.

Participating members of the mine staff included:

- Mine Production Supervisors;
- Safety Officers; and
- Operators.

3. Scope of Assessment

This assessment is done taking cognisance of the interactions between all possible geographical conditions, functional activities and all kinetic energy in as far as the use of the link and pin system for coupling and uncoupling of rolling stock.

The approach yielded the following areas and situations for assessment:

Activities (step by step):

- The person(s) involved or exposed;
- Type of rolling stock involved;
- Site of activity;
- Instructions and supervision;
- Obstructions and clearances;
- Load (equipment, material); and
- Training.

Focus was placed on aspects meeting the objectives of the assessment. Any area, activity or situation not covered in this assessment could be the subject of further assessments. Due to the many variations from the original standard coupling this assessment does not include any alterations or changes made by the user to the original product.

4. Methods Applied

A qualitative approach was used to determine the activities, which causes the greatest potential to failure related to the coupling and uncoupling of rolling stock using the link and pin system. Once these activities were identified the hazard identification process was initiated.

4.1 Risk Assessment Process

The outcome of the assessment depended greatly on the input from a selected team of persons with suitable, practical knowledge and experience of the coupling system and the environment in which it is used. During the application of the Risk Assessment technique all systems and sub systems of the coupling process were considered through a structured brainstorming effort. By raising questions about realistic deviations from the normal intended operation of the task and related activity the likelihood of an accident / incident, the potential consequences and the adequacy of safeguards to prevent or mitigate it is assessed.

The technique addressed the following aspects:

- Functional hazards;
- Geographical hazards;
- Any kinetic energy involved;
- Mining layout hazards;
- Possible system failures;
- Likelihood of failures;
- Consequence of failures;
- Qualitative evaluation of safety and health effects;
- Engineering and administrative controls; and
- All relevant legislation.

Risk assessment is described as a tool that can be used to remedy the status quo. This

view is supported internationally on condition that it involves the participation of employees at all levels so providing a bottom up approach to the system.

Risk assessment is the process of: -

- Identifying the hazards in the workplace that are likely to hurt peoples or cause damage to equipment or production with the emphasis of being injured;
- Defining the risks associated with each hazard – the likelihood of the hazardous event occurring; and
- Put measures in place to control the risk at source, either eliminating the risk completely or minimising the risk to an acceptable level.

In order to address the critical issues that emanates from the risk assessment each hazardous event identified must be risk ranked (prioritised) in terms of its likelihood of occurrence and severity.

The risk assessment process described above was applied to the coupling/uncoupling of rolling stock. The outcome of the risk assessment is explained in detail in the “Risk Assessment Worksheet” section.

Each potential consequence caused by a deviation from safe practice has been allocated a criticality ranking. The Risk Assessment Matrix is used to calculate the final criticality rank and is done as follows: -

Step 1

Determine the severity/consequence category of a potential consequence as per column 4 in risk assessment worksheet, using table A.

Step 2

Determine the frequency/probability category of a potential consequence, as per column 4 in risk assessment worksheet using table B.

Step 3

Multiply the severity rating determined in step 1 by the frequency/probability rating determined in Step 2 to find the final criticality ranking.

Step 4

Potential consequences of a deviation need to be prioritised in order to decide how significant the associated risk is. To determine whether the risk is **intolerable** or **tolerable** the criticality ranking determined through step 3 above is compared with prioritisation Table C. From this table one can determine whether the risk is intolerable or tolerable.

Working Example: -

- Step 1 :** Consider a potential consequence from the worksheet.
- Step 2 :** Determine the severity of the potential consequence occurring from table A, say it is F6.
- Step 3 :** Determine the probability from table B say it is H2
- Step 4 :** Severity x Probability = F6 x H2 = Criticality ranking of 12
- Step 5 :** Determine the priority from Table C by placing the criticality ranking of 12 where it belongs which in this case is H12 (considered to be a tolerable risk)

The risk associated with this particular potential consequence is considered a tolerable risk since it falls in the low risk area of table C. The above process is repeated for each potential consequence identified in the risk assessment.

5. Graphical Presentation of Risk Assessment Results

The following graph depicts the profiles generated from the Risk Assessment results detailed in the "Risk Assessment Worksheet" section.

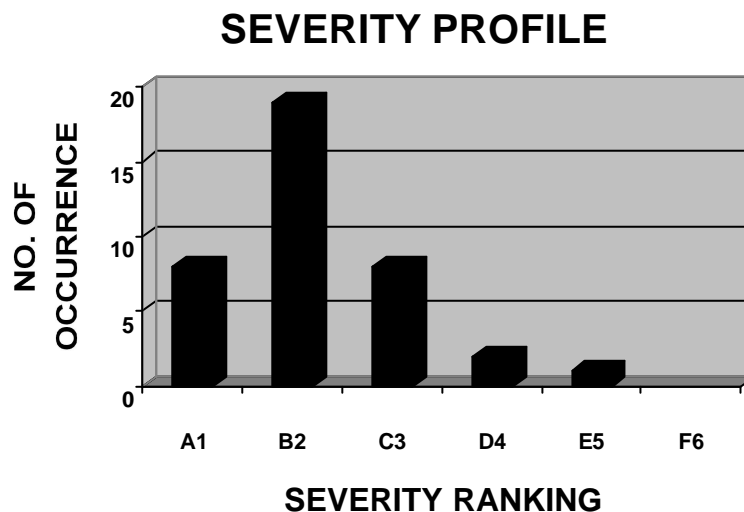


Figure 5.1 Severity Profile

Each deviation identified during the activities of coupling and uncoupling of rolling stock resulted in one or more potential consequences. A severity rating is allocated in accordance with table "A" on page 22 ranging from F6 being the lowest and A1 the highest.

Figure 5.1 highlights the fact that most **potential consequences** of the deviations identified has a high severity ranking indicating that there is a high potential for a person to be injured as a result of the deviations.

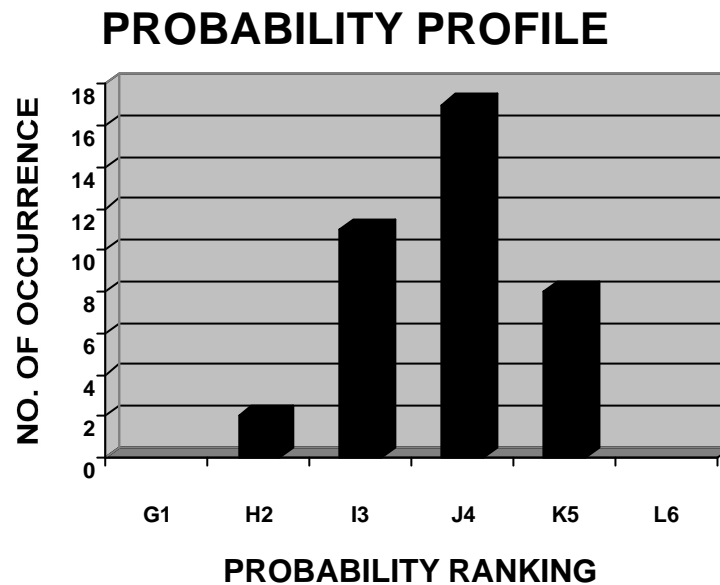


Figure 5.2 Probability Profile

In Figure 5.2 each **potential consequence** resulting from the deviations identified are allocated a probability/frequency ranking in accordance with table B ranging from G1 being the highest and L6 the lowest.

This chart highlights the fact that the **probability** of the **potential consequences** identified actually becoming reality, ranges from H2 (probable) to K5 (rare) with I3 (can happen) second highest and J4 (low likelihood) being the highest.

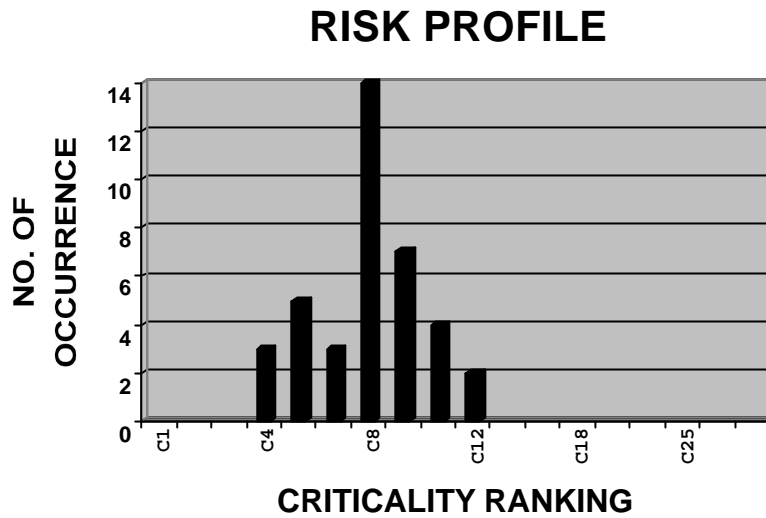


Figure 5.3 Risk Profile

In order to **prioritise** the **potential consequences** resulting from a deviation a **criticality ranking** is allocated to each potential consequence using the formula of *severity x probability = critical ranking*. The higher the criticality ranking the more critical the potential consequence in question becomes.

It is clear from Figure 5.3 that most of the potential consequences, resulting from the deviations identified with coupling and uncoupling of rolling stock, ends up in the *intolerable risk* section of table C.

It became apparent from the risk assessment that 71,05% of the total risks identified carries a **high severity** but with an **average probability or likelihood**. Caution should be taken against the risks with a potential of severe injuries (C3 classification) as they could easily result into major mishaps if slightly different circumstances prevail.

6. Risk Assessment Results and Recommendations

The risk assessment carried out on the link and pin coupling system, highlighted several Design Operational and training issues that need to be addressed, and include:

6.1 Design/Operational

As a minimum it is suggested that the following Design and Operational issues be addressed to minimise the risk of injury:

- No changes to the original buffer should be made without a proper risk assessment;
- No attachments should be made to the link or pin without a proper risk assessment;

- Mine specific standards should address all types of links and pins in use with the correct application as assessed by the supplier, manufacturer and the mine; and
- Standardisation of the critical components on a specific mine is essential. This would inter alia include the following:
 - Buffer heights;
 - Type and size of pins and links;
 - Types of handles fitted to pins; and
 - Method of fitting buffers to hoppers.

6.2 Training

Training of users of the coupling system, their supervisor's etc. remains the most important aspect in the prevention of accidents involving this type of coupling.

- The mine procedural training manuals should take cognisance of the findings and recommendations of the risk assessments carried out on the type of coupling (including any alterations) used by the mine.
- Ensure training is evaluated against actual practices underground and on surface.
- Emergency situations should form part of the training process for new, transferred and refresher programmes.
- Personnel involved with the assessment process should address deficiencies in the content of training manuals.
- Supervisors should be trained and equipped with the necessary knowledge to provide on the job training of hazard awareness to their employees.
- Person moving between jobs even from one level to the next should be retrained on the use of the coupling system in his new work environment, regardless of the insignificance of the alteration to the coupling system.
- Training should include the various conditions and scenarios under which coupling of hoppers are being carried out. Most training manuals address only the obvious situation i.e. when the coupling is carried out under ideal conditions.

6.3 Conclusion from Risk Assessment

This assessment revealed that a great amount of onus is placed on the operator to perform the coupling and uncoupling operations in a safe manner. He is the person who has to work closely to the danger zone between the rolling stock, to assess the immediate conditions and ensure correct actions are taken. There is a general opinion that training is not comprehensive enough and could be improved considerably. Operators should also carry out a risk assessment as part of his training syllabus. Standardisation of equipment and related conditions are essential. Manufacturers and suppliers and mines should work closely together to find a real solution to the problem.

RISK ASSESSMENT WORKSHEET

<p>Project Title: Risk assessment Coupling & Uncoupling of Rolling Stock</p> <p>Unit: Link and Pin System</p>	<p>Project Team Leader: S W Lubbe</p>
---	--

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	Risk Rating			Existing Controls	Recommendations
				S	P	C		
What if	Incorrect positioning of operator	Inadequate training Obstructions Lack of skill Position of equipment after derailment Deliberate disregard of rules, standards, etc.	Slip and fall Caught between object / load and car or hopper Caught between two cars / hoppers Being run over by moving train	D4 B2 B2 B2	I3 K5 I3 J4	12 10 6 8	<p>A procedure is in place to ensure that:-</p> <ul style="list-style-type: none"> • Operator positions himself clear from obstructions and aside the rolling stock. • Operator not allowed entering opening between rolling stock whilst in motion. 	<ul style="list-style-type: none"> • Operator training should address all potential accident causing factors. • Coupling equipment should be redesigned to allow operator to be positioned away from the danger zone during coupling.

Note:

• **S = Severity X P = Probability = C – Criticality Ranking**

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	Risk Rating			Existing Controls	Recommendations
				S	P	C		
What if	Height differences of buffers	Incorrect design application on hopper or buffer. Different type of rolling stock Abnormal wear and tear of buffers Loose buffer as a result of inadequate maintenance.	<ul style="list-style-type: none"> Link fail to enter, then used instead to couple, if detached can result into runaway vehicle. Body parts i.e. hands, fingers, feet can get caught. 	A1	J4	4	<ul style="list-style-type: none"> Enforcement of good maintenance practices. This also varies from workplace to workplace and level to level. Main stores are supposed to ensure that standard buffer is supplied to section. <p>Main stores are supposed to supply section with stand hopper.</p>	<ul style="list-style-type: none"> Standardize buffer heights Coupling pins should not be extended to cater for the differences in height between the cars. Cars with differences in buffer heights should be transported independently.

Note:

- **S = Severity X P = Probability = C – Criticality Ranking**

RISK ASSESSMENT WORKSHEET

Project Title: Risk assessment
Coupling &
Uncoupling of
Rolling Stock

Project Team Leader: S W Lubbe

Unit: Link and Pin
System

<i>Guide Word</i>	<i>Deviation Response</i>	<i>Possible Cause (Short Coming)</i>	<i>Potential Consequences</i>	<i>Risk Rating</i>			<i>Existing Controls</i>	<i>Recommendations</i>
				<i>S</i>	<i>P</i>	<i>C</i>		
What if	Incorrect size of holes in links	<ul style="list-style-type: none"> Abnormal wear and tear Incorrect designs resulting in excessive impact load. Oversize pin resulting in pin being forced into hole. Undersize pin increasing impact load 	<ul style="list-style-type: none"> Pin fail to enter, use of chain, detachment result into runaway vehicle or derailments on curves. Pins fall through and hoppers become detached. 	A1	J4	4	<ul style="list-style-type: none"> Inspection of coupling units and carried out regularly. Results are recorded and corrective action taken. 	<ul style="list-style-type: none"> Coupling pins and links, which show signs of distortion, should be discarded. Accept only correct equipment from store that is compatible to what is used on a particular level.
				C3	I3	9		

Note:

- **S = Severity** **P = Probability** **C – Criticality Ranking**

RISK ASSESSMENT WORKSHEET

Project Title: Risk assessment Coupling & Uncoupling of Rolling Stock Unit: Link and Pin System	Project Team Leader: S W Lubbe
---	---------------------------------------

<i>Guide Word</i>	<i>Deviation Response</i>	<i>Possible Cause (Short Coming)</i>	<i>Potential Consequences</i>	<i>Risk Rating</i>			<i>Existing Controls</i>	<i>Recommendations</i>
				<i>S</i>	<i>P</i>	<i>C</i>		
What if	Incorrect manufact. Of link or pin	<ul style="list-style-type: none"> • Incorrect design parameter • Incorrect fabrication (not to specification) • Homemade link and pin fabricated. 	<ul style="list-style-type: none"> • Link fail to enter buffer slot, use alternative unsafe method for coupling with potential detachment • Reduction in clearance between cars • Failure of the link / pin • Detachment on flat dip or incline shaft. Operator to enter danger zone to remove or install link / pin with difficulty – being crushed between cars 	A1	K5	5	<ul style="list-style-type: none"> • No real control. Main stores are supposed to check that correct item ordered are delivered to the mine. • Mine use standard link and pin as well as buffer design specs when ordering. 	<ul style="list-style-type: none"> • Suppliers of links and pins should supply the mine with an assessment of the product clearly indicating the proper use of it. • Manufacturers should comply with design approved by the responsible person. • The free slack present in the link between cars has a major influence on the total impact load. Equipment design should cater for the total impact load.
				B2	J4	8		
				A1 B2	K5 J4	5 8		

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	Risk Rating			Existing Controls	Recommendations
				S	P	C		
What if	Damaged buffers	<ul style="list-style-type: none"> Inadequate maintenance Abnormal wear and tear Incorrect length of link Failure of doughnut rubbers Poor initial fitting Metal fatigue Physical abuse 	<ul style="list-style-type: none"> Drooping buffer result in operator caught between cars in the attempt to inserting link Failure of buffer, detachment derailment Progressive damage to coupling equipment 	B2	J4	8	<ul style="list-style-type: none"> Reactive planned maintenance programme is in place. (Not vigorously followed). 	<ul style="list-style-type: none"> Link and pin design should include the amount of impact forces during coupling and tramming to lessen the wear and tear on the buffer. Pre-use checklists for car examination should be considered. Pro-active planned maintenance system should be strictly enforced.

Note:

- **S = Severity X P = Probability = C – Criticality Ranking**

RISK ASSESSMENT WORKSHEET

<p>Project Title: Risk assessment Coupling & Uncoupling of Rolling Stock</p> <p>Unit: Link and Pin System</p>	<p>Project Team Leader: S W Lubbe</p>
---	--

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	Risk Rating			Existing Controls	Recommendations
				S	P	C		
What if	Inadequate clearances between cars	<ul style="list-style-type: none"> • Incorrect length of link • Use of chains • Overhang of material loaded or material loaded too high on car. • Alterations on cars • (Un-) Coupling on inner side of curve • (Un-) Coupling at decline or incline exit from shaft • (Un-) Coupling at derailment 	<ul style="list-style-type: none"> • Operator caught between load and car • Operator crushed between cars • Being run over after uncoupling 	C3	I3	9	Standard operating and training is carried out.	<ul style="list-style-type: none"> • Training manuals should include the risks of (un-) coupling cars at curves and any other area or situation that might reduce the clearances between the cars. <p style="margin-top: 20px;">This should include the unpredicted actions of uncoupling cars being pulled from inclined shafts.</p>
B2			J4	8				
C3			I3	9				

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	Risk Rating			Existing Controls	Recommendations
				S	P	C		
What if	Excessive speed during coupling	<ul style="list-style-type: none"> • Incorrect signaling • Malfunctioning of loco controller / controls • Production pressure Attempt to force link into damaged buffer or visa versa • Coupling at unsafe inclination requiring loco to speed. • Poor condition of rails restricting movement of loco at normal speed. 	<ul style="list-style-type: none"> • Operator crushed between cars • Abnormal wear and tear of links and buffers • Derailment, operator being struck by car or load • Derailment, operator being run over by car 	B2	J4	8	<ul style="list-style-type: none"> • Standard operating and training is carried out. • Disciplinary action taken when loco drivers are found to be speeding. 	<ul style="list-style-type: none"> • Supervisors should issue special rules in abnormal situations. • Enforce the mine standard in respect of speed restrictions during coupling activity. • Address the factors that force driver to speed in order to execute coupling of hoppers.
				E5	H2	10		
				C3	I3	9		
				B2	J4	8		

SK ASSESSMENT WORKSHEET

Project Title: Risk assessment Coupling & Uncoupling of Rolling Stock Unit: Link and Pin System	Project Team Leader: S W Lubbe
---	---------------------------------------

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	Risk Rating			Existing Controls	Recommendations
				S	P	C		
What if	Incompetent operator or driver	<ul style="list-style-type: none"> • Inadequate training • Insufficient physical capability • Newly appointed • Intoxicated driver/operator • New type of loco or alterations introduced and without persons being trained properly. 	<ul style="list-style-type: none"> • Operator crushed between cars • Bystanders struck by or caught between cars / load during derailment / rerailment • Incorrect coupling, detachment result into runaway car • Over speeding during (un-) coupling • Collision with other train where (un-) coupling is in progress 	B2	J4	8	<ul style="list-style-type: none"> • Physical capability tests • Continuous upgrading of training • Random test for intoxication 	<ul style="list-style-type: none"> • Physical capability test should include dealing with emergency situation and simulated to the full extent. • Front line supervisors should include regular task observations on the tramming discipline as part of their workplace assessment programme. • Loco drivers and operators should be trained together as a team. • Introduce a system whereby refresher training automatically occurs when new or altered equipment is introduced.
				C3	J4	12		
				A1	K5	5		
				B2	I3	6		
				B2	I3	6		

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	Risk Rating			Existing Controls	Recommendations
				S	P	C		
What if	Poor illumination	<ul style="list-style-type: none"> Insufficient light fittings Poor maintenance on electrical lights and fittings Defective cap lamps 	<ul style="list-style-type: none"> Operator unable to recognize movement properly, impact on reaction – caught between cars Struck by falling load Incorrect coupling, pin not in proper position result in detachment – runaway car 	B2 C3 A1	K5 I3 J4	10 9 4	<ul style="list-style-type: none"> Illumination is in place in most areas. (The standard however varies from very poor to good). 	<ul style="list-style-type: none"> Proper illumination at all tramping areas should be maintained. Training should include emergency situations such as power failure. Risk assessments should be carried out with specific focus on coupling operations and illumination levels.

