Development of an Intelligent Proximity Detection System for Continuous Mining Machines

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Proximity Warning Systems for Mining Equipment
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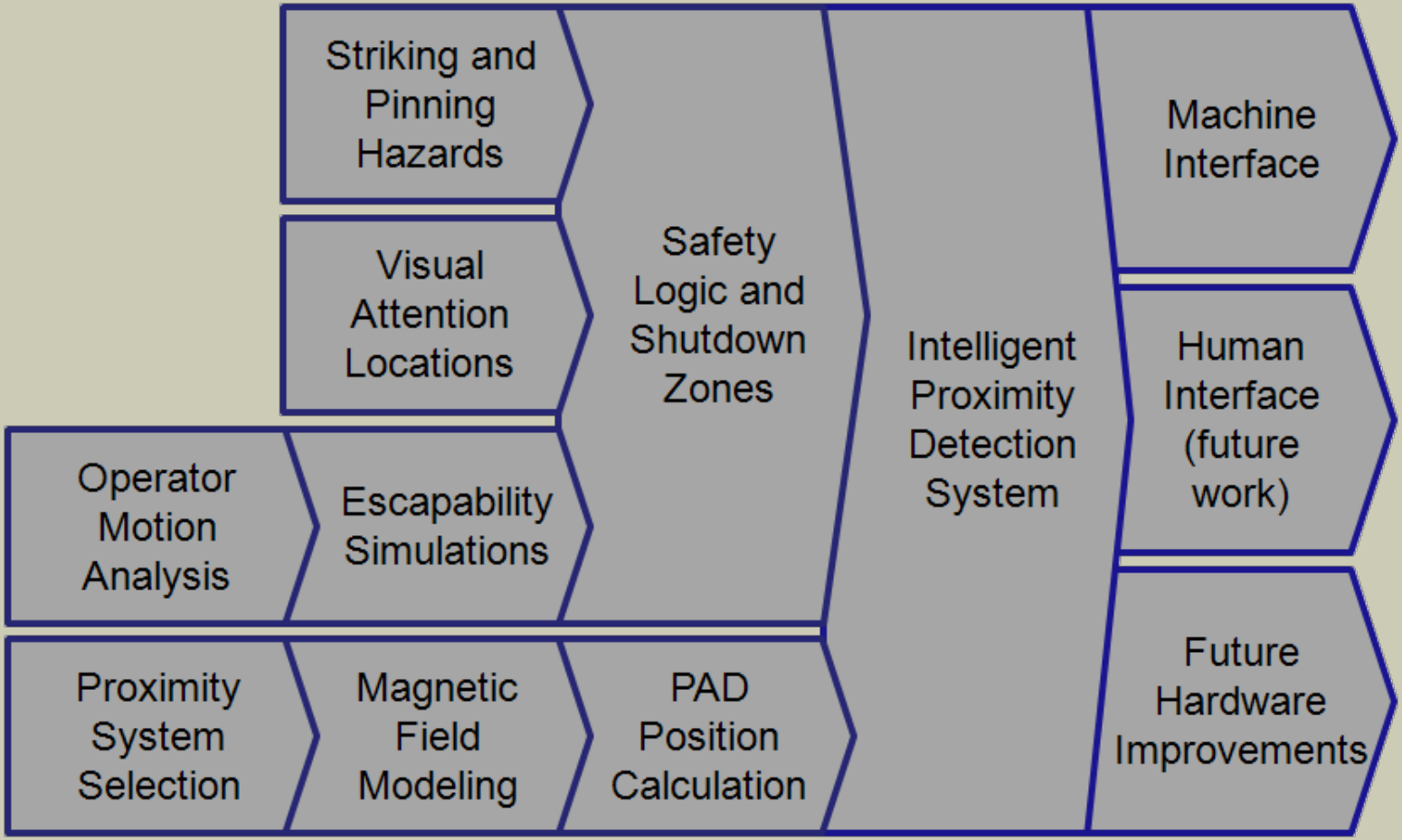
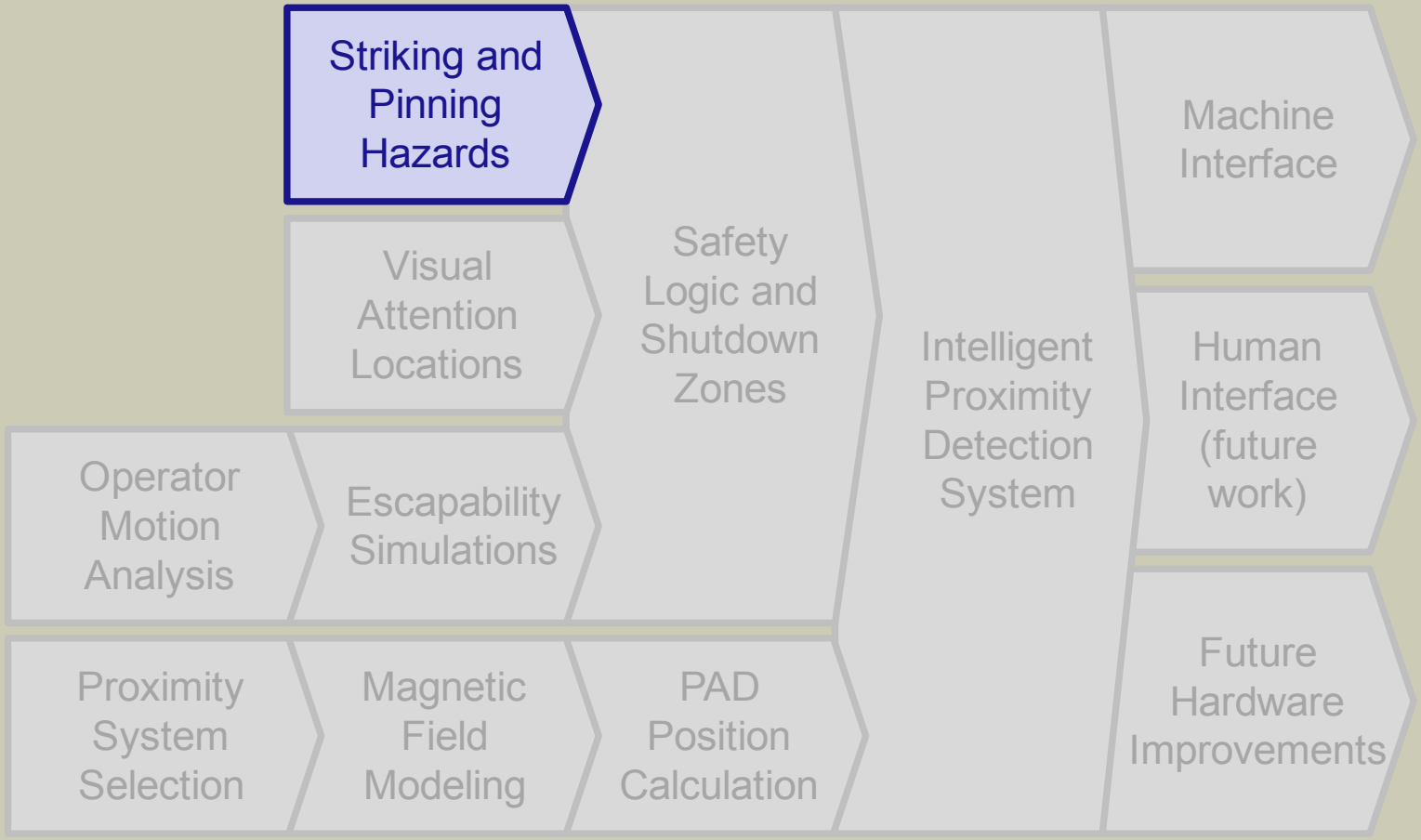
Presentation Outline




Striking and Pinning Hazards
Visual Attention Locations
Operator Motion Analysis
Escapability Simulations
Proximity System Selection
Magnetic Field Modeling
PAD Position Calculation
Safety Logic and Shutdown Zones
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Machine Interface
Human Interface (future work)
Future Hardware Improvements

Striking and Pinning Hazards

- Operator injuries involving continuous mining machines averaged 248 annually for the past 5 years
- Contributing Factor - Complex Work Environment
  - Radio remote control allows freedom of movement
  - Large moving equipment in confined environment
  - Dynamic work area

