

# Collision avoidance and operator guidance - Innovating mine vehicle safety

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### **1 Abstract**

There is no doubt that vehicle operators of heavy equipment have to accomplish difficult tasks. The increase in mine productivity has led to a proportional increase in equipment size. Most vehicles have considerable blind spots, due to scale alone. Combine normal variations in environmental conditions, in-vehicle management systems, navigation systems and radio communications; the most experienced operator can be challenged by multiple distractions. Despite the best efforts of operators, accidents on mine sites remain an industry wide problem. The reasons for accidents are diverse, so too are the collision scenarios.

Building on experience in the development of advanced driver assistance systems including: Adaptive Cruise Control; Automatic Emergency Braking; Pedestrian Protection; Lane Departure Warning; up to complete Autonomous Driving platforms; SICK has introduced a family of turnkey Collision Warning Systems. SICK has invested in the adaptation and the combination of different proven technologies in a way to be truly fit for purpose.

### **2 Introduction**

Safety & Health Commissioner, Stewart Bell estimates that greater than 50% of mining operations in Queensland are currently trailing or operating Proximity Detection Systems (PDT) on heavy mining vehicles. Sadly, the majority of fatalities in mines are still been the result of interaction between humans and mining equipment. The varieties of accidents demand a combination of technologies to assist operators and reduce risk.

Having captured the automotive market in the recent past, advanced driver assistant systems are now on the move to conquer industrial vehicles in mining. SICK has consequently introduced a family of turnkey Proximity and Collision Detection Systems for the OEM and retrofit market back in the beginning of 2010.

Meaning systems that actively assist the machine operator to safely and efficiently manoeuvre large mobile equipment like wheel loaders, haul trucks and excavators. Accidents are often serious, causing enormous costs through repair and lost production.

Special focus is given to human factors. Developed to be an accepted aid and not an annoyance, the system adopts behaviour recognition, automatic warning zone adjustment and context switching according to different driving manoeuvres. The paper also exemplifies the importance of the end user's dedication to the project and ownership of the technology by means of successful installations.

SICK has invested in the adaptation of proven technologies in a way to be utilized by mining companies. This has resulted in a product that is easily installed onto a variety of

vehicle types and makes; a “plug and play” system without the necessity to be integrated into the vehicles control and sensor system. This allows for cost effective adaptation and offers further integration into fleet management or other collision awareness systems as required. A number of proximity detection systems are available on the market, all of which are designed to help save lives.

This paper provides an overview of the

- Advances on the road from manned to autonomous mining
- Situational Awareness & environmental perception sensors
- Awareness System overview
  - Human Machine Interface (HMI)
  - Systems fit for purpose
- Operator assistance in the manned underground mining operation
  - The information that lies in tunnel walls
- Conquering technical challenges in implementation

### **3 Advances on the road from manned to autonomous mining**

Australia is in a unique situation where institutes like CSIRO, CRC Mining and the ACFR do a lot of research and functional prototyping for huge automation projects like the “Mine of the future”. Mining Companies’ programmes include improvements to mining processes of extracting minerals, reducing environmental impacts and improvements in safety up to fully integrated, automated operations. One of the three key themes is autonomy. One important part of the move to greater autonomy will be the introduction of a fleet of new driverless trucks, loaders, drills, trains and remote controlled equipment. These new technologies aim to improve productivity and safety and will enable employees to work from a work place which is distant from the mine site [1]. All the traffic lights are set to “green” for automation technology.

### **4 Situational Awareness**

Environmental Perception technology is the key to reduce the impact the human factor can have. The primary goal of the environmental perception technology is to provide a set of data that describes the environment sufficiently in a model. This model allows us to track objects and develop an effective strategy to avoid or mitigate the impact of collisions through impaired visibility or loss of control. Modern driver assistant systems like the road departure warning today show the potential of semi automatized driving functions.

The quality of the situational awareness determines the set of actions (or warnings) the system can issue with high confidence. If some conditions, e.g. weather decrease the quality of the situational awareness, the systems reaction must be appropriate to secure a safe operator (vehicle) reaction in bad road conditions. The most important requirements on a sensor for longitudinal and lateral guidance on mobile equipment are described below. The following tables were developed in collaboration with international mine managers and industry experts during a Mine Automation Summit in South Africa [7].

