# Collision Avoidance Technology: The use of Fourth Industrial Revolution (4IR) for Safe Mining.

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## Abstract

A mining company called "Kanyon coal mine" is introducing collision avoidance technology as a means to minimize accidents and incidents, this is in line with global trends for safe mining. The mine is introducing collision avoidance through Radar, Global Positioning System (GPS), and Global System for Mobile Communications (GSM). This paper is a study of the effects of introducing new technology to the existing one; the use of technology for safe mining. The mining equipment is upgraded with new technology at the coal mine and this created an unintended problem of safety, the mining equipment uses echolocation, GPS, GSM, and Rader as means to assess possible collision of machines with each other in the dark, during poor visibility or due to operator negligence. All these systems we call "anti-collision system", these translate to an "emergency engine kill switch" (EEKS) in case the driver is unaware of the pending danger, which will result in the switching off of the engine and engaging the braking system, by locking the wheels in place, the problem here is; after the power dies what will happen to the momentum of the truck, and what are the safety measures to counter slip of the locked wheels on gravel roads, resulting in a deadweight collision anyway. The study investigated the braking system, the slope and the mechanics the truck in statics. The paper argues that the unintended consequence is as a results of doing as engine kill on a wrong slope level, this was studied intently using Coulomb's law and results presented.

## Keywords
Vehicle dynamics, Breaking Systems, Friction, Slope, Tractive effort and Slip

## 1. Introduction

### 1.1 Background

Kanyon Coal Mine in Mpumalanga is one of 19 coal mines in South Africa; these mines supply power stations like Majuba, Matimba and Medupe to name but a few. The coal industry is the backbone of a grid that supplies about seven countries with electricity, that is South Africa, Zimbabwe, Zambia, Lesotho, eSwatini, Namibia, DRC, and Mozambique, the electricity regulator produces over 54 400 MW of power of which 40 000 MW is owed to the coal industry, that is 73.52% of power supplying seven countries. (Salaza et al, 1990)

Figure 1 (a)

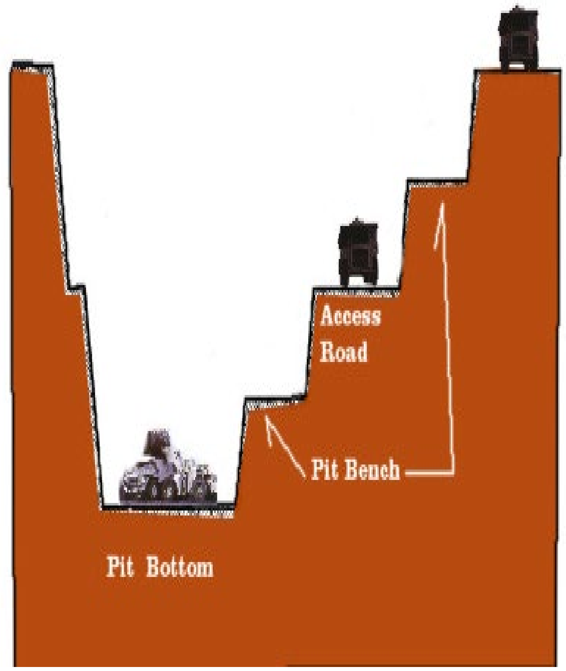


figure 2 (b)

Figure 1 (a) and (b) open cast or surface mining of coal in South Africa (Source: Gref, 2020)

The project focusses on the first part of the process "Mining operations"; the mining equipment's braking system to be exact; there are three basic types of braking systems in the trucks at Kanyon coal; service break, parking brake, and emergency braking system. All these are designed to ensure Safety, improving stopping performance (Smith et al, 2010). This paper will study the dynamics of a suddenly stopped vehicle either in a straight path with a load and on a slope with a load, and the momentum of the truck, if it will stop, or slip and collide with the other truck or worse slip off the slopes of the mines. Figure 1 (a) and (b) shows depictions of both open cast and surface mining.

**1.2 Bell B40 E Trucks Braking systems**

Technical data obtained during the testing of the B40 E trucks on their breaking systems is such that the Service Brake: which is a Dual circuit, full hydraulic actuation wet disc brakes on front, middle and rear axles. Wet brake oil is circulated through a filtration and cooling system. The brakes produce Maximum brake force of 488 kN. The Park & Emergency braking system is spring applied, air released driveline mounted disc which produces a maximum brake force of 218 kN, the trucks are also fitted with an auxiliary Brake which is an Automatic Jacobs Engine Brake® that is the automatic retardation through electronic activation of wet brake system. Generating a total of 963kw of breaking force.