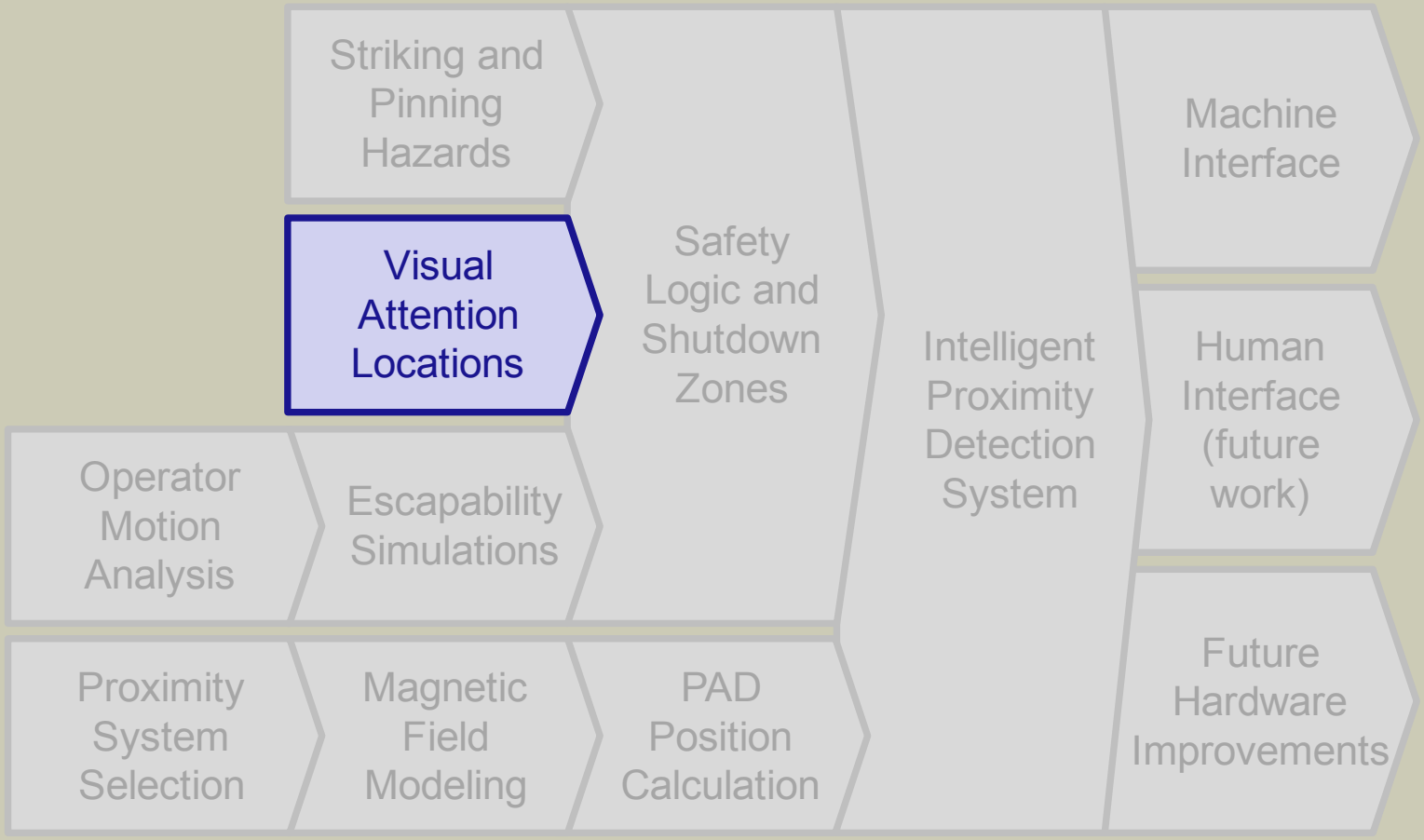
Striking and Pinning Hazards

Weight: >100,000 lb

Max Speed: ~85 fpm

Pivot Rate: ~19°/s

6 fps at corner of rear bumper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Operator Visual Attention Locations (VALs)

Objective - to analyze the effect of operator cues on work positions:

- Structured interviews
- Ranking to evaluate cue significance
- Computer simulation to evaluate operator view by position
- Assessment of operator view in multiple postures

Operator Visual Attention Locations (VALs)

Typical Positions During Complete Cutting Cycle

Operator Position	
1	11%
2	13%
3	9%
4	16%
5	15%
6	17%
7	14%
8	2%
9	2%
10	1%

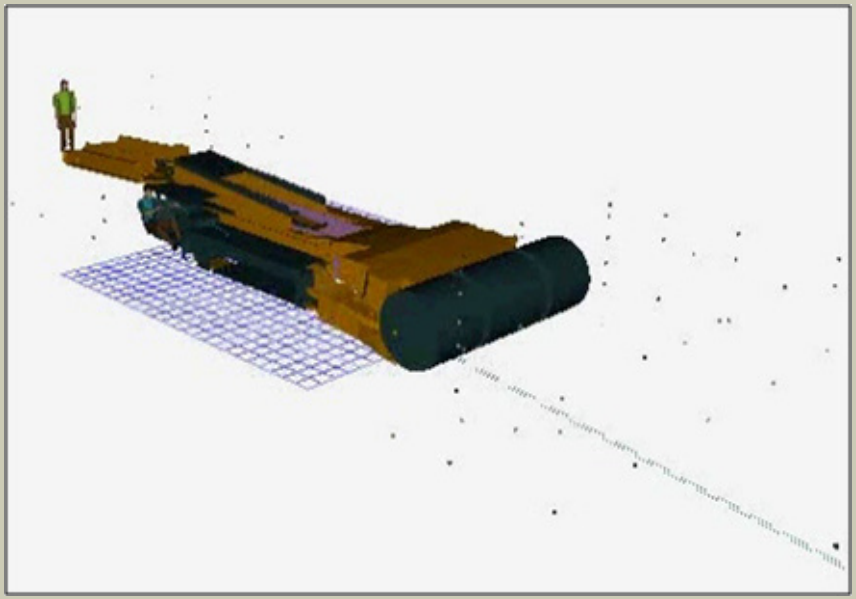
Operator Visual Attention Locations (VALs)

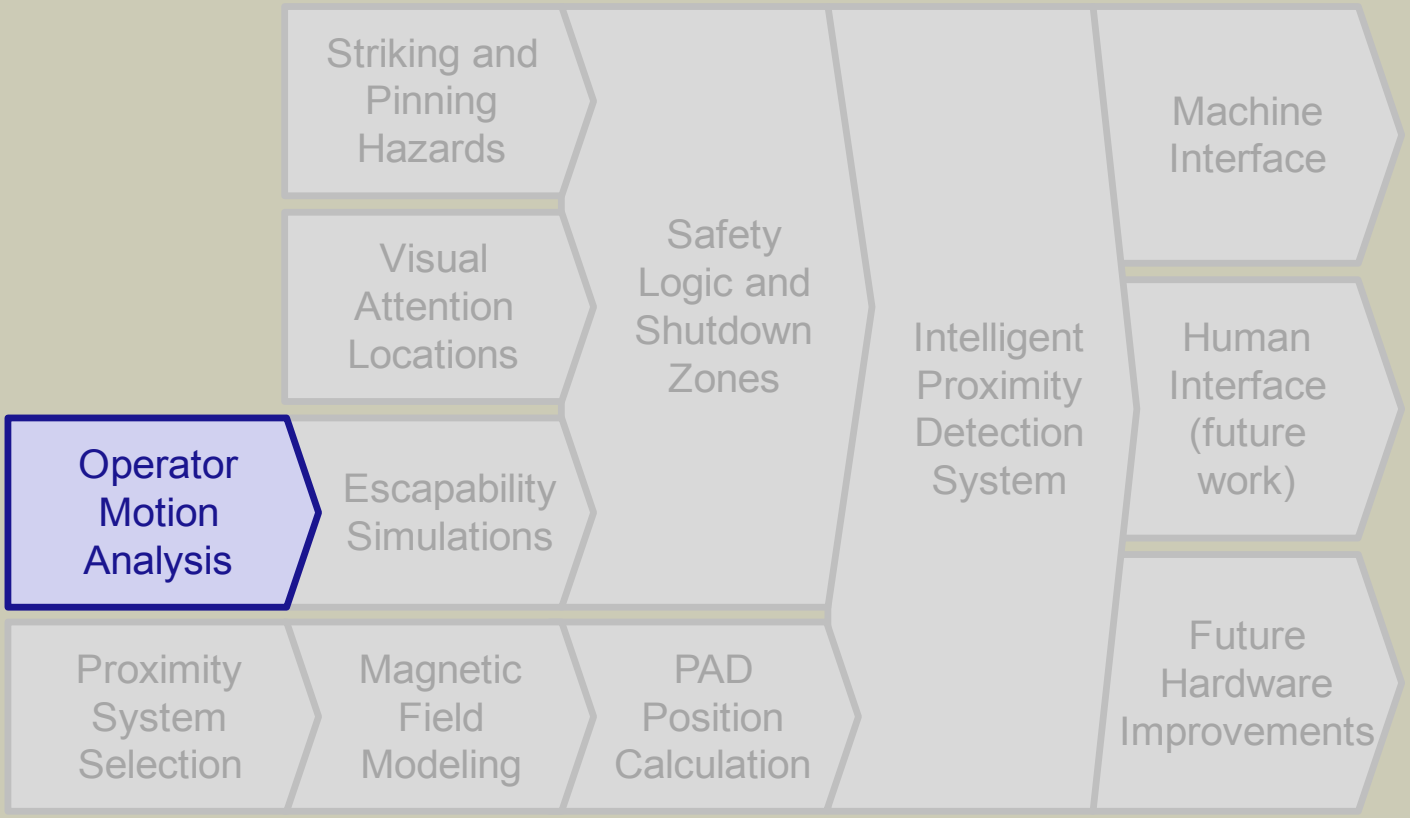
Visual Areas Defined as a Matrix of Points