<b>relevant criteria</b>	<b>Magnetic field (VLF) Antenna</b>	<b>Laser scanner (LIDAR)</b>	<b>Radar (77Ghz Doppler and monopulse)</b>	<b>Traffic Monitoring Systems - GPS tracking</b>	<b>Traffic Monitoring Systems - WIFI</b>	<b>Video - stereo vision</b>	<b>Ultrasound</b>
<b>Range</b>	2..15m	>150m	>150m	dependent on the radio in use	dependent on the radio in and RFID tags used (active 100...150m, passive 5...7m)	>150m	up to 8m
<b>distance accuracy</b>	m (sub meter only under ideal conditions)	very high precision (20 mm)	m (sub meter only under ideal conditions)	sub meter only with high precision (base stations etc.)	Meter	usually > 1m	0.2mm
<b>angular resolution</b>	very limited directional perception	0.1deg	2...4 deg	dependent on the GPS bearing quality	very limited directional perception	pixel usually 1..4 deg	8..10deg
<b>Field of perception (single unit)</b>	360 deg	up to 360 deg	17...50deg (single beam... multi beam)	360 deg	360 deg	up to 127 deg	8...10 deg
<b>Update rate</b>	Ms	10ms	70ms	sec	sec	40ms	Ms
<b>deposits at sensor active surface</b>	usually no issue	dirt & blockage detection standard. Mounting Precautions necessary	blockage recognition standard. mounting precautions necessary.	usually no issue	usually no issue	mounting and protection precautions necessary	mounting and protection precautions necessary
<b>dust, fog, rain and snow impairment</b>	No	impaired in dust, if no further hard and software processing e.g. multi echo, detection threshold adaption, filtering and internal dust classification	scattering noises possible	Impairment – usually no issues	Impairment	vision impaired.	impaired detection
<b>Ambient light, sunlight impairment</b>	No	Independent of illumination, internal dazzle filters standard	No	No	No	Yes	No
<b>requires Tags</b>	Yes (PAD: personal alarm devices necessary)	No	No	Yes, every vehicle needs to be equipped with this technology	Yes, every vehicle needs to be equipped	No	No
<b>requires line of sight</b>	Limited perception around corners (in tunnels) possible (VLF)	Yes	Yes	GPS (requires "line of sight"), RF communication impaired	WIFI 2...6GHZ, VHF/UHF com very limited (1...5m around corners)	Yes	Yes
<b>Coal mines (EX approved), types of mining)</b>	Yes	Possible. Laser scanners used in flameproof enclosures	Possible	No	Yes	Possible	No
<b>Availability / Reliability</b>	High	High	High	GPS very much dependent on the environment.	Increased availability through multi channel transmission	High	High

**Priority: Highly available and reliable system components**

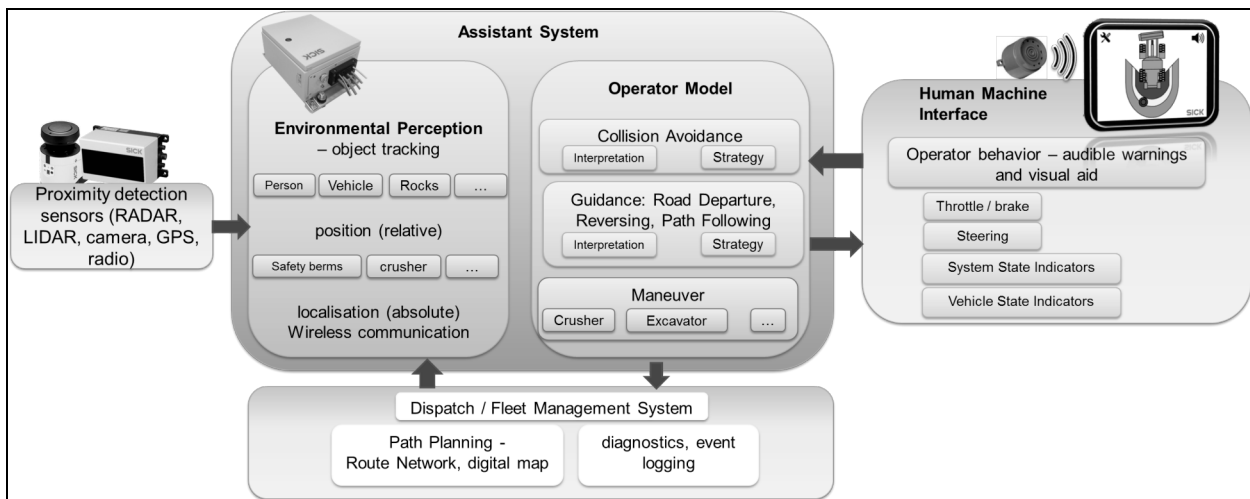
The development of the system functions can be done by utilising state of the art driver assistant application modules. The requirements on a situational awareness sensor describe the feasibility to develop certain assistant system applications in a mining environment.

