EMESRT

Earth Moving Equipment Safety Round Table

PERFORMANCE REQUIREMENT 5A

VEHICLE INTERACTION SYSTEMS

WORKING WITH INDUSTRY SINCE 2006

EMESRT.ORG

DOCUMENT CONTROL

1. REVISION HISTORY

REV	DATE	DESCRIPTION	PREPARED BY	CHECKED BY	APPROVED BY
1.0	April 2016	Initial document prepared	Mining3 and Tony Egan	VI Working Group	EMESRT Advisory Group
2.0	August 2019	Reviewed and updated content	Neil Pollard, Eve McDonald and Tony Egan	VI Working Group	EMESRT Advisory Group
3.0	September 2024	Reviewed, updated content including functional performance scenario storyboards	Adam Ferris, Eve McDonald and Tony Egan	VI Working Group	EMESRT Advisory Group

2. DISCLAIMER

While every attempt has been made to validate the contents of this Performance Requirement 5A (PR-5A) document, the content has been collated from industry leading practice and therefore may change over time. For this reason, EMESRT reserves its right to update and re-issue PR-5A as industry practice evolves.

3. CONDITIONS OF USE

EMESRT has an ambition to reduce the Health and Safety risks from operating and maintaining mobile earth moving equipment. This is achieved by sharing leading practice information that can be referenced by users and designers when seeking to reduce the level of risk to personnel. Connecting through a community collaboration of; end users, OEM's, researchers, and third-party suppliers it allows a deep understanding of the problems needed to be addressed to support industry level improvement.

PR-5A has been developed to embellish the understanding of problems set out in potential unwanted events.

3.1 TRANSLATIONS

PR-5A was developed and reviewed in English only. If PR-5A content, in part or in its entirety is translated, only the English version published by EMESRT is the approved version.

3.2 USAGE

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- No financial gain is to be made by using PR-5A in part or in its entirety

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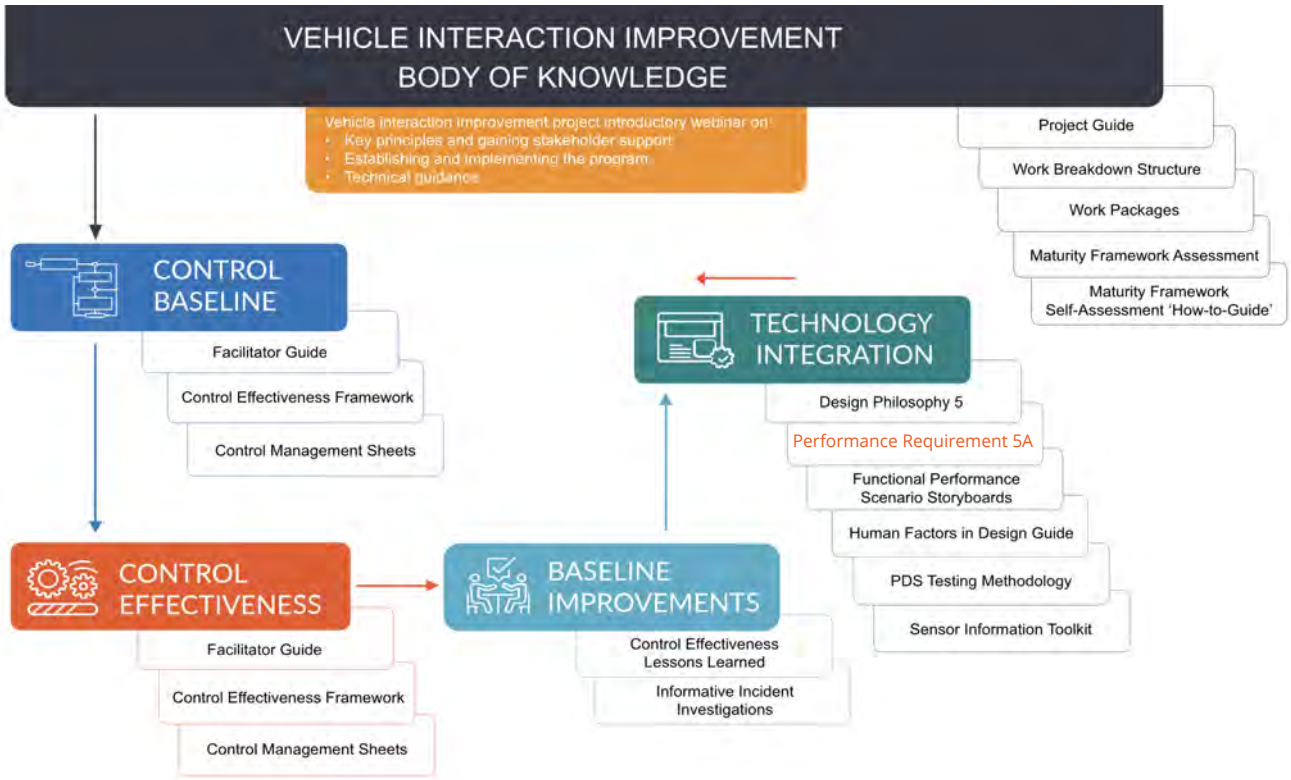
The diagram below provides an understanding of where PR-5A integrates into the overall Vehicle Interaction industry resources.



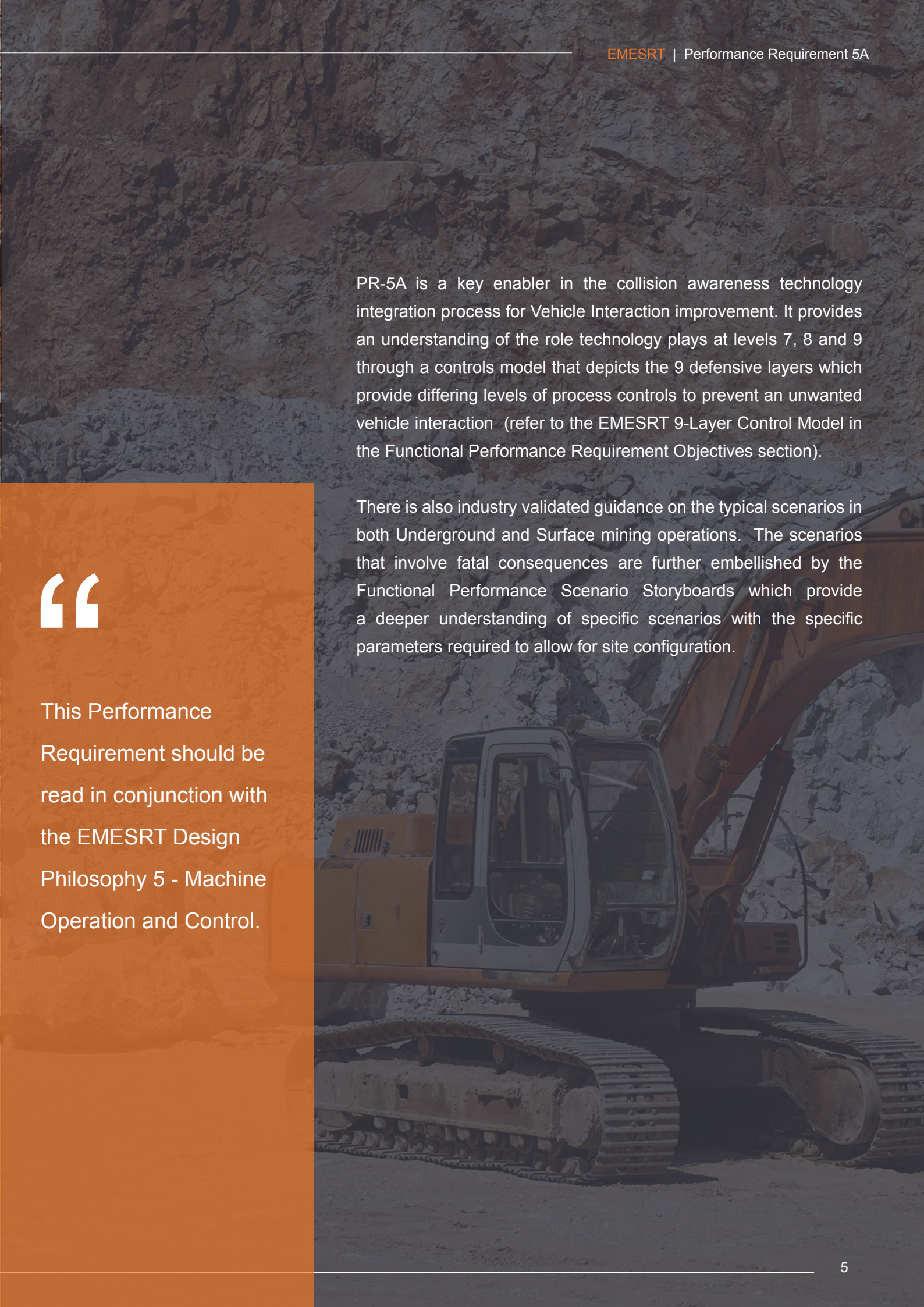
1.0 Overview

This Performance Requirement (PR) has been developed to augment interpretation of EMESRT Design Philosophy 5, Machine Operation and Control in the following causal pathway scenarios:

5.1	Harm from restricted or impeded operator field of vision of the surrounding environment and for tool operation.
5.2	Harm from incorrect use of equipment controls, incorrect/inaccurate calibration or ineffective maintenance due to inadequately designed controls and displays.
5.3	Harm from misinterpretation of information due to displays or labels.
5.4	Harm, including cognitive impairment, causing warnings and alarms to be overlooked, ignored or not heard.
5.5	Harm from impaired visibility (including distorted or degraded vision) or impaired awareness of hazards in a variety of operating conditions.

PR-5A is a key enabler in the collision awareness technology integration process for Vehicle Interaction improvement. It provides an understanding of the role technology plays at levels 7, 8 and 9 through a controls model that depicts the 9 defensive layers which provide differing levels of process controls to prevent an unwanted vehicle interaction (refer to the EMESRT 9-Layer Control Model in the Functional Performance Requirement Objectives section).

There is also industry validated guidance on the typical scenarios in both Underground and Surface mining operations. The scenarios that involve fatal consequences are further embellished by the Functional Performance Scenario Storyboards which provide a deeper understanding of specific scenarios with the specific parameters required to allow for site configuration.



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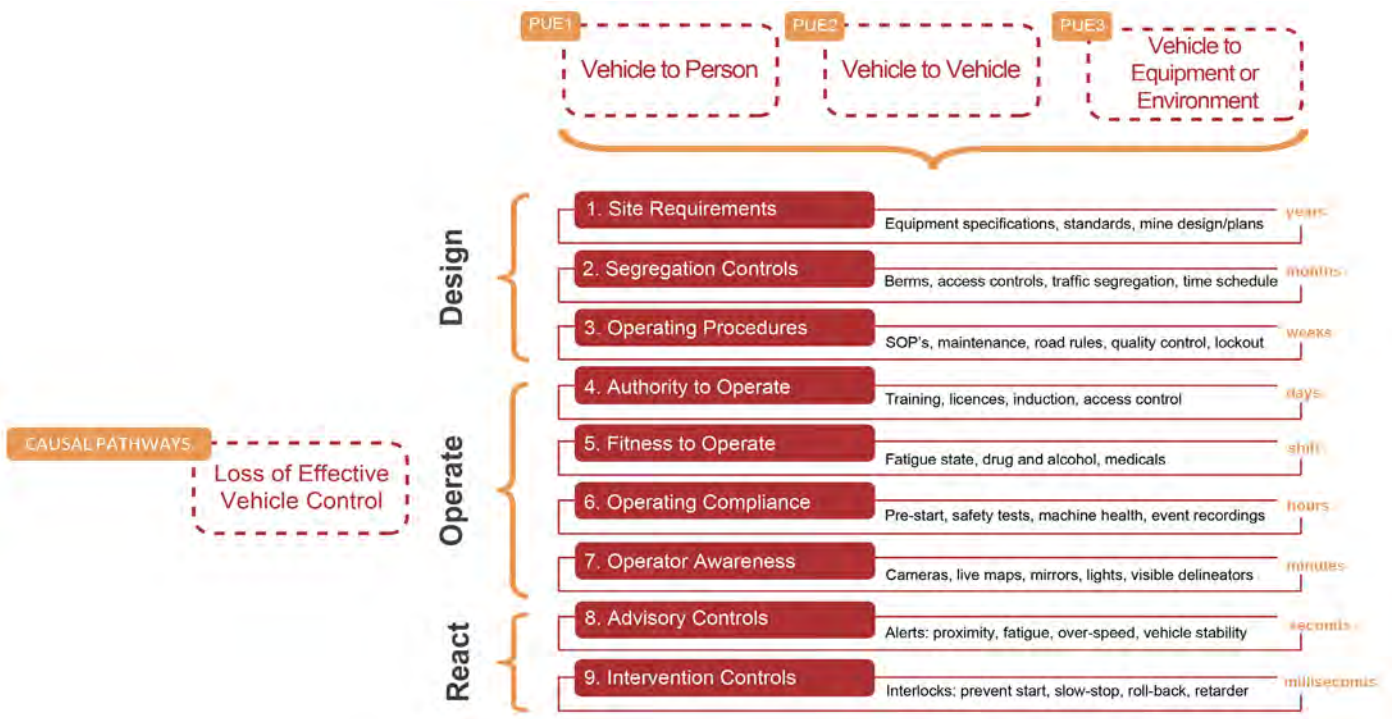
This Performance Requirement should be read in conjunction with the EMESRT Design Philosophy 5 - Machine Operation and Control.