Operator Visual Attention Locations (VALs)

Simulated Scanning to Determine Visibility

- Visibility - best positions are closer to the machine
- Safety - best positions are farther from mining equipment

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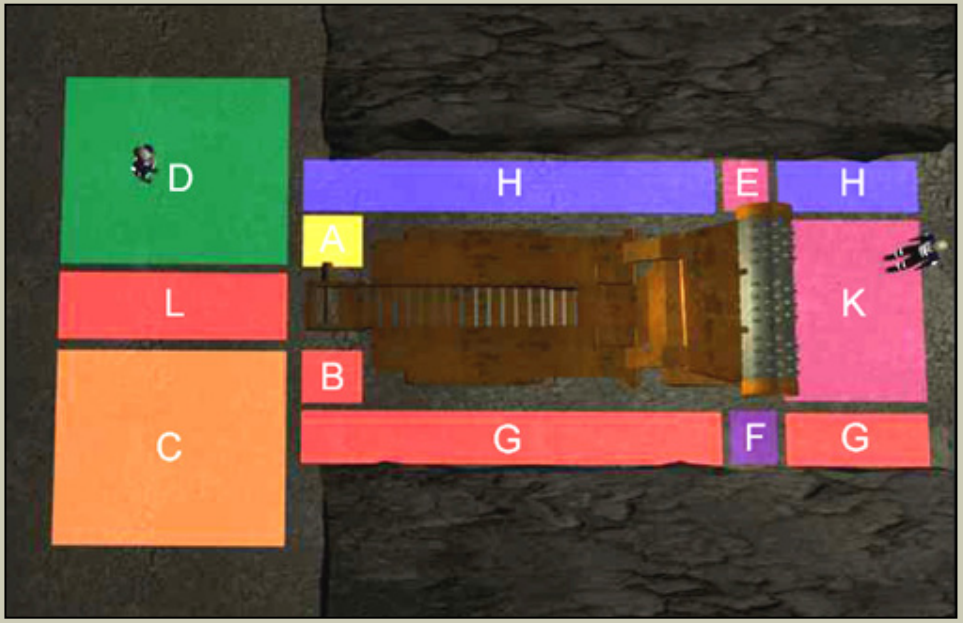
Operator Motion Analysis Research

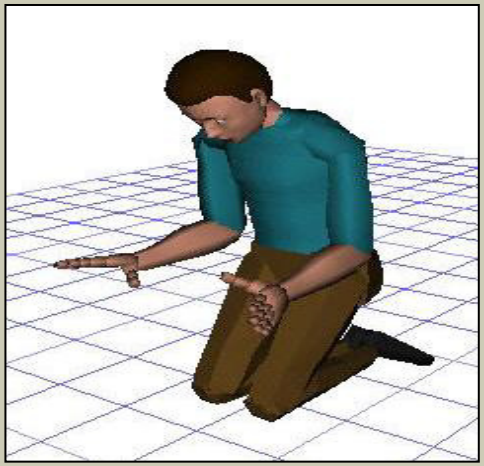
All Position Related Injuries 2004 - 2008

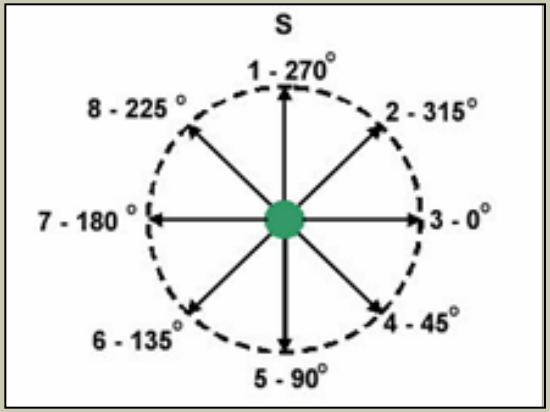
Position Related Accidents by Zone	
A) Tail Left	3%
B) Tail Right	11%
C) Center Right	6%
D) Center Left	2%
E) Drum Left	1%
F) Drum Right	2%
G) Rib Right	12%
H) Rib Left	2%
I) Unknown (Supported Roof)	45%
J) Unknown (Unsupported Roof)	1%
K) Front	1%
L) Rear	14%