The trucks that Mercedes Benz (MTU) engine produces gross power of 380kW, through a reduction gearbox with a gear ratio. The inertia forces are assumed to pass through the front middle and back, for this reason the forces will be assumed to pass through the center of gravity. The braking system is tested and has been certified to work, in the sense of locking the wheels successfully (Dence, 1963). Figure 2 shows rolling resistance against the mass of the truck as well as the gross tractive effort against speed while Figure 3 (a) and (b) shows the Bell trucks on different terrains.

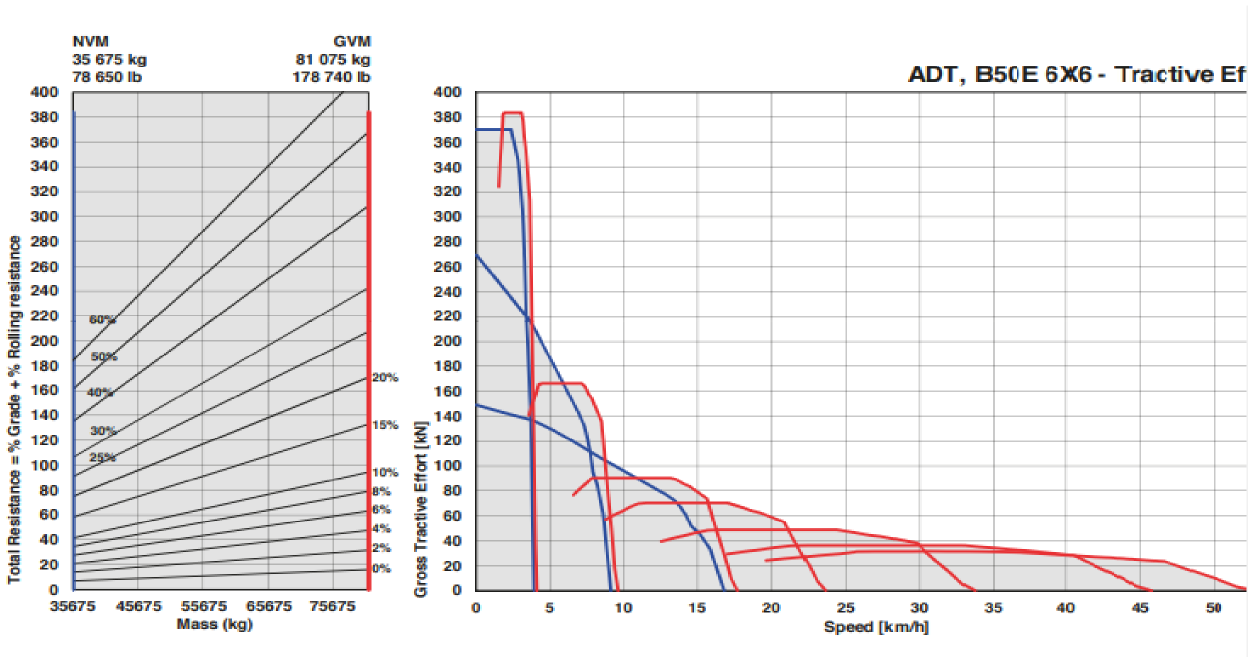


Figure 2: Rolling resistance verses Mass of truck and Gross Tractive Effort vs. Speed (Bell International, 2020)

### 1.3 Mining terrain

Figure 3 (a)

Figure 3(b)

Figure 3 (a) and (b) shows a Bell trucks in different terrains (Bell International, 2020)

The tires behave according to the environment they are in, some terrain causes slip, even if the wheels are locked, the conditions of slip are the application of coulombs law as shown in Figure 4.