Note:

- **S = Severity X P = Probability = C – Criticality Ranking**

RISK ASSESSMENT WORKSHEET

Project Title: Risk assessment Coupling & Uncoupling of Rolling Stock Unit: Link and Pin System	Project Team Leader: S W Lubbe
--	---------------------------------------

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	S	P	R	Existing Controls	Recommendations
What if	Derailment on tip and (un-) coupling	<ul style="list-style-type: none"> • Poor track conditions • Large rocks in hoppers discharge • Defective tipping ramp or device • Over speeding through top area 	<ul style="list-style-type: none"> • Operator caught between hoppers • Falling down excavation 	B2 B2	K5 J4	10 8	<ul style="list-style-type: none"> • The use of lifelines is enforced. • A standard procedure is in place. • Maintenance programme on tipping ramp and associated structure. 	<ul style="list-style-type: none"> • Training manuals should include abnormal situations. • Tip platforms should be closed prior to re-railment, coupling or uncoupling operations. • Maintenance programmes should be pro-active not reactive.

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	S	P	R	Existing Controls	Recommendations
What if	Excessive play between link and pin	<ul style="list-style-type: none"> Abnormal wear and tear Incorrect design Misuse of links and pins 	<ul style="list-style-type: none"> Link sag resulting in operator entering danger zone to lift link into position during coupling – caught between cars Excessive wear and tear of the buffer, link and pin as a result of increased impact load. 	B2 D4	J4 H2	8 8	<ul style="list-style-type: none"> Procedure is in place whereby damaged items should be discarded. 	<ul style="list-style-type: none"> Pre-use checks should be carried out and incorrect or damaged equipment should not be used.

Note:

- **S = Severity X P = Probability = C – Criticality Ranking**

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	S	P	R	Existing Controls	Recommendations
What if	Substitute pins used	<ul style="list-style-type: none"> Inadequate supply of correct type Damaged pins supplied Lack of knowledge in respect of the consequence of using substitute devices not purposely designed and fabricated. Poor supervision and discipline 	<ul style="list-style-type: none"> Failure of the substitute resulting in detachment and runaway car(s) Prolonged exposure of operator to risk of injury whilst struggling to couple up using incorrect pin. 	A1 B2	K5 J4	5 8	<ul style="list-style-type: none"> There is a procedure in place prohibiting operators from using incorrect pin. Training programmes ensures that operator can identify substandard equipment. 	<ul style="list-style-type: none"> Proper storage facilities should be provided. Operators should check on the number of links/pins required prior to coupling operations. Any other object that might be used to substitute the pin should be discarded.

Note:

- S = Severity X P = Probability = C – Criticality Ranking**

RISK ASSESSMENT WORKSHEET

Project Title: Risk assessment Coupling & Uncoupling of Rolling Stock	Project Team Leader: S W Lubbe
Unit: Link and Pin System	

Guide Word	Deviation Response	Possible Cause (Short Coming)	Potential Consequences	Risk Ranking			Existing Controls	Recommendations
				S	P	R		
What if	Incorrect or insufficient signaling	Lack of knowledge No / defective signalling device or unit Excessive noise Incorrect interpretation Driver and operator not trained together as a team.	<ul style="list-style-type: none"> • Incorrect direction of movement – operator caught between cars • Inadvertent movement – operator caught between cars • Caught between link and buffer or between buffers 	B2	J4	8	Standard signalling procedural arrangements are in place	<ul style="list-style-type: none"> • Operator should ensure the locomotive driver could clearly hear and interpret signal during coupling or uncoupling operations. • Special precautions to be taken when the operator is out of sight of the driver and at noisy areas. • Action should be taken to ensure there are no conflicts between signal rules, that they are simple so as to encouraging conformance. • Front line supervisors should conduct regular task observations to detect non-compliance and the reasons therefore. • Driver and operator should be trained together as a team.
				B2	J4	8		
				C3	I3	9		

Note:

- **S = Severity X P = Probability = C – Criticality Ranking**

RISK ASSESSMENT MATRIX

TABLE A

SEVERITY/CONSEQUENCE CATEGORY							
		A	B	C	D	E	F
CONSEQUENCE EVALUATION	CLASSIFICATION OF RISK	CATASTROPHIC	MAJOR	SEVERE	SERIOUS	MINOR	NO
	WEIGHT EFFECT	1	2	3	4	5	6
	MATERIAL (Rand)	$>5 \times 10^6$	$>1 \times 10^5$	$>5 \times 10^4$	$>5 \times 10^3$	$>1 \times 10^3$	NIL
EFFECT (EML)	EQUIPMENT (Rand)	$>5 \times 10^6$	$>1 \times 10^5$	$>5 \times 10^4$	$>5 \times 10^3$	$>1 \times 10^3$	NIL
	ENVIRONMENT (Rand)	$>5 \times 10^6$	$>1 \times 10^5$	$>5 \times 10^4$	$>5 \times 10^3$	$>1 \times 10^3$	NIL
	PEOPLE	MULTIPLE FATALITIES	FATALITY/ PERM/ DISABILITY	REPORT INJURY	DISABLING INJURY	DRESSING CASE	NO INJURY

TABLE B

FREQUENCY/PROBABILITY CATEGORY							
FREQUENCY EVALUATION	CLASSIFICATION OF RISK	L	K	J	I	H	G
	DESCRIPTION	HIGHLY UNLIKELY	RARE	LOW LIKELIHOOD	CAN HAPPEN	PROBABLE	REGULAR
	WEIGHT FREQUENCY	6	5	4	3	2	1
EVALUATION DESCRIPTION		EXPECTED NEVER TO HAPPEN	CAN HAPPEN ONCE/ YEAR	CAN HAPPEN ONCE MONTH	CAN HAPPEN ONCE/ WEEK	FEW TIMES PER DAY (1-2)	MANY TIMES PER DAY (>3)

TABLE C

CLASSIFICATION OF RISK			PRIORITISATION TABLE					
HAZARD CATEGORY		FREQUENCY RATE	L	K	J	I	H	G
			6	5	4	3	2	1
Catastrophic	A	1	6	5	4	3	2	1
Major	B	2	12	10	8	6	4	2
Severe	C	3	18	15	12	9	6	3
Serious	D	4	24	20	16	12	8	4
Minor	E	5	30	25	20	15	10	5
None	F	6	36	30	24	18	12	6
CLASSIFICATION	WEIGHT EFFECT		TOLERABLE RISKS					

RISK INTOLERABLE

Appendix 7

Estimate of the number of units on the gold and platinum mines

Based on the interviews with the major equipment manufacturers as per Appendix 1, together with some historical data gathered by the project team, an attempt was made to estimate the total numbers of units of rolling stock in use underground on the gold and platinum mines. The estimate of total number of units is somewhat subjective, however, from these estimates, a feel can be derived as to the order of magnitude.

1. Based on Mining House A Data (1997)

Gold Fields of SA Cost and Statistics Book 1997 –

Number of locomotives on the Gold Mines in the Group:

Diesel	1 134
Battery	180
Electric overhead trolley	<u>81</u>
Total	1 395

Assume 6 hoppers per loco – number of hoppers:	8 370
Assume 9 material cars per loco – no. of material cars:	<u>12 555</u>
Estimate of total no. of rolling stock (in the Mining House A):	22 320

Estimate of total no. in Gold & Platinum Industry: **90 000**

2. Company A's estimate

They estimate some 32 000 hoppers in the SA mining industry.

Number of hoppers (at 6 per span)	32 000
Number of locomotives of all types (at one per 6 hoppers)	5 300
Number of material cars (at 9 per loco):	<u>48 000</u>
Estimated total:	85 300

4. Company B's estimate

They estimate that there is population of Goodman battery locomotives in the industry of 3350 units. This implies :

Number of battery locomotives of all types: estimate	5 000
Number of hoppers (at 6 per span)	30 000
Number of material cars (at 9 per loco)	<u>45 000</u>
Total (excluding diesel locomotives)	80 000

3. Company C's estimate

Estimate some 30 000 to 50 000 units of rolling stock on the mines.

From the above estimates, it is not unreasonable to estimate for the gold and platinum mines:

Total number of locomotives:	5 000 - 5 500
Number of hoppers:	30 000 - 33 000
Number of material cars, etc.:	<u>45 000 - 49 500</u>
Total units of rolling stock:	80 000 - 88 000
Number of locomotive drivers:	10 000
Number of guards :	10 000

Appendix 8

Clearances between cars

Track gauge and hopper dimensions

The early mines (pre-1970) were largely standardised on a track gauge of two-foot (610 mm).

In the 1970's, a number of mines moved to 750mm and 762mm-track gauge with a few modern mines using 910-mm track gauge.

The overall dimensions of hoppers (pre 1960) was limited to

Track gauge:	2'	610 mm
Wheel base:	3' (2' 8" – 3')	915 mm (810-915 mm)
Hopper length (incl. buffers):	10' (7' 4" - 11' 4")	3050mm(2235-3450 mm)
Hopper width:	4' (4'-4' 9")	1220mm (1220-1450 mm)

The overall dimensions of hoppers (post 1960) typically are:

Track gauge:	610 mm/ 750 mm/ 910 mm
Wheel base:	915 mm – 1000 mm
Hopper length (incl. buffers):	2160 mm – 3150 mm
Hopper width:	1180 mm – 1300 mm
Hopper payload:	3000 kg – 5000 kg

Space between Hoppers

On all the systems in the market, there is restricted space (typically 300 mm) between the two-coupled hoppers. The feasibility of increasing this difference by either:

- Extending the buffer head
- Lengthening of the link
was investigated by the project team.

Factors to be considered are the derailment potential that is a function of:

- Track gauge
- Wheel base
- Wheel profile
- Overhang of vehicle (length of vehicle, buffer and link)
- Radius of curvature of track bends

Currently the link length of the standard link and pin system in use does not allow sufficient space to include a semi-automatic/automatic linking device within the link. The concepts developed in Appendix 11, presents concept that incorporates coupling devices within the link itself. The purpose of this investigation is thus to determine the effect on a train progressing through a curve with a lengthened link. Typically the forces that could cause derailment will be investigated.

Rail and Hopper specifications

The following are rail and hopper specifications. The rail specifications were obtained from: **1964. Underground Rail Practice, Investigations Committee Report No. 1.06, GOLD FIELDS OF SOUTH AFRICA LIMITED, p 3-5.**

As examples of hopper the Hudson Autoflow Radial Door Hopper and Hudson Tippler Hopper were used. The results can be applied to any other hoppers with the same basic specifications. This analysis will be based on a train consisting of a 10-ton loco-motive coupled to ten 6-ton hoppers. The hopper specifications are as follows:

Table 1.1
Hopper specification

Tippler Hopper		Units
Capacity (gold ore)	6	ton
Volume	3,4	m ³
Overall Width	1300	mm
Length including buffer	3150	mm
Length excluding buffer	2720	mm
Height above tracks	1630	mm
Weight complete	2.09	ton
Rail gauge	610	mm
Wheel base	1000	mm
Radial Door Hopper		Units
Capacity (gold ore)	6.6	ton
Volume	3,75	m ³
Overall Width	1220	mm
Length including buffer	3500	mm
Length excluding buffer	2950	mm
Height above tracks	1704	mm
Weight complete	2.09	ton
Rail gauge	610	mm
Wheel base	1000	mm

Figure 1 presents the Trimming Speed versus the Minimum radius of rail curve.

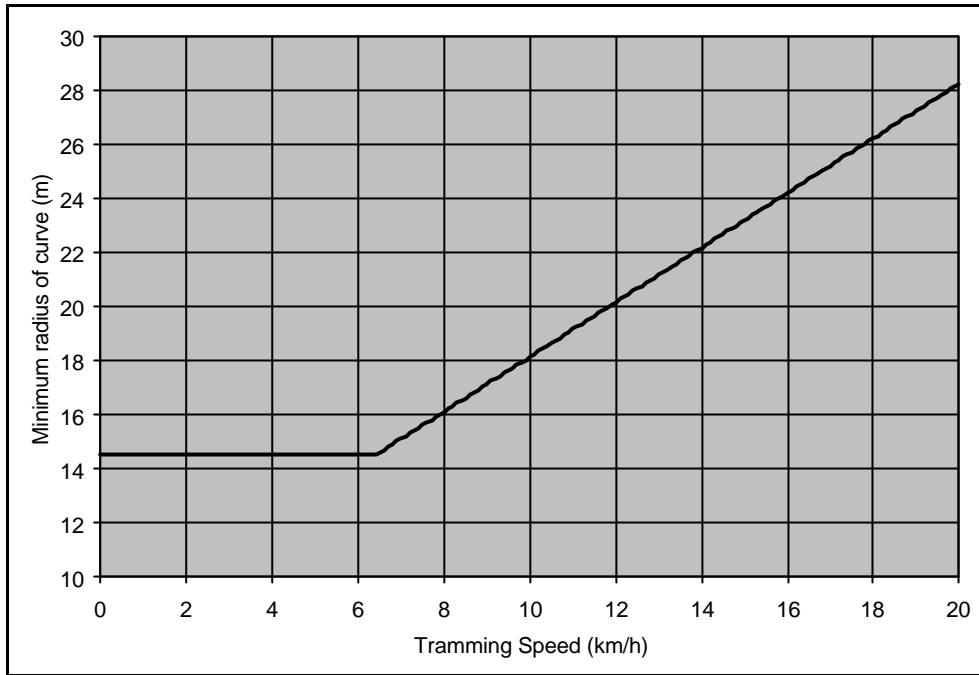


Figure 1. Tramming speed versus radius of curve

Centre of mass

Two analyses are performed. The one with the hoppers empty and the other with fully loaded hoppers.

Empty Hoppers

For the empty hoppers it is assumed that the mass of the hopper is evenly distributed along its height. Thus the vertical centre of mass, ECM_y , is halfway between the track and the height of the hopper. In this case the maximum value of the two hoppers in Table 1.1 is used.

$$ECM_y = 0.852 \text{ m}$$

The horizontal centre of mass, ECM_x , is situated between the tracks, thus:

$$ECM_x = 0.31 \text{ m}$$

Loaded Hoppers

For the loaded hoppers it is assumed that the mass of the hopper and load is evenly distributed within the ore volume. Thus the vertical centre of mass, FCM_y , is halfway between the bottom of the hopper bucket and the height of the hopper. In this case the maximum values of the two hoppers in Table 1.1 is used. The hopper bucket height, H , is calculated by assuming a rectangular box, thus dividing the volume capacity by the product of the width and length as follows:

$$H = \frac{Volume}{Width \cdot Length} = \frac{3.75m^3}{1.22m \cdot 2.95m} = 1.04m$$

Thus

$$FCM_y = HopperHeight - H + \frac{H}{2} = 1.702 - 1.04 + \frac{1.04}{2} = 1.19 \text{ m}$$

The horizontal centre of mass, CM_x , is situated between the tracks, thus:

$$FCM_x = 0.31 \text{ m}$$

Rail curve calculations

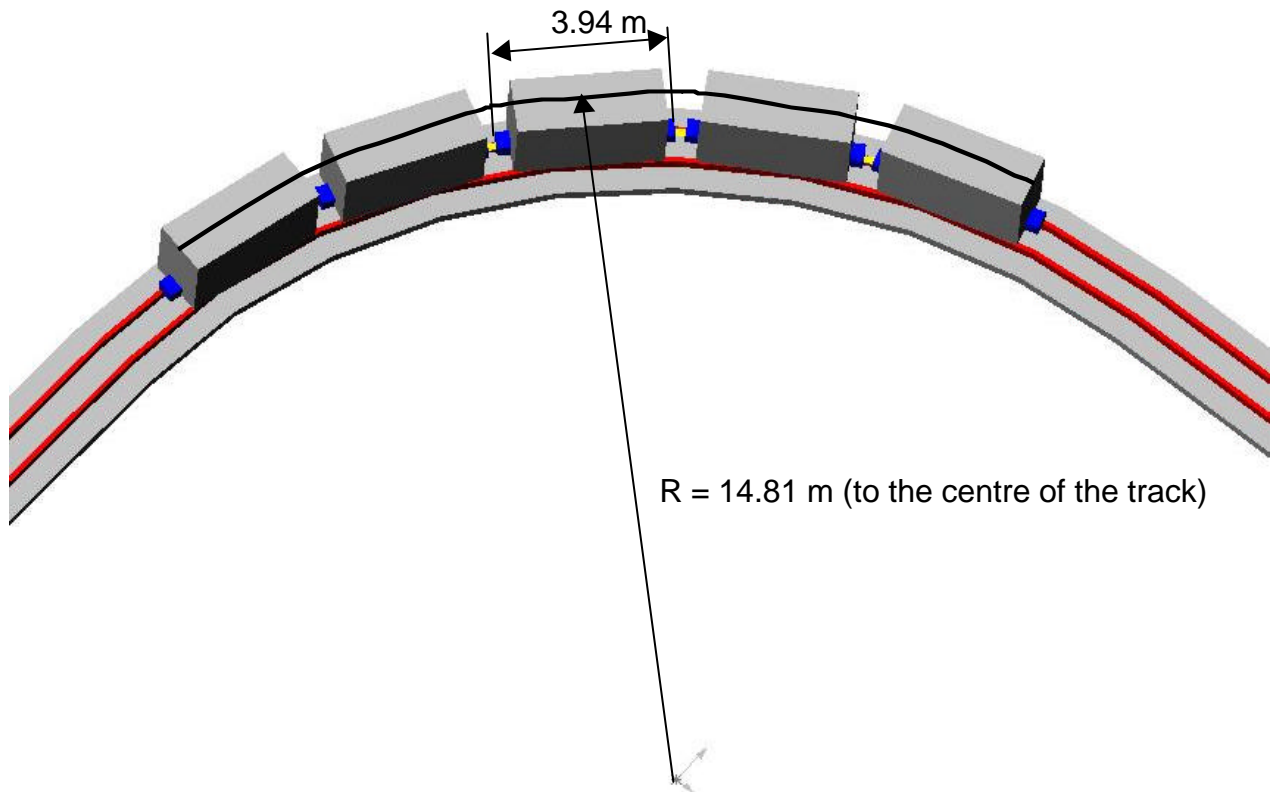


Figure 2 On scale Hoppers on minimum curve.