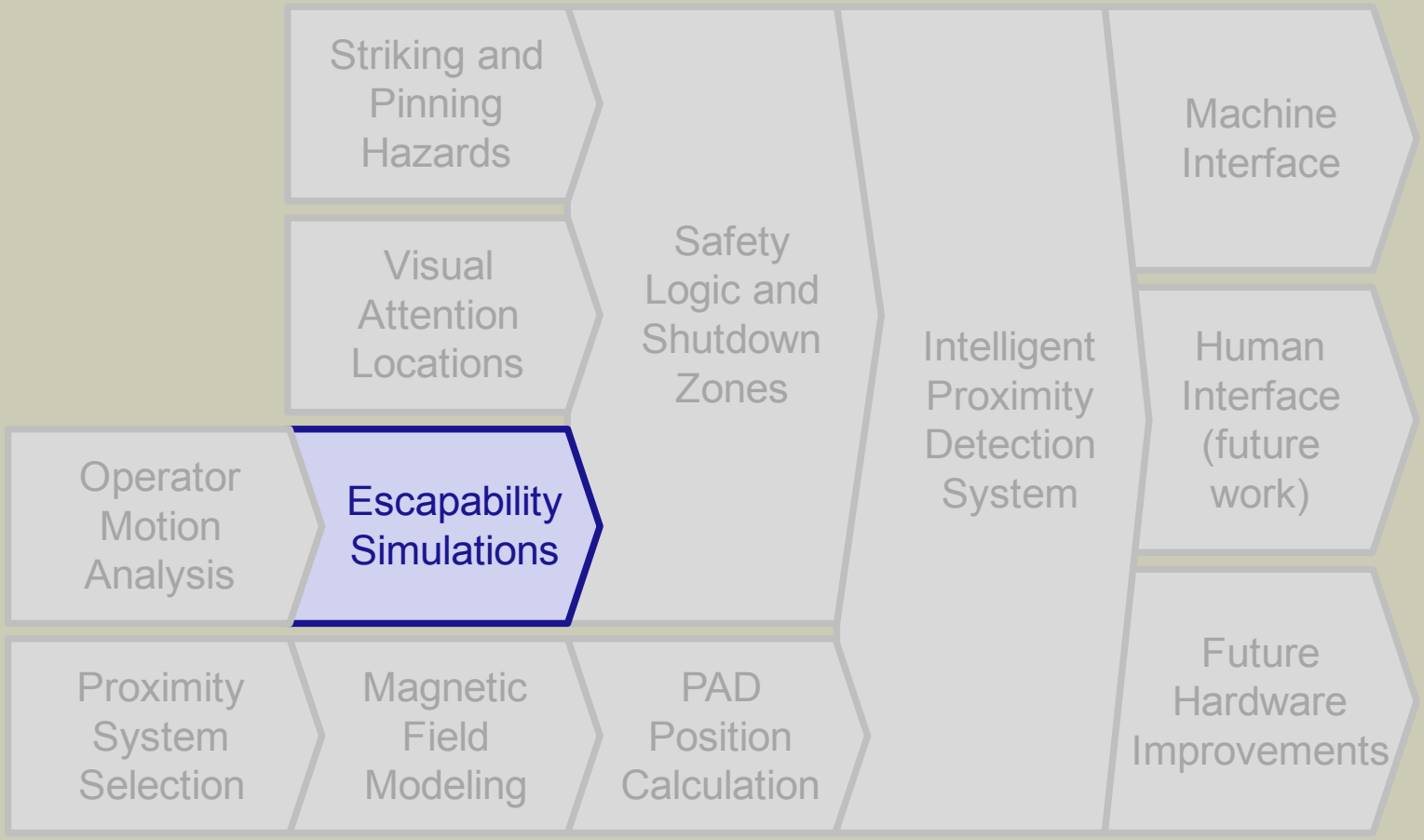


Operator Motion Analysis Research
Motion Data Capture

- 3 postures
- 3 facing directions
- 8 escape directions



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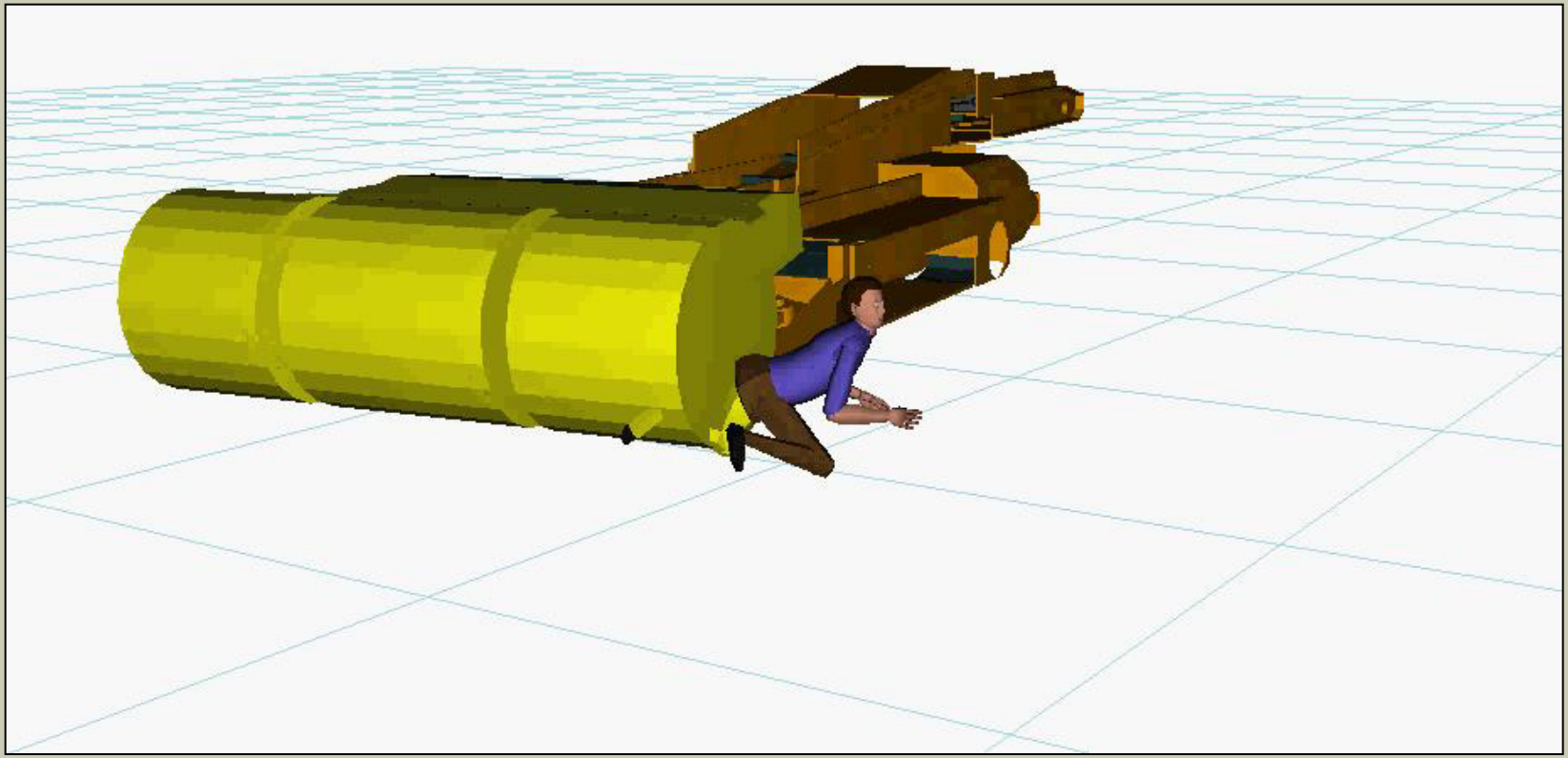
Operator Escapability Computer Simulations

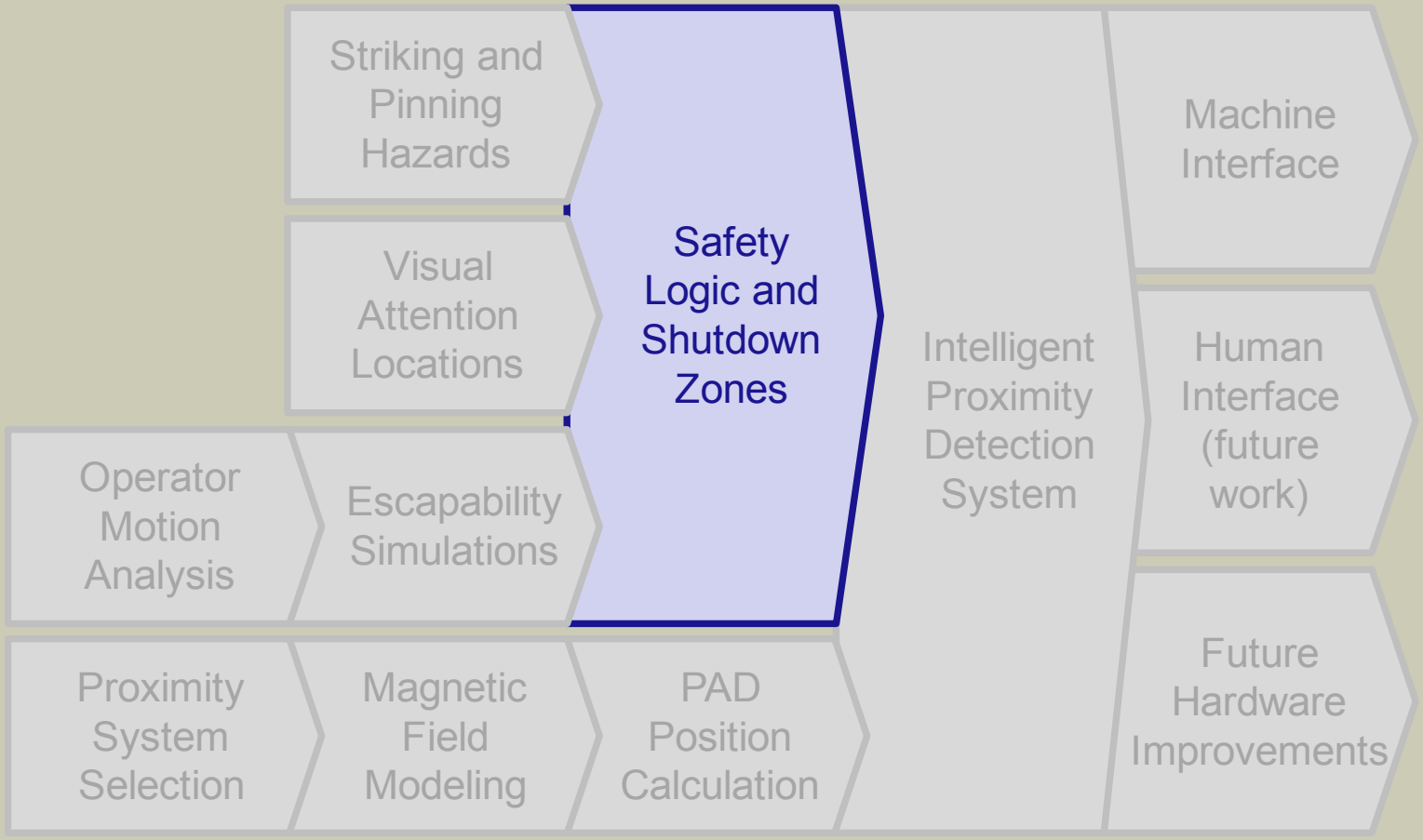
Simulation of Machine Movement with Motion Data