$Fs\ frictional\ force\ (emergency\ brakes): kN$
$Fn\ Normal\ force\ (\mathrm{mgSin}(\Theta) = \mathrm{Fn}): kN$

$F_s > F_n : No\ slip$

$F_s \geq F_n$ : *Pending motion*
$F_s < F_n$ : *Slip Motion*

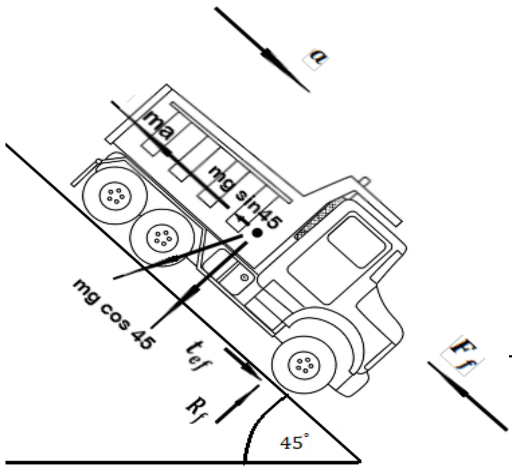


Figure 4 (a)

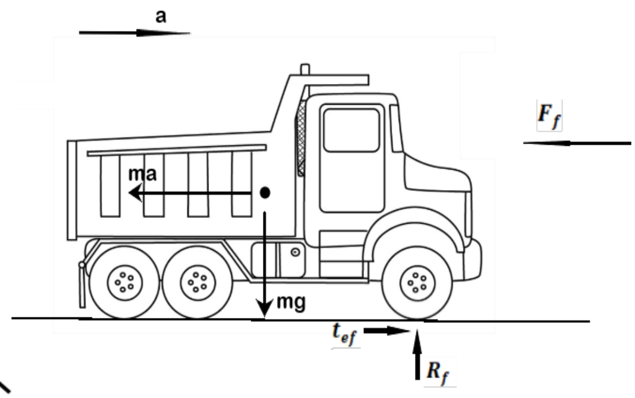


Figure 4 (b)

Figure 4 (a) and (b) demonstrates the truck on different slopes and forces acting on them.

## 2. Methodology

The research studied the actual truck, before slip, pending slip and slip motion when the wheels were locked by emergency collision avoidance technology. This was achieved by using the equations of static friction (Table 1) and application of coulombs law while changing the slope.

Table 1: Summary of Coulombs law

| | | |
|---|---|---|
| No-apparent motion | $\sum F=0$ | $Fs=P_{APPLIED}$, $P<F$ |
| Impending Motion | $\sum F=0$ | $F=P=F_s$ |
| Motion | $\sum f\neq 0$ | $P>F_s$ |

Summary of formula in the plane of the linear motion of the truck at any angle theta.

$$mgSin(\Theta) = Fn \quad (1)$$
$$F=\mu P \quad (2)$$

The applied load is as a results of the truck weight, and the frictional force is the force that needed to overcome the applied motion in order for the truck to remain stationary when the emergency brakes are applied. This is best explained by Figure 5 (Coulomb's law of static friction), from the linear slope the truck is stationary; at the point of "instant of motion" the truck is sliding and this will be modelled mathematically (Salaza et al, 1990).

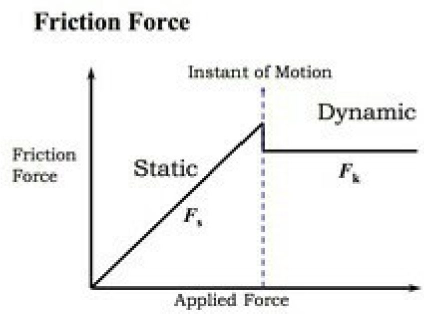


Figure 5: Frictional force vs. applied load (Source: Drescher et al, 1989)

## 3. Results

The results derived from measurements in operation are shown in Table 2. The slope or the inclination was varied from zero to the maximum of 45 degrees, using increments of 5 degrees. The findings were such that when the truck was unloaded, the instantaneous slip was between 30 and 35 degrees, this meant that at 35 degrees the truck would slip and move to the state of linear dynamics as shown in Figure 5. Similarly, when the truck was loaded it would slip at 15 degrees. The results were obtained using the principle of static friction or Coulomb's law which characterizes an object as shown in Table 1. When the sum of the normal forces was zero, then the frictional force was equal to the applied force and the friction factor was 1 and/or the frictional force was greater than the applied or the normal force, therefore there was no apparent motion. (Shield, 1955*)*

The second condition of Coulomb's law Table 1 (middle row): The applied force or sum of forces is equal to the frictional force and the friction factor is 1 the truck is just before instantaneous motion, this is demonstrated by Figure 5, the dotted lines indicate the moment before the truck starts to slip or move. And lastly the point where the applied force or the normal force is greater than the frictional force, causing the truck to slip and enter into a field of vehicle dynamics, where an accident might occur.