Figure 3 describes the angles and radius involved while the linked hoppers are progressing around a curve. The following describes the notations in Figure 3:

- CT Radius to centre of track
- Lk Link length
- Hop Hopper length (buffer to buffer)

In order to calculate the angle between the buffer and the link, $\theta + \beta$, the following relations is established.

$$\mathbf{b} = \tan^{-1}\left(\frac{CT}{0.5 \cdot Hop}\right) \quad (1)$$

$$OA = \frac{CT}{\sin(\mathbf{b})} \quad (2)$$

$$\mathbf{q} = \cos^{-1}\left(\frac{Lk}{2 \cdot OA}\right) \quad (3)$$

The forces involved in the link and hopper are presented in Figure 4.

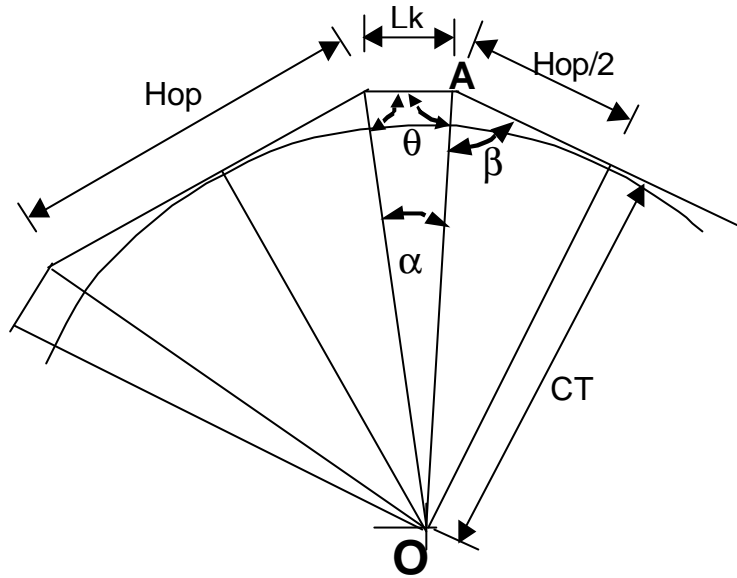


Figure 3 Schematic of hoppers on curve.

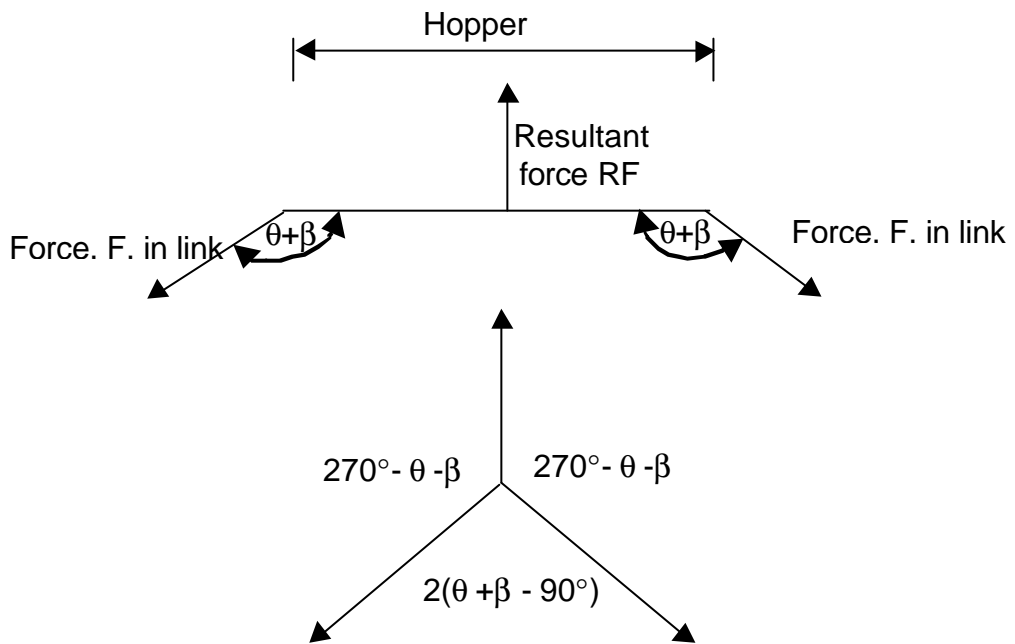


Figure 4 Force diagram of hopper and link

The magnitude of the resultant force is calculated as:

$$RF = 2 \cdot F \cdot \cos(\mathbf{q} + \mathbf{b} - 90^\circ) \quad (4)$$

Using equation (1), (2) and (3) the resultant force becomes:

$$RF = 2 \cdot F \cdot \cos\left[\cos^{-1}\left(\frac{Lk \cdot \sin(\mathbf{b})}{2 \cdot CT}\right) + \tan^{-1}\left(\frac{CT}{0.5 \cdot Hop}\right) - 90^\circ\right] \quad (5)$$

$$= 2 \cdot F \cdot \cos\left[\cos^{-1}\left(\frac{Lk \cdot \sin(\tan^{-1}(\frac{CT}{0.5 \cdot Hop}))}{2 \cdot CT}\right) + \tan^{-1}\left(\frac{CT}{0.5 \cdot Hop}\right) - 90^\circ\right] \quad (6)$$

Equation (6) can be simplified by considering the following. A typical minimum value for CT is 14.81 m and a typical value for Lk would range from 0.23 m to 1 m if the link were lengthened. The length of the hopper is taken as 3.5 m. If these values are inserted in equation (6) the following is observed:

- $\sin(\tan^{-1}(\frac{CT}{0.5 \cdot Hop}))$ is very close to 1 and moves closer as CT is increased

Equation (6) can thus be simplified to:

$$RF = 2 \cdot F \cdot \cos\left[\cos^{-1}\left(\frac{Lk}{2 \cdot CT}\right) + \tan^{-1}\left(\frac{CT}{0.5 \cdot Hop}\right) - 90^\circ\right] \quad (7)$$

Since Lk is very small in comparison to $2 \cdot CT$, equation (7) can further be simplified to:

$$\begin{aligned} RF &= 2 \cdot F \cdot \cos\left[90^\circ + \tan^{-1}\left(\frac{CT}{0.5 \cdot Hop}\right) - 90^\circ\right] \quad (8) \\ &= 2 \cdot F \cdot \cos\left[\tan^{-1}\left(\frac{CT}{0.5 \cdot Hop}\right)\right] \\ &= 2 \cdot F \cdot \cos\left[\tan^{-1}\left(\frac{2 \cdot CT}{Hop}\right)\right] \end{aligned}$$

Equation (8) is true for typical values for CT and Lk. It can thus be seen that if the link were lengthened up to 1 m it would have no effect on the resultant force RF, applied to the hopper since this force is only a function of CT and Hop. Using equation (8) with Hop = 3.5 m, CT = 14.8 m and F = 40 kN, (See Appendix 10) FR is calculated as:

$$FR = 2 \cdot 40 \cdot \cos\left[\tan^{-1}\left(\frac{2 \cdot 14.8}{3.5}\right)\right] = 9.39 \text{ kN or } 936 \text{ kg} \quad (9)$$

Figure 5 presents the hopper situation with RF applied. If FR=0, when there is no force applied in the link, the values of forces FO and FI are equal and equal to half the mass of the hopper.

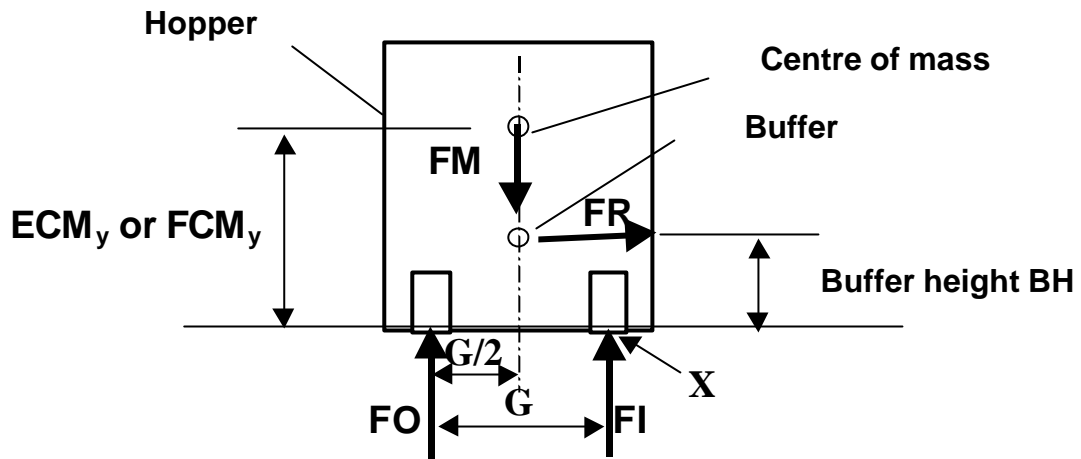


Figure 5 Resultant force, RF , effect on Hopper

Taking the sum of moments around point X gives:

$$FO \cdot G + FR \cdot BH = FM \cdot \frac{G}{2} \quad (10)$$

$$FO = \frac{0.5 \cdot FM \cdot G - FR \cdot BH}{G}$$

$$FO = 0.5 \cdot FM - \frac{FR \cdot BH}{G} \quad (11)$$

When FO approaches zero it would suggest that the Hopper would be in danger of tipping over to the inside and thus a condition in which derailment can occur. From equation (10) this condition is more likely with a minimum value of FM , thus an empty Hopper. FO is calculated using the following:

- $FM = 20.9$ kN from Table 1.1
- $FR = 9.39$ kN from equation (9)
- $G = 0.61$ m from Table 1.1
- $BH = 0.5$ m typical buffer height

$$FO = 0.5 \cdot 20.9 - \frac{9.39 \cdot 0.5}{0.61} = 2.75 \text{ kN}$$

It can thus be concluded that the above still presents a safe condition and that the lengthening of the link up to 1 m should have no effect on the stability of the train. The above analysis presents the link in pulling. If the loco is pushing the train the forces in Figure 4 are in the opposite direction. No forces included the centrifugal force as the train moves through a curve since this force is velocity dependant and the above analysis was done to prove that the link lengthening will have no effect on the stability of the train.

Min Radius

The following section calculates the minimum curve at which the links will lock to the side of the buffer and thus cause derailment. This value was measured from the CAD model as $\theta + \beta = 150^\circ$. Figure 6 presents this configuration.

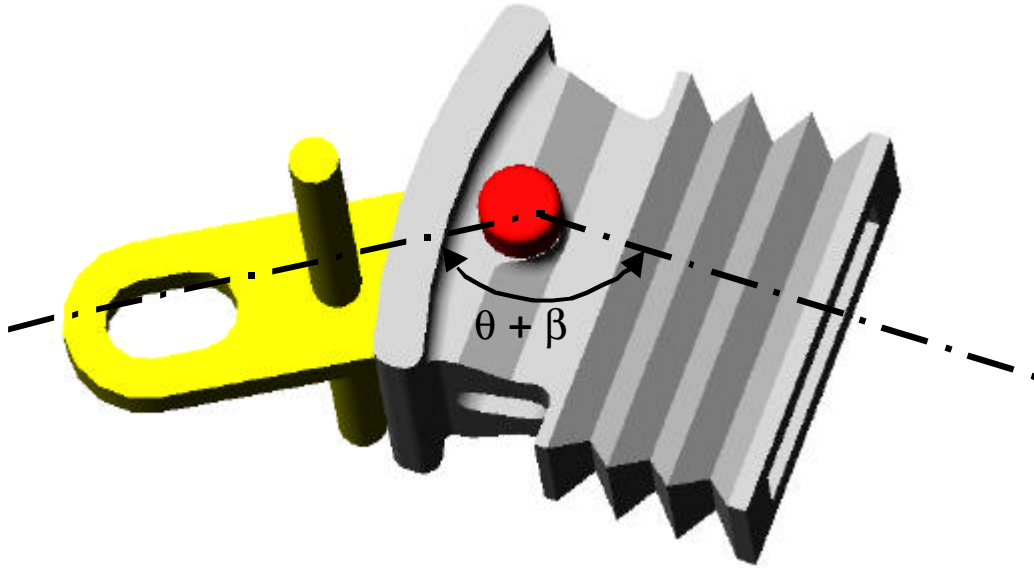


Figure 6 Link locking position.

The angle $\theta + \beta$ corresponds to the same angle in Figure 3. By using equation (1) to (3) this angle can be written as:

$$\mathbf{q} + \mathbf{b} = \cos^{-1} \left(\frac{\frac{Lk}{CT}}{\sin(\mathbf{b})} \right) + \tan^{-1} \left(\frac{CT}{0.5 \cdot Hop} \right) \quad (12)$$

By numerically solving for CT gives $CT = 3.3$ m for $Lk = 0.23$ mm, $Hop = 3.5$ m and $\theta + \beta = 150^\circ$

A value of 1m for Lk produced a numerically calculated $CT = 4.1$ m.

It is thus concluded that the locking of the link to the side of the buffer will only occur on a very small radius. This type of radius will imply an extreme violation of the specified minimum radius of 14.8 m

Appendix 9

Discussion on Links and Pins

Links

Every mine has its own idea about links and pins. The links are generally made of flat bar with slotted holes to pick up the locking pins. Some of the link designs include handles (pipe, cruciform, flexible rubber) to try and keep hands and fingers out of the impact zone. The flexible types of handles are also intended to minimise the risk of pinching injuries.

If the link is too wide (or conversely the slot in the buffer not wide enough), the car tends to derail on tight radius bends.

If the link is too thick (or conversely the slot in the buffer too narrow), then it is difficult to engage the link into the buffer slot, resulting in force being required – often resulting in accidents.

The slotted hole has a number of functions, real and claimed:

- The nature of the slot gives a big tolerance, so facilitating the insertion and removal of the pin;
- When a hopper is being propelled (pushed) the two buffer mouths abut, and due to the slots, the load is then taken off the link. The links thus tend to act mainly in tension, not in compression; and
- The slotted holes allegedly are beneficial in allowing a locomotive to pick up the load of a span of hoppers sequentially. The impact loading caused by the hoppers being accelerated from standstill due to the backlash results in severe impact loading, which must cause damage.

Pins

There is a wide range of pins in use in the industry. They are generally made of round bar of diameter between 25 mm and 50 mm.

A number of versions exist with different types of extended handles, these include round bar, steel rope, electrical cable and hose handles. The intention is to try and keep hands and fingers out of the impact zone. The flexible types of handles are also intended to minimise the risk of pinching injuries.

In practice, these pins are used for a multiple other functions (hammer, sprag, crowbar, etc.) are often damaged or lost. Damaged pins can make coupling and uncoupling difficult, so leading to accidents.

If the pins are lost, then inadequate substitutes are often used (drill steel, steel bar, handtools, the locating pins off the buffer, bolts, etc) – often with resultant accidents. Having suitably sized pins as well as adequate bearing area for the pin in the buffer is important to prevent wear, plastic deformation and consequential problems.

A number of designs allow for captive pins, either locked in the buffer housing or welded to the housing by chains. A storage seat or hole on the buffer housing is supplied in some models. This allows for the safe storage of the pin when not in use.

The poor state of tracks and rolling stock in the industry leads to numerous derailments. These derailments, as determined in GAP 520, also result in a number of accidents as

well as significant production disruption. In a severe derailment, it is important that the cars or hoppers can be fairly readily uncoupled to allow individual cars to be re-railed. The link and pin system lends itself to this, with the pin being fairly readily dislodged. A disadvantage of chain systems (such as the Rhino buffer) and automatic systems such as the Willison and Galison Auto Lock is that they are not as readily uncoupled after a derailment.

Appendix 10

Impact loading and Resilience

It is taken as a given in the industry that resilient type buffers should be used on hoppers underground (the medium to heavy-duty application), while generally rigid buffers are used on material cars.

Most design and testwork appears to be based on static loading conditions. The impact of:

- Excessive play between the slotted holes on the link and the pin;
- Impact through the tipping arrangements;
- Poor track conditions; and
- Poor conditions of wheels and bearings.

is significant, resulting in severe impact loading being experienced. This results in plastic deformation of the load bearing areas of the coupling. The premature failure of the resilient buffers is also probably attributable to this factor.

The number of buffer designs that, on failure or loss of the resilient rubbers, lead to drooping of the buffer head also contribute significantly to the difficulties associated with coupling.

Analysis was then carried out by the project team to:

- Estimate the size of the impact loads being experienced (as detailed in this appendix);
- Quantify the minimum load bearing areas required to ensure plastic deformation is minimised; and
- Assess the shock loading characteristics and impact absorption characteristics of the rubber used.

Initial discussions with the manufacturer of the rubbers indicate that:

- The impact loading are too high;
- The size of the rubbers too small; and
- The geometry of the rubbers not corrects.

Overall, it appears that the rubbers as currently used are ineffective in absorbing impact. Instead, they tend to fail rapidly, increasing the backlash (and so the impact loading) and the drooping effect.

Once the analyses was complete the project team focussed on three distinct areas:

1. Existing link and pin coupling systems

Considered how these should be modified so that they can handle the impact loads being experienced without experiencing the plastic deformation and mechanical damage currently being experienced. In parallel with this suggestion were made as to what modifications can be made to minimise the backlash.

2. Willison Coupling

The Willison coupling has a number of advantages:

- Well proven system
- Internationally accepted
- Minimises backlash

It has a number of disadvantages:

- Performance on tight radius curves
- Performance in a derailment
- Complexity & cost
- Not interchangeable with current systems

The project team considers that it is practical to modify the Willison design to overcome some if not all of these disadvantages.

3. Develop an alternative design

To, in parallel with 1 & 2, develop a viable conceptual alternative that satisfies the coupling evaluation criteria. In Appendix 11, are some preliminary concepts developed by the project team.

4. Impact loading simulation

In order to determine the actual forces involved during train pull away, as well as the effects of backlash in the links, the pull away of a loco and hoppers were simulated using a spreadsheet. The resultant forces together with a CAD model of the Kudu buffer was used to do a Finite Element Modelling analysis in order to determine the stress concentrations on the buffer.

Stress concentration with values above the elastic deformation limit causes permanent deformation. In cases where the stress concentration is surrounded by supporting material, wear results, or in cases of no supporting material, failure.

4.1. Spreadsheet simulated train

The following Hopper information, in Table 1.1 page 71 Appendix 8 were used as input:

***Table 4.1.1
Hopper information***

	Hopper	
Amount	Mass(empty)	Mass (Loaded)
	kg	Kg
10	1500	5500

Where

- Amount Amount of Hoppers in the train
- Mass (empty) Mass of empty Hopper
- Mass (Loaded) Mass of loaded Hopper

The following Locomotive information, in Table 4.1.2, was used as input:

Table 4.1.2
Loco information

Loco				
Rolling Force	Mass	Fric Coef	Power	Max Pulling Force
kN	Kg		kW	kN
2.00	10000.00	0.400	42	40.000

Where

- Rolling Force The force needed to overcome friction while Loco-motive is moving. This force is used for the Loco as well as for each Hopper.
- Mass Mass of Loco-motive
- Fric Coef Coefficient of friction between the Loco-motive wheels and the rail.
- Power The effective maximum power output of the

Loco at the wheels

- MaxPulling force The maximum pulling force the Loco-motive can apply to the train calculated as follows:

$$\text{Max Pulling Force} = \text{Mass} \times \text{Fric Coef}$$

The Loco specifications in Table 1.2 presents a 10 ton electric loco. Also in use is the 5-ton electric Loco with power output between 14 and 21 kW.