<b>Requirements for application</b>	<b>Magnetic field (VLF) Antenna</b>	<b>Laser Scanner (LIDAR)</b>	<b>Radar (77Ghz Doppler and mono pulse)</b>	<b>Traffic Monitoring Systems - GPS tracking</b>	<b>Traffic Monitoring Systems - WIFI</b>	<b>Video - stereo vision, 3D</b>	<b>Ultrasound</b>
<b>collision avoidance speed range 0...vmax</b>	Low speed (dependent on vehicle)	Achieved	high speed scenarios are still not applied to mine sites (discrimination between road surface and obstacle reflections difficult)	the functionalities are widely used in Traffic Awareness Systems opposed to collision avoidance	Update rate and accuracy critical, the functionalities are widely used in Traffic Awareness Systems opposed to collision avoidance	in road traffic systems used as complementary system	No
<b>road departure warning (guidance)</b>	No	Achieved	artificial mine structures necessary for tracking	if high precision GPS and accurate map available, positional navigation possible	if high precision GPS and accurate map available, positional navigation possible	in road traffic systems first systems in use	No
<b>detection of merging traffic, oncoming traffic, stockpiles, infrastructure, crusher etc.</b>	No	Achieved	limitations in detection of crossing traffic (due to detail, resolution and field of vision)	No	No	technically possible	No
<b>discrimination of intersections and road side objects</b>	No	Achieved	limitations in detail and resolution and field of vision	if high precision GPS and accurate map available, positional match possible	No	Achieved	No
<b>Above ground</b>	Possible	Yes	Yes	Yes	Yes	Yes	No
<b>Underground / coal</b>	Yes/Yes	yes/possible	Questionable	No		Yes/possible	No
<b>Safety</b>	fail safe available	safety sensors available.	fail safe available, use of reference targets	Increased reliability through multi channel transmission	Increased reliability through multi channel transmission	-	-
Always dependent on other system components (safety PLC, watchdogs, observers, system diagnostics etc) for the measurement technology to ensure availability and fail to safe if necessary							
<b>beneficial technology combination</b>	Combinations with WIFI common	some systems already include GPS and V2V radio. Combination with radar and camera possible	most systems combine already with GPS, V2V radio - LIDAR recommended for high speed scenarios and guidance	combination with LIDAR or RADAR necessary in order to detect the untagged environment	combination with LIDAR or RADAR necessary in order to detect the untagged environment	cameras are not used in mine automation tasks, but complementary item as a passive assist or for remote controls	Range and resolution prevents from an extensive use for collision avoidance on mobile equipment.

As mining equipment is used in very different environmental conditions (e.g. surface and underground) and in different tasks, there is no “one fits all” solution. In the context of the application, the availability of the sensor as a component plays the most important role. Modern sensor diagnostics allow e.g. feedback and fail safe functions.

## 5 Awareness System Overview

Passive Operator Guidance by means of mirrors and complementary cameras (reverse, side and blind spot) is important for an operator – active Proximity Detection Systems have to warn when the human fails. The building blocks of any operator assistant system are a number of environmental perception sensors used cooperatively with other additional sources of information like GPS.



**Figure 1 Operator assistant system overview**

Established driver assistant system concepts based on local vehicle sensors have to provide the warning under the adherence of a reaction time. Recognised studies [3] define a suitable time window for “imminent crash warnings” with 700-1500ms before collision. A window of more than 1500ms can therefore be used to provide driver information (called “advisory warning” [3]) to address the potential hazard, catch operators attention and establish readiness to react. Audible operator warnings are aimed to a direct operator reaction. The established timing structure can therefore be augmented in adding an early time component to enhance the effectiveness of the system.