Operator Escapability Computer Simulations

Simulation Results

- Initial assumption - CM speed would be the most significant factor in struck-by accidents
- Finding - Statistical analysis indicated location was the most important factor
- Data showed that a position farther than 3 ft from a moving machine part could significantly reduce the likelihood of an operator being struck by the CM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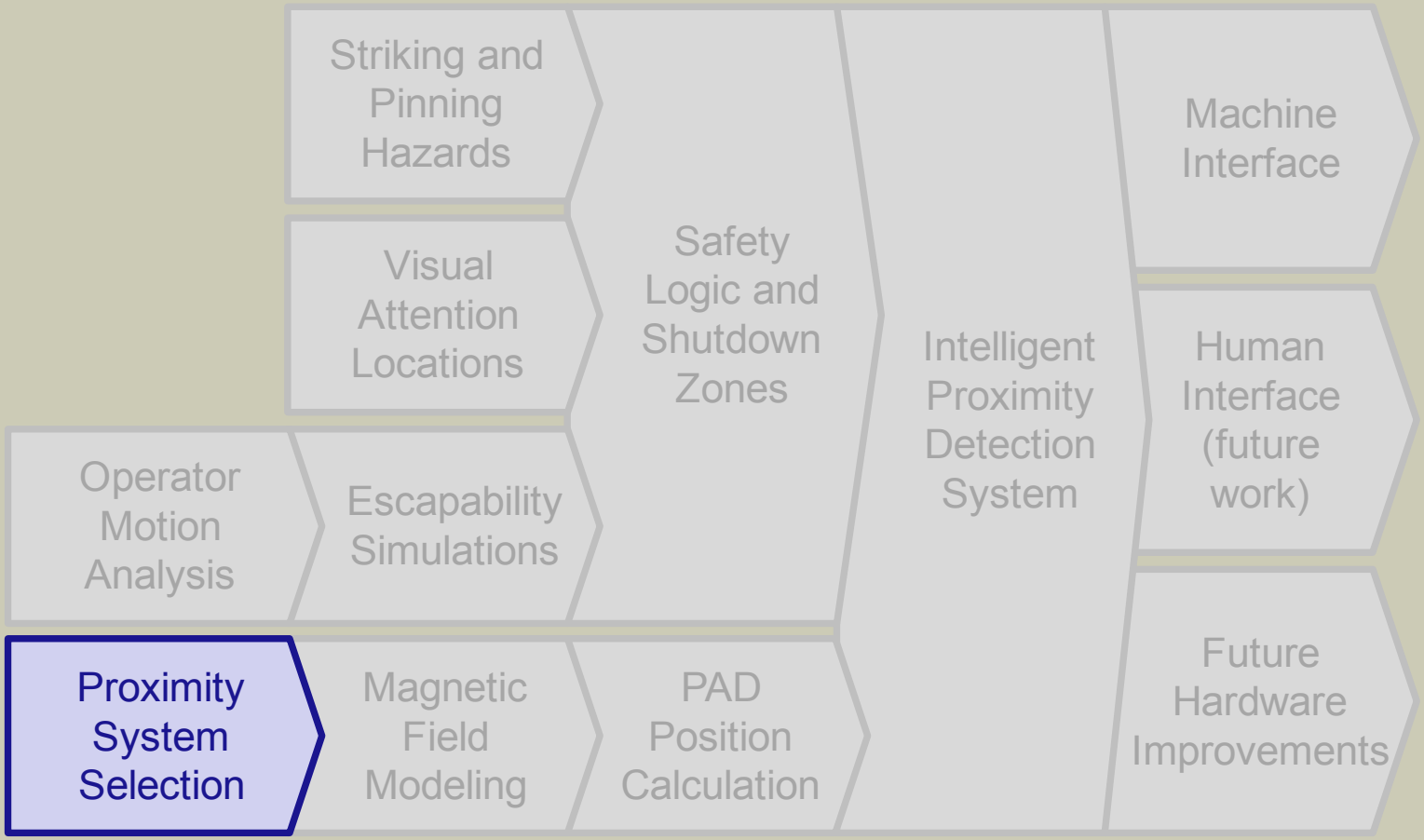
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Proximity Detection Method Selection

- Systems relying on GPS or vision were either not possible or practical
- NIOSH has previously developed an active proximity warning system called HASARD (Hazardous Area Signaling and Ranging Device) for warning workers as they approach known dangerous areas around heavy mining equipment and other dangerous work zones
- Commercially available proximity detection hardware based on this research was selected in conjunction with a modified controller to yield the information needed for the Intelligent Proximity Detection System

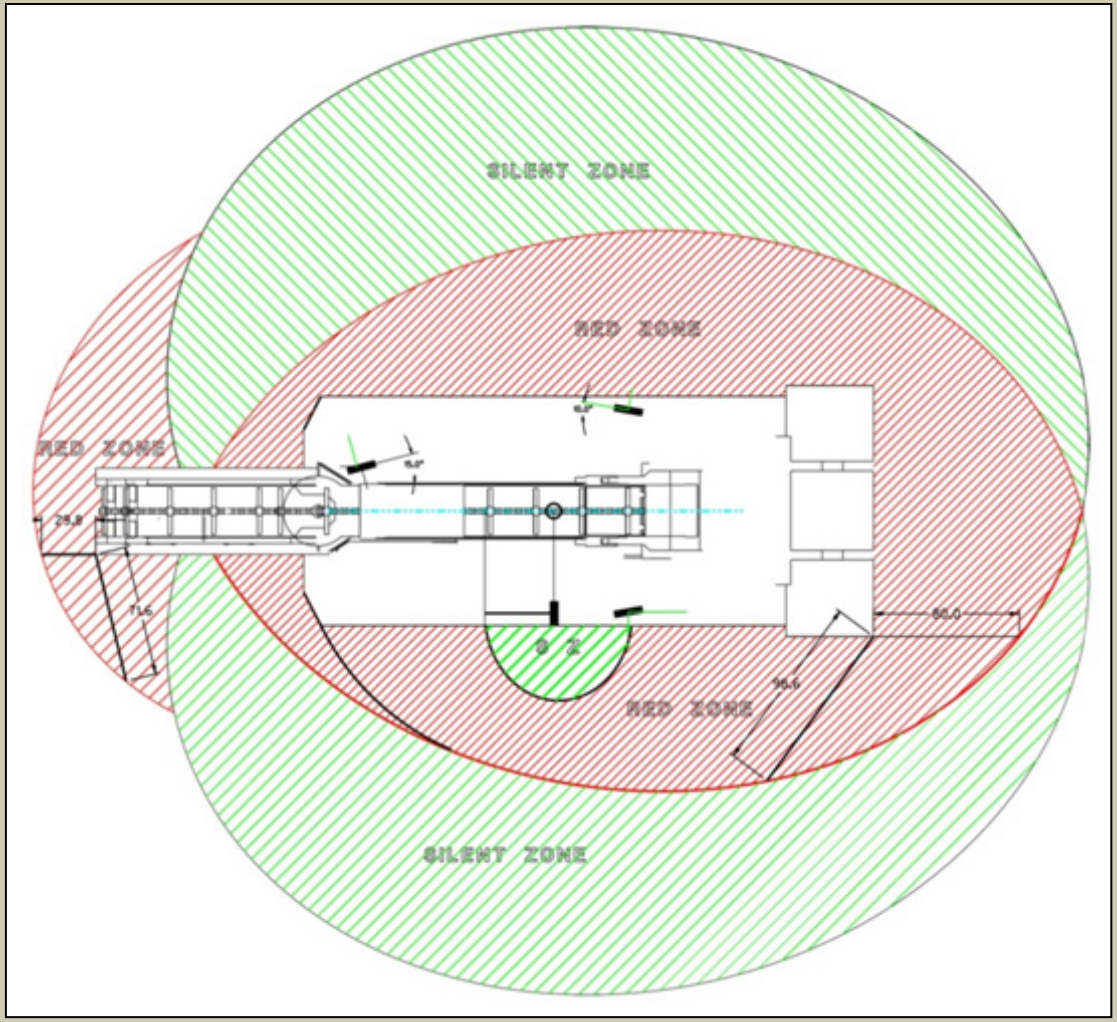
Current Proximity Detection Technology

Ferrite-Cored Magnetic Field Generator

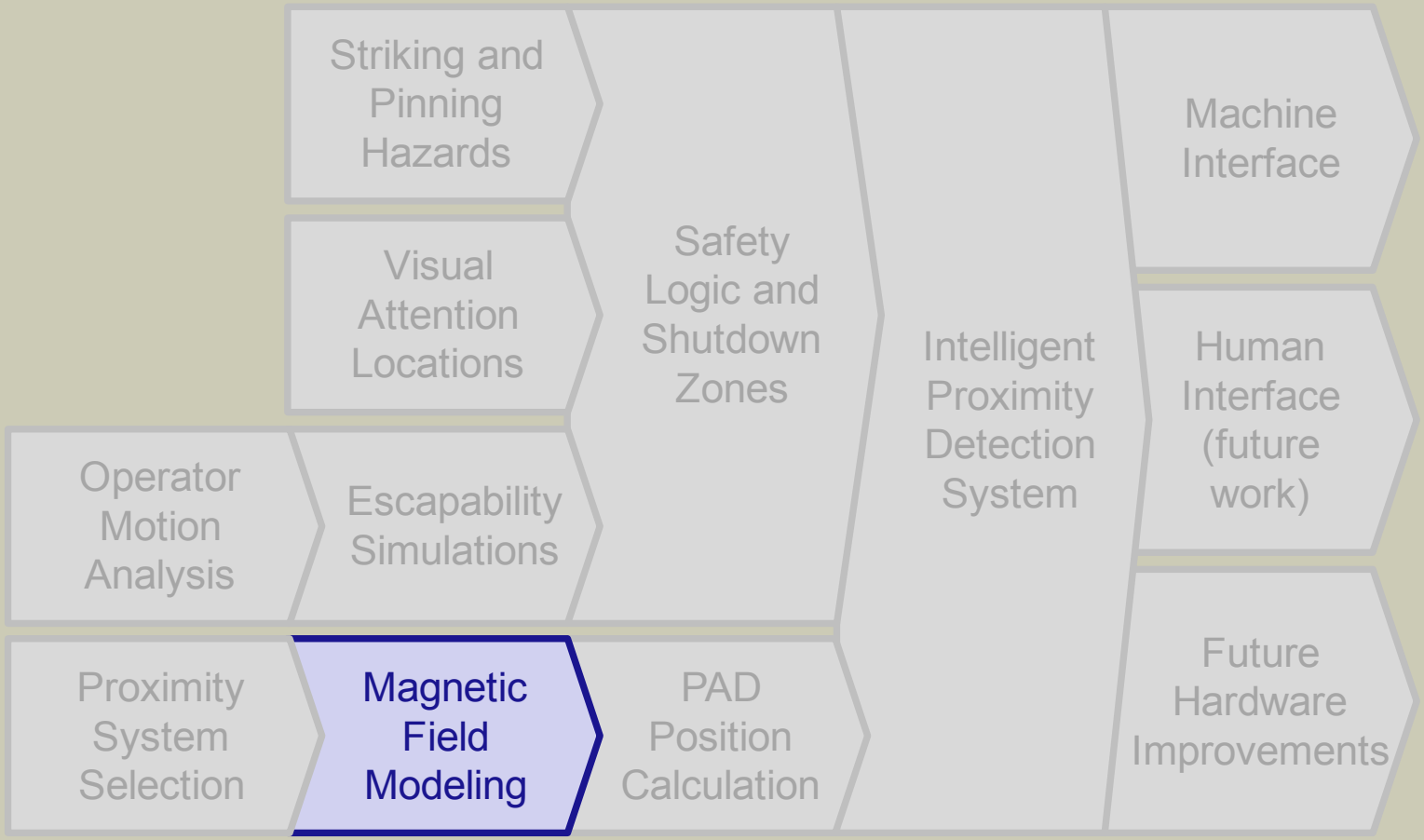
Increasing Magnetic Flux Density

Personal Alarm Device (PAD)