The following Linking information, in Table 1.3, was used as input:

Table 4.1.3
Linking information.

	Linking		
Interval	Backlash/link	Max Impulse Time	Impulse factor
Sec	M	Sec	
0.0020	0.050	0.01	0

Where

- Interval The time intervals at which the calculations are performed
- Backlash/Link The average backlash that exists in each

Hopper to Hopper and Loco to Hopper link

- Max Impulse Time The maximum time it takes for a Hopper to reach train speed after all the backlash in the link has been taken up.
- Impulse factor A factor to decrease impulse time as a linear function of train speed as follows:

$$\text{Impulse Time} = \text{Max Impulse Time} - \text{Impulse Factor} \times \text{Train Speed}$$

The simulation assumes that the entire backlash in the train is taken up by compression, thus the situation after the train has been stopped by the Loco applying its brakes, as an initial condition.

The following are the calculations of parameters as the Loco accelerates from 0 velocity. All the calculations and graph are included in the attached Excell file Impuls.xls.

Table 4.1.4
Column A to H of simulation

A	B	C	D	E	F	G	H
Time	Linked Hoppers	Train Mass	Pulling Force	Acceleration	Velocity	Distance	Momentum
Sec	Number	kg	KN	m/s ²	m/s	M	kg.m/s
0	0	10000	40.00	3.80	0.00	0.000	0
0.002	0	10000	40.00	3.80	0.01	0.000	76
0.004	0	10000	40.00	3.80	0.02	0.000	152

The following are descriptions of the formulas used in each column of Table 1.4. In each case the formulas of row 14 is included.

Column	Formula Description
A	Each row is incremented with the Interval Time in Table 1.3, starting from 0 Cell Formula: =+A13+\$A\$9
B	If the same row in column I, see Table 1.5, has a value of 0 and the previous row of column B is not equal to the number of Hoppers in Table 1.1 add 1 to the previous row of column B otherwise keep the value of the previous row of column B Cell Formula: =+IF(I13=0,IF(B13=\$A\$4,B13,B13+1),B13)
C	The mass of the Loco in Table 1.2 added to the mass of the loaded Hopper, in Table 1.1 times the number of Hoppers in the train in column B of the same row. Cell Formula: =+\$F\$4+\$C\$4*B14
D	If the power rating of the Loco in Table 1.2 is greater than the calculated Power in the previous row of Column M then use the Power value in Table 1.2 otherwise use the Power value in Table 1.2 divided by the Velocity in the previous row of column F Cell Formula: =+IF(M13>\$H\$4,\$H\$4/F13,\$I\$4)
E	The acceleration of the train is calculated as $1000 \times (\text{column D of the same row} - (\text{column B of the same row} + 1) \times \text{rolling force in Table 1.2}) / \text{column C of the same row}$. Cell Formula: =1000*(D14-(B14+1)*\$E\$4)/C14
F	IF column I of the previous row is equal to 0 then calculate the train velocity as column H of the previous row divided by column C of the current row. This ensures constant momentum before and after the newly engaged hopper. Else calculate the velocity as column F of the previous row added to column E of the current row times the difference between the current and previous rows of column A. Cell Formula: =+IF(I13=0,H13/C14,F13+E14*(A14-A13))
G	If column I of the previous row is equal to 0 then calculate the distance as the product of column F of the same row and the difference between the current and previous rows of column A. This represents the distance travelled due to an initial velocity. The distance travelled due to the acceleration of the train is calculated as the product of 0.5 and column E of the same row and the square of the difference between the current and previous row of column A.

	If column I of the previous row is not equal to 0 then add the previous row of column G to the above calculation. Cell Formula: =+IF(I13=0,F14*(A14-A13)+0.5*E14*(A14-A13)^2,G13+F14*(A14-A13)+0.5*E14*(A14-A13)^2)
H	The momentum of the train is calculated as the product of the train velocity and mass thus the product of column F and C of the same row Cell Formula: +F14*C14

Table 4.1.5
Column I to N of simulation

I	J	K	L	M	N
Backlash Remaining	Speed		Distance Travelled	Hopper Power	Status
M	km/h		M	kW	
0.050	0.000	0.000	0.000	0.00	Pulling
0.050	0.027	0.000	0.000	0.30	Pulling
0.050	0.055	0.000	0.000	0.61	Pulling

The following are descriptions of the formulas used in each column of Table 1.5. In each case the formulas of row 14 is included.

I	This column represents the remaining backlash before the next hopper starts to move. If the difference between the Backlash/link in Table1.3 and the value of column G of the same row is greater than 0 then insert this value in the cell otherwise insert 0. A zero in this column thus serves as an indication that the next hopper is engaged and thus the next row will be used to calculate the impulse. Cell Formula: =+IF(\$N\$4-G14>0,\$N\$4-G14,0)
J	This column presents the train speed in km/hour and is calculated from the same row in column F Cell Formula: =+F14*3.6
K	This column calculates the distance travelled for the time duration of the current row as follows: (Compare to column G) Cell Formula: =+F14*(A14-A13)+0.5*E14*(A14-A13)^2
L	This column presents the total distance travelled by the train and thus adds the value of the previous row of this column to the value of column K in the same row. Cell Formula: =+L13+K14
M	This column presents the current power consumption of the loco. It is calculated as the product of the velocity of the train and the pulling force of the loco, thus the product of column F and D of the same row. Cell Formula: =+D14*F14
N	This column used the value of column I in the previous row to determine if the train is Pulling or if the next hopper is added. Cell Formula: =+IF(I13=0,"Hopper added","Pulling")

Table 4.1.6
Column O to R of simulation

O	P	Q	R
Hopper Impulse	Hopper Accel		Impulse Dis
Sec	m/s ²	kN	Mm
-	-	-	-
-	-	-	-
-	-	-	-

The following are descriptions of the formulas used in each column of Table 1.6. In each case the formulas of row 14 is included.

O	This column checks the value in column N of the same row if a hopper is added. If true the impulse time is calculated by subtracting the product of the velocity in column F of the same row and the impulse factor in Table 1.3 from the maximum impulse time in Table 1.2. Cell Formula: =+IF(N14="Hopper Added",+\$O\$4-F14*\$P\$4,"-")
P	Whenever the next hopper is engaged, determined by column N of the same row, the hopper acceleration from zero velocity to the current train velocity is calculated by dividing column F by column O of the same row. Cell Formula: =+IF(N14="Hopper Added",F14/O14,"-")
Q	The impact force on the newly engaged hopper is calculated as the hopper acceleration, in column P of the same row and the hopper mass in Table 1.1. The formula for this cell also includes a check to verify that not all the hoppers specified in the number of hoppers in Table 1.1 have been engaged. Cell Formula: =+IF(N14="Hopper Added",IF(B13<>\$A\$4,P14*\$C\$4/1000,"-"),"-")
R	The distance travelled during the impulse time of the newly engaged hopper is calculated in this column as the product of the current train velocity in column F and the impulse time in column O of the same row. Cell Formula: =+IF(N14="Hopper Added",1000*F14*O14,"-")

Table 4.1.7
Column S to Y of simulation

T	U	V	W	X	Y	Z
Time	Speed km/h	Hoppers	Impuls N*10⁴	Energy kJ	Mom kg.m/s * 10⁴	Distance mm *10²
0	0.00	0.00	0.00	0.00	0.00	0.000
0.002	0.03	0.00	0.00	0.00	0.01	0.000
0.004	0.05	0.00	0.00	0.00	0.02	0.001

The columns in Table 1.7 is used to generate the plot in Figure 2.1 The columns are copied and scaled from previous columns in order to fit on the same graph. In each case the formulas of row 14 is included.

T	This column is a copy of column A Cell Formula: =+A14
U	This column is a copy of column J and scaled. Cell Formula: =+J14*\$U\$7
V	This column is a copy of column B. Cell Formula: =+B14
W	If column Q of the same row is not equal to – then copy and scale the column. Cell Formula: =+IF(Q14="-",0,Q14*\$W\$7)
X	The kinetic energy of the train is calculated by the product of 0.5 with the mass of the train in column C with the square of the train velocity in column F of the same row. The result is scaled. Cell Formula: =0.5*C14*F14*F14*\$X\$7
Y	This column is copied from column H and scaled. Cell Formula: =+H14*\$Y\$7
Z	This column is copied from column L and scaled. Cell Formula: =+L14*\$Z\$7

4.2. Results

Table 4.2.1
Simulation Inputs

Simulation number	1	2	3	Unit
Amount of Hoppers	10	10	10	
Loaded Hopper mass	5500	5500	5500	Kg
Hopper and Loco rolling force	2	2	2	KN
Loco mass	10000	10000	10000	kg
Coefficient of friction – Loco and rail	0.4	0.4	0.4	
Loco power	42	42	42	kW
Simulation interval	0.0025	0.002	0.0008	Sec
Backlash/link	0.100	0.05	0.01	M/link
Max impulse time	0.01	0.01	0.01	Sec
Impulse Factor	0	0	0	
Max-Impulse Displacement	6.98	4.92	2.2	mm

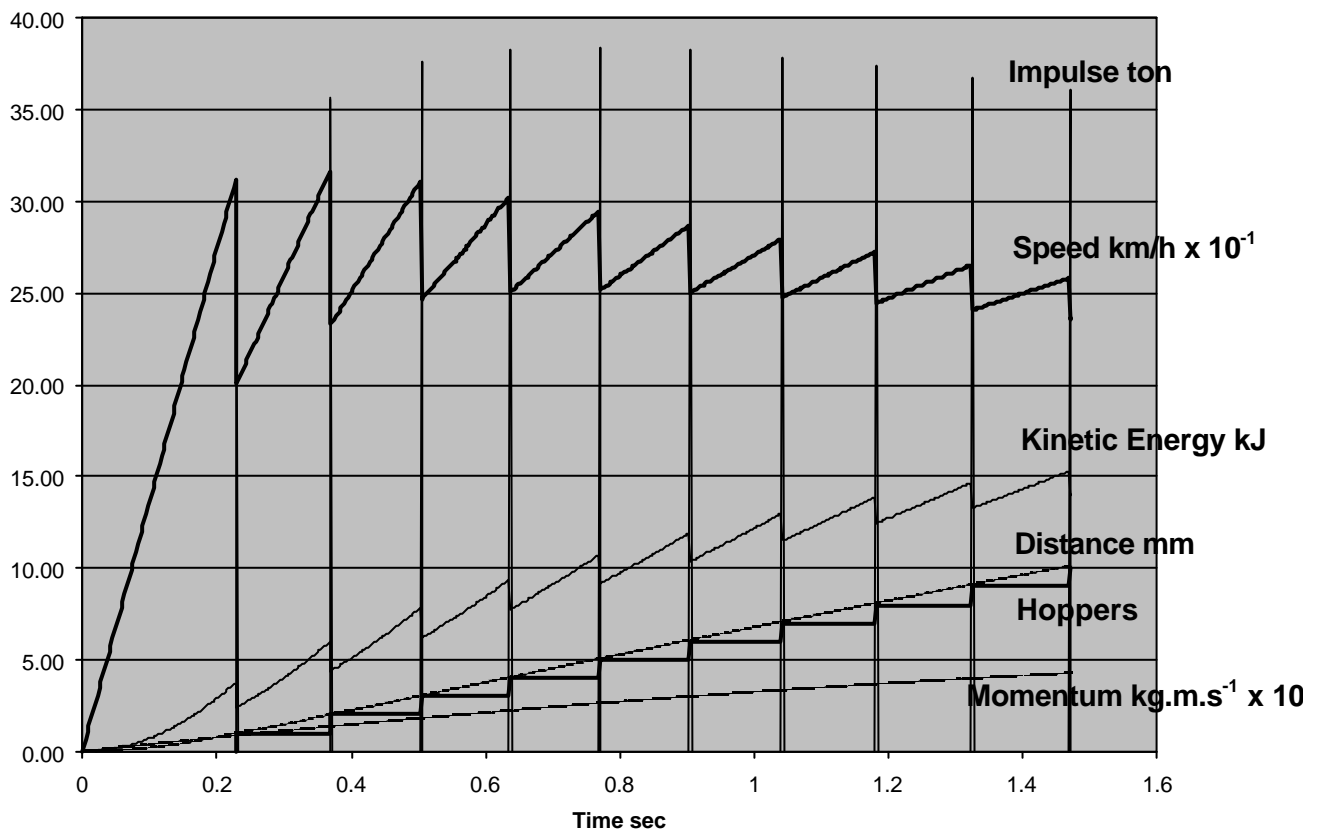


Figure 4.2.1 Simulation 1 results

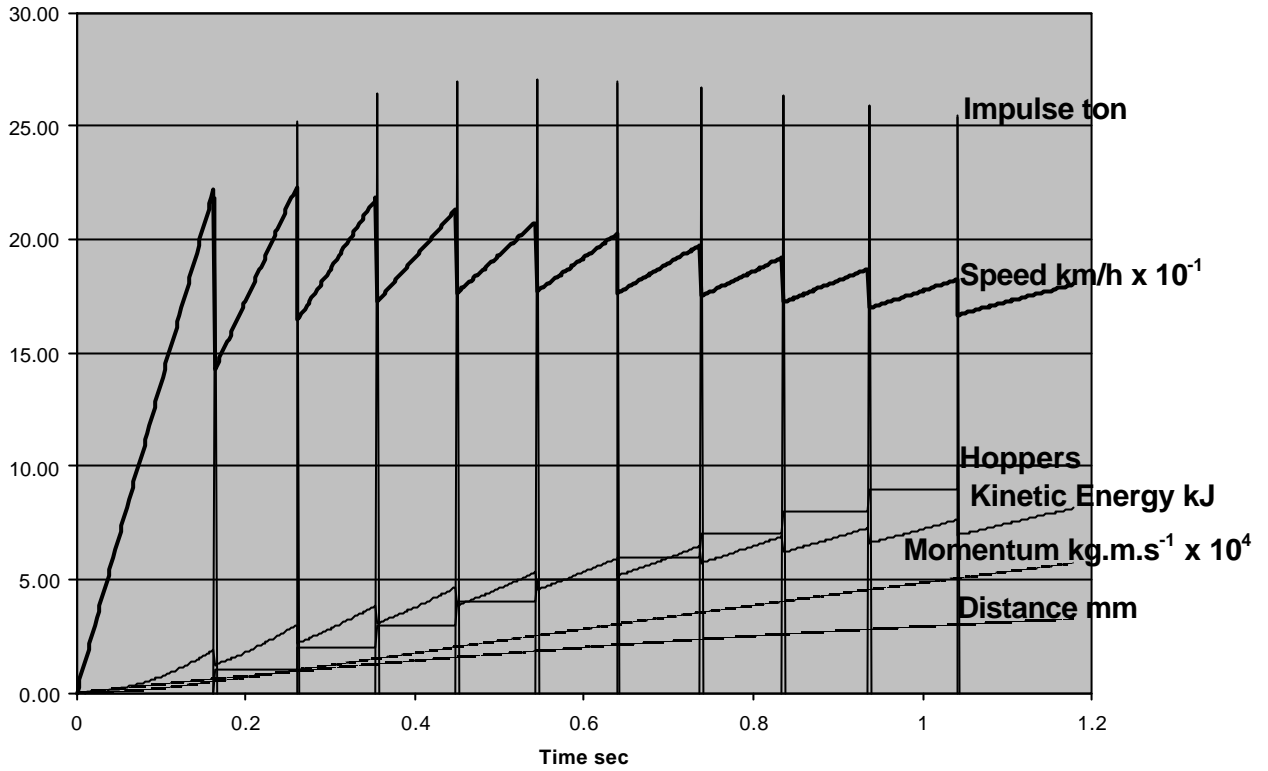


Figure 4.2.2 Simulation 2 results

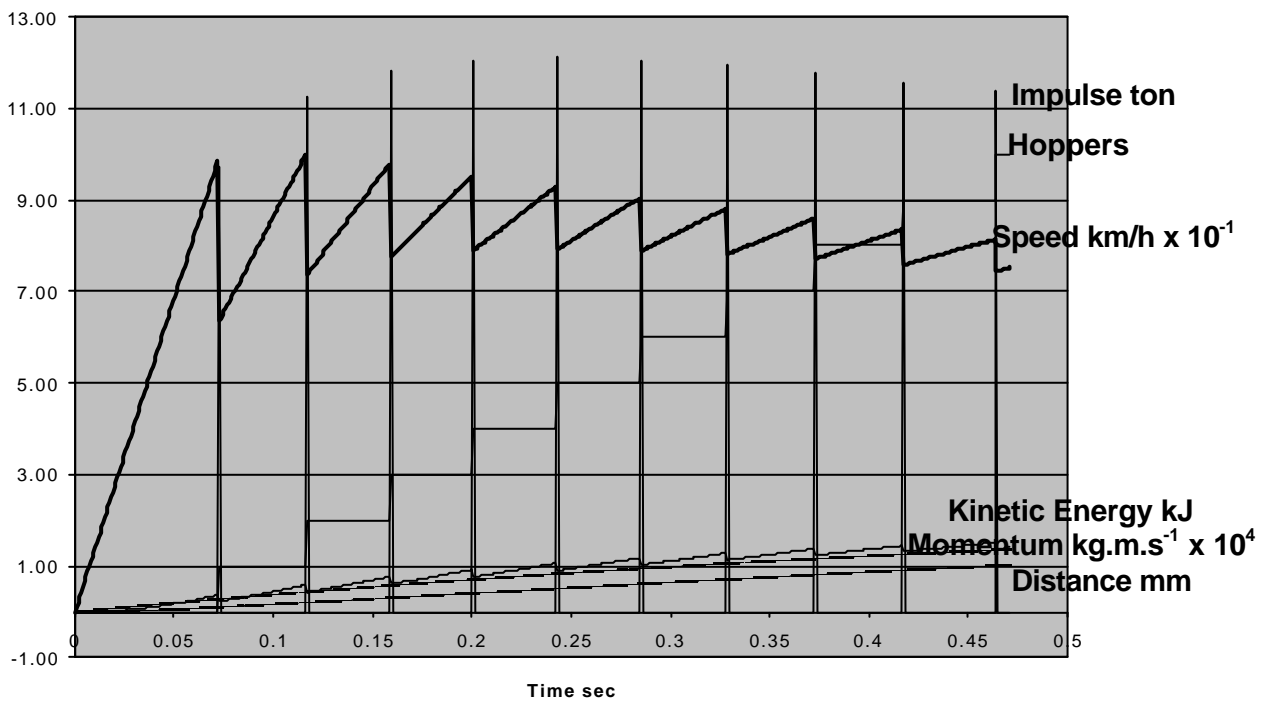


Figure 4.2.3 Simulation 3 results

4.3. FEM analysis of Kudu buffer

The 3D modelling of the Kudu buffer was done on SolidWorks2000 and the FEM analysis on COSMOS, which functions as an add-in to SolidWorks. The following are the parameters used in the analysis:

- Material
 - Poisson ratio 0.32
 - Youngs Modulus 200 GPa
 - Yield Strength 248 MPa
 - Density 7800 kg.m³
- Analysis
 - Maximum mesh size 12 mm
 - Elements 13025
 - Corner nodes 3586
 - Degrees of freedom 68925

Figure 4.3.1 presents the meshed 3D model and Figure 4.3.2 the model with the forces applied. The maximum impact force of 38 ton, calculated in the simulation, was applied to the inside half surface of the two pinholes. Thus 19 ton on each. (See Figure 4.3.2.). The back end of the buffer was kept fixed.