Table 2. Results Derived from Measurements in Operation

| | | | Unladen (m=35675 kg) | | Laden (m=81075 kg) | |
|---|---|---|---|---|---|---|
| Slope | Unladen | Laden | Braking Force kN | Normal Force (kN) mgSin(Θ)=$F_n$ | Braking Force kN | Normal Force (kN) mgSin(Θ)=$F_n$ |
| 0 | No-Slip | No-Slip | 218 kN | 0.00 | 218 kN | 0.00 |
| 5 | No-Slip | No-Slip | 218 kN | 30.5 | 218 kN | 69.32 |
| 10 | No-Slip | No-Slip | 218 kN | 60.77 | 218 kN | 138.11 |
| 15 | No-Slip | Pending | 218 kN | 90.58 | 218 kN | 205.85 |
| 20 | No-Slip | Slip | 218 kN | 119.74 | 218 kN | 272.02 |
| 25 | No-Slip | Slip | 218 kN | 147.90 | 218 kN | 336.13 |
| 30 | No-Slip | Slip | 218 kN | 174.99 | 218 kN | 397.67 |
| 35 | Pending | Slip | 218 kN | 200.74 | 218 kN | 456.19 |
| 40 | Slip | Slip | 218 kN | 224.57 | 218 kN | 511.24 |
| 45 | Slip | Slip | 218 kN | 247.47 | 218 kN | 562.39 |

Figure 6 characterized the load of the truck when it was empty and when it was fully loaded against the manufacturers specified park & emergency braking system; which was spring applied, and air released driveline mounted disc which produces a maximum brake force of 218 kN. The graph illustrates the slip clearly in both cases, where the unloaded and laden graphs cut the constant frictional force of 218kN, beyond that point the truck goes into constant dynamic mode and starts moving uncontrollably (Rajamani 2011). For the loaded truck the slip is slightly below 15° and for an empty truck the slip is between 35° and 40°. (Bell International, 2020)