2.0 Functional performance requirement objectives

The objective is to prevent a person or vehicle causing a PUE in the following three PUE categories resulting in injury or equipment damage:

1. Vehicle to Person
2. Vehicle to Vehicle
3. Vehicle to Equipment or Environment

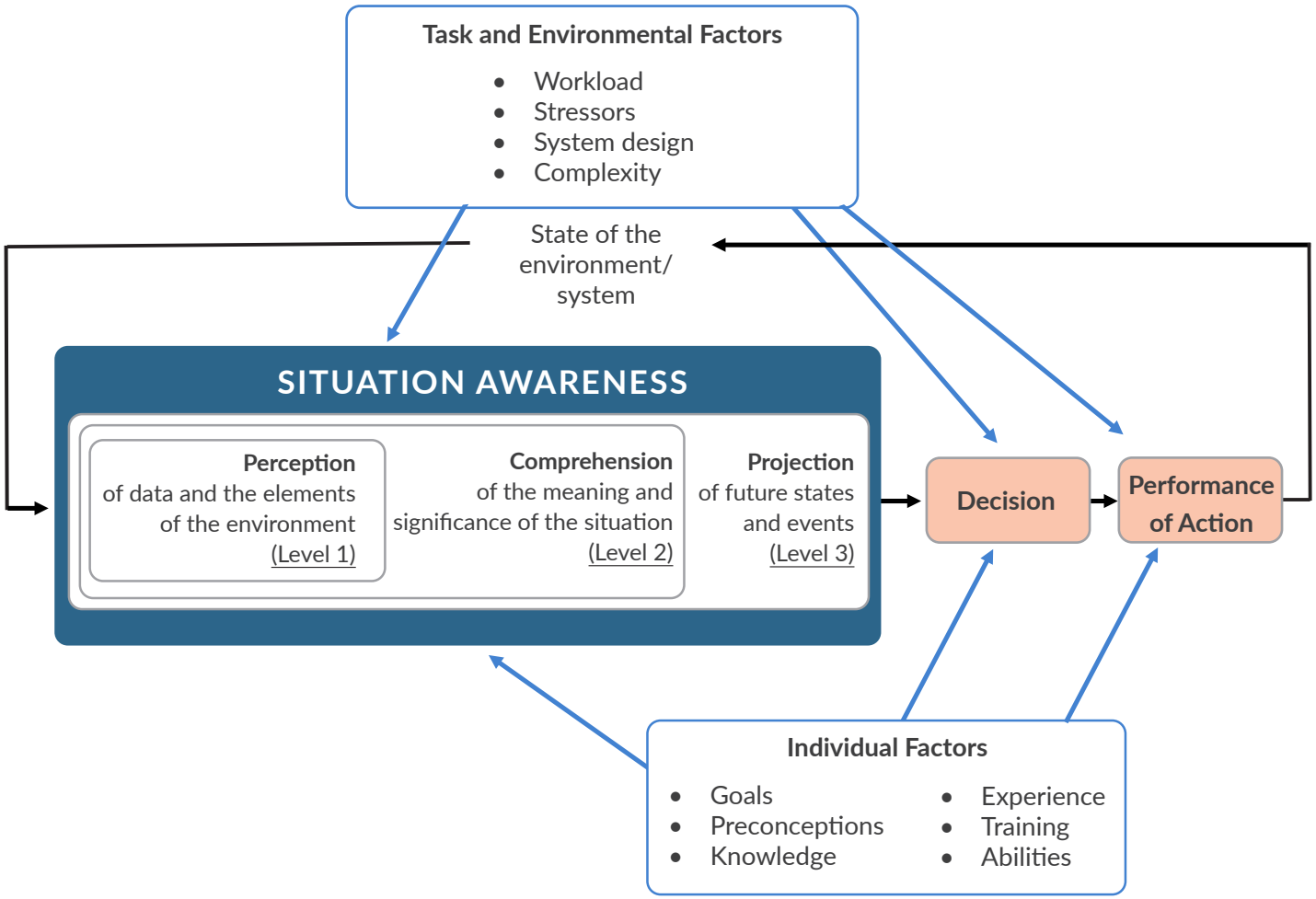
These are depicted in context in the model below.

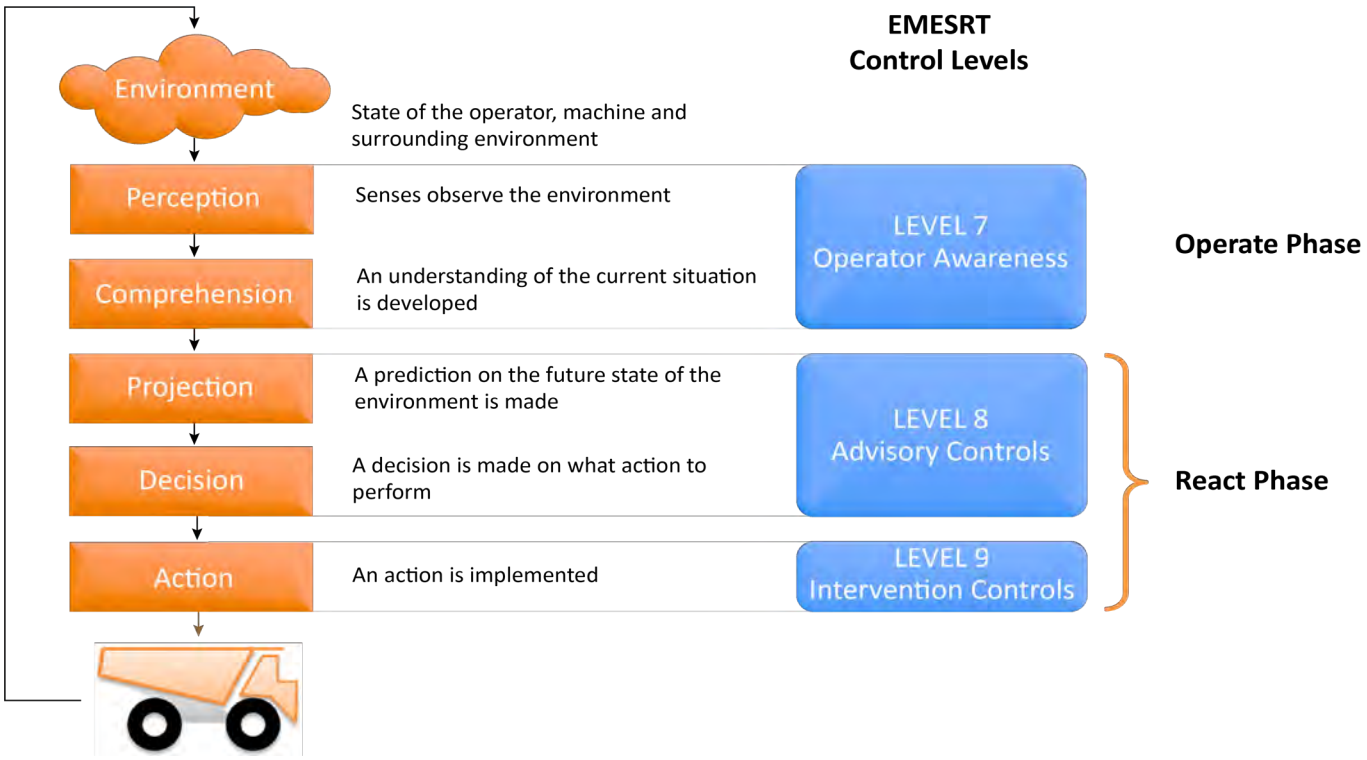


3.0 Vehicle interaction situational awareness model

Effective situational awareness occurs by means of timely, repeatable, dependent and accurate information being presented to a pedestrian, the vehicle operator or the vehicle itself so that appropriate action can be taken by the pedestrian, the operator or the vehicle itself to eliminate or mitigate the potential significant consequences of the three PUE's.

Below is Endsley's model of Situational Awareness. This is a synthesis of versions she has given in several sources, notably in 1995 and 2000. EMESRT has utilised this model to develop an integrated VI model that aligns with levels 7,8 and 9 in the EMESRT 9-Layer Control Model depicted above. The fundamental role of technology should be to mitigate/eliminate the potential for human error in each phase of the situational awareness process. The user interface design is a key element in this process and is discussed further in this section.





Adapted from the Model of Situational Awareness - Mica Endsley 1998.

4.0 Control level functional performance parameters

Level 7 - Situational Awareness

Technologies that provide information to enhance the ability to observe the immediate environment and understand potential hazards in the vicinity through providing:

- Enhanced situational awareness
- An alert on potential abnormal scenarios
- Contextual information of the threat in an abnormal scenario such as
  - Where is it?
  - What is it?
  - How far away is it?
  - What is its heading?
  - How fast is it going?
- Visual confirmation a potential abnormal situation

Level 8 - Advisory Controls

Technologies that provide alarms and/or specific instruction to enhance the ability to predict a potential unsafe interaction and the corrective action required by:

- Determining an imminent threat of collision
- Providing a specific instruction signal to the vehicle operator to react
- Prompting the operator to consider other contributing situational factors prior to reacting to prevent a collision or mitigate the potential significant consequences

Level 9 - Intervention Controls

Technologies that automatically intervene and take some form of vehicle control to prevent a collision or mitigate the potential significant consequences by:

- Providing a specific instruction signal to the vehicle to react
- The vehicle assessing the instruction in relation to other contributing factors prior to reacting to prevent a collision or mitigate the potential significant consequences
- Relinquishing intervention control to the operator should they take evasive action
- Providing a manual over-ride to recover after a collision intervention scenario has occurred