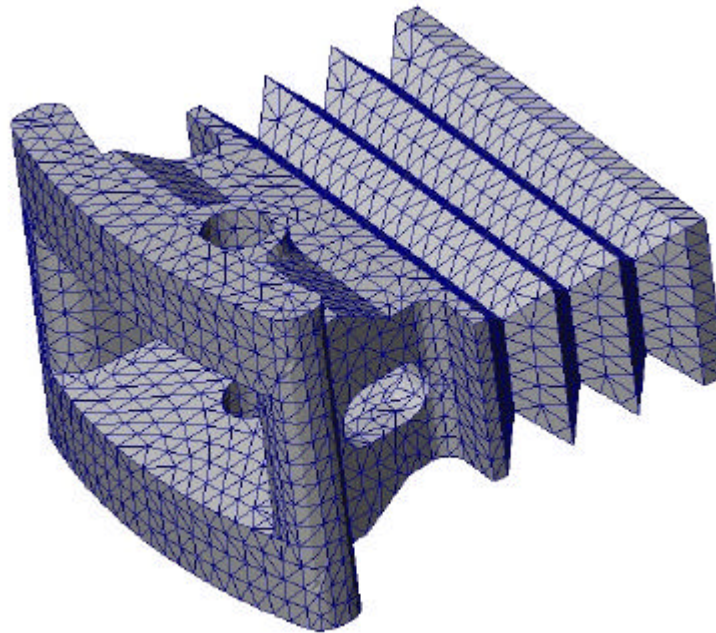


Figure 4.3.1 FEM analysis mesh

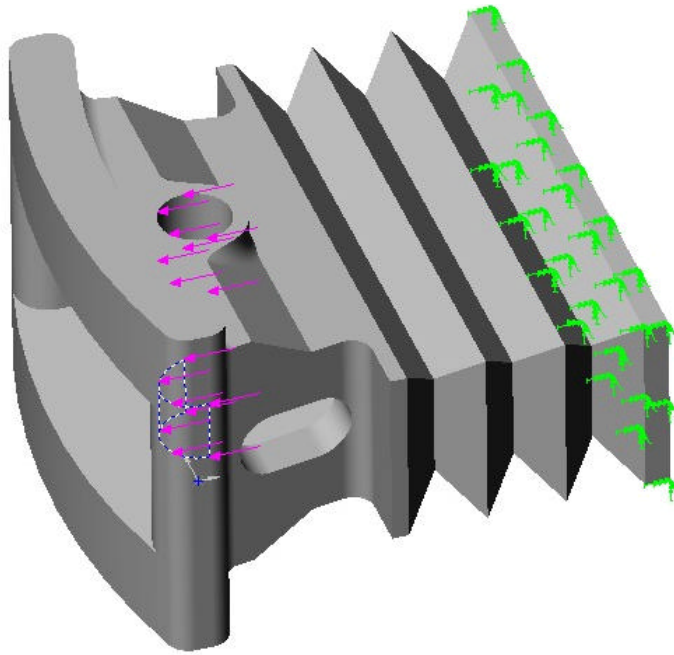


Figure 4.3.2 Forces and restraints on 3D model.

shock-Buffer :: Process-Bends Nodal Stress
 Units : MPa

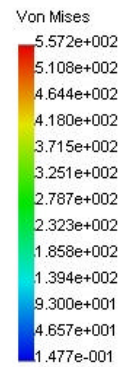
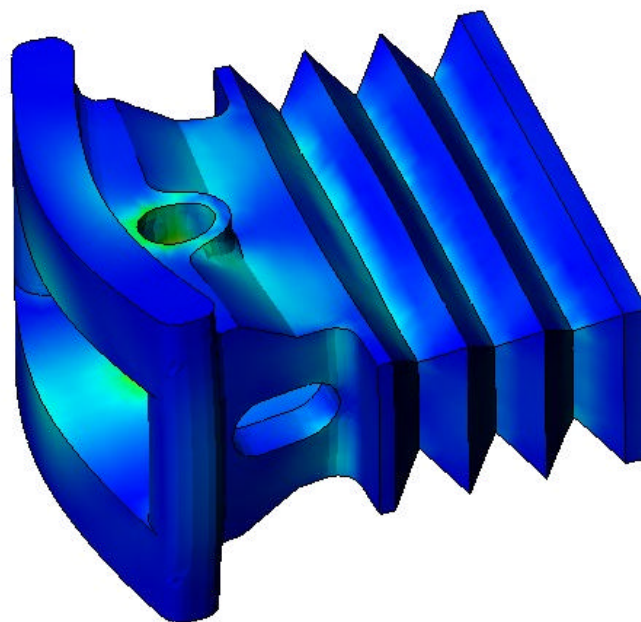


Figure 4.3.3 a Stress results (side view)

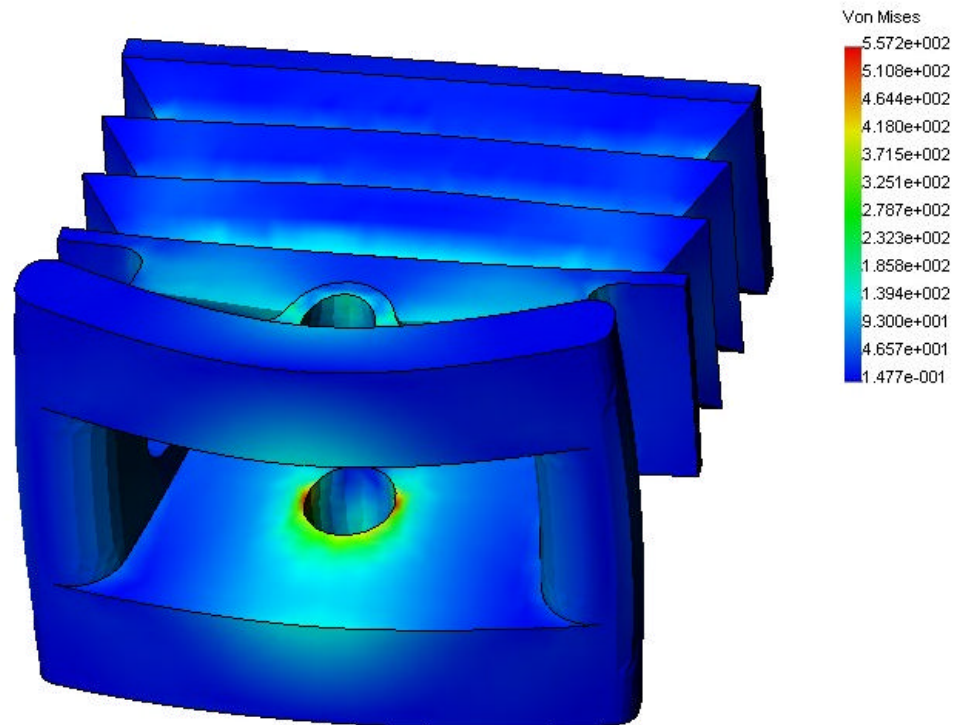


Figure 4.3.3 b Stress results (front view)

Figure 4.3.3 a and b presents the stress results on the model. The maximum stress is found at the inside of the buffer around the hole.

4.4. Discussion

The most important parameter in the above simulations is the Max Impulse Time. This parameter refers to the time duration in which the newly engaged hopper accelerates from zero velocity to the velocity of the train after the entire backlash in the links has been taken up. The value of 10 ms was used in all the calculations. This value was estimated, but can be determined by, for example, attaching accelerometers to the hoppers. The estimated value of the Max Impulse Time is supported by observing the maximum value of the displacement during the impulse time. See Table 4.2.1 and column R in Table 4.1.6. These values of 6.98, 4.92 and 2.2 mm respectively were evaluated as reasonable.

In the case of zero backlash the maximum force on the buffer would be equal to the maximum pulling force of the Loco thus 40 kN or 4 ton. If Figure 4.2.1 to 4.2.3 are examined, the Impulse increases as backlash increases up to a maximum of 38 ton. (See Figure 4.2.1). In this case backlash of 100 mm was used. This presents a factor of 9.5 over the zero backlash case.

Figure 4.4.1 presents the dimensions of the slots in the currently used links.

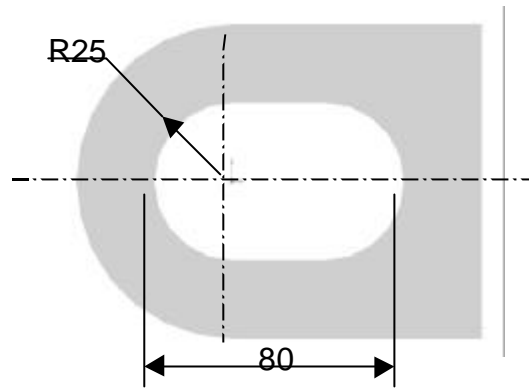


Figure 4.4.1 Link slot dimensions

If a pin of diameter 30 mm is used a backlash of 50 mm is created in above slot. The standard buffer is manufactured with a 35-mm diameter hole. This adds another 5 mm to the backlash. Thus in a standard new link and buffer set-up a total backlash of 110 mm exist.

If the absorption/elastic material within the buffer configuration is worn or has fallen out, the backlash is further increased. Loose bolts, which attach the buffer to, the hopper phenomenon also adds to the backlash.

Figure 4.3.3 a and b presents the results of the FEM analysis. From this follows that the area around the pin hole experiences a stress of 557 MPa. This stress is higher than the yield stress of cast iron of about 250 MPa. It is thus concluded that permanent deformation in this area would occur and thus the reason for the wear on the pin holes of buffers.

It is recommended that a linking system that presents as little as possible backlash be implemented.

It is also recommended that the load bearing area of the pin on the buffer be increased to bring the impact load stress at least below the yield stress. If a value of 50 MPa is used as reference for the load bearing area, A_L , can be calculated as:

$$A_L = \frac{380kN}{50MPa} = 0.007.6m^2 = 7500mm^2$$

where

- | | |
|--------|--|
| 380 kN | -Impact load resulting from 100 mm backlash (see Figure 4.2.1) |
| 50 MPa | - Chosen maximum allowable stress on load bearing areas. |

If a pin of 35 mm diameter is used the minimum length of the load bearing area within the buffer, L_L , is calculated as:

$$L_L = \frac{A_L}{35mm} = \frac{7600mm^2}{35mm} = 217mm$$

Currently the Kudu buffer has a load bearing surface area of 3346 mm² and the Elephant buffer 3386. However the current standard link is only 25 mm thick and thus wear on the link will still remain excessive. It is thus emphasised again that backlash should be minimised in order to minimise the impact forces.

Appendix 11

New Concepts

The project team developed a number of possible new concepts for consideration as replacements for the existing link and pin systems, as well as proposals for possible modifications to conventional system.

1.1 Side Lock Link

Figure 1.1.1 presents the Side Lock Link in the closed (locked) position. The modelled buffer used in this concept is the Elephant buffer from Gopro.

1.2 Link Operation

The link consists of a bell-mouthed section and a wedge shaped insert to the bell mouthed section. The two sections are locked by a Locking Pin inserted from the side (horizontally). For the disengaging operation the Locking Pin is rotated 180° and pulled out. See Figure 1.1.2 and 1.1.3. The locking mechanism (See Figure 1.1.3) ensures, by way of gravity on the Locking Pin handle, that the Locking Pin stays locked at all times. Figure 1.1.4 and 1.1.5 presents the disengaged link and link parts respectively.

Advantages

- Automatic engagement of bell mouth and wedge shaped sections even when drooping of buffers exists.
- Manual pin engagement/disengagement from the sides (horizontally) to facilitate manual operation by an operator.
- Pin insertion possible from both sides. (Locking mechanisms exists on both sides).
- Fit on any existing buffer.
- Positive locking.
- Safer coupling and de-coupling.

Disadvantages

- Link consists of two different sections. (Bell mouth and wedge shaped).
- Not fully automated coupling.
- Cost in comparison to existing link and pin.
- Not symmetrical

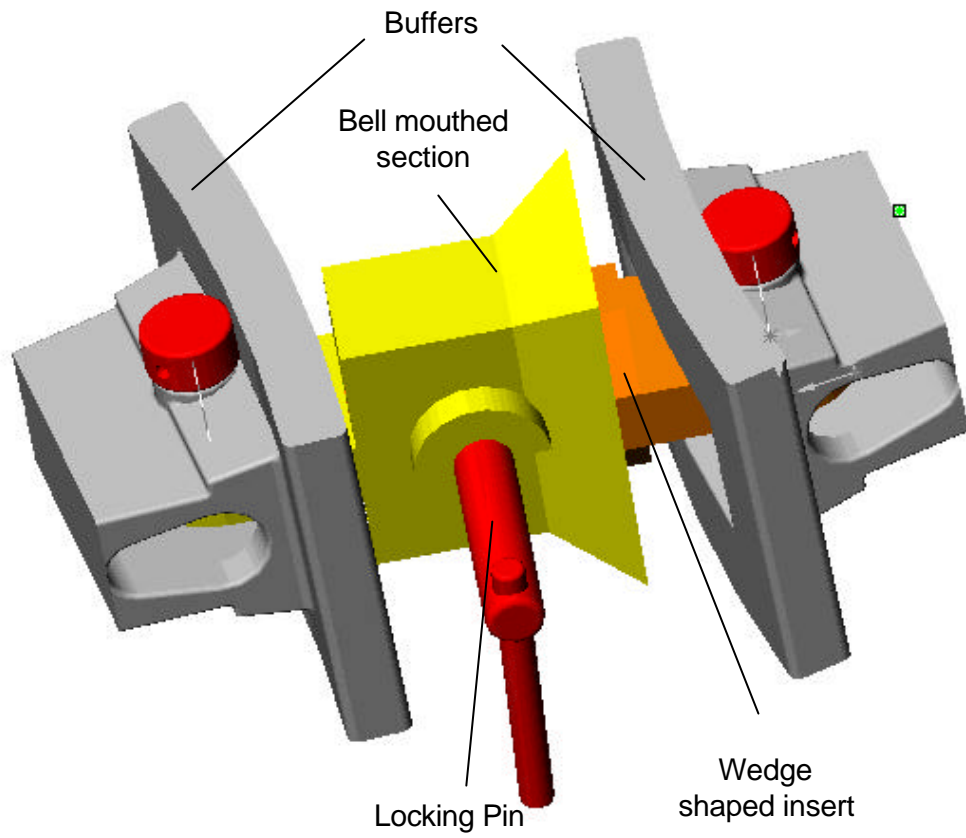


Figure 1.1.1 Linked closed.