Current Proximity Detection Technology



- Field shaping can be difficult
- Complex generator arrangements are required to provide desired coverage
- System only knows what zone the operator is in, not the operators position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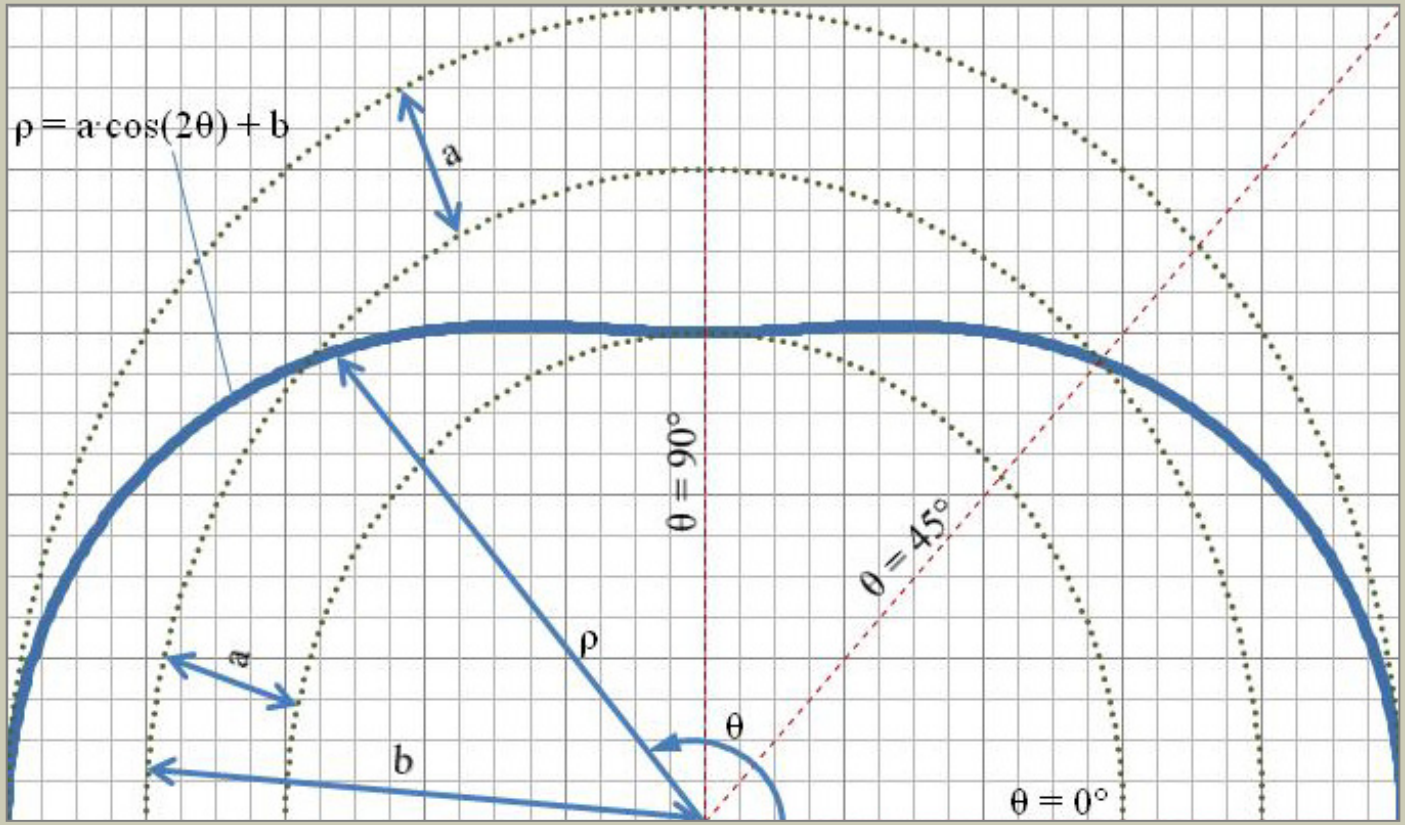
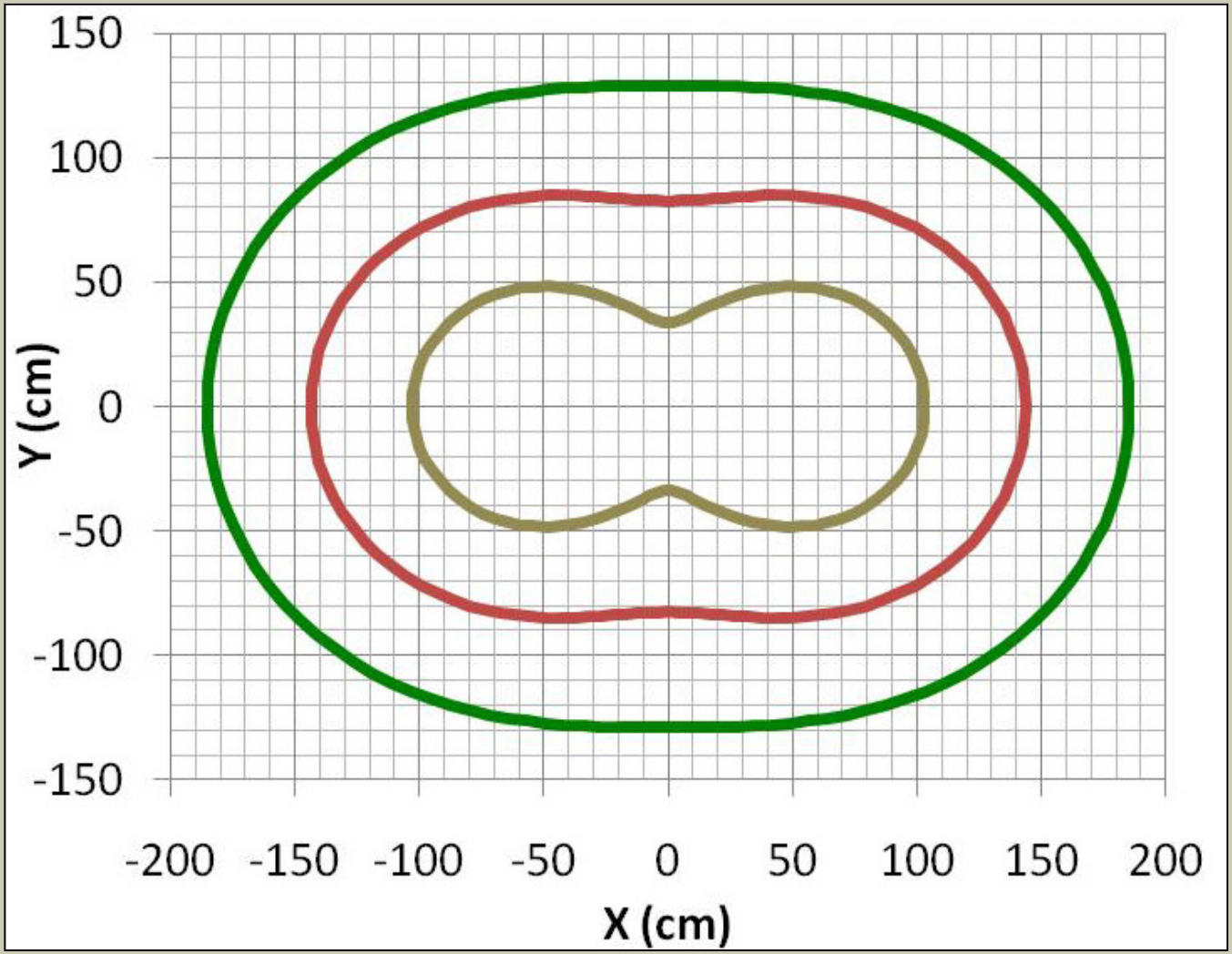
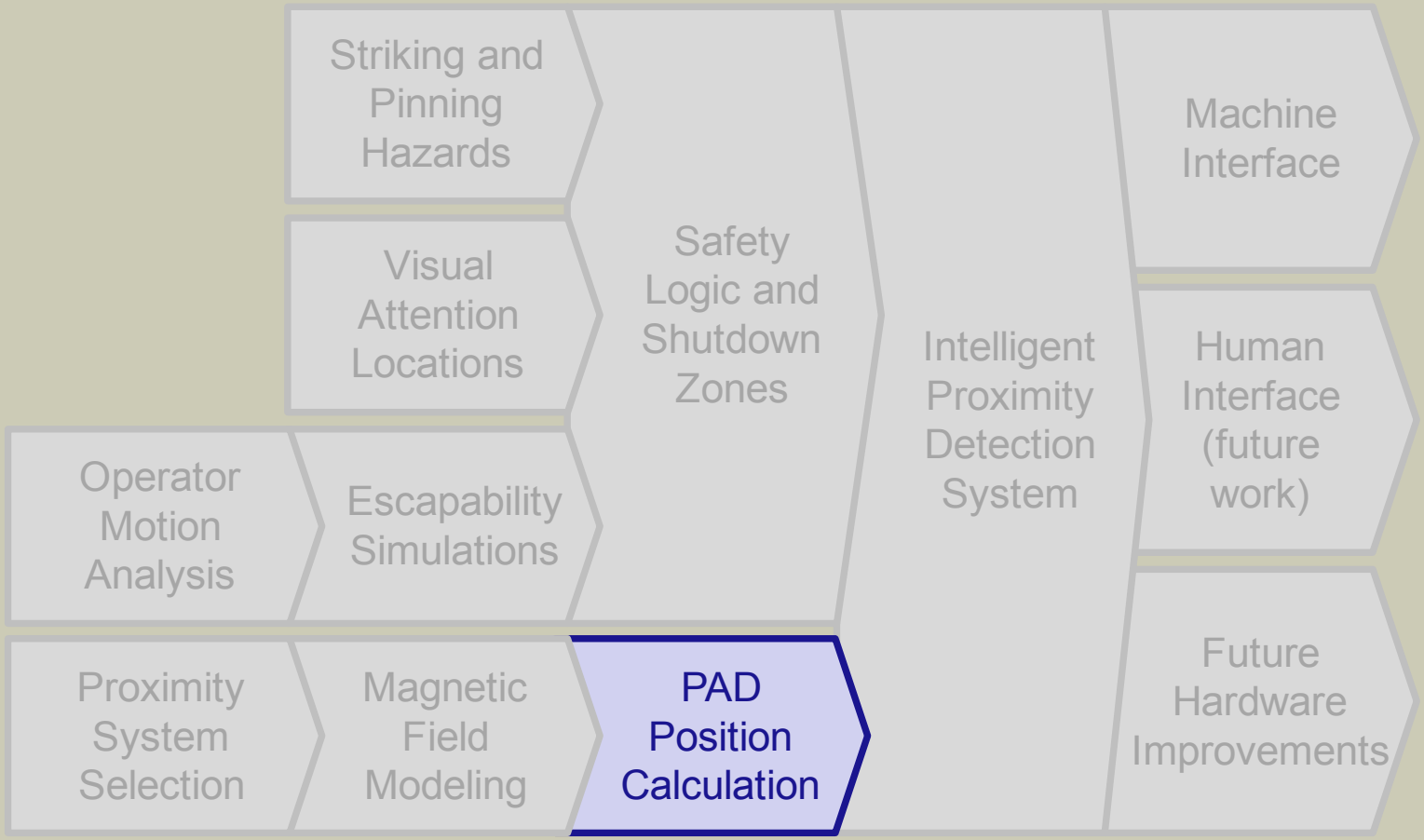
Magnetic Field Modeling