4.1 Operator / equipment interface design principles

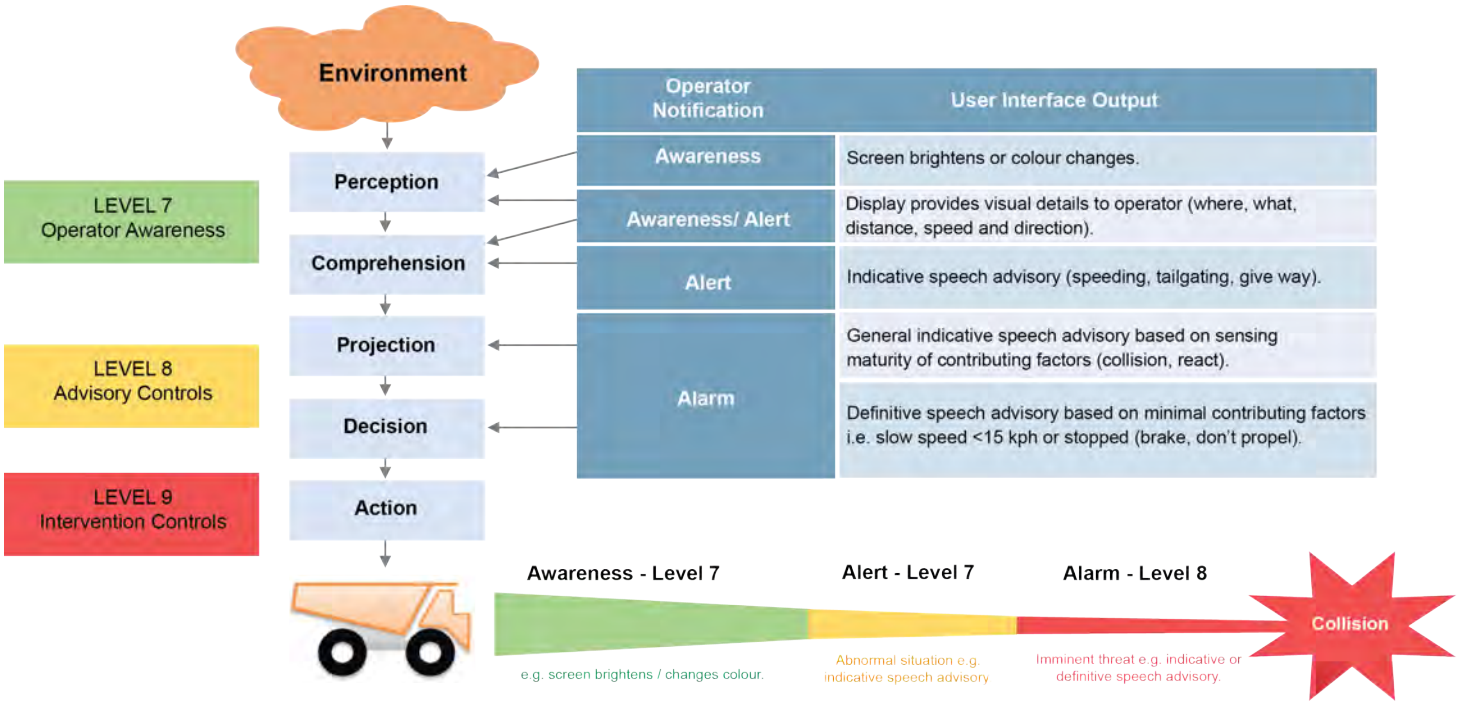
The model below combines the EMESRT 9 layer model with the situation awareness model to provide potential operator interface methods. Ultimately the purpose of the operator / machine interface is to provide clarity of response for a given situation. This can be described in 3 functional stages:

1. For a detected specific situation/scenario
2. Deliver a specific prompt to the operator/equipment
3. Which elicits a specific response from the operator or equipment

The more generic/broad the parameters in each of the three steps, then there is a higher potential for both human and machine error. Considerable effort is required to fully understand the interface design requirements and should be a high focus element for users when deploying VI technology at sites.
The Functional Performance Scenario Storyboards depicted further in this document provide the basis of the requirement to consider in the 3 steps detailed above.

Combining Models for a deeper understanding
Example from a Glencore Surface Mining Vehicle Interaction Technology Implementation Project.

- Human Factor Interaction Model
- EMESRT Nine Layer Model of Control Effectiveness
- Mica Endsley Model of Situational Awareness



For further technical definition, please refer to the EMESRT technical reference *Human Factors in Design Guide* available on the EMESRT website. This guide summarises relevant human factors issues (situation awareness principles, consequence of nuisance alarms, etc), and provides a description of the human centred design process that should be followed by technology developers and outline the importance and methods of evaluating human factors issues during procurement.

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4.2 Vehicle interaction functional performance requirement indicative application examples

Potential Unwanted Event types	General Requirements	Control Type		
		Level 7 (Situational Awareness)	Level 8 (Advisory)	Level 9 (Intervention)
Vehicle to person	Vehicle is in control by the operator. People entering the at-risk zone of the vehicle are detectable. The at-risk zone is mobile equipment type and closure speed dependent. The system is active during vehicle start-up, running and shutdown.	*Operator is made aware of people by:* • Providing information on the presence of personnel in the at-risk zone • Providing information on the location of personnel in the at-risk zone • Providing information on the location of personnel in the surrounding area	*Operator is alerted to the presence of people by:* • Alarming the presence of people in a significant operator blind-spot • Alarming the presence of people in the at-risk zone • Alarming the location of people in the at-risk zone *Operator is advised to undertake a prescribed action to avoid/mitigate a collision with people by:* • Alarm with advice to prohibit specific actions • Alarm with advice to undertake specific actions	*Automatic control of specific vehicle functions is taken in order to avoid/mitigate a collision with people by:* • Modifying or limiting operator inputs for specific vehicle controls • Modifying or limiting specific vehicle functions • Asserting full control over the vehicle
Vehicle to Vehicle	Vehicle is in control by the operator. Vehicle entering the at-risk zone of the vehicle are detectable. The at-risk zone is mobile equipment type and closure speed dependent. The system is active during vehicle start-up, running and shut-down.	*Operator is made aware of other equipment and vehicles by:* • Providing information on the presence of equipment and vehicles in the at-risk zone • Providing information on the type, location, heading and speed of equipment and vehicles in the at-risk zone • Providing information on the location, type, heading and speed of equipment and vehicles in the surrounding area	Operator is alerted to the presence of other equipment and vehicles by: • Alarming the presence of other equipment and vehicles in a significant operator blind-spot • Alarming the presence of other equipment and vehicles in the at-risk zone • Alarming the type, location, heading and speed of equipment and vehicles in the at-risk zone *Operator is advised to undertake a prescribed action to avoid/mitigate a collision with mobile equipment or vehicles by:* • Alarm with advice to prohibit specific actions • Alarm with advice to undertake specific actions	*Automatic control of specific vehicle functions is taken in order to avoid/mitigate a collision with other equipment and vehicles by:* • Modifying or limiting operator inputs for specific vehicle controls • Modifying or limiting specific vehicle functions • Asserting full control over the vehicle
Vehicle to Equipment	Vehicle is in control by the operator. The equipment in at-risk zone of the vehicle is detectable. The at-risk zone is mobile equipment type and closure speed dependent. The system is active during vehicle start-up, running and shut-down.	*Operator is made aware of infrastructure and objects by:* • Providing information on the presence of infrastructure and objects in the at-risk zone • Providing information on the type and location of infrastructure and objects in the at-risk zone • Providing information on the type and location of infrastructure and objects in the surrounding area	*Operator is alerted to the presence of infrastructure and objects by:* • Alarming the presence of infrastructure and objects in a significant operator blind-spot • Alarming the presence of infrastructure and objects in the at-risk zone • Alarming the type and location of infrastructure and objects in the at-risk zone *Operator is advised to undertake a prescribed action to avoid/mitigate a collision with infrastructure and objects by:* • Alarm with advice to prohibit specific actions • Alarm with advice to undertake specific actions	*Automatic control of specific vehicle functions is taken in order to avoid/mitigate a collision with infrastructure and objects by:* • Modifying or limiting operator inputs for specific vehicle controls • Modifying or limiting specific vehicle functions • Asserting full control over the vehicle

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4.2 Vehicle interaction functional performance requirement indicative application examples, *cont...*

Potential Unwanted Event types	General Requirements	Control Type		
		Level 7 - Situational Awareness	Level 8 - Advisory	Level 9 - Intervention
Vehicle to Environment (Includes entry into prohibited areas)	Vehicle has been in control by the operator. Environment hazards in the at-risk zone are detectable. The at-risk zone is mobile equipment type and closure speed dependent. The system is active during vehicle start-up, running and shut-down.	*Operator is made aware of environmental conditions by:* • Providing information on the conditions in the at-risk zone • Providing information on the type and location of conditions in the at-risk zone • Providing information on the type and location of conditions in the surrounding area	*Operator is alerted to the environmental conditions by:* • Alarming the presence of adverse conditions in the at-risk zone • Alarming the type and location of adverse conditions in the at-risk zone • Alarming the type of loss of control *Operator is advised to undertake a prescribed action to avoid/mitigate the loss of control by:* • Alarm with advice to prohibit specific actions Alarm with advice to undertake specific actions	*Automatic control of particular vehicle functions is taken in order to avoid/mitigate the loss of control by:* • Modifying or limiting operator inputs for specific vehicle controls • Modifying or limiting specific vehicle functions • Asserting full control over the vehicle

Note: Loss of control includes loss of drive, traction, steering, braking, and stability due to adverse operating surface conditions.

5.0 Vehicle Interaction Scenarios - Design / Systems Interdependence

Given the range and brands of equipment in use in the mining industry and that there is an array of technologies and suppliers that may be utilised to meet the objectives of Levels 7, 8 and 9 designs, consideration of the differing systems/technologies interdependence will be a key requirement in design performance objectives.

Local Object (LO)	Remote Object (RO)
The interactor in the best position to avoid the interaction - generally the interactor with the highest energy. There is only one Local Object in any interaction, and it must be capable of taking preventative action.	The 'other' participant in the interaction, generally with limited preventative controls available.

The intended design outcome should include/consider but not be limited to the following interaction scenarios:

Scenario	Definitions
PI - Person (direct)	Person on foot (RO) in immediate vicinity around machine (LO)
P3 - Person (indirect)	Person on foot that is a bystander in an interaction between machines and/or infrastructure
P4 - Access and egress	Person getting on or off stationary machine (see Access and Egress DP-1)
L1 - Head-on	RO directly in the path of a LO moving (or intending to move) forward
L2 - Backup	RO directly behind a LO moving (or intending to move) in reverse
L3 - Reverse-on	Two machines (LO and RO) reversing towards each other
L4 - Dovetailing	LO following a RO with both moving in the forward direction
L5 - Passing head-on	Two machines (LO and RO) passing each other in opposite directions with both moving forward
L6 - Passing reverse-on	Two machines oriented in same direction with the forward-moving LO passing a stationary or reversing RO
L7 - Overtaking	LO pulling out and overtaking a RO with both moving forward
L8 - Blind approach	Forward-moving LO with limited or no visibility approaching a stationary or moving RO (blinded or obstructed)
C1 - Curving head-on	Two machines (LO and RO) approaching in opposite directions around a bend with both moving forward
C2 - Curving dovetail	Two machines (LO and RO) following each other around a bend with both moving forward
C3 - Curving reverse-on	LO approaching a stationery or reversing RO around a bend
T1 - Merge	LO approaching a merge intersection with a RO traveling straight-through
T2 - Crossover	LO intending to turn across path of oncoming RO
T4 - Intersection	LO approaching a ~90 degree four-way intersection with RO traveling straight-through
R1 - Swing	Machine with rotating body (LO) operating with another machine (RO) near-by e.g. shovel-truck
R2 - Drop	Machine with elevated load (LO) transferring material to another machine (RO)
O1 - Obstacle	Machine (LO) entering a no-go area (RO) e.g. road or tip edge, limited clearance, soft barrier, electrical cable
V1 - Void	Machine (LO) entering a no-go area (RO) e.g. road or tip edge, limited clearance, soft barrier, electrical cable
V4 - Loss of control	Operator not in control of machine (LO) and none of the above scenarios apply (P1, P3, L1-8, C1-3, T1-3, O1, R1-2, V12)
V6 - Congested area	Machine (LO) operating with multiple (more than 2) other machines in close proximity e.g. workshop area, LV/HV parking area

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5.1 Surface vehicle interaction scenarios - designing scenarios out of operations is the most effective method of elimination unwanted VI interactions. e.g., T4 - 4 way intersection

P1 - Person (direct)

L4 - Dovetailing

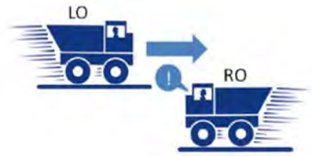
C1 - Curving Head-on

T2 - Crossover

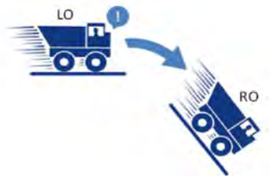
V1-Void

P3 - Person (indirect)