**Figure 2 SICK operator display - early advisory warning (obstacle monitoring zone: only visual, no audible warning)**

The interpretation of measurements has to be done by the system itself, which warns and indicates possible incidents to react or to mitigate an impact and to safeguard the persons involved. Qualified obstacle information from these sensors is utilized in a sophisticated warning strategy, which alerts the operator, via a simple user interface to take evasive action. The same technology has been widely used in passenger vehicles to automatically control the vehicle, adapt the speed to a safe distance and to avoid the collision.

## 5.1 Human Machine Interface

A driver assistant system exists only with the operator “in the loop”. This fact requires special attention. The operator models’ task (cp. Fig 1) is the situational interpretation and to derive strategies to assist safe operation. The human factor plays an important role in the development of HMI’s. Operator focus must remain on tasks at hand. Unfiltered visualisation of the environmental data inevitably leads to information overload. The operator has to filter and extract the relevant information. This task costs precious time

which is not available, when a collision is pending. The objective of a warning system must lie in the delivery of information that assists in the current situation.

The system has to decide on timing, modality and content of information [6], which is usually provided by means of visual display and/or audible information. Audible warnings have to be limited to imminent crash warnings. Particularly frequent activation or false alarms will lead to ignoring and even a contrary effect on the operator performance. Further importance is given [6] to the specific direction (location) and probability (risk) of the collision, which can influence the effectiveness of a warning system.