$$\rho = a \cdot \cos(2 \cdot \theta) + b$$



Magnetic Field Modeling

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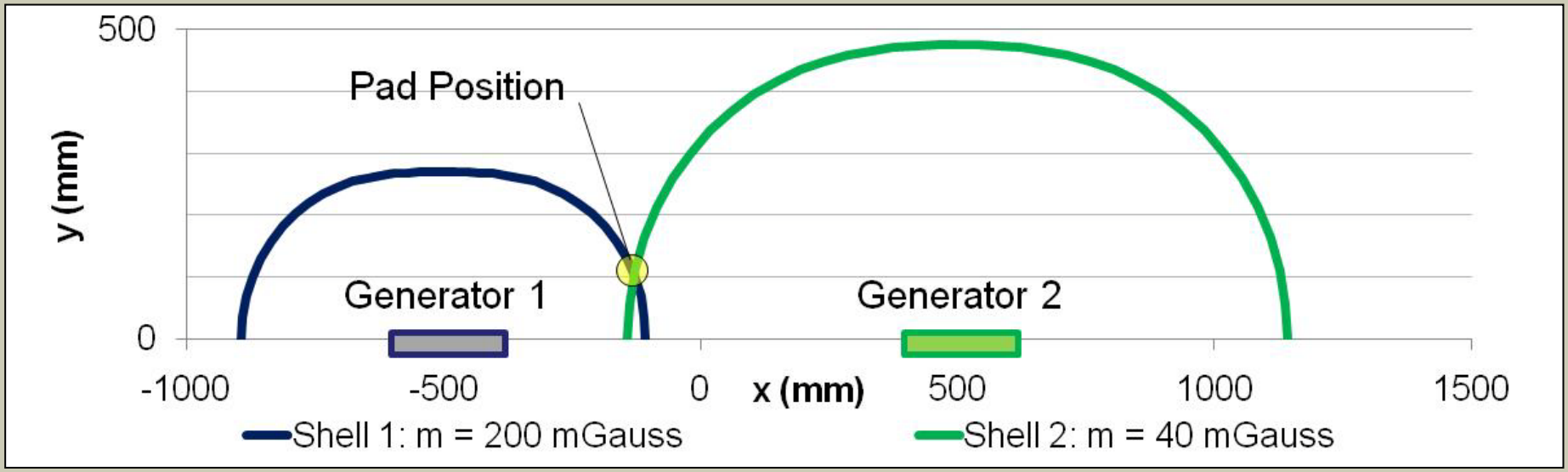
Triangulation Techniques



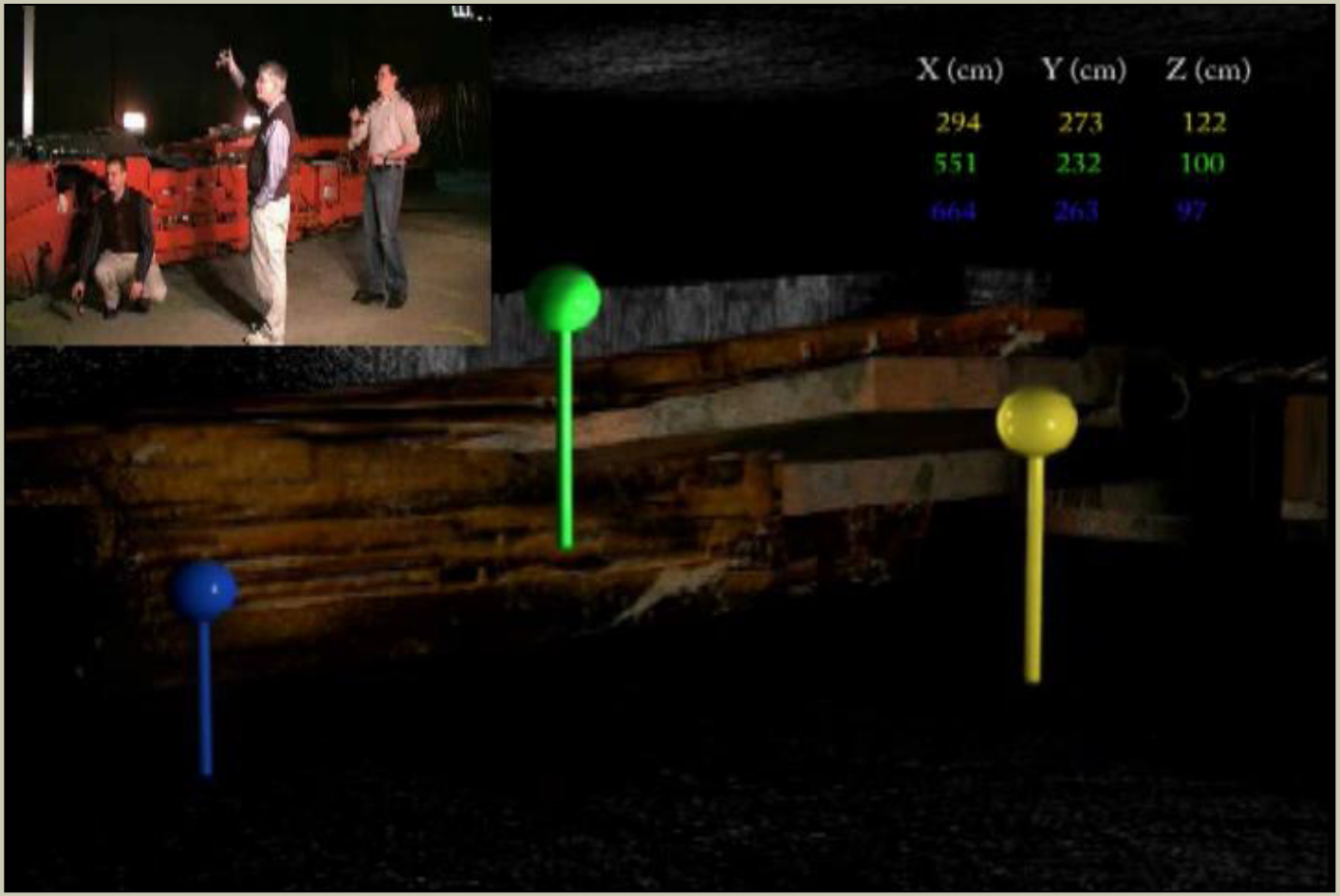
- Determining the exact location of the PAD isn't easy due to the magnetic field shapes
- Two novel triangulation techniques were developed to deal with the irregularities in the field shapes