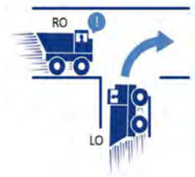
L5 - Passing head-on



C2 - Curving Dovetail



T3 - Junction



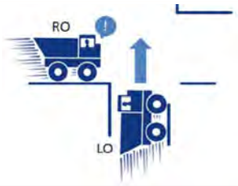
V4 - Loss of control

P4 - Access and egress

L6 - Passing reverse-on

C3 - Curving reverse-on

T4 - Intersection

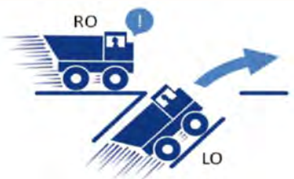


V6 - Congested area

L1 - Head-on

L7 - Overtaking

T1 - Merge



O1 - Obstacle

R1 - Swing

L2 - Backup

L8 - Blind approach

R1 - Drop

L3 - Reverse-on

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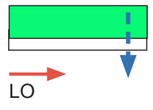
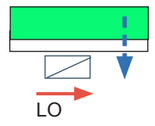
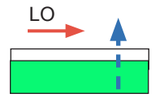
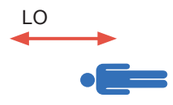
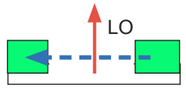
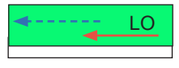
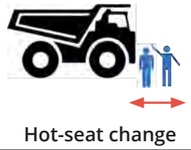
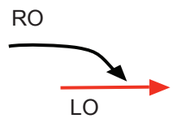
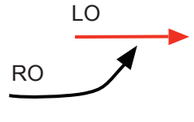
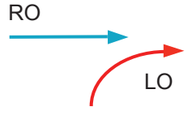
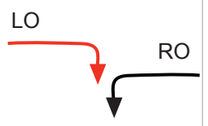
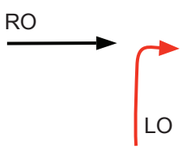
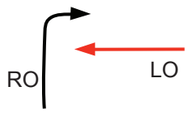
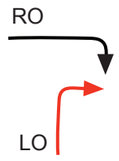
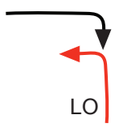
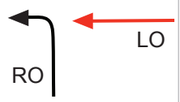
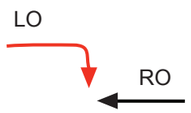
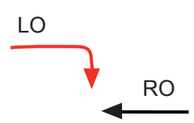
5.1.1 Sub-scenario variations - surface

PUE 1 - VEHICLE TO PERSON		01	02	03	04	05	06	07	08	09	XX
P1	P1 - Person (direct) 	 Near-side	 Emerging	 Far-side	 Working lying, standing	 Walking with traffic	 Walking against traffic	 Driveway	 On walkway		Other
P2	P3 - Person (indirect) 	 Spotting	 Materials handling								Other
P4	P4 - Access and egress 	 Boarding	 Alighting	 Hot-seat change							Other

PUE 2 - VEHICLE TO VEHICLE		01	02	03	04	05	06	07	08	09	XX
T1	T1 - Merge 	 Left-merge	 Right-merge	 Merge-left	 Merge-right						Other
T2	T2 - Crossover 	 Left-crossover	 Right-crossover	 Right-left							Other
T3	T3 - Junction 	 Right-through	 Straight-right	 Right-right	 Left-right	 Straight-left	 Right-straight				Other
T4	T4 - Intersection 	 Through-through	 Right-straight								Other

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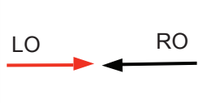
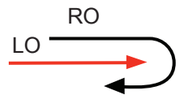
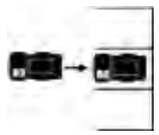
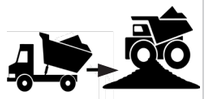
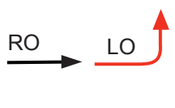
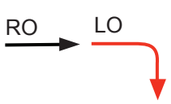
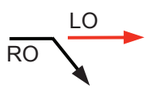
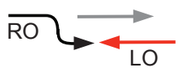
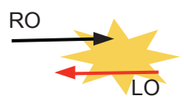
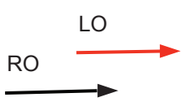
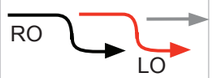
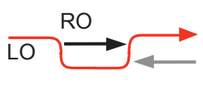
5.1.1 Sub-scenario variations - surface, *cont...*

PUE 2 - VEHICLE TO VEHICLE

		01	02	03	04	05	06	07	08	09	XX
L1	L1 - Head-on 	 On-path	 U-loop								Other
L2	L2 - Backup 	 Reversing at park-up area	 Loading	 Reversing at dump							Other
L3	L3 - Reverse-on 	 Reversing									Other
L4	L4 - Dovetailing 	 Rear-end	 Left-rear	 Right-rear	 Pullout-rear						Other
L5	L5 - Passing head-on 	 Head-on into oncoming path	 Misjudged clearance								Other
L6	L6 - Passing reverse-on 	 Lane incursion	 Pulling out	 Cutting in							Other

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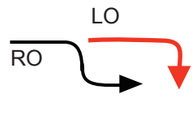
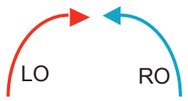
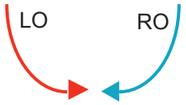
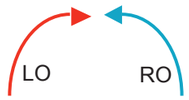
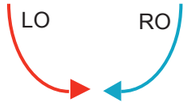
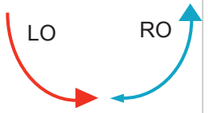
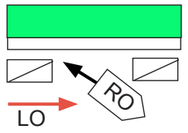
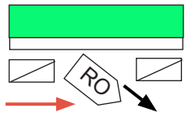
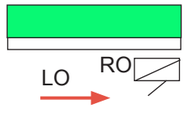
5.1.1 Sub-scenario variations - surface, *cont...*

		01	02	03	04	05	06	07	08	09	XX
L7	L7 - Overtaking 	 Pulling out	 Overtake-right								Other
L8	L8 - Blind approach 	 Sun glare	 Bright light	 Reflection	 Rain / fog / snow / weather	 Mine or road design					Other
C1	C1 - Curving head-on 	 LO cutting corner	 LO swinging wide	 RO oversteer	 RO understeer						Other
C2	C2 - Curving dove-tail	Outside head-tail	Inside head-tail								Other
C3	C3 - Curving reverse-on 	 Outside reverse-up	 Inside reverse-up								Other
V6	V6 - Congested area 	 Enter park-bay	 Leave park-bay	 Door / ladder							Other

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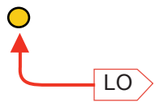
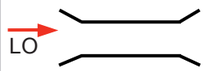
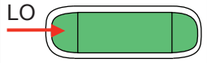
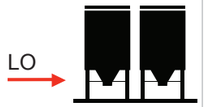
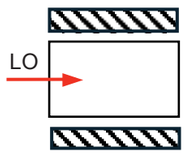
5.1.1 Sub-scenario variations - surface, *cont...*

PUE 3 - VEHICLE TO EQUIPMENT TO ENVIRONMENT

		01	02	03	04	05	06	07	08	09	XX
O1	O1 - Obstacle 	 Reversing into object	 Permanent construction	 Temporary road-works	 Temporary object on road	 Animal on road	 Drove into berm	 Drove into infrastructure	 Accident or breakdown		Other
V1	V1 - Void 	 No go zone	 Unstable ground								Other

PUE 4 - LOSS OF CONTROL

		01	02	03	04	05	06	07	08	09	XX
V4	V - Loss of control	* Rollaway on road									Other

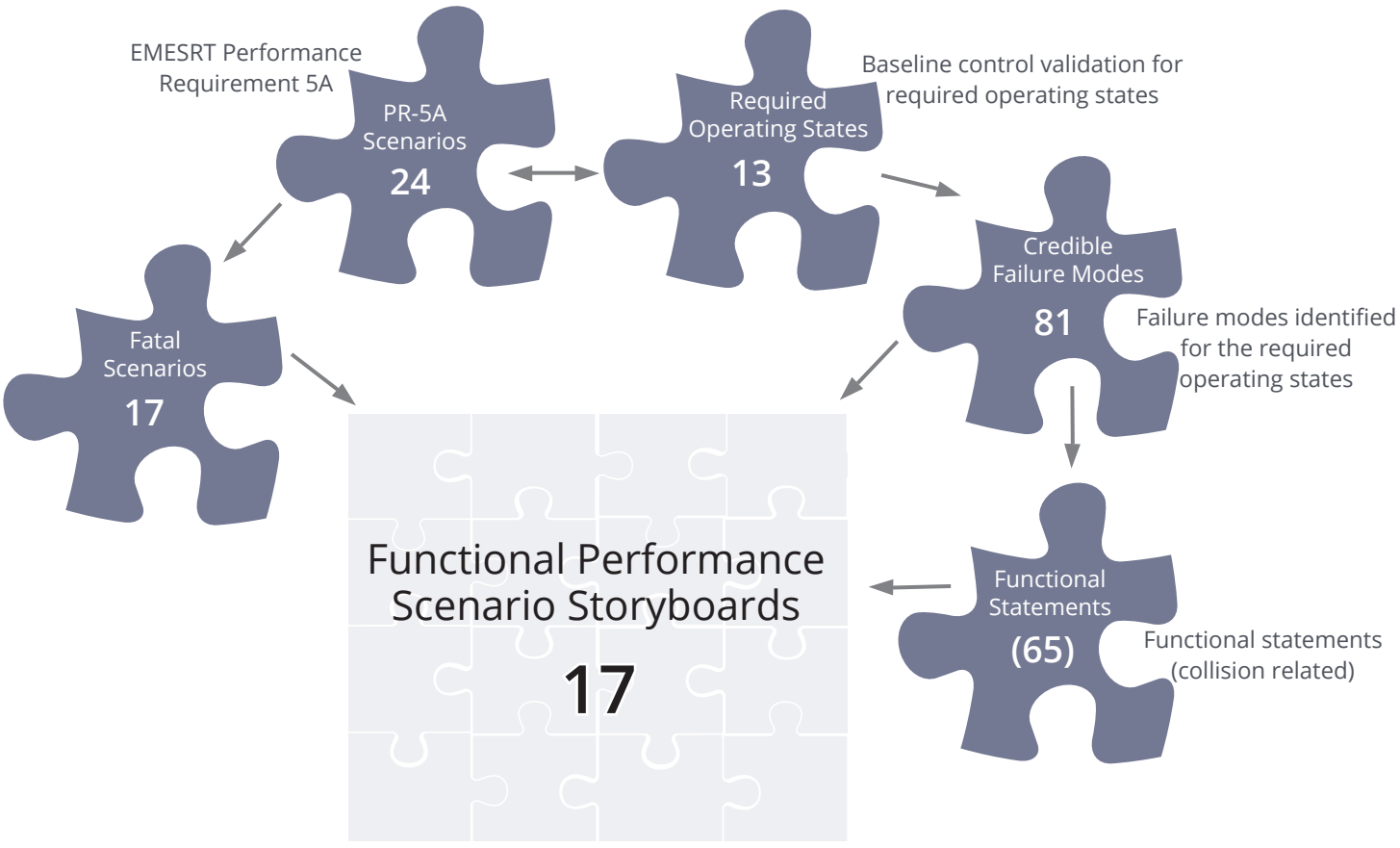
* PUE 4 includes: Loss of control caused by speeding, operator fatigue/distraction, mechanical failure, watered road (manual/ environmental).

5.2 Surface functional performance scenario storyboards

The scenarios depicted above are functionally indicative but lack the specific functional and performance parameters to effectively design and configure VI technology. The scenarios are a single snapshot depiction of what is actually a variable process that evolves dependant on many factors in the moments that an unwanted interaction develops. The Functional Performance Scenario Storyboards (FPSS) were developed to articulate to both users and designers the requirements that need to be detailed for specific animated situations. The storyboard snap-shot on Page 27 is illustrative only. To access and download the full animated storyboards, provided as a PowerPoint and video file, go to the **EMESRT website**.