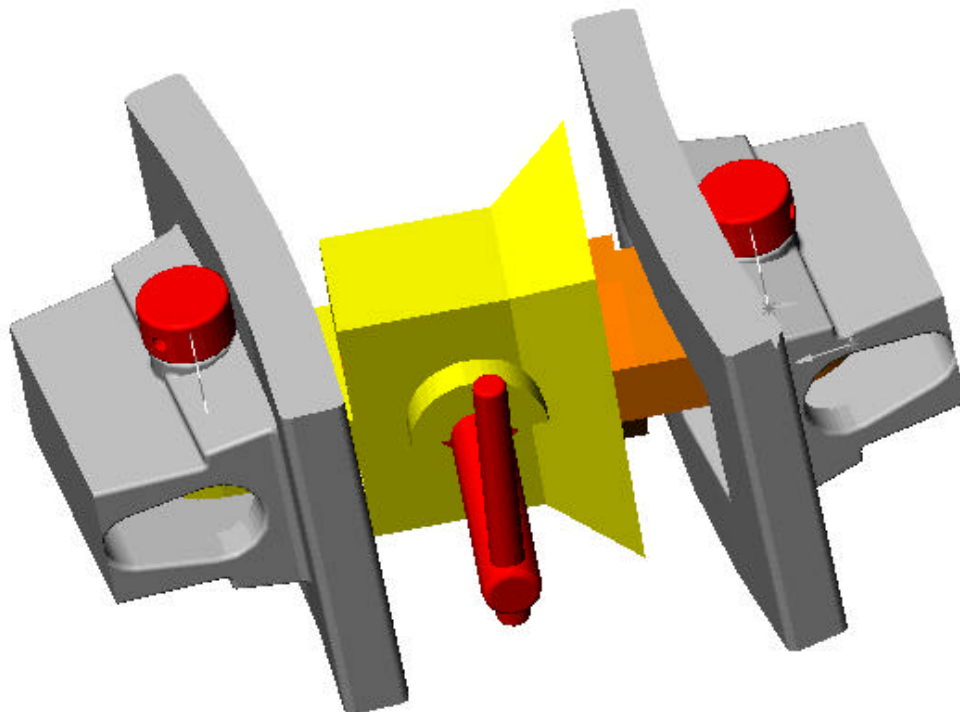


Figure 1.1.2. Pin unlocked

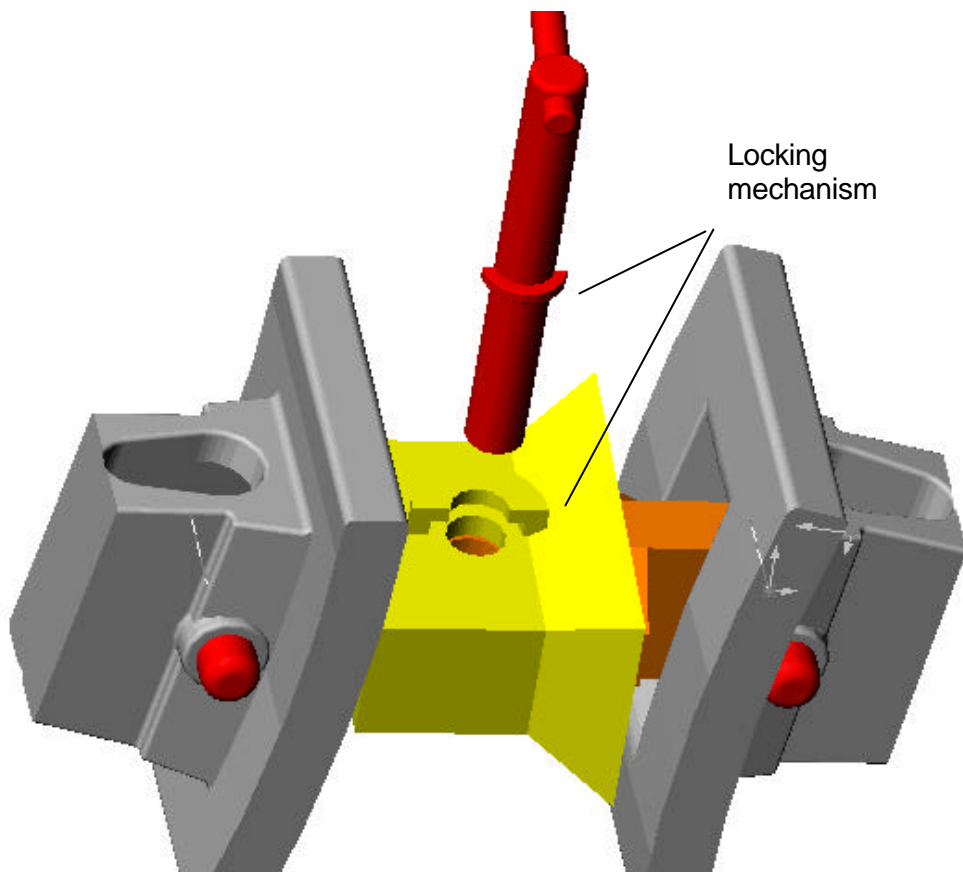


Figure 1.1.3. Pin removed

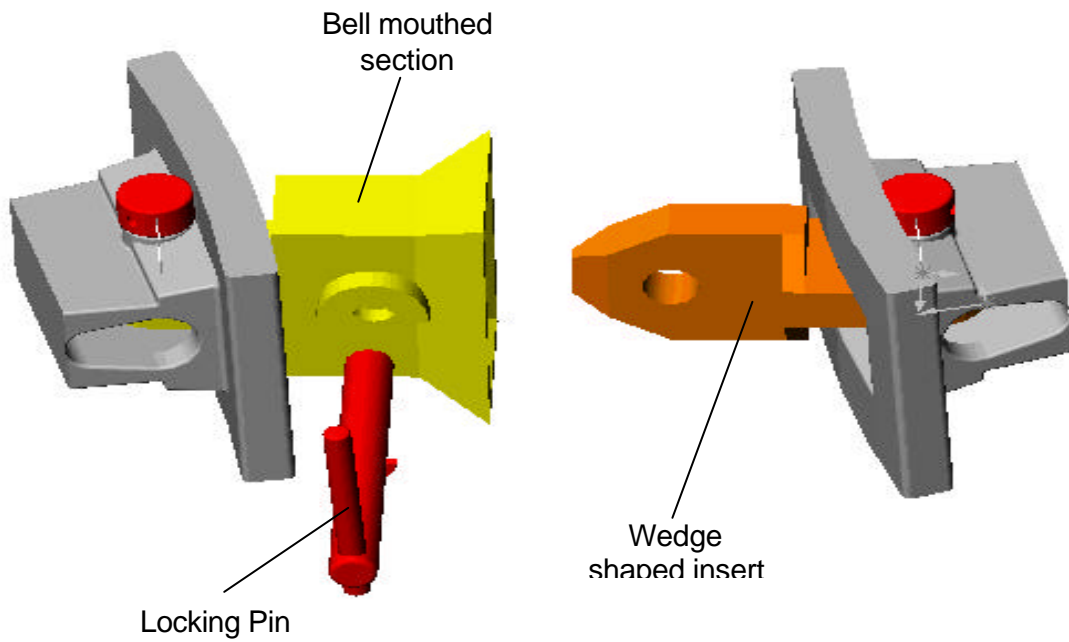


Figure 1.1.4. Link disengaged

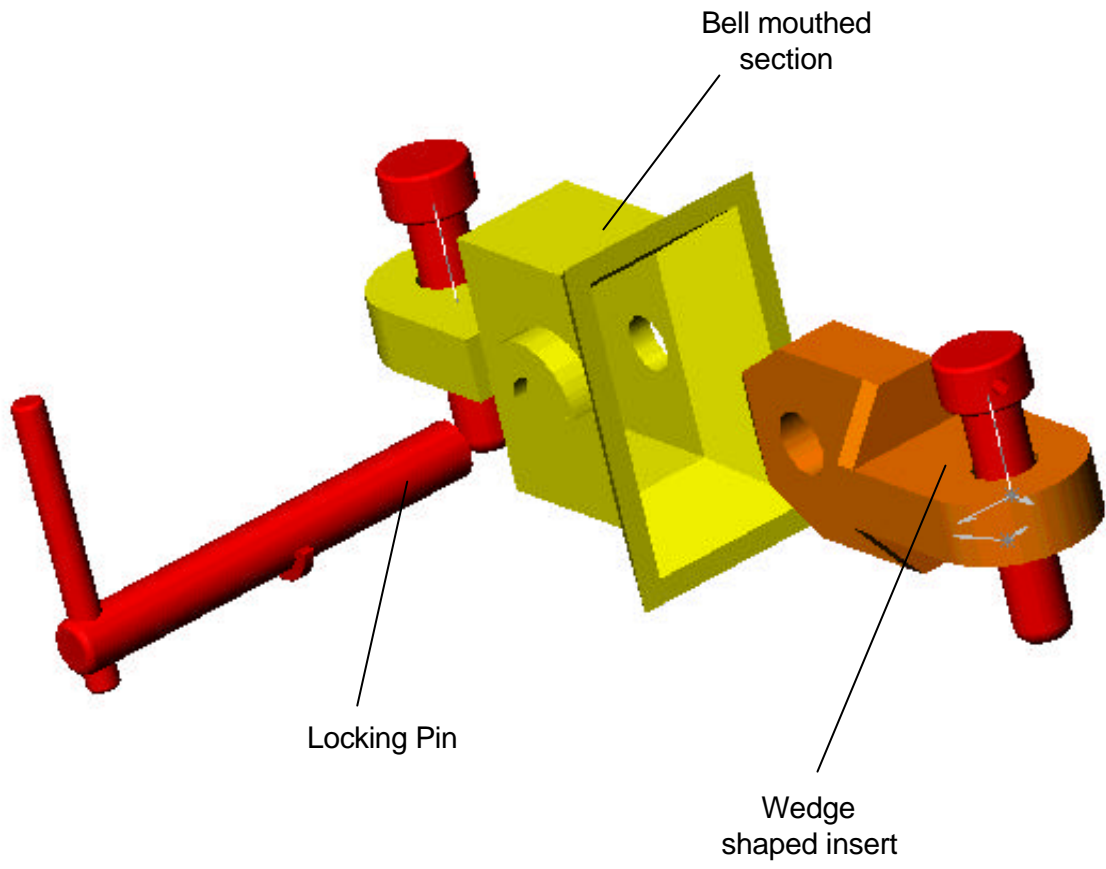


Figure 1.1.5. Link parts

2. Automated Side Lock Link

Figure 2.1.3 a and b presents the Automated Side Lock Link in the closed position.

2.1 Link Operation

The operation of this link is the same as with the Side lock Link with the difference being in the locking mechanism. In this case the Locking Pin is spring loaded and retained by a spring loaded Retaining Pin. Figure 2.1.1 a and b presents a cut away of the open link. As the Wedge shape section engages the Retaining Pin is pushed back and the Locking Pin engages (See Figure 2.1.2 and 2.1.3). De-coupling is accomplished by an operator pulling the Locking Pin to the side, the Wedge shaped section disengages and the Retaining Pin moves into position to hold the Locking Pin.

Advantages

- Automatic engagement of bell mouth and wedge shaped sections even when drooping of buffers exists.
- Automatic coupling.
- Manual pin disengagement from the sides (horizontally) to facilitate operation by an operator.
- Fit on any existing buffer.
- Positive locking.
- Safer coupling and de-coupling.

Disadvantages

- Locking Pin operation possible from only one side.
- Link consists of two different sections. (Bell mouth and Wedge shaped section).
- Cost in comparison to existing link and pin.
- Not symmetrical

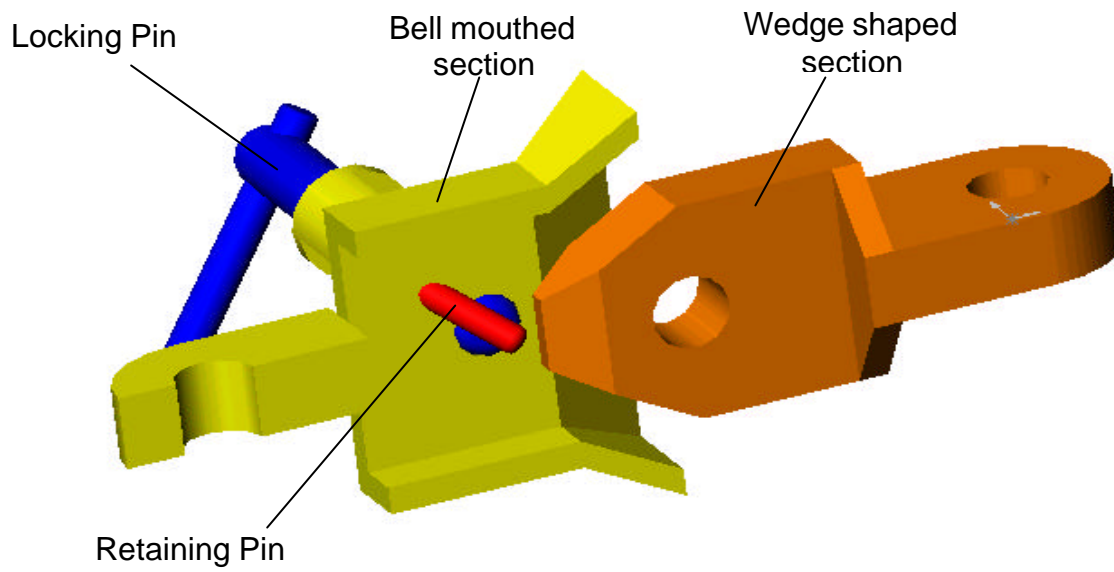


Figure 2.1 .1 a. Link open

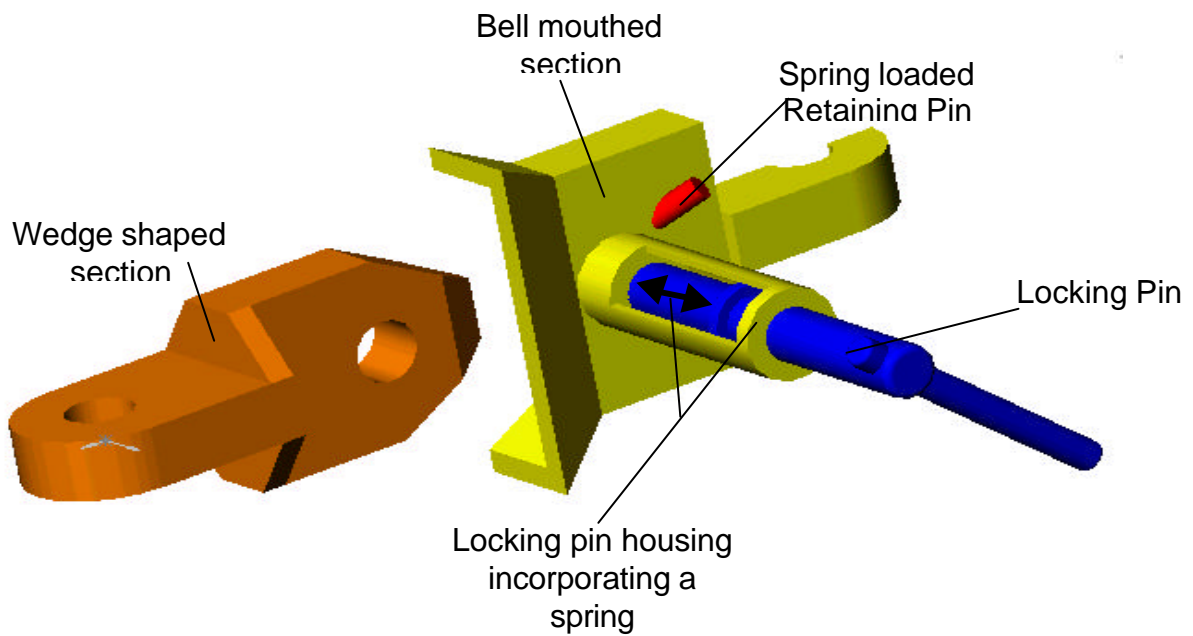


Figure 2.1.1 b Link open

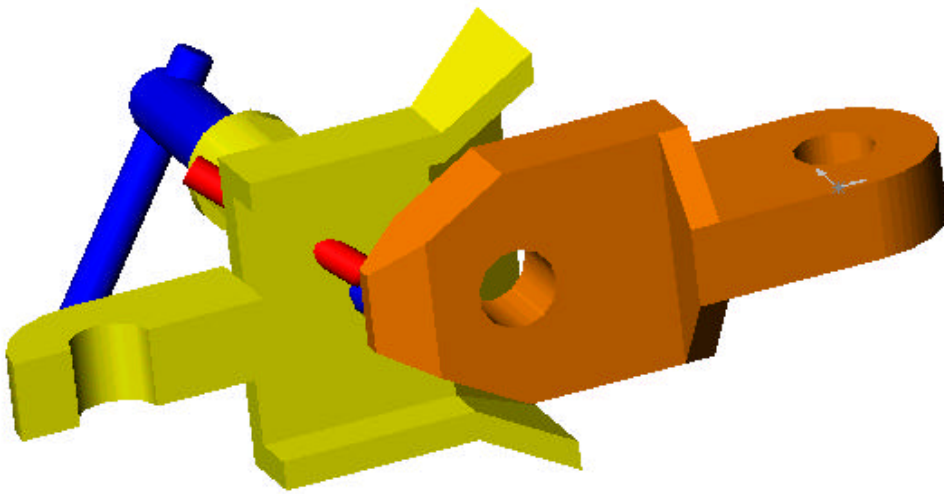


Figure 2.1.2. Link closing.

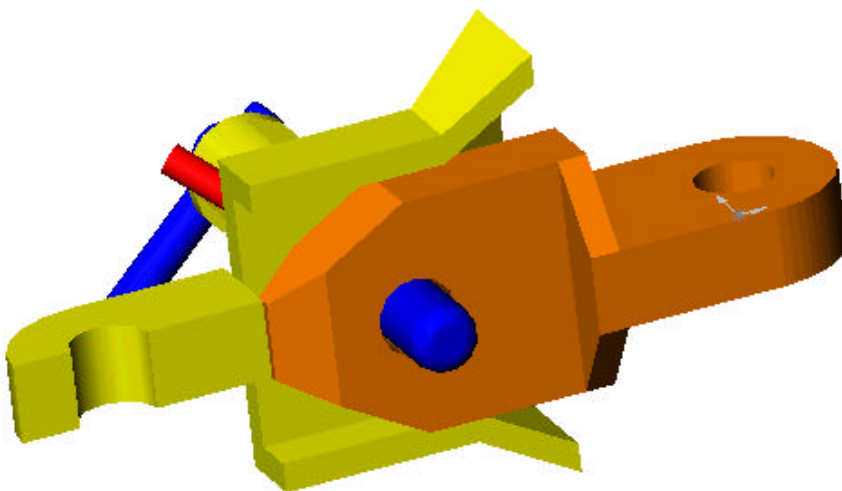


Figure 2.1.3 a Link closed.

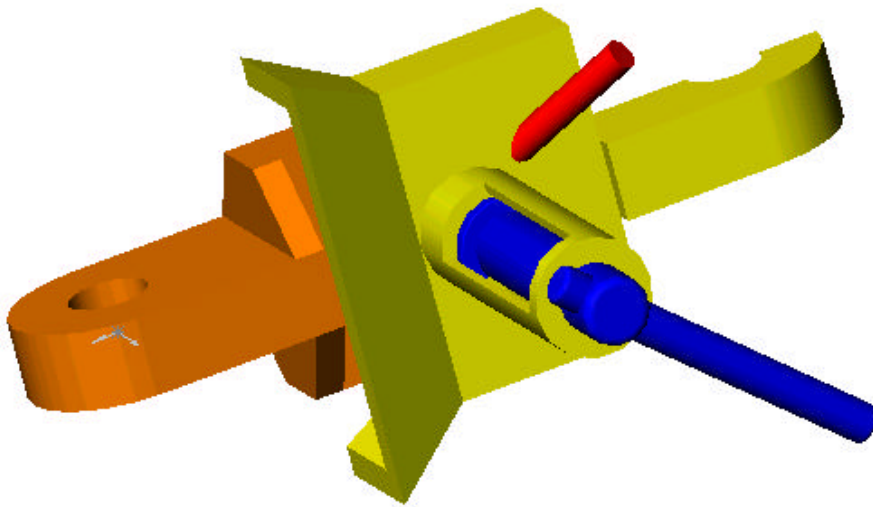


Figure 2.1.3 b. Link closed

3. Top Locking Buffer

Figure 3.1.1 presents a cut away view of the Top Locking Buffer in uncoupled position. The modelled buffer used in this concept is the Elephant buffer from Gopro.

3.1 Link Operation

The link makes use of any existing buffer together with the standard links in service. A locking mechanism is added to the standard buffers. It consists of a spring-loaded Locking Pin and Retainer Pin added to a standard buffer. Figure 3.1.1 presents a cut away of the open link. As the Link engages the Retaining Pin is pushed back and the Locking Pin engages (See Figure 3.1.2 a and b). De-coupling is accomplished by an operator pulling the Locking Pin upwards, the Link disengages and the Retaining Pin moves into position to hold the Locking Pin. If the above concept is used with the bell mouth shaped buffers, engagement of the Link will still be automatic even if the buffers are drooping. This concept is the same as the Automated Side Lock Link but operates in a vertical position on standard buffers.

Advantages

- Automatic engagement if bell mouth buffers are used even when drooping of buffers exists.
- Compatible with cross type links which enhances the link engagement when buffers are drooping.
- Automatic coupling.
- Use existing links.
- Existing buffer can be modified to incorporate the locking mechanism.
- Positive locking.
- Safer coupling.
- Cost effective.

Disadvantages

- Manual pin disengagement from the top – operator situated between hoppers.