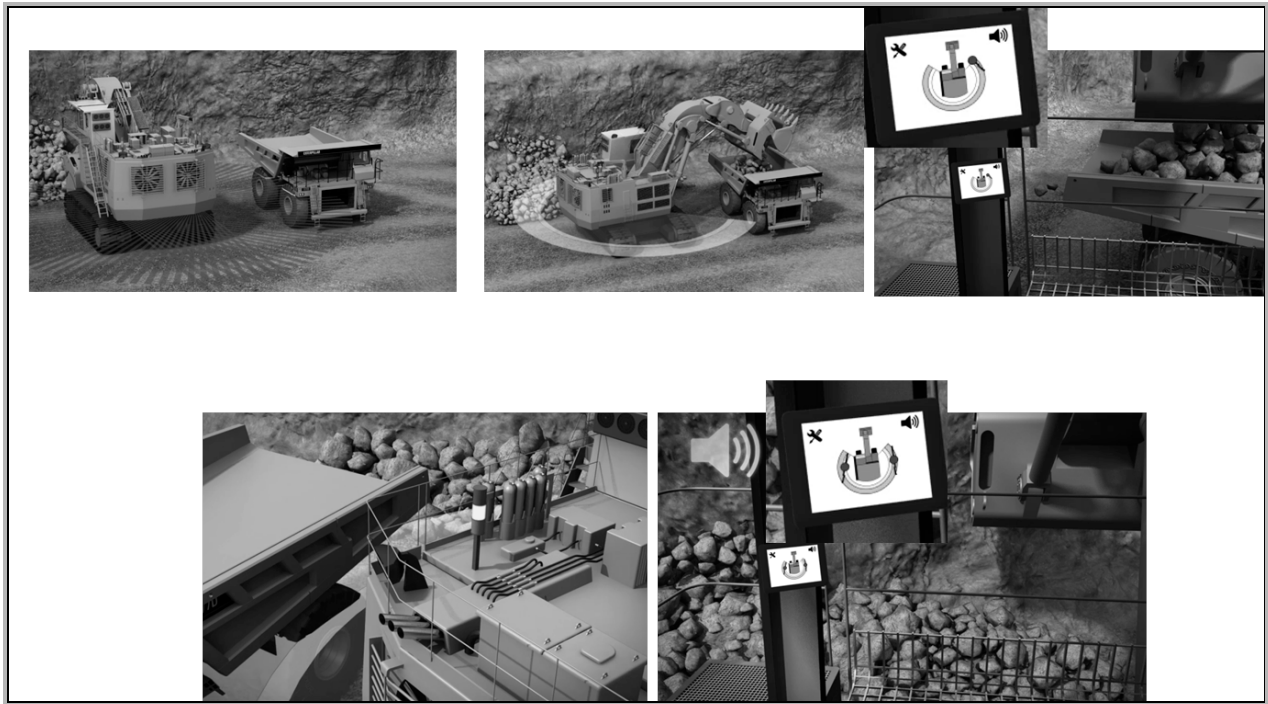
## **5.2 Systems fit for purpose**

The operator has to be certain about the system functionality in critical situations and current system limits in case of a component failure. A system limitation has to lead to a clear indication to the operator. It is dangerous to assume that the majority of accidents occur in low speed interactions, if it is a means to obscure the fact, that the avoidance and assistance technology applied cannot prevent high speed collisions. It is also dangerous to have a singular focus on high speed haul road scenarios.

The effective combination of technologies is a sensible approach, considering that fatalities and serious injury can occur in all possible scenarios from: a close proximity crush; an operator misjudgement during a precision loading or unloading process; a micro-sleep whilst at the controls of a vehicle. Ultimately, people working within the mines bear the costs of such incidents. Questions have to be asked when deciding for a technology, these include amongst other things:

- What are most critical vehicle interactions in the particular site? For further information see [2] and [3]. This information is usually part of a risk analysis.
- What is involved in an installation (time and effort, service shift is usually the critical limit e.g. for a complete TPS)?
- Warning strategy applicable to particular mine site (adjustable & dynamic warning zones)?
- Does the entire fleet have to be equipped with the technology in order to be effective? Is successive installation possible?
- Layout active warning strategy (audible and visual) → operator's focus lies on tasks at hand; operator information management (What's comfort? What's necessary?)
- Does it provide interfaces fleet management systems (application event protocol, event logging)
- Reliability and robustness
- Availability / Maintenance - system self-diagnostics available. Ease of fault identification. Suited for onsite service by customer himself who stocks spare parts?
- Operator acceptance: False alarm & nuisance alarm rate. Is the warning strategy reasonable, annoying or a real help and pays off?
- Is local & competent service network available?
- Are we prepared to take ownership of this new technology

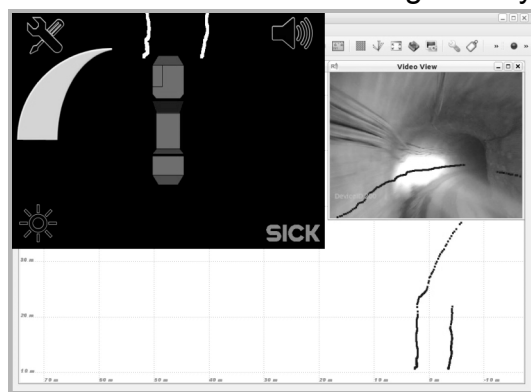
Below an example of a system that fits for purpose with the ability to assist in situations that couldn't be protected before.



**Figure 3** Example SICK Excavator Protection System (collision warning system and precise loading assist at the same time), on top = standard operation, bottom = too close for loading → Redirect!

## 6 Operator assistance in the manned underground mining operation

Some of the large mining companies currently invest in the development of block cave mining and fast tunnel development technologies – which allows them to extract ore from bodies without having to dig an open pit at the surface. In order to safeguard the operation underground, a tunnel collision warning system has been especially designed as part of the SICK collision awareness system family to assist the operation in tunnels. The system issues warnings when the equipment operates too close to the walls. Cornering and entering intersections is automatically recognised, analysed and signalled if the operator overshoots or cuts corners. The system furthermore provides a manoeuvring assist for confined spaces. The operator screen displays a distance profile of the surrounding and the vehicle in a birds eye view – similar to modern navigation systems, but more accurate.



**Figure 4** data collection for evaluation – an important task during the development of the final warning strategy for the operator screen display (upper left hand corner)

Heart of the system is a small touch screen display with integrated industrial computer, which displays relevant information dependent on the current situation, like a modern Navigation system. The data of the surrounding is delivered by a front and a rear laser scanner. All the information is processed in the display – application and warning strategies are computed. The design of the system fits perfectly to the underground haul

truck from Powertrans, an Australian mine vehicle manufacturer, which operates with this technology.