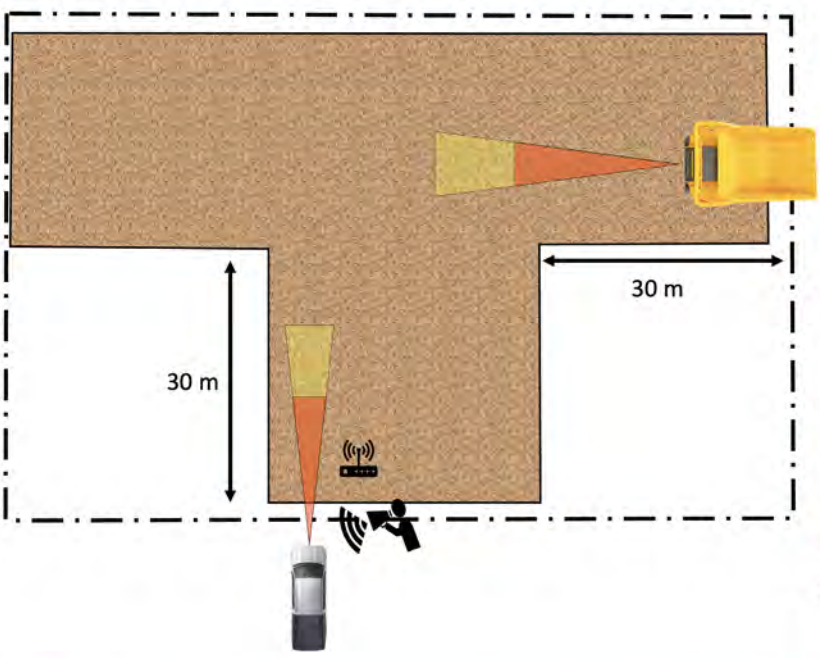
The model below depicts the development of the surface FPSS's and how the baseline control effectiveness parameters and the scenarios have been merged to deliver a clear understanding of a specific situation.

Surface Functional Performance Scenario Storyboard development model.



The 17 storyboards
1. Tailgating heavy vehicle to heave vehicle
2A. Speeding
2B. Speed on ramp approach
3. Wet roads due to overwatering
4. T-intersection - light vehicle perspective
5. Dump areas - dozer configuration
6A. Loading areas - rotating tracked loading unit
6B. Loading areas - wheeled loading unit
7A. Passing stationary heavy vehicle - dump and dig face
7B. Accessing heavy vehicle - maintenance activities
7C. Accessing heavy vehicle - operational activities
7D. Accessing stationary heavy vehicle - assumed un-manned
7E. Light vehicle inside 30 m of stationary heavy vehicle
8. Segregated roads
9. Passing roadwork vehicles
10. Standard CAS - general operational interactions
11. Unknown grade change

Snap-shot of functional performance scenario storyboard **4: T-intersection - light vehicle perspective.**



- LO (LV) approaches a formal T intersection configured with an intersection geo-fence
- When the inner beam of the LO (LV) enters the geo-fenced intersection (30 m from intersection) CAS will scan for other CAS units that are located within the geo-fence
- The geo-fence will have a speed limit of 40 km/h applied and will be activate when LV's and MV's enter regardless of the presence of an RO
- If T intersection geo-fence becomes occupied by the body of any other vehicle whilst the LO (LV) is in the intersection the following will occur:
  - User interface will brighten in LO and RO's
  - Audible message of "Give Way" repeated twice will only activate in LV designated vehicles not in HV's
- If the LO (HV or LV) becomes the only vehicle inside the geo-fenced intersection or departs the geo-fenced intersection the user interface will then dim
- Audible message will activate once only per entry into geo-fence

Applicable for LV's and MV's when they are the LO.

Not applicable for dozers, drills and tracked loading units when they are the RO.

NOTE: the text in red provides examples of parameters that should be considered during development and site configuration.

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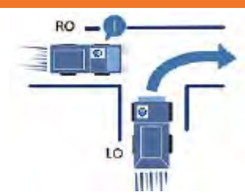
5.3 Underground vehicle interaction scenarios - designing scenarios out of operations is the most effective method of elimination unwanted VI interactions. e.g., T4 - 4 way intersection

P1 - Person (direct)

L4 - Dovetailing

C2-Curving dovetail

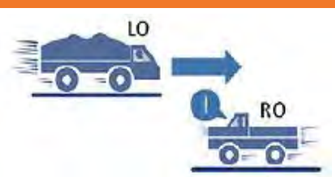
T3-Junction



V1-Void

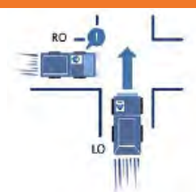
P3 - Person (indirect)

L5 - Passing head-on



C3 - Curving reverse-on

T4 - Intersection

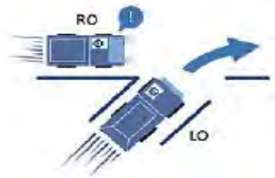


V4 - Loss of control

P4 - Access and egress

L6 - Passing reverse-on

T1 - Merge



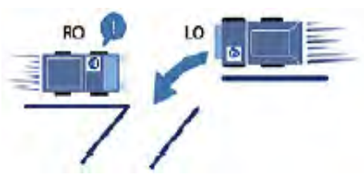
O1 - Obstacle

V6 - Congested area

L1 - Head-on

L7 - Overtaking

T2 - Crossover



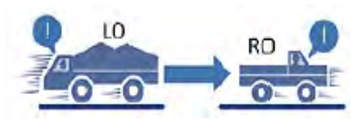
R1 - Swing

L2 - Backup

L8 - Blind approach

R1 - Drop

L3 - Reverse-on



C1 - Curving head-on

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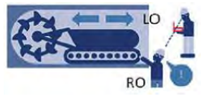
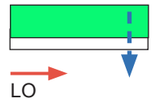
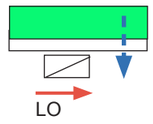
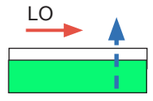
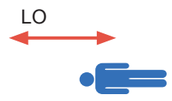
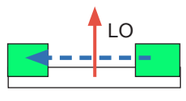
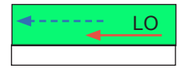
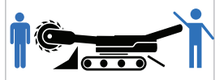
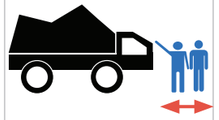
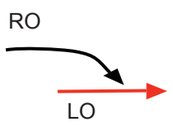
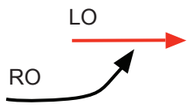
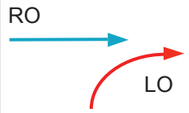
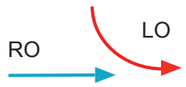
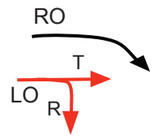
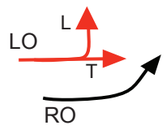
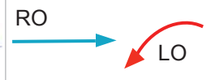
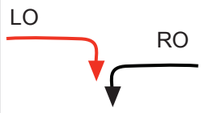
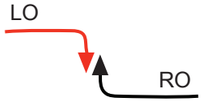
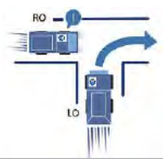
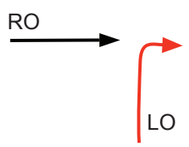
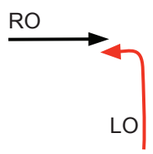
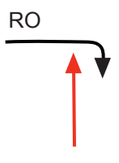
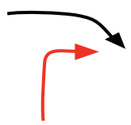
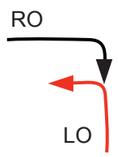
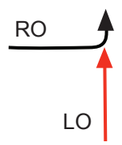
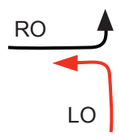
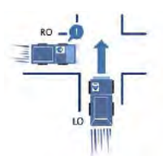
5.3.1 Sub-scenario variations - underground

PUE 1 - EQUIPMENT TO PERSON

		01	02	03	04	05	06	07	08	09	XX
P1	P1 - Person (direct) 	 Near-side	 Emerging	 Far-side	 Working lying, standing	 Walking with traffic	 Walking against traffic	 Driveway	 On walkway		Other
P3	P3 - Person (indirect) 	 Spotting	 Materials handling								Other
P4	P4 - Access and egress 	 Boarding	 Alighting	 Hot-seat change							Other

PUE 2 - EQUIPMENT TO EQUIPMENT

		01	02	03	04	05	06	07	08	09	XX
T1	T1 - Merge 	 Left-merge	 Right-merge	 Merge-left	 Merge-right	 U-turn	 Right-swipe	 Left-swipe			Other
T2	T2 - Crossover 	 Left-crossover	 Right-crossover	 Right-left	 Right-right						Other
T3	T3 - Junction 	 Right-through	 Left-through	 Through-right	 Right-right	 Left-right	 Through-left	 Left-left	 Through-left		Other
T4	T4 - Intersection 	 Through-through	Right-left	Left-left	Right-straight						Other

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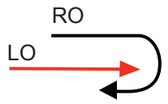
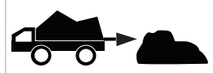
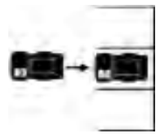
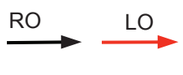
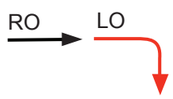
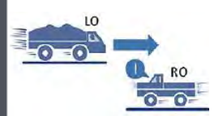
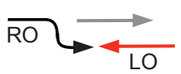
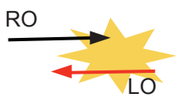
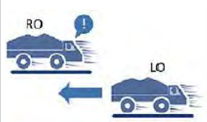
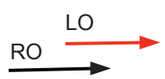
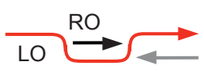
5.3.1 Sub-scenario variations - underground, *cont...*

PUE 2 - EQUIPMENT TO EQUIPMENT *cont....*

		01	02	03	04	05	06	07	08	09	XX
L1	L1 - Head-on 	 On-Path	 U-loop								Other
L2	L2 - Backup 	 Reversing dump	 Reversing at park-up area	 Loading							Other
L3	L3 - Reverse-on 	 Reversing									Other
L4	L4 - Dovetailing 	 Rear-end	 Left-rear	 Right-rear	 Pullout-rear						Other
L5	L5 - Passing head-on 	 Head-on into oncoming path	 Misjudged clearance								Other
L6	L6 - Passing reverse-on 	 Lane incursion	 Pulling out	 Cutting in							Other

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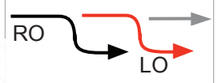
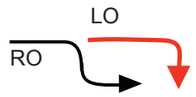
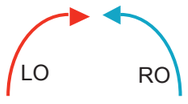
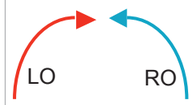
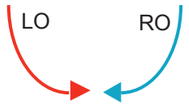
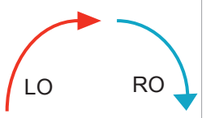
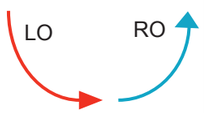
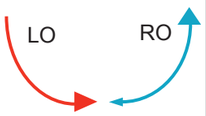
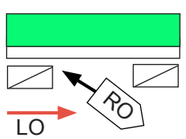
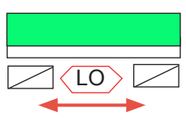
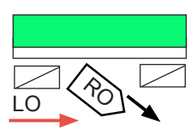
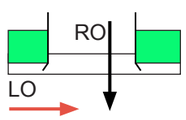
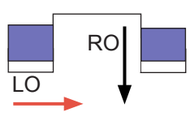
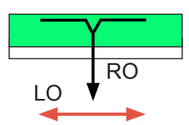
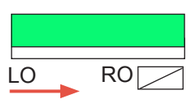
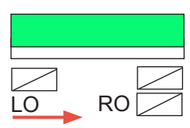
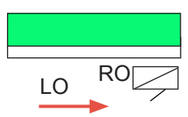
5.3.1 Sub-scenario variations - underground, *cont...*

PUE 2 - EQUIPMENT TO EQUIPMENT *cont....*

		01	02	03	04	05	06	07	08	09	XX
L7	L7 - Overtaking 	 Pulling out	 Overtake-right								Other
L8	L8 - Blind approach 	 Bright light	 Reflection								Other
C1	C1 - Curving head-on 	 LO cutting corner	 LO swinging wide	 RO oversteer	 RO understeer						Other
C2	C2 - Curving dove-tail 	 Outside head-tail	 Inside head-tail								Other
C3	C3 - Curving reverse-on 	 Outside reverse-up	 Inside reverse-up								Other
V6	V6 - Congested area 	 Enter park-bay	 In park-bay	 Leave park-bay	 Leaving driveway	 Loading bay	 From footway	 Limited space	 Double park	 Door / ladder	Other