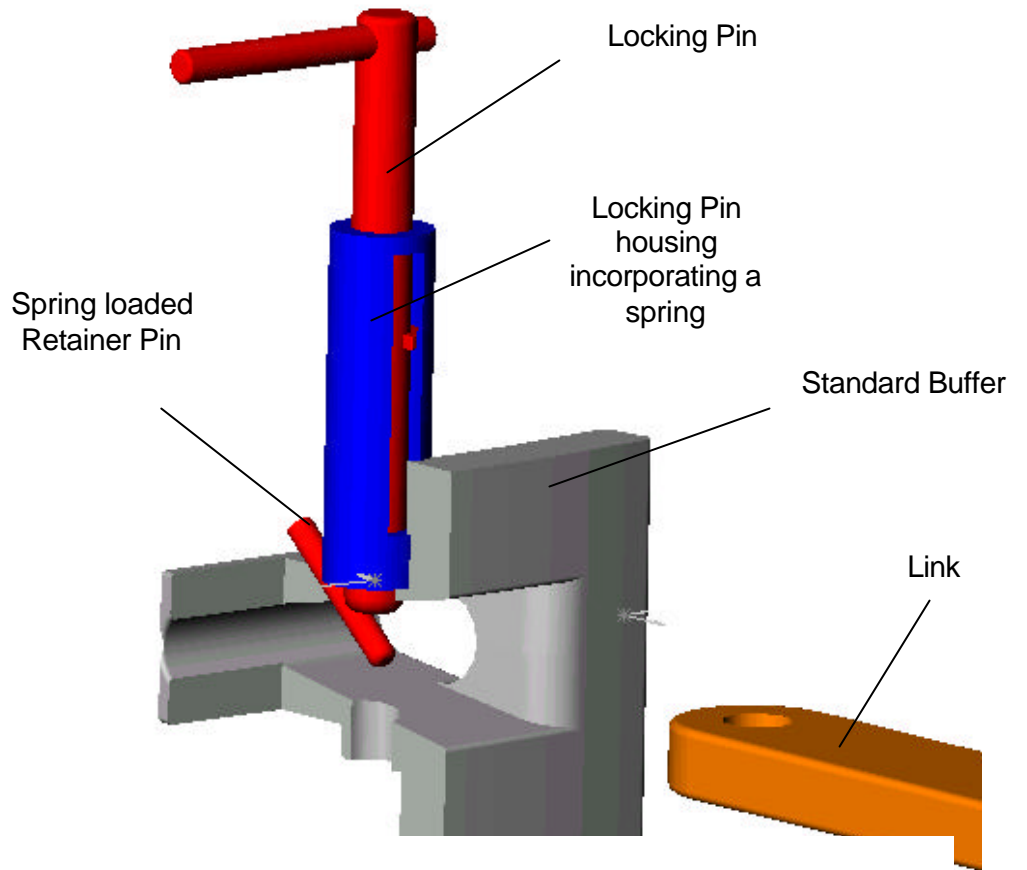


Figure 3.1.1 Uncoupled link

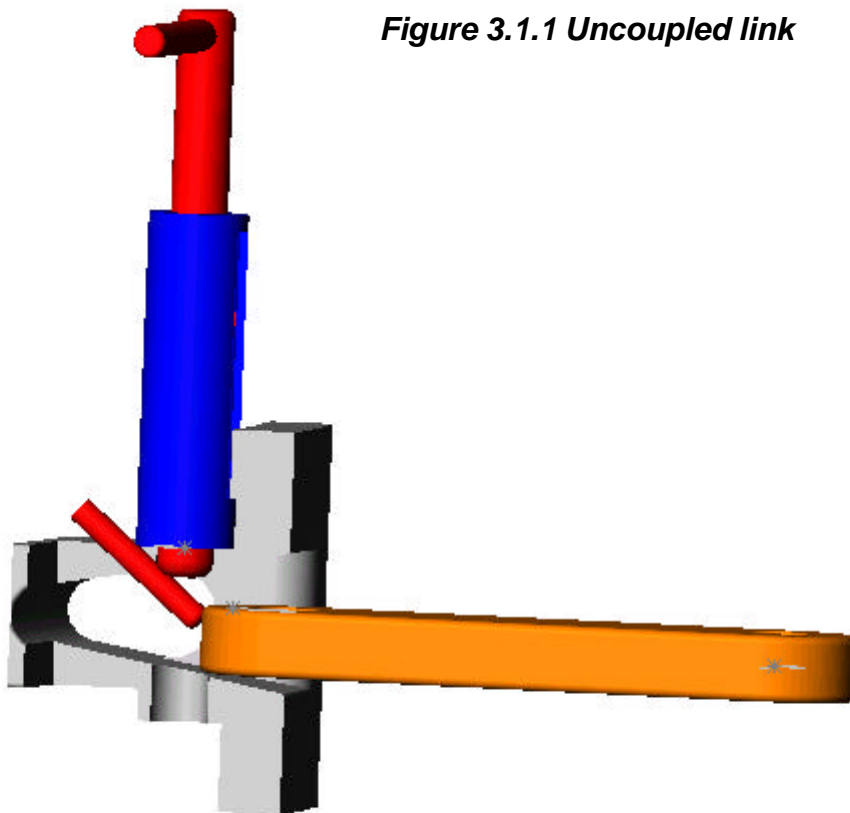


Figure 3.1.2. a Engaging Link

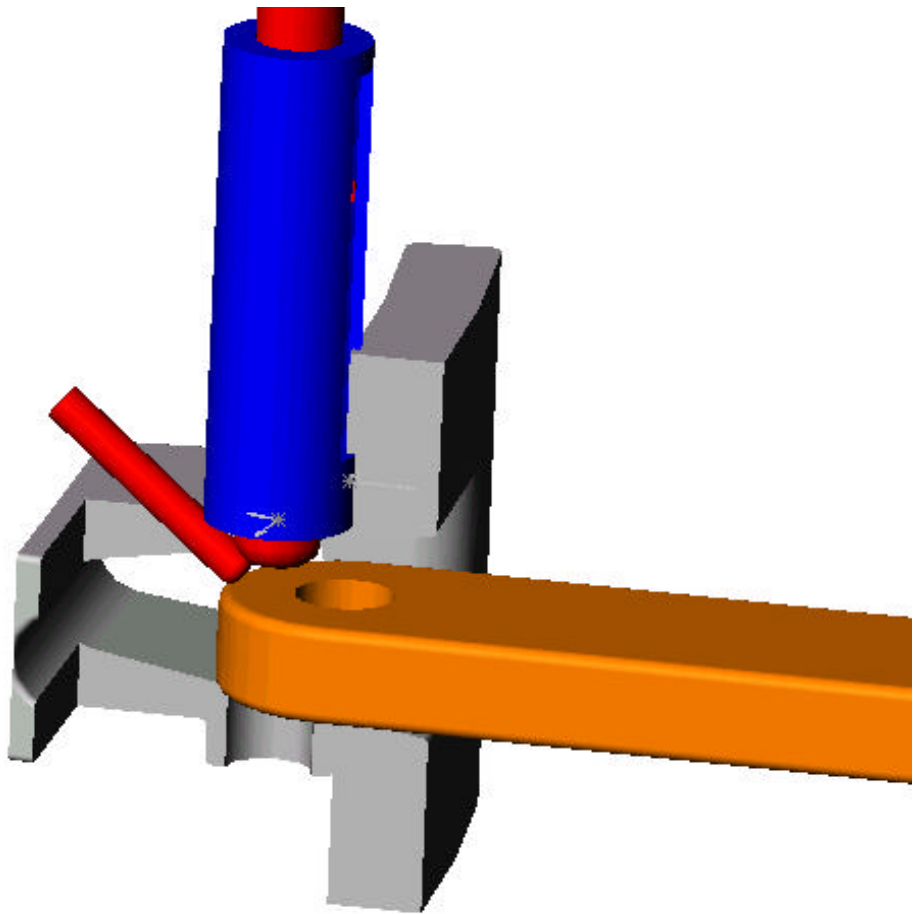


Figure 3.1.2. b Engaging Link

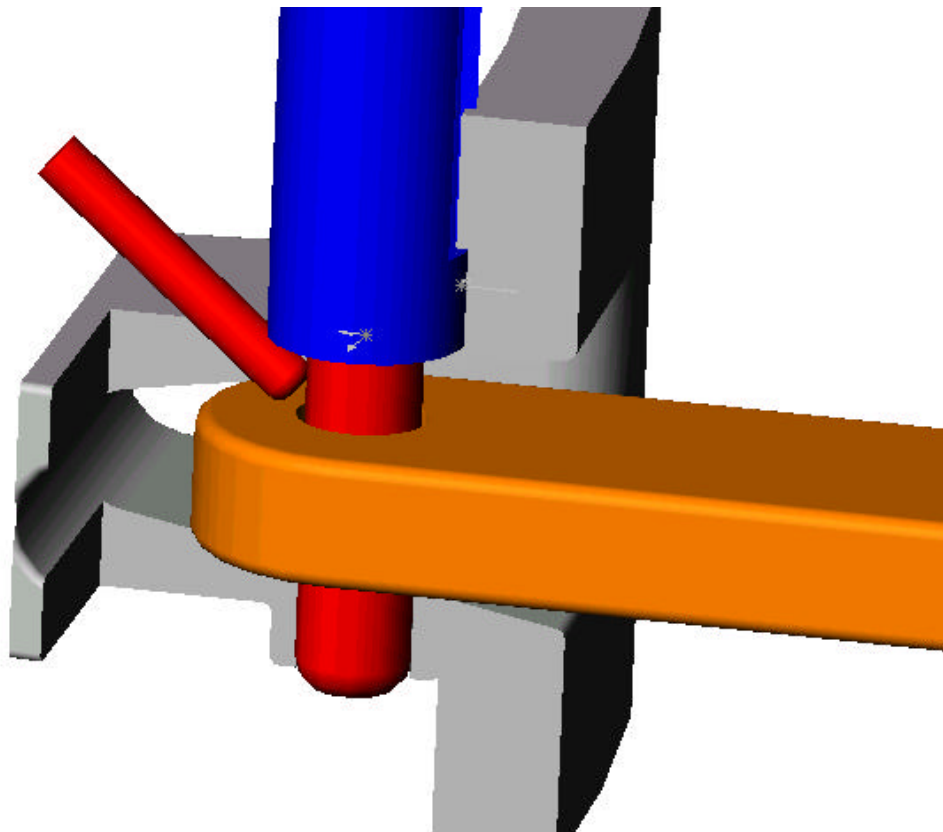


Figure 3.1.3 Coupled Link

4. Automated Screw Link

Figure 4.1.1 presents a cut away view of the Automated Screw Lock Link in the open position.

4.1 Link Operation

As the Screw Section approaches the Engaging Section the bell mouth of the Engaging Section (See Figure 4.1.1) guides the Screw Section. When the front of the Screw Section reaches the Locking Handle the wedge shaped tip of the Screw Section engages into the Locking Handle (See Figure 4.1.2 a and b). The Locking Handle is rotated through 90° and drops back into a locking position. (See Figure 4.1.3 a and b). Uncoupling is done by simple rotating the Locking Handle 90° upwards.

Advantages

- Automatic engagement even when drooping of buffers exists.
- Automatic coupling.
- Manual handle disengagement from the sides (horizontally) to facilitate operation by an operator.
- Fit on any existing buffer.
- Positive locking.
- Safer coupling and de-coupling.
- Consists of only three components.

Disadvantages

- Link consists of two different sections. (Screw Section and Engagement Section).
- Cost in comparison to existing link and pin.
- Not symmetrical.