**Figure 5** Powertrans underground haul truck

## **6.1 The information that lies in tunnel walls**

Current speed measuring devices on underground vehicles are not very accurate. Revolution counters measure the rotations of the wheel, which is used to calculate the velocity. This technique and the result are dependent on the road surface condition. A complete halt on the tachometer doesn't necessarily mean the truck has stopped and lost traction. The load of course increases this effect. Inertia opposes the change of motion. Loss of traction must not be underestimated especially in corners and in breaking manoeuvres. Accurate speed information which is fed into the system would therefore improve algorithms and increase the overall performance dramatically.

SICK knew that the scan data of an underground automation system contains the information to compute speed information. A thesis has been written to the topic and prototype developed [5]. More accurate speed information instantly adds value to the vehicle control system and improves motion estimation, driving path calculation and further algorithms in the operator assistant system. The solution has to be built of algorithms describing tunnel walls, computing free field (unobstructed areas) and predict motion. The information delivered by a laser scanner in a tunnel can be used to:

- describe the tunnel wall in polygons
- evaluate the free space (unobstructed accessible area for the vehicle)
- evaluate velocity and turning rate (yaw rate)
- estimate possible driving paths
- estimate the movement of the ego-vehicle



**Figure 6** scan of an area (like a tunnel) and a corresponding 2D online map (black: detected objects and structures; grey: undiscovered area; white: unobstructed accessible area)

Modern laser scanners produce 10 to 100 scans per second. A scan can consist of a couple of hundred measurements with multiple characteristics like distance and intensity.

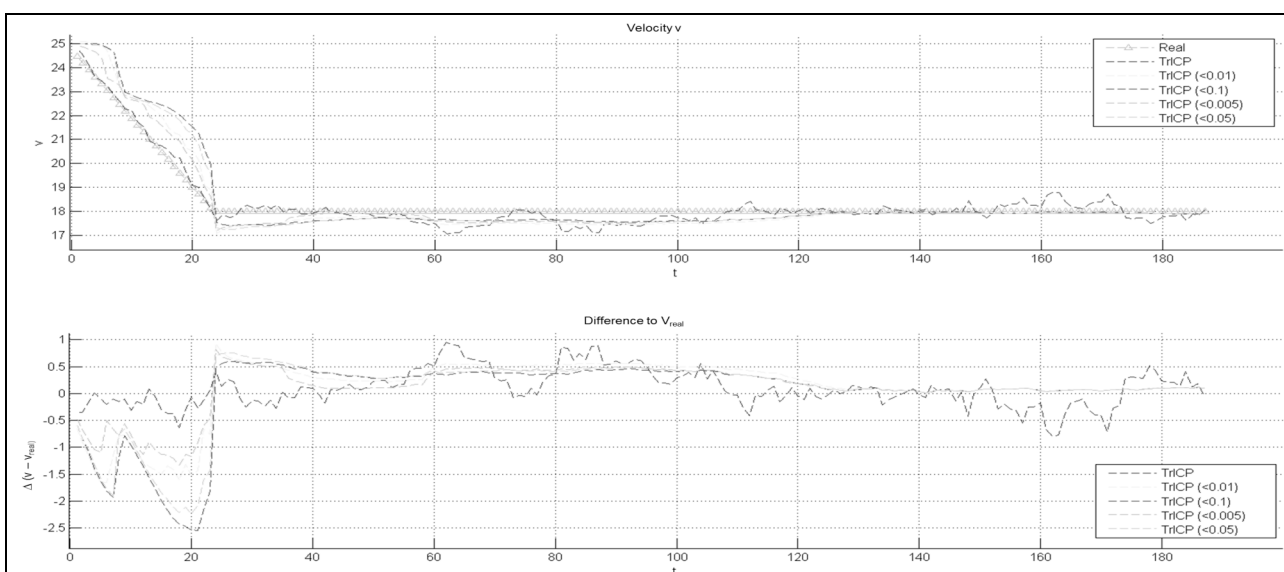


The system development always has to deal with the constraint of an embedded industrial architecture. The data therefore has to be reduced to significant points. An envelope build of polygonal lines includes all this points and can be used as the barrier and thus define the drivable path. Assuming normal distribution of scan points as a certainty around measurement values is an approach to compute a safety distance and can be used to evaluate the drivable area for the vehicle. White areas are open areas for the vehicle, grey areas are undiscovered (see fig.6).