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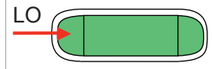
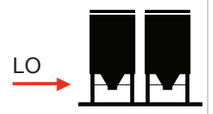
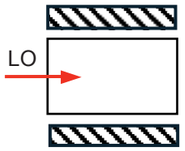
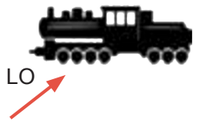
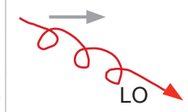
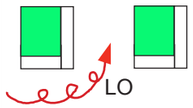
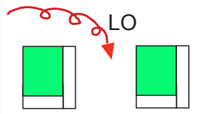
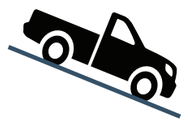
5.3.1 Sub-scenario variations - underground, *cont...*

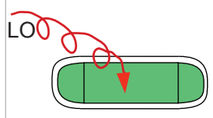
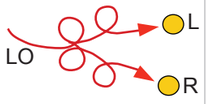
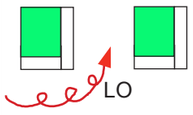
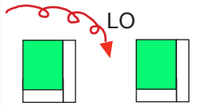
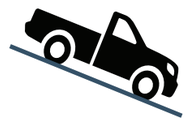
PUE 3 - EQUIPMENT TO ENVIRONMENT

		01	02	03	04	05	06	07	08	09	XX
O1	O1 - Obstacle 	 Reversing into object	 Permanent construction	 Temporary roadworks	 Temporary object on road	 Load hits vehicle	 Drove into berm	 Drove into infrastructure			Other
V1	V1 - Void 	 Accident or breakdown	 Maintenance area	 Unstable ground	 On rail tracks						Other

PUE 4 - LOSS OF CONTROL

		01	02	03	04	05	06	07	08	09	10
V4	V4 - Loss of control 	 Operator not in control	 Out of control on straight road	 Off road to left	 Off road to right	 Off road to left into object	 Off road to right into object	 Loss control turning left	 Loss of control turning right	 Rollaway on road	Other

V4 *continues*

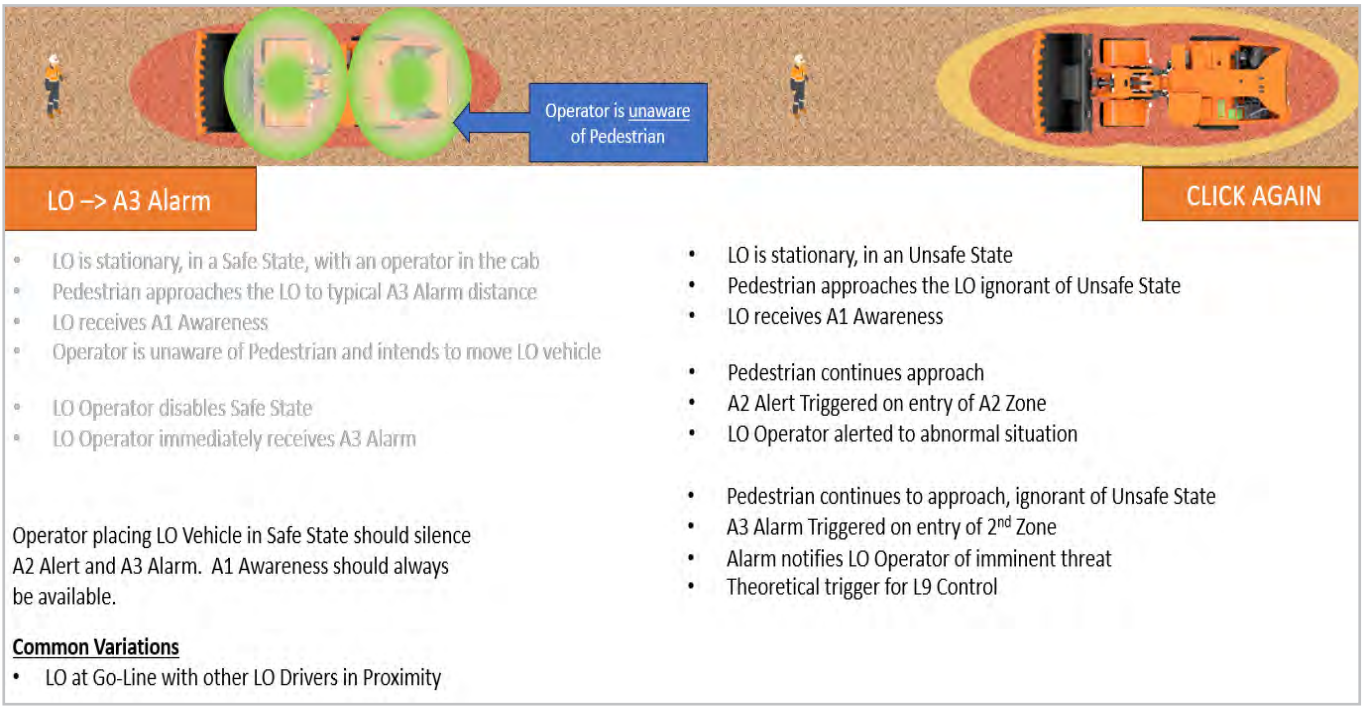
11	12	13	14	15	16	17	18	19	XX
 Lost control into berm	 Out of control on bend	 Off road on right bend	 Off road on left bend	 Off road on right bend into object	 Off road on left bend into object	 Lost control on left bend	 Lost control on right bend	 Rollaway off road	Other

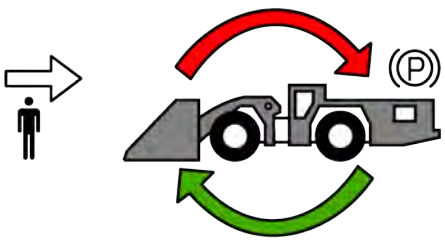
5.4 Underground functional performance scenario storyboards

The 5 storyboards
1. Pedestrian approaching static vehicle
2. Vehicle moving towards a person / equipment / vehicle
3. Two vehicles approaching each other
4. Vehicle turning towards a person / equipment / vehicle
5. Vehicle approaching environment hazard

The scenario storyboards can be accessed via the EMESRT website.

SCENARIO 1: PEDESTRIAN APPROACHING STATIC VEHICLE



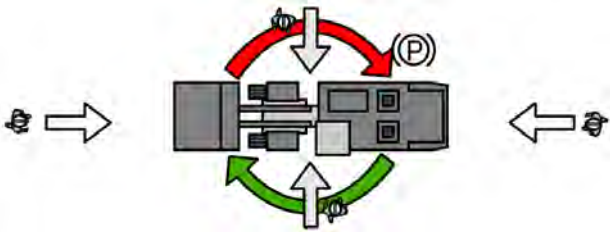
Scenario

Pedestrian approaching static vehicle

Variations

Approaching safe vehicle

Approaching unsafe vehicle

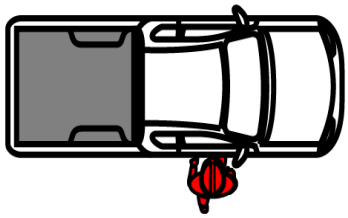
Modifications to variations



Approach from all directions

False negatives

Inside sensor field (e.g. inside articulation)

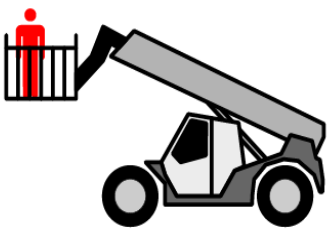


Inside vehicle space

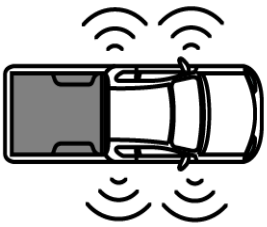
Under vehicle

Environment and infrastructure affected

False positives



Working in basket



Multiple passengers in vehicle

SCENARIO 2: VEHICLE MOVING TOWARDS A PERSON / EQUIPMENT / VEHICLE

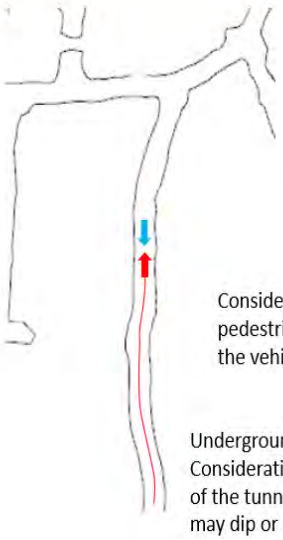
LO –> A3 Alarm

FINISHED

- LO approaching pedestrian or LV (RO) in a roadway
- Operating state of LO is visible to RO
- RO has A1 Awareness on approach
- A2 Alert Triggered on entry of 1st Zone
- LO Operator alerted to abnormal situation
- A3 Alarm Triggered on entry of 2nd Zone
- Alarm notifies LO Operator of imminent threat
- Theoretical trigger for L9 Control

Common Variations

- LO Reversing into RO
- RO is moving as LO Approaches
- LO approaching a workshop or service bay



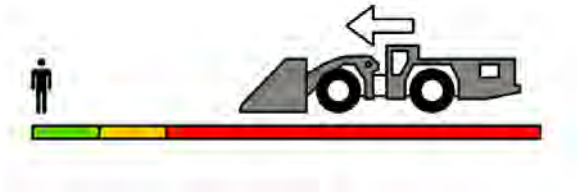
Example Parameters to Consider:

- Mass of Machine
- Operating Speed of Machine
- Grade of the Drive

Consideration should be given to the variation of this scenario involving a pedestrian behind an inactive vehicle. The LO should still detect the RO behind the vehicle and ensure that the inactive vehicle is not "pushed" onto the RO.

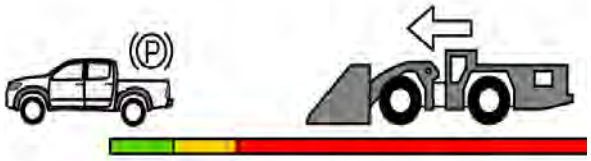
Underground tunnels are rarely perfectly straight. Consideration must be given for the constant change in shape of the tunnel. Additionally, the tunnel may not be flat, but may dip or crest.

Scenario



Vehicle approaching object

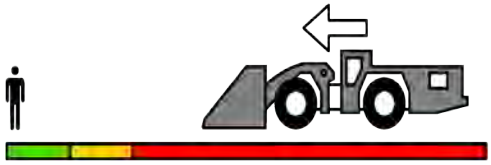
Variations



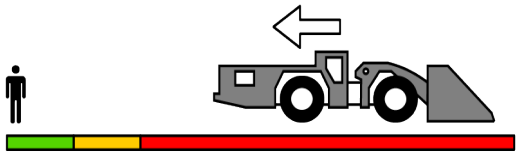
Machine approaching pedestrian

Vehicle approaching HV

Modifications to variations

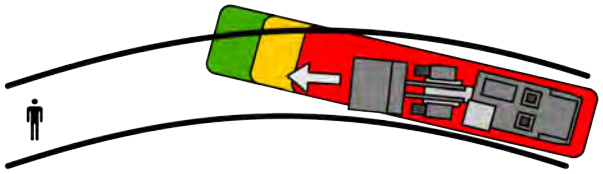


Forwards

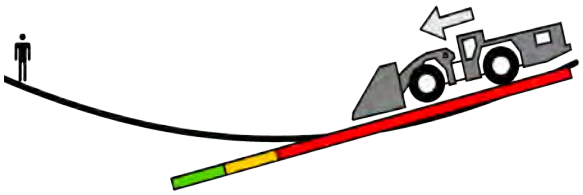


Backwards

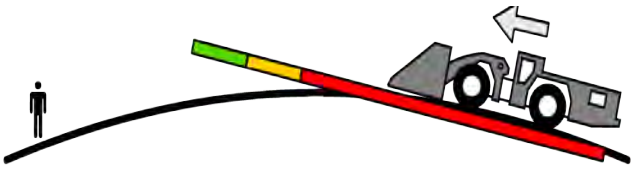
Factors affecting or influencing performance