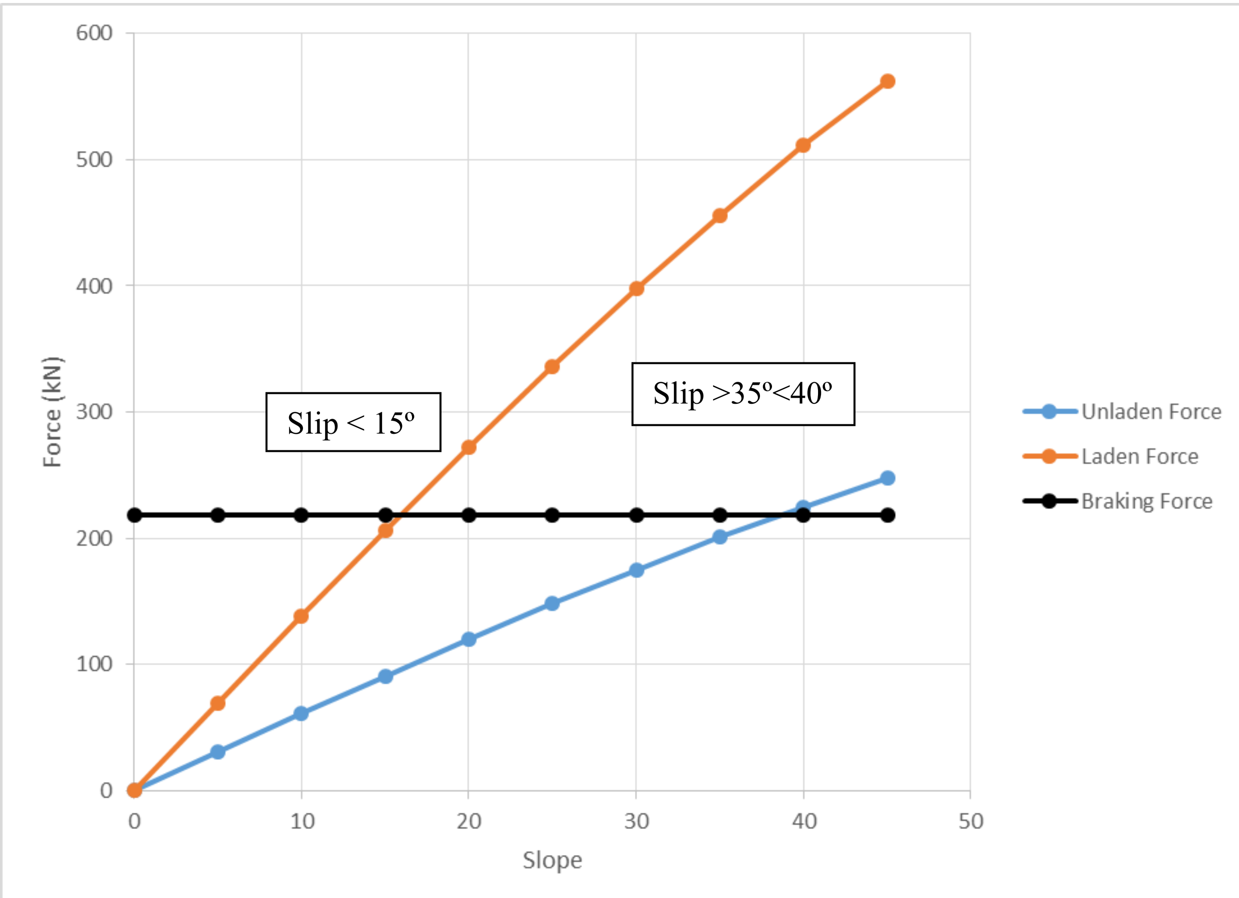


Figure 6: Loaded and unloaded force against slope

## 4. Discussion

The bell company prides itself with being satisfied with the highest standards of safety in their three braking systems, from the service brake to the emergency braking and the electrical wet braking systems. This paper is addressing the question of when the power is suddenly cut off at what slope will the operation cause a dead weight accident. This only limits us to statics and just before dynamics happens. Hence the friction under discuss is static friction and the applied load due to the mass of the truck. (Bell International, 2020)

Two possible scenarios were studied;

- When the truck is un-loaded which weight $m$ = 35675 kg at different slope angles as in Figure 4 (a) to (b).
- When the truck is fully loaded to the maximum weight of $m$ = 81075 kg at various slope angles, as calculated in Table 2 and demonstrated in Figure 4 (a) to (b).

Coulombs law (Table 1) enabled us to determine the slope at which the truck begins to slip, for the unloaded truck the slip is just before 35º and for the loaded truck the slip angle is much smaller at just before 15º, making the difference between a loaded truck and unloaded truck about 20º apart, this tells us that for the 218kN emergency braking force as rated by the manufacture (Bell International, 2020) for the unloaded truck we can switch off the engine for slopes at lower than 35º and for loaded trucks we can only switch off the engine at slopes of lower than 15º. Figure 6 shows that the normal force to the slope follows the theoretical trajectory of Figure 5, and follows coulomb's law of static friction. Industry problems require solutions that save them money and time, it is very important for an engineer to go further and add the element of safety and controlled mining, the technology we are introducing is one that priorities safety of people and machines, hence the company has invested such a lot of money in the collision avoidance technology, The shorter the distance the trucks have to travel the more it saves on fuel costs, hence the engineer has to constantly work around other engineers to make sure that safety is not compromised, ideally the maximum slope of a mine is about 12 º but some have gone as high as 45º, so this paper contradicts any slope that is more than 35 degrees and not just reckless but a danger to the people and machines. (Zare et al, 2013)

## Conclusions

Mechanical engineering work primarily rely on problem solving while mechanical equipment is supplied standard from the manufacture or suppliers. However, because there are different departments in industry pushing for maximum production at minimum cost, there are codes and practices that are modified, in some instances, some even 'cut corners'. For example, there is a minimum slope angle for open cast mining but in reality user experience has been pushing boundaries and making a mismatch between legal requirements and codes of practice, in a sense that the mechanical engineer's job is to harmonize these two to ensure maximum safe working environment for the people and the machines. An engineer's job and function becomes dynamic in the sense that this may not necessarily end where it was intended. The paper was set to address the issue of a slipping truck and as a result unintended consequence of dead weight collision, and in this set up minimum slope angles to which the Collison Avoidance Technology can be used to switch off the truck or rather safe slope angles, measured by the digital inclinometer for the performance of engine kill manoeuver, which was 15º for loaded trucks and 35º for unloaded trucks.

## Acknowledgements

The collaboration between industry and academia is available to academics who are fairly new and lack "some" industrial experience to enable them to better explain theoretical concepts dealt with in class room setups for the benefit of their students. The authors would like to acknowledge the support from the Royal Academy of Engineering (RAE) through the Higher Education Partnerships for Sub-Saharan Arica (HEP SSA) project at University of Zimbabwe for supporting this work by way of secondment from the University of Johannesburg to Mikrodev Southern Africa.

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## Biographies

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