Extracting freely and safely accessible areas of scans or scan accumulations (over time) offers benefits to an operator assistant system. This area can therefore be used for collision avoidance and path planning. The technique that correlates between scans and this local area map is called map-matching. In many applications like mapping, road departure warning or collision warning only the area surrounding the vehicles driving path is of interest. This knowledge can further reduce the amount of data kept in memory.

GPS is not available in underground mine sites. Inertial Measurement Platforms (IMU's) are expensive and difficult to commission. Odometry data is therefore only available from vehicle sensors like encoders and accelerometers. Being independent of odometry data increases the field of operation for automation systems and reduces the need for additional sensors. A simplification has been made in this work that the possible driving paths consist of circles with constant radius (clothoids) and yaw rate. A straight line is therefore a circle with infinitesimal radius. The turning circle describes the yaw rate dependent on the speed. The objective is the computation of possible impact points for the vehicle at end points of these circles. Using the length of each circle leads to a good estimate of the speed and a very important information, the Time-To-Collision.

The environment in tunnels is usually stationary and not changing. This fact eases the prediction of the movement of the ego-vehicle. One scan has to be matched with the features of an earlier scan in order to detect movement. Empty corridors without features except smooth walls are therefore a major challenge for an accurate scan matching. The walls of mine sites deliver far more features. The results of this velocity estimation are very promising. The accuracy on stationary data is approx. 2kph (following a short transient oscillation time). This information adds value to the overall performance of an assistant system as e.g. length of warning zones can be automatically adjusted to speed information etc.



**Figure 7** the estimated velocity ranges between 19.5 and 20.3 (analysis of the scan data features between scans in this situation calculates the speed to: 18.5kph)

## 7 Conquering technical challenges in implementation

The first installation of the SICK Collision Awareness System was completed in cooperation with BEC Engineering at Alcoa's Huntly mine site in 2010. The success of the implementation exemplified the importance of the end user's dedication to the project and ownership of the technology.

Unintended road departure, potential collisions as well as reversing incidents are prevented by alerting the operator, displaying only relevant information and alarming audibly, if necessary. Besides performance, usability and serviceability, one major objective in the development constituted of "operator acceptance" – thus lowest possible false alarm rate. An inbuilt awareness of intentional driving behaviour (e.g. the avoidance of a pothole, turning at an intersection) was developed as part of this goal. It also automatically adapts warning zone dimensions according to the speed and switches the context between reversing, travelling forward, crossing roads, turning and loading. A digital map is used to raise operator's attention in his approach to predefined hazardous areas like intersections and construction sites.

The interest from the mine management shouldn't arise from pending regulation, but from the interest to overcome existing challenges, and the desire to be reputed as an industry innovator. This requires comprehensive risk assessment, followed by the implementation of robust process and the effective utilization of suitable collision avoidance technology. This approach means "safety first". Acceptance of this technology requires the commitment and dedication of personnel to safeguard a successful implementation. If it is agreed with Stewart Bell that technological limitations are no longer an impediment, we are likely to see a mandate for collision avoidance and proximity detection systems.

## References

- [1] [http://www.riotinto.com/ourapproach/17203\\_mine\\_of\\_the\\_future.asp](http://www.riotinto.com/ourapproach/17203_mine_of_the_future.asp)
- [2] <http://mines.industry.qld.gov.au/safety-and-health/coal-open-cut-safety-statistics.htm>
- [3] <http://cdc.gov/niosh/mining>
- [4] Lenné, M. G. & Triggs, T. J. (2009). "Warning drivers of approaching hazards: The importance of location cues and multi-sensory cues." Maastricht: Shaker Publishing.
- [5] Quenzel, J (2012). "Auswertung von Laserscannerdaten als Grundlage eines Assistenzsystems für Tunnelfahrzeuge"
- [6] Rhede, J. G., Wäller, C. & Oel, P. (2011). "Der FAS Warnbaukasten – Strategie für die systematische Entwicklung und Ausgabe von HMI-Warnungen." Düsseldorf: VDI Verlag GmbH.
- [7] IQPC – "2nd Annual Mine Site Automation & Communication Africa 2012", 23 - 25 July, 2012, Sandton, South Africa