Non straight drives

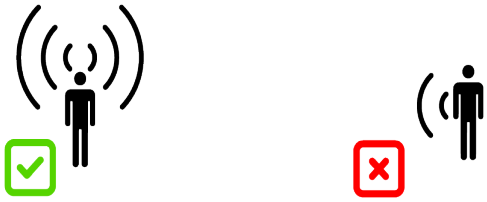


Dips

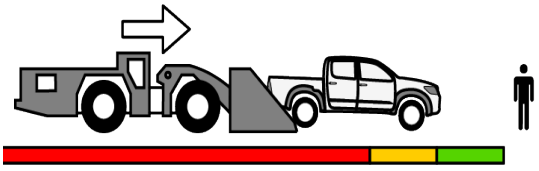


Crests

False negatives



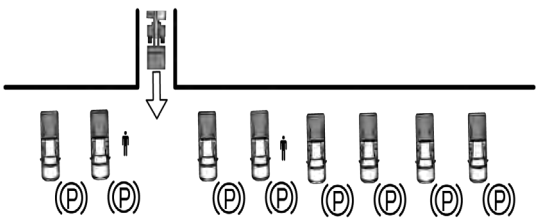
Pedestrian wearing sensor incorrectly



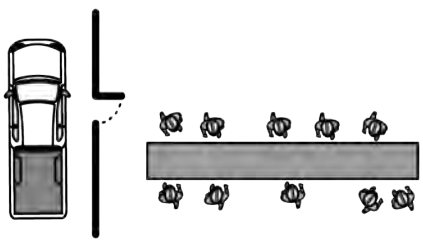
Inactive machine that is hit and pushed onto pedestrian

Environment and infrastructure affected

False positives



Deliberate approach



Congestion (horizontal or vertical)

SCENARIO 3: TWO VEHICLES APPROACHING EACH OTHER

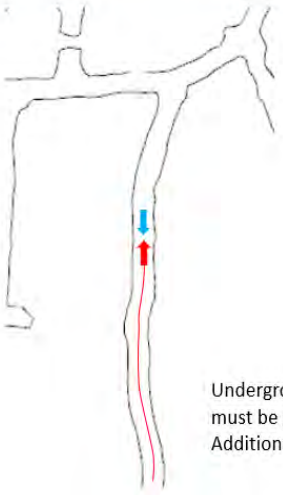
LO –> A3 Alarm | RO –> A3 Alarm | FINISHED

- LO approaching RO in a roadway
- Intention is for both vehicles to continue on straight course
- Operating state of LO is visible to RO and vice versa
- RO has A1 and LO has A1 Awareness on approach

- A2 Alert Triggered on entry of 1st Zone on both RO and LO
- RO and LO Operator alerted to abnormal situation

- A3 Alarm Triggered on entry of 2nd Zone on both RO and LO
- Alarm notifies RO and LO Operator of imminent threat
- Theoretical trigger for L9 Control

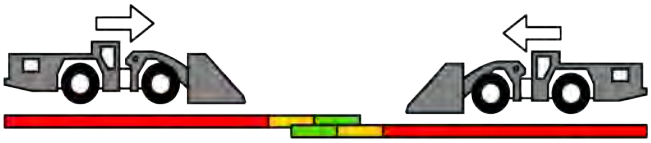
Common Variations
- Head to Head, Head to Tail and Tail to Tail
- RO is moving or stationary as LO Approaches



Example Parameters to Consider:
- Mass of the Machines
- Operating Speed of Machines
- Grade of the Drive

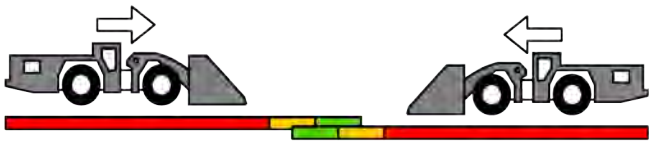
Underground tunnels are rarely perfectly straight. Consideration must be given for the constant change in shape of the tunnel. Additionally, the tunnel may not be flat, but may dip or crest.

Scenario

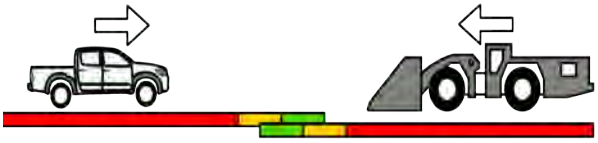


Two vehicles approaching each other

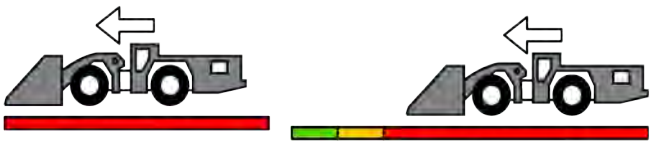
Variations



HV approaching HV

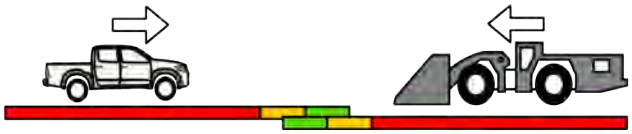


HV approaching LV

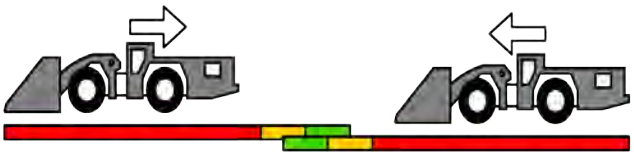


Vehicle catching up to another vehicle (tailgating)

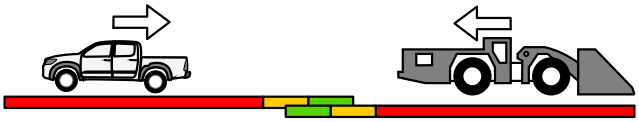
Modifications to variations



Head to head

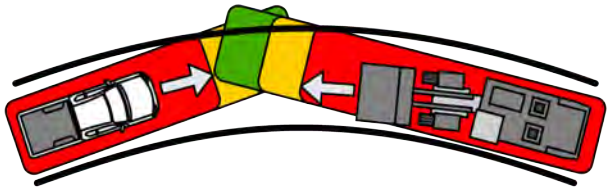


Head to tail

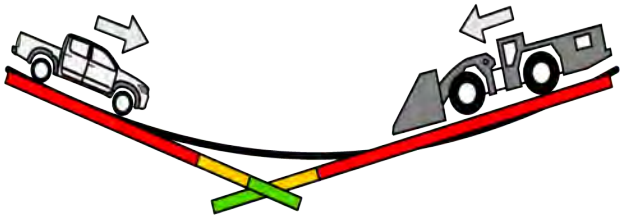


Tail to tail

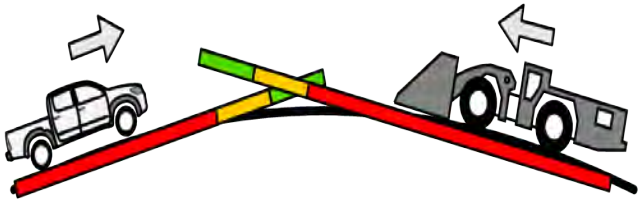
Factors affecting or influencing performance



Non straight drives



Dips

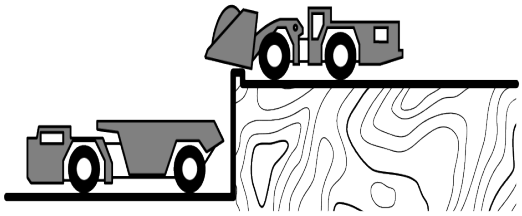
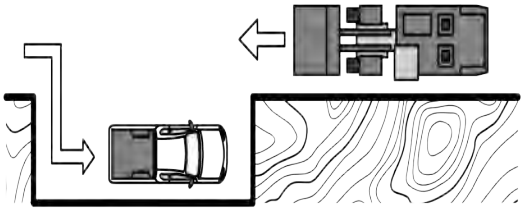


Crests

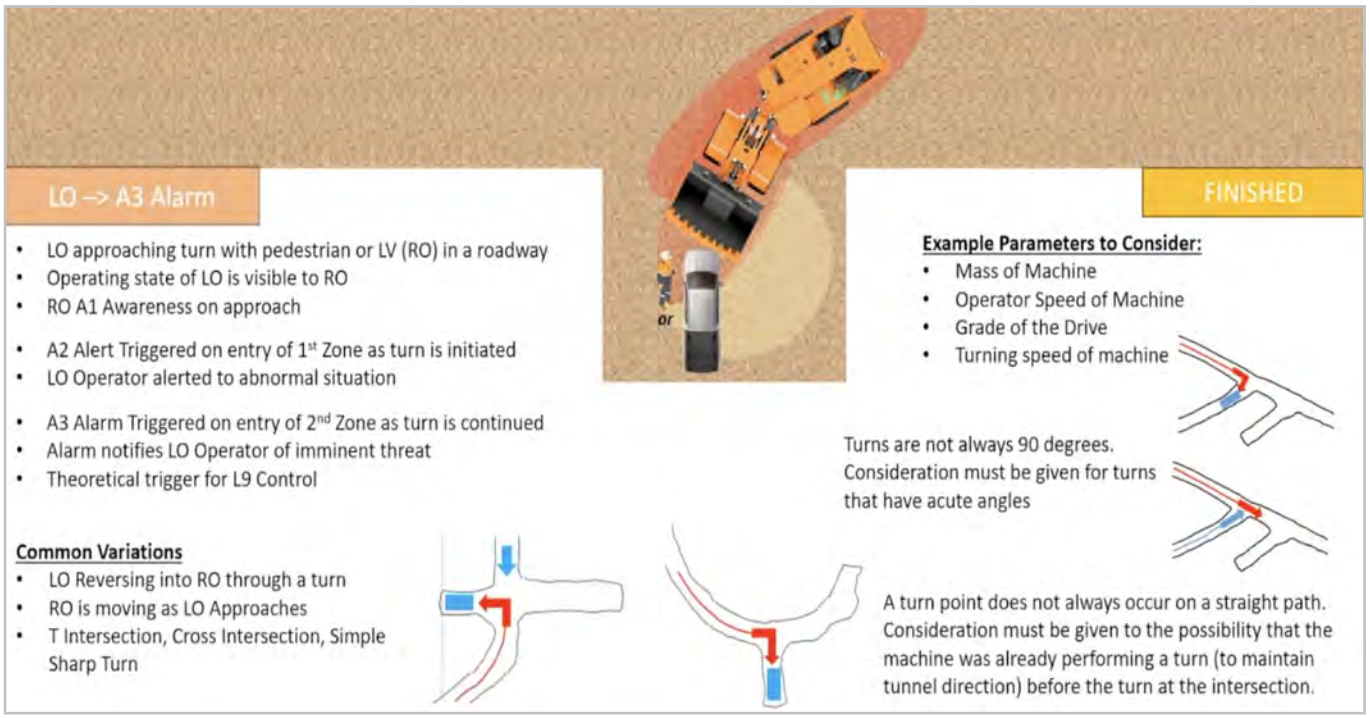
False negatives

Environment and infrastructure affected

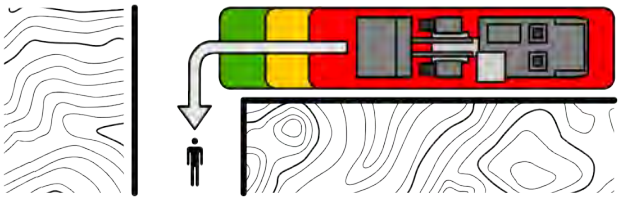
SCENARIO 3: TWO VEHICLES APPROACHING EACH OTHER