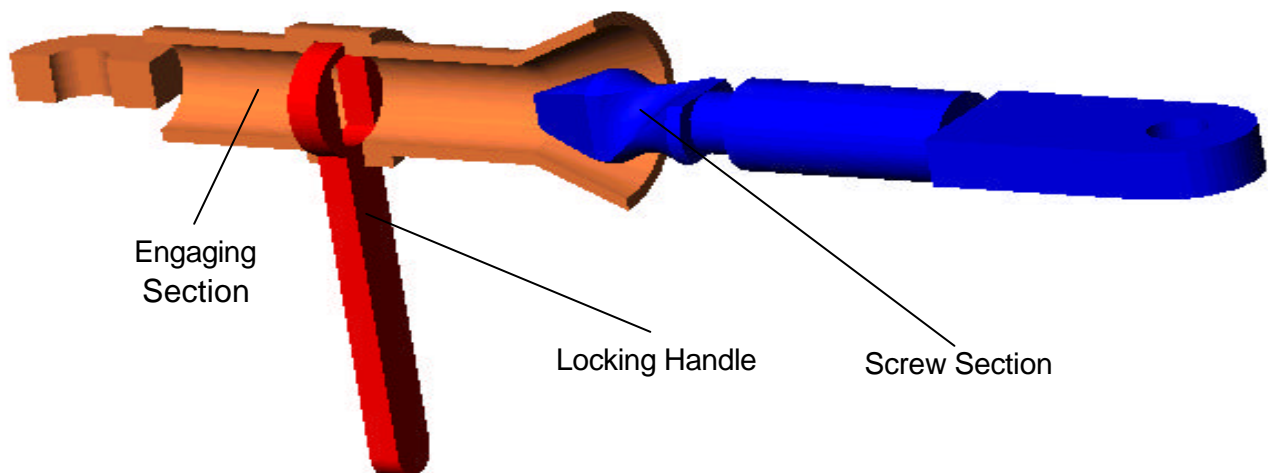


Figure 4.1.1 Open Screw Link

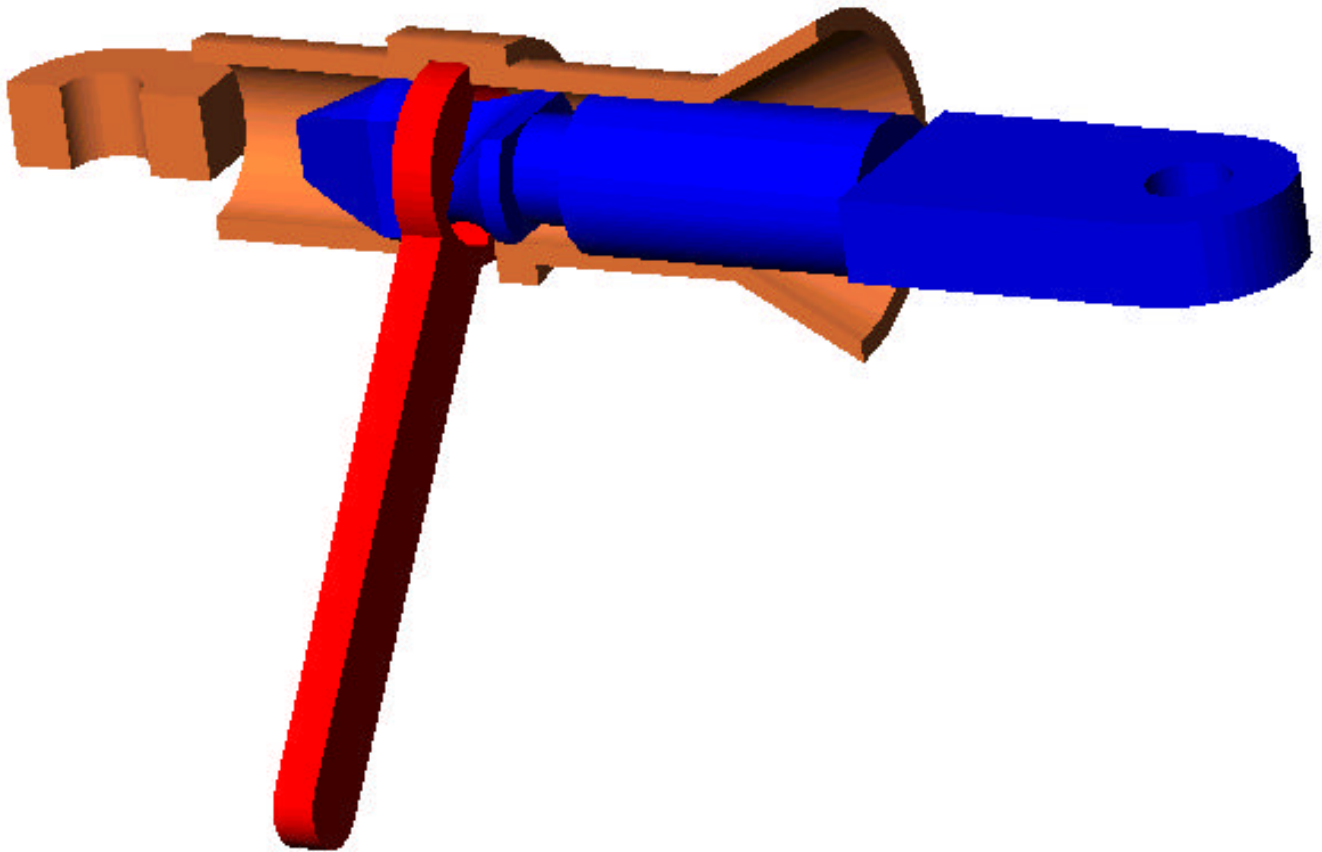


Figure 4.1.2 a Engaging Screw Link

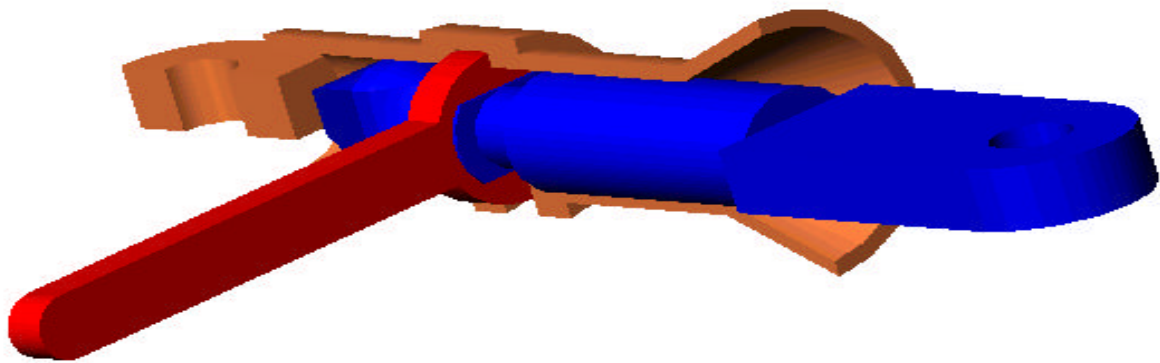


Figure 4.1.2 b Engaging Screw Link

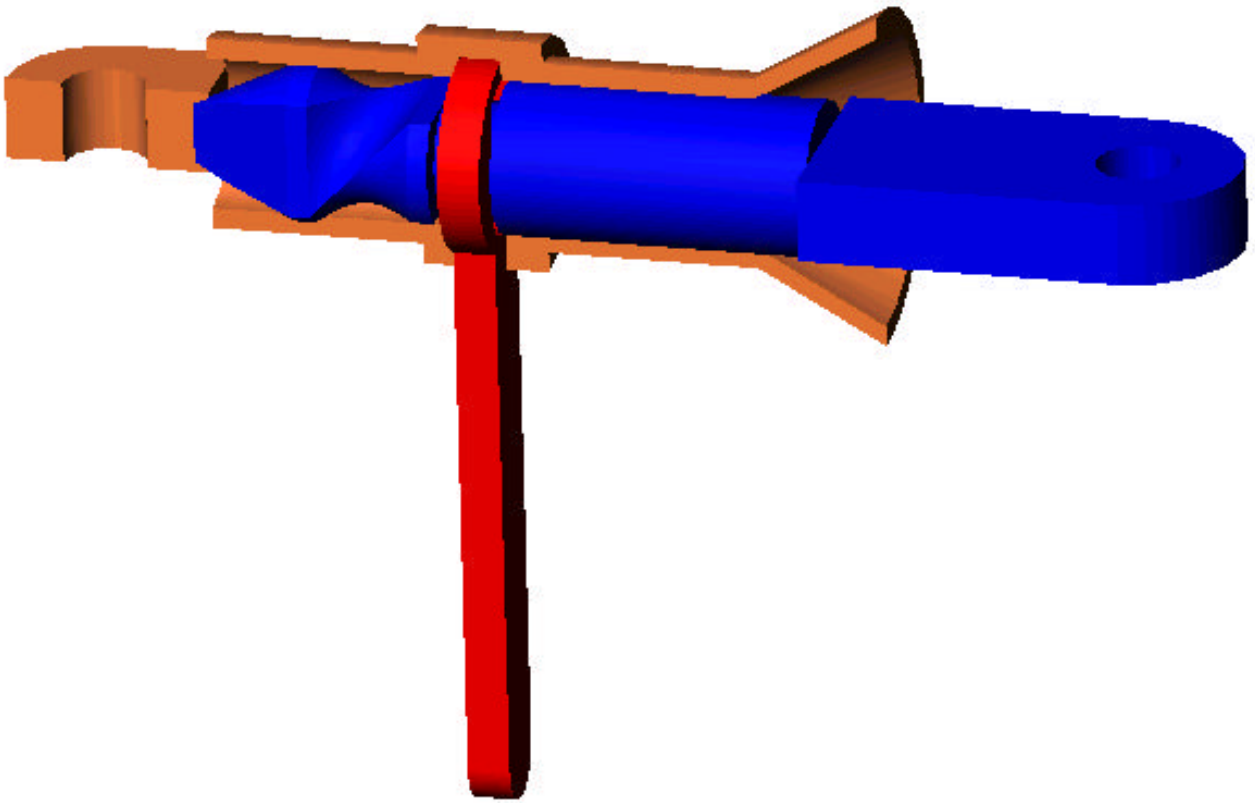


Figure 4.1.3 a Coupled Screw Link

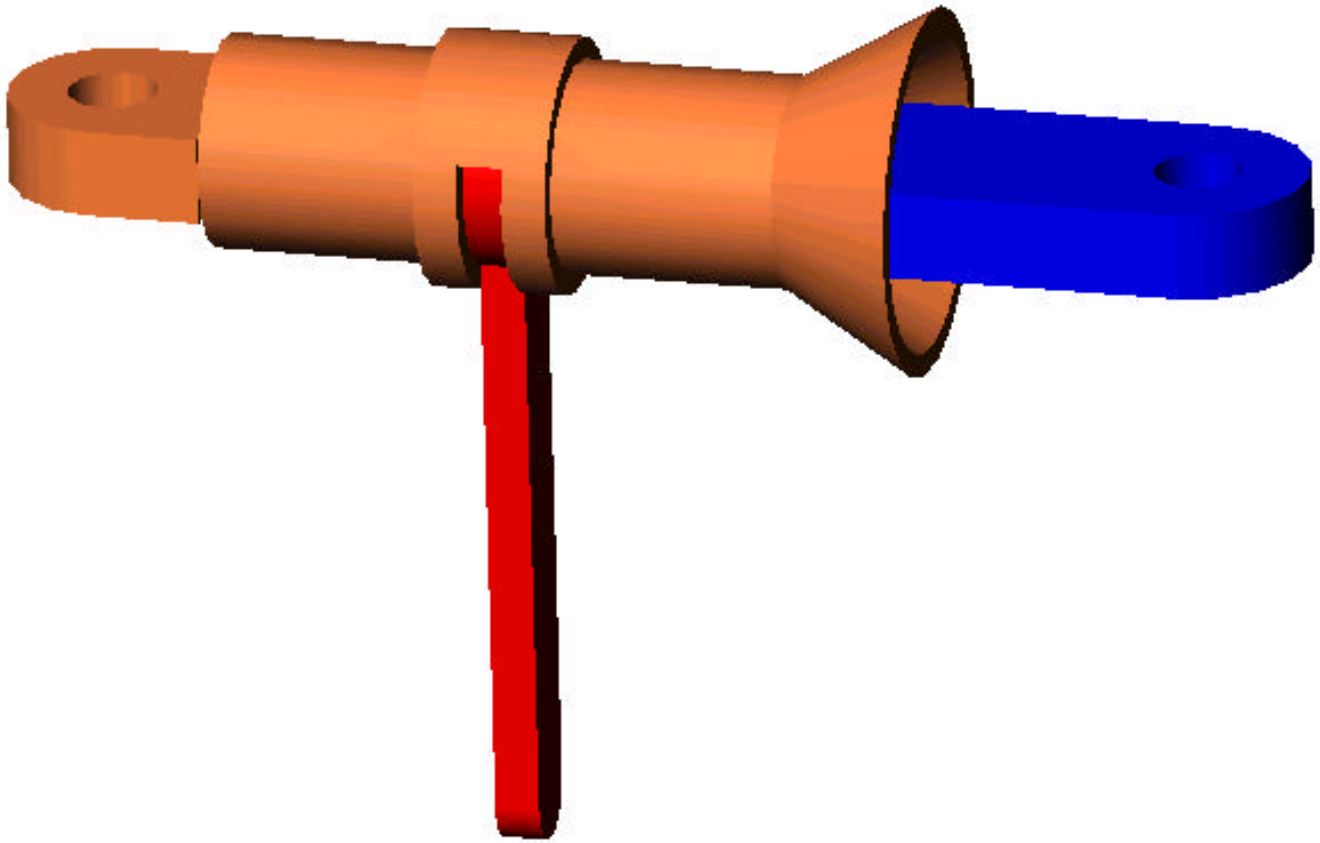


Figure 4.1.3 b Coupled Screw Link

5. Modified Standard Link

Figure 5.1.1 and 5.1.2 presents the Modified Standard Link

5.1 Link Operation

The link functions in exactly the same way as the standard link. Modifications include a smaller hole slotted sideways. This will decrease the large amount of backlash in the standard link. The modified link is also widened around the slotted holes (see Figure 5.1.2) to ensure the same strength as the standard link. The distance between the two holes on the modified link is such that if the two buffers are pushed against each other, with the link handle (See Figure 5.1.1), in-between the slotted holes, the slotted holes align with the buffer holes. This feature enhances the ease of coupling. This modified link also features more sideways movement as well as a larger swing angle than the standard link.

Advantages

- Same cost as standard link
- Minimises backlash
- Easy to implement
- Fit on any existing buffer.
- Safer coupling and de-coupling.

Disadvantages

- None

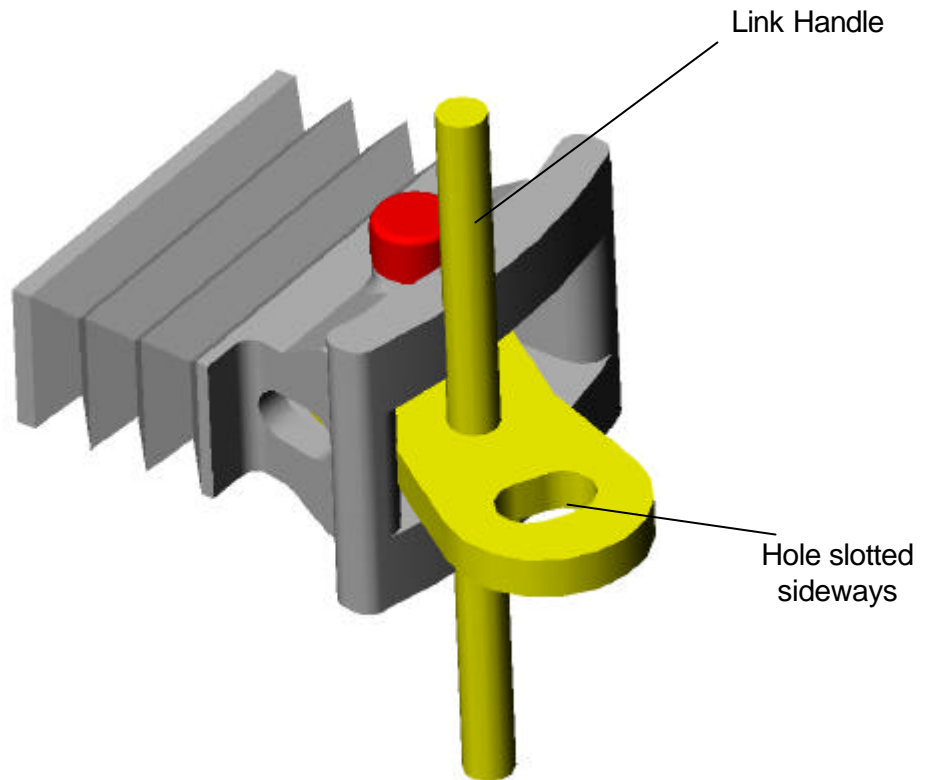


Figure 5.1.1 Modified Standard Link

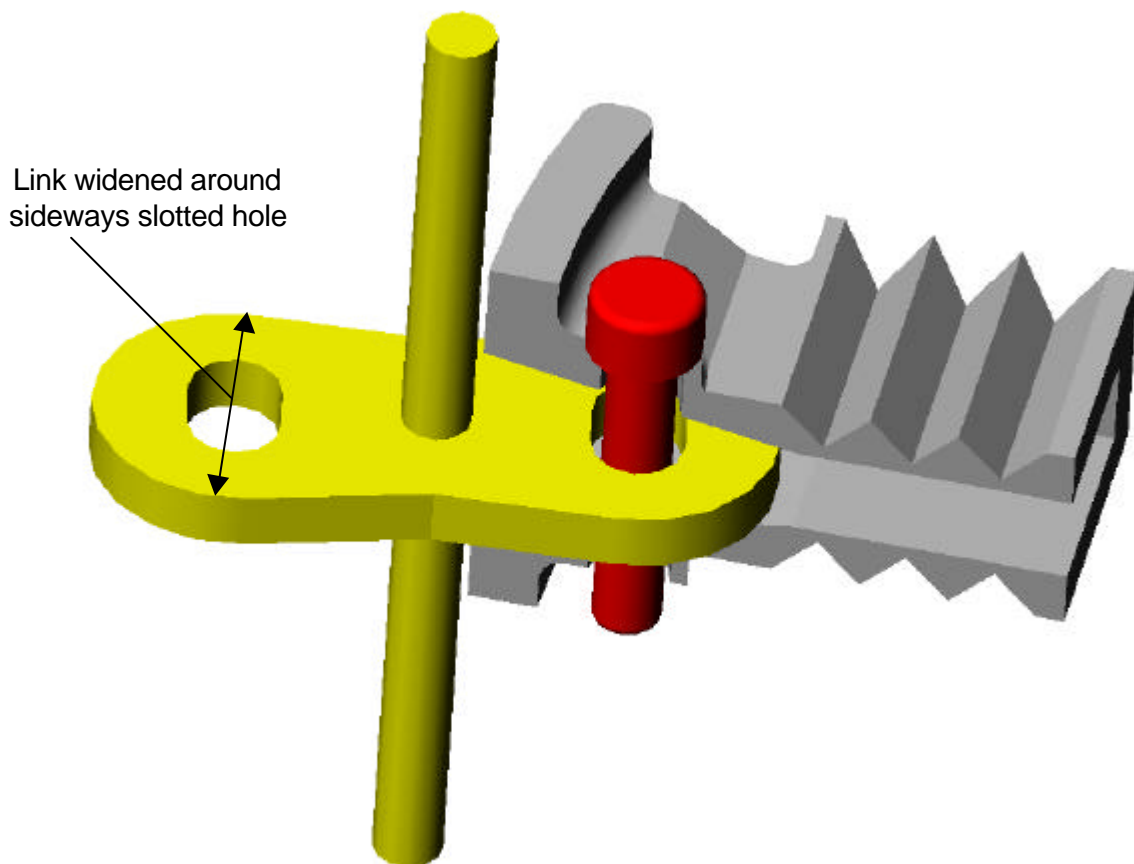


Figure 5.1.2 Cut away of Modified standard Link

Appendix 12

Evaluation of existing and proposed couplings

The existing coupling systems in use in the industry, as well as alternatives proposed in this project, were evaluated against the criteria as specified below and as discussed in section 3.2. Not one coupling satisfied all these criteria. Unless a coupling design satisfies all of the criteria specified, the project team does not believe it is ideal for use.

Coupling criteria:

- Simplicity
- Robust
- Inherently safe as a coupling
- Low maintenance
- Ergonomically suitable/safe for coupling and uncoupling
- Price
- Compatible with existing coupling systems
- Performance in a derailment situation
- Minimise shock/impact loads

Assessment of existing models and proposed alternative designs of buffers

Willison

- | | |
|---|------------------------|
| • Simple | No |
| • Robust | Reasonable |
| • Inherently safe as a coupling | Yes |
| • Low maintenance | No |
| • Ergonomically suitable/safe for coupling and uncoupling | Yes |
| • Price | No |
| • Compatible with existing coupling systems | No |
| • Performance in a derailment situation | No |
| • Minimise shock/impact loads | Yes (minimal backlash) |

Galison Auto Lock

- | | |
|---|---------------------------------------|
| • Simple | Yes |
| • Robust | Yes |
| • Inherently safe as a coupling | No (unless additional lock installed) |
| • Low maintenance | No |
| • Ergonomically suitable/safe for coupling and uncoupling | Yes |
| • Price | Yes |
| • Compatible with existing coupling systems | Yes |
| • Performance in a derailment situation | No |
| • Minimise shock/impact loads
(slotted links induce shock loading) | No |

Existing Link and Pin type systems

- Simple Yes
- Robust Yes
- Inherently safe as a coupling Yes
- Low maintenance No
- Ergonomically suitable/safe for coupling and uncoupling No
- Price Yes
- Compatible with existing coupling systems Yes
- Performance in a derailment situation Yes
- Minimise shock/impact loads No
(slotted links induce shock loading)

Existing Chain and Pin type systems (Rhino coupling)

- Simple No
- Robust Yes
- Inherently safe as a coupling Yes
- Low maintenance No
- Ergonomically suitable/safe for coupling and uncoupling No
- Price Yes
- Compatible with existing coupling systems Yes
- Performance in a derailment situation No
- Minimise shock/impact loads No
(chain links induce shock loading)

Link and Pin type systems (with pre-setting of pin)

- Simple No
- Robust Yes
- Inherently safe as a coupling Yes
- Low maintenance No
- Ergonomically suitable/safe for coupling and uncoupling Reasonably suitable
- Price Yes
- Compatible with existing coupling systems Yes
- Performance in a derailment situation Yes
- Minimise shock/impact loads No
(slotted links induce shock loading)

Modified Top Locking Buffer (as per Appendix 11)

- Simple No
- Robust Yes
- Inherently safe as a coupling Yes
- Low maintenance Yes
- Ergonomically suitable/safe for coupling and uncoupling Yes
- Price Yes
- Compatible with existing coupling systems Yes

- Performance in a derailment situation Yes
 - Minimise shock/impact loads Partially
- (slotted links induce shock loading)

Alternate Coupling no. 1 Side Lock Link (as per Appendix 11)

- Simple No
- Robust ?
- Inherently safe as a coupling ?
- Low maintenance ?
- Ergonomically suitable/safe for coupling and uncoupling Yes
- Price ?
- Compatible with existing coupling systems ?
- Performance in a derailment situation ?
- Minimise shock/impact loads Yes

Alternate Coupling No. 2 – Screw Link (as per Appendix 11)

- Simple ?
- Robust ?
- Inherently safe as a coupling ?
- Low maintenance ?
- Ergonomically suitable/safe for coupling and uncoupling Yes
- Price ?
- Compatible with existing coupling systems Yes
- Performance in a derailment situation Yes
- Minimise shock/impact loads Yes

Alternate Coupling No. 3 – Modified Standard Link (as per section 5, Appendix 11)

- Simple Yes
- Robust Yes
- Inherently safe as a coupling Yes
- Low maintenance Yes
- Ergonomically suitable/safe for coupling and uncoupling Yes
- Price Yes
- Compatible with existing coupling systems Yes
- Performance in a derailment situation Yes
- Minimise shock/impact loads Yes

Appendix 13

Synopsis of Coupling Related aspects of GAP 520

The GAP 703 project team analysed the findings of the GAP 520 project dated March 1999 ('Investigate safety of rail vehicles and systems operating in South African gold mines'). GAP 520 was a broadly focussed project on all causes of accidents as related to underground rolling stock. This synopsis of GAP 520 was drawn up by the GAP703 team to extract the data relevant to couplings and related accidents.

GAP 520 ('Investigate safety of rail vehicles and systems operating in South African gold mines')

During this study the accident reports (Detail Accident Report Form MA-P-005 by the Department of Minerals and Energy) for the period 1988 to 1997 were analysed to investigate the safety of rail vehicles and systems operating in the South African gold and platinum mines. Approximately some 2000 accident reports were analysed. From this analysis, it emerged that over this period:

- Accidents involving rail mounted vehicles accounted for :
 - 12% of all reported accidents
 - 10% of all fatalities
 - 12.5% of all non-fatal accidents

- The ranking of all rail accidents in terms of frequency of occurrence was:

Ranking	Activity	% of all rail accidents
1	Coupling	20%
2	Walking	14%
3	Derailment	9%
4	Re-railing	6%
5	Collision	6%
6	Travelling on	5%

- The ranking of fatal rail accidents in terms of frequency of occurrence was:

Ranking	Activity	% of all rail accidents
1	Walking	20.5%
2	Travelling on	18.5%
3	Collision	13.5%
4	Derailment	5.5%
8	Coupling	3.5%

- The two above rankings were combined to get an overall ranking :

Ranking	Activity	Rank no.
1	Walking	100
2	Derailment	84
3	Collision	80
4	Travelling on	80
5	Coupling	76

The reported fatal accidents for the period 1987 to 1997 averaged at 3 fatalities every 2 years. The number of accidents attributable to rail mounted vehicles

averaged 0.099 accidents per 1000 employees per annum. Members of the train teams were victims in 49% of the accidents. Members of the train teams were victims in 72% of the fatal accidents.

Types of vehicle (as per GAP 520)

The involvement of different rail mounted vehicles in accidents was found to be as shown below:

Vehicle	All accidents	Fatal accidents
Hoppers	58%	35%
Battery locomotives		24%
Diesel locomotives	30%	9%
Material cars	12%	9%
Other (loaders, drills, etc.)	<u>0%</u>	<u>23%</u>
	100%	100%

Type of injury (as per GAP 520)

The accident reports that gave details of the type of accident or body part injured were analysed.

	All accidents	Fatal
accidents		
“Struck”/”Crushed”	28%	62%
Fingers, hands & arms	27%	
Legs	16%	
Heads	2%	6%
Not specified	<u>27%</u>	<u>32%</u>
	100%	100%

Site of the accident (as per GAP 520)

From the accident reports, the sites of accidents were found to be:

	All accidents	Fatal accidents
Haulages	47%	68%
Cross cuts	30%	15%
Stations and tips	13%	
Reef and collection drives		6%
Other	<u>10%</u>	<u>11%</u>
	100%	100%

Gold versus Platinum (as per GAP 520)

The accident rates for rail related accidents on platinum mines were lower than the gold mines.

Couplings (as per GAP 520)

Most countries (UK, USA, SA Australia and Canada) require a safety chain in addition to the coupling when transporting men underground. Only the UK specify a standard coupling height, and this for man carriages only. The UK coal mines use mainly the Willison and Allen couplings. The US Coal mines require a system

that permits automatic coupling and remote uncoupling – the Willison appears to be extensively used.

Track Standards (as per GAP 520)

Derailment and re-railing are two of the major causes of accidents and are often associated with poor track standards.

Couplings (as per GAP 520)

The couplings used at the mines visited were of the type that required a pin to be inserted manually through a coupling bar between adjacent vehicles. The guard or shunter therefore had to reach between the cars in order to couple, although some coupling pins had been extended so that he did not have to stoop. Presumably, most coupling operations occur due to the movement of the cars during the coupling operation. It was also seen that the height of couplings varied from vehicle to vehicle so that the line of action of the forces between vehicles introduced a moment that was capable of reducing the down force on some of the wheels and thus causing a derailment.

Issues to be addressed (as per GAP 520)

- Automatic or remotely operated couplings should be fitted to rolling stock, including locomotives
- Couplings should be set a constant height
- Driver and guard training should be segregated

Proposed regulations and codes of practice (as per GAP 520)

Training

Guards shall undergo a suitable accredited training course.

Locomotive drivers shall undergo a suitable accredited training course only after successful completion of a guard training course and a suitable period of acting as a guard on a mine.

Couplings

Locomotives shall be fitted with impact and energy absorbing couplings.

Couplings, and all parts of the locomotive lying on the line of action of the couplings shall be designed with a minimum factor of safety of ten based on the locomotive drawbar pull.

Couplings of locomotives and vehicles used on each haulage shall be set at the same height.

Safety chains shall be fitted to man carriages and provision shall be made for them on locomotives.

Couplings shall be designed to enable coupling and uncoupling to be carried out from outside nip points, e.g. by remote operation or automatic engagement.

Marshalling

No coupling or uncoupling shall be carried out whilst the train is in motion.

Conduct of persons

Persons shall not get on or off moving equipment

Persons shall not go over, under or between cars unless the train has stopped and the driver has been notified.

Proposed changes to Regulations

Strength of coupling

Standard height

Safety chains for man riding cars

Automatic or remote operation

Appendix 14

Proposed regulations and codes of practice

The GAP 703 project team largely agrees with the suggestions made by the GAP 520 team in terms of areas that should be addressed either in regulations or in codes of practice, as amended GAP 703 team below:

Training

Tramming crews should undergo suitable accredited training courses.

Couplings

Couplings, and all parts of the locomotive lying on the line of action of the couplings shall be designed with:

- a minimum factor of safety of 15 based on the locomotive drawbar pull.
- a minimum factor of safety of 1.5 based on the impact loading.

Couplings of locomotives and vehicles used in each haulage shall be set at the same height.

Safety chains shall be fitted to man carriages and provision shall be made for them on locomotives.

Marshalling

No coupling or uncoupling shall be carried out whilst the train is in motion.

Couplings shall be designed to enable coupling and uncoupling to be carried out whilst the train is stationary.

The train moving to effect engagement or disengagement of the coupling or link should only occur when the guard is standing clear of the vehicles

Conduct of persons

Persons shall not get on or off moving equipment.

Persons shall not go over, under or between cars unless the train has stopped and the driver has been notified.

Persons shall not carry out coupling or uncoupling on the inside radius of a curve.