False positives	
 Deliberate approach	 Congestion
 Passing bay	

SCENARIO 4: VEHICLE TURNING TOWARDS A PERSON / EQUIPMENT / VEHICLE

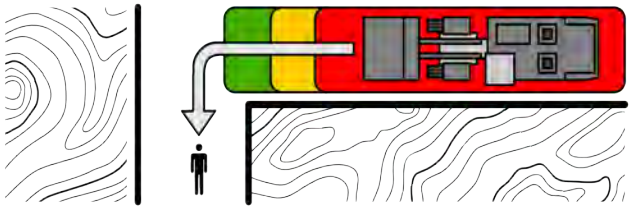


Scenario

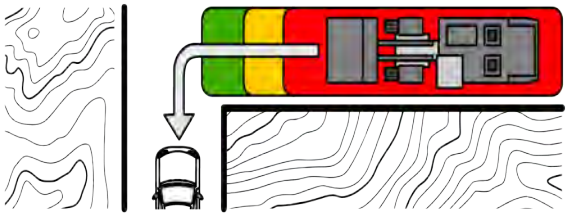


Vehicle performing turn

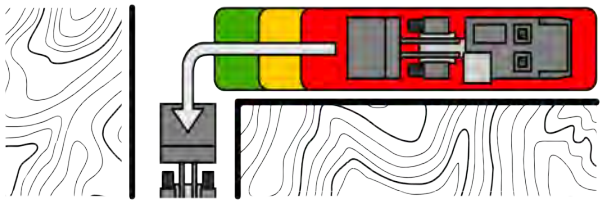
Variations



Vehicle turning into pedestrian

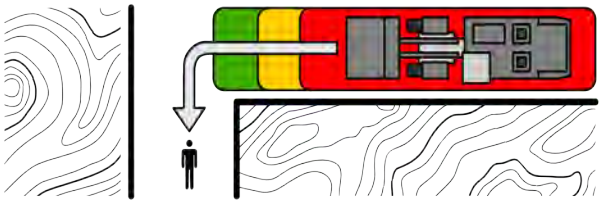


Vehicle turning into LV

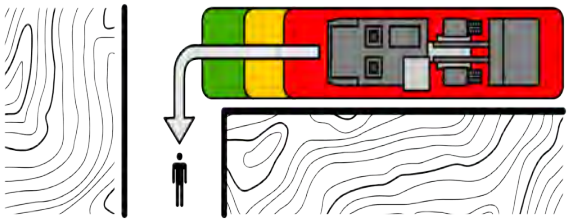


Vehicle turning into HV

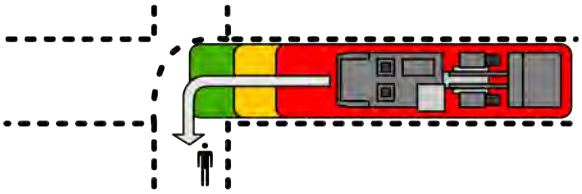
Modifications to variations



Forwards

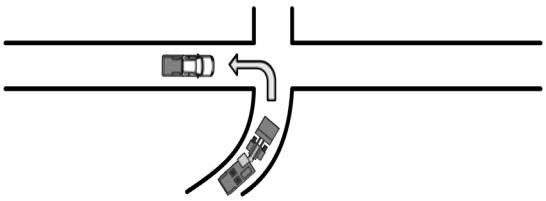


Backwards

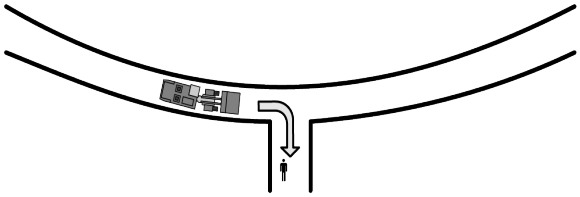


T, cross, turn

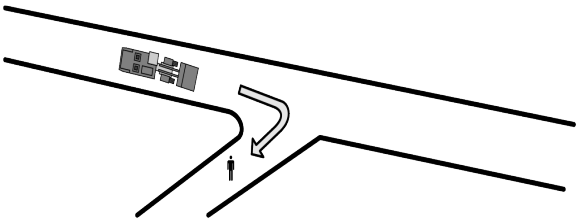
Factors affecting or influencing performance



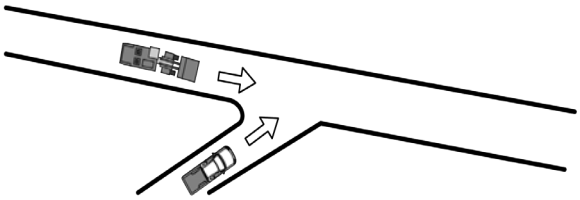
Gradual turn before full turn



Gradual turn before opposite full turn

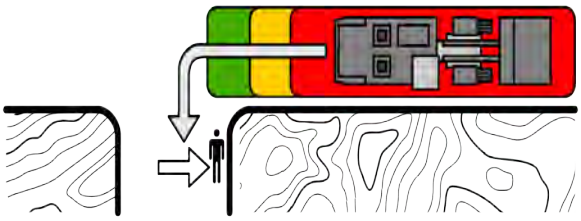


Acute angle turning

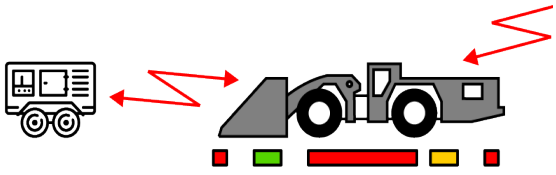


Merge

False negatives

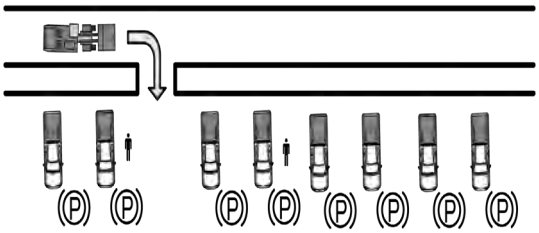


Pedestrian at toe of bay

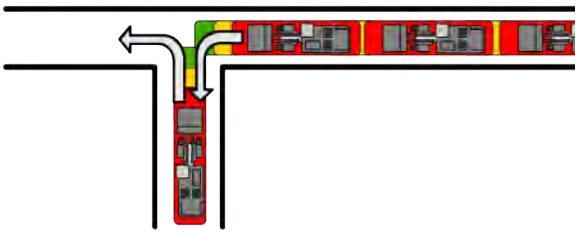


Environment and infrastructure affected

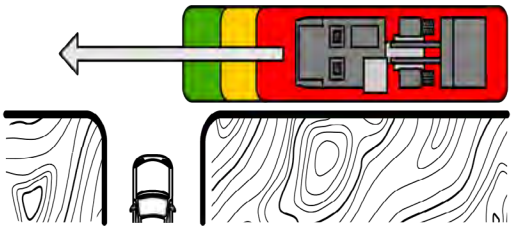
False positives



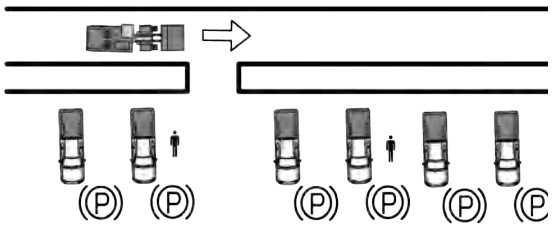
Deliberate approach



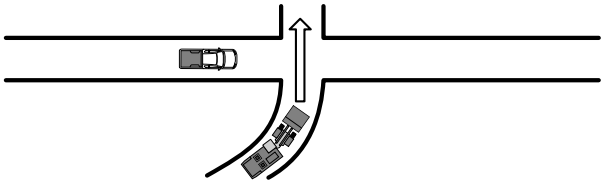
Congestion



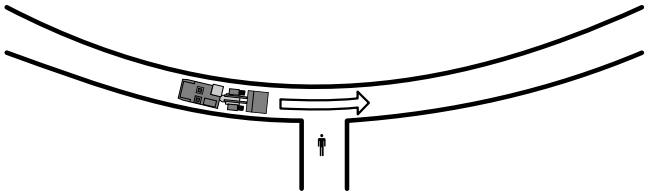
Passing occupied bay



Passing workshop



Passing occupied gradual turn



Passing occupied off turn

SCENARIO 5: VEHICLE APPROACHING ENVIRONMENT HAZARD

LO –> A3 Alarm

FINISHED

- LO approaching hazard
- RO A1 Awareness on approach

- A2 Alert Triggered on hazard entry of 1st Zone
- LO Operator alerted to abnormal situation

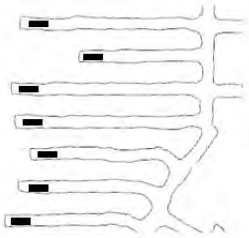
- A3 Alarm Triggered on entry of 2nd Zone
- Alarm notifies LO Operator of imminent threat
- Theoretical trigger for L9 Control

Common Variations

- LO Approaching open stop or pass
- LO approaching unsupported ground
- LO approaching sump
- LO approaching critical infrastructure such as electrical substations
- LO approaching temporary installations (drills)

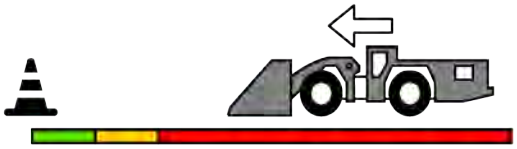
Example Parameters to Consider:

- Mass of Machine
- Operating Speed of Machine
- Grade of the drive



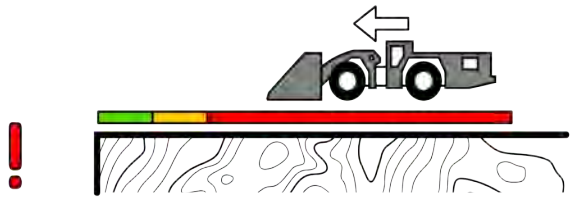
For mining operations that utilise Stope Extraction techniques, dangerous ground zones behind barricades are numerous, with multiples per level. Consideration must be given to the number of zones at the operation.

Scenario

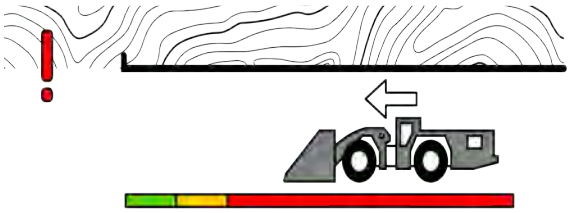


Vehicle approaching fixed hazard

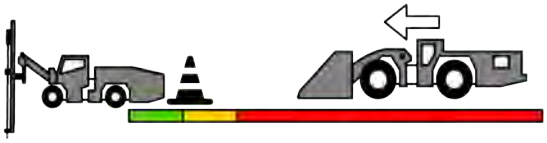
Variations



Vehicle approaching void



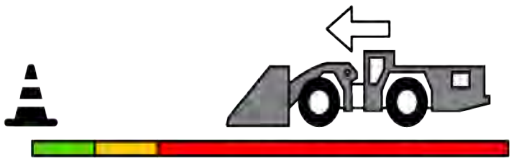
Vehicle approaching unsupported ground



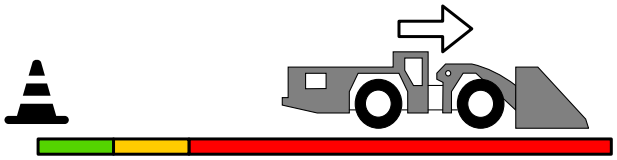
Vehicle approaching temporary infrastructure (e.g. diamond/raisebore)

Vehicle approaching fixed infrastructure (e.g. substation)

Modifications to variations

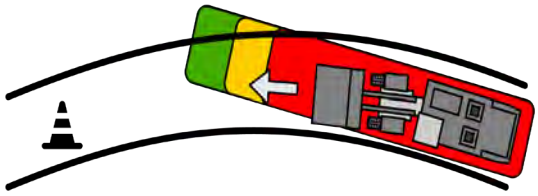


Forwards

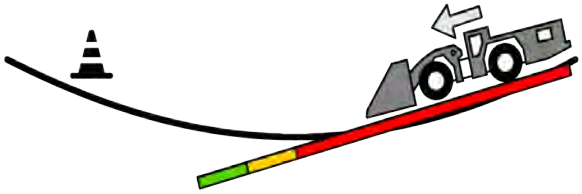


Backwards

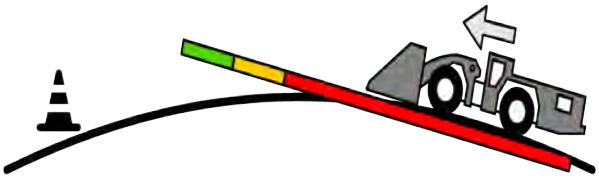
Factors affecting or influencing performance



Non straight drives

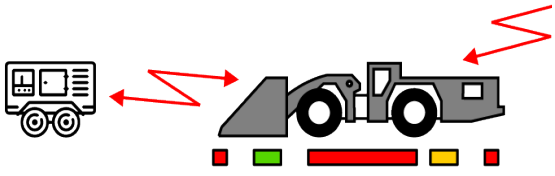


Dips



Crests

False negatives



Environment and infrastructure affected

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enquiries@emesrt.org

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PR-5A

This Performance Requirement should be read in conjunction with the EMESRT Design Philosophy 5 - Machine Operation and Control.