Triangulation Techniques

Three Generators Yielding 2D Position

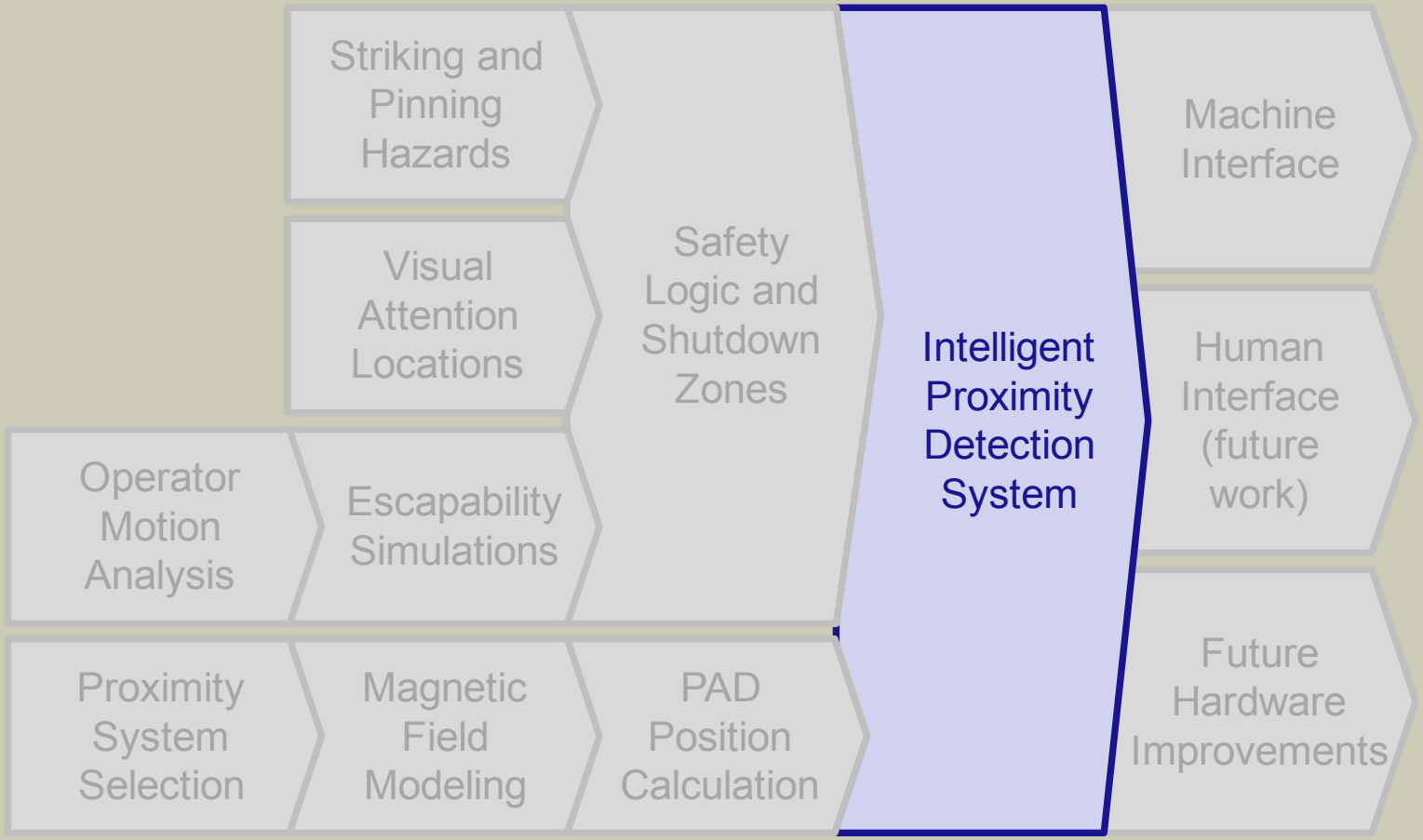
Triangulation Techniques

Four Generators with Vertical Displacement Yielding 3D information



Triangulation Techniques

Extrapolation of 3D Technique to Posture Identification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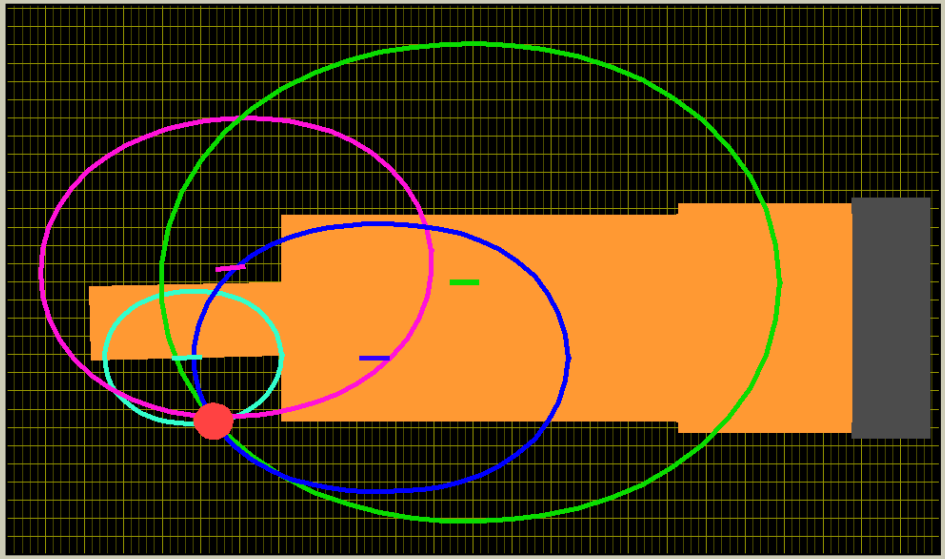
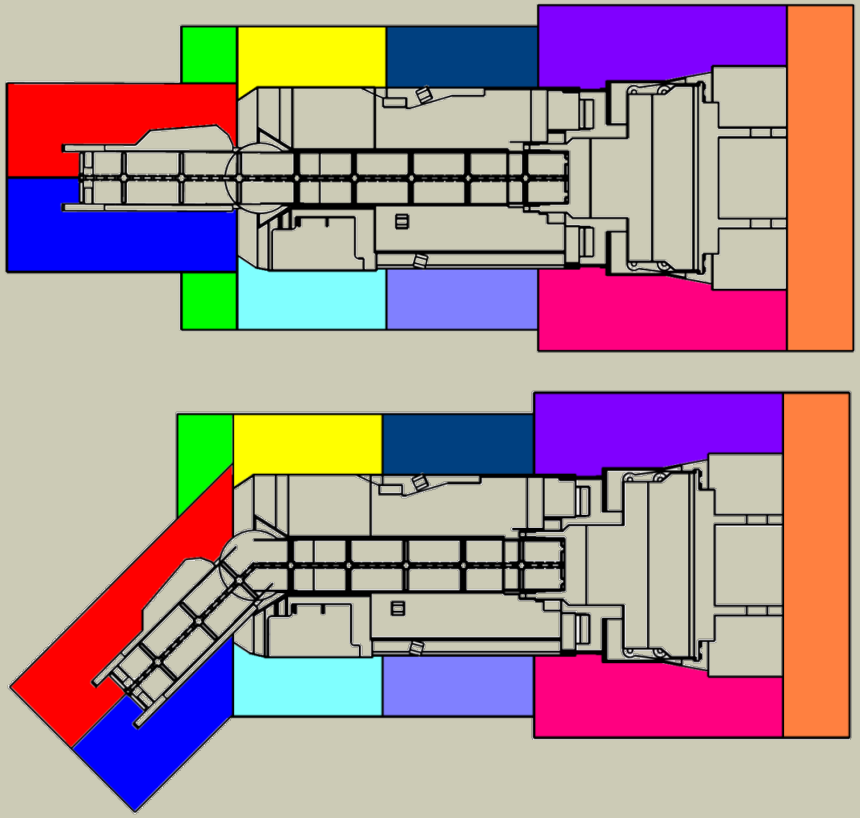
Intelligent Proximity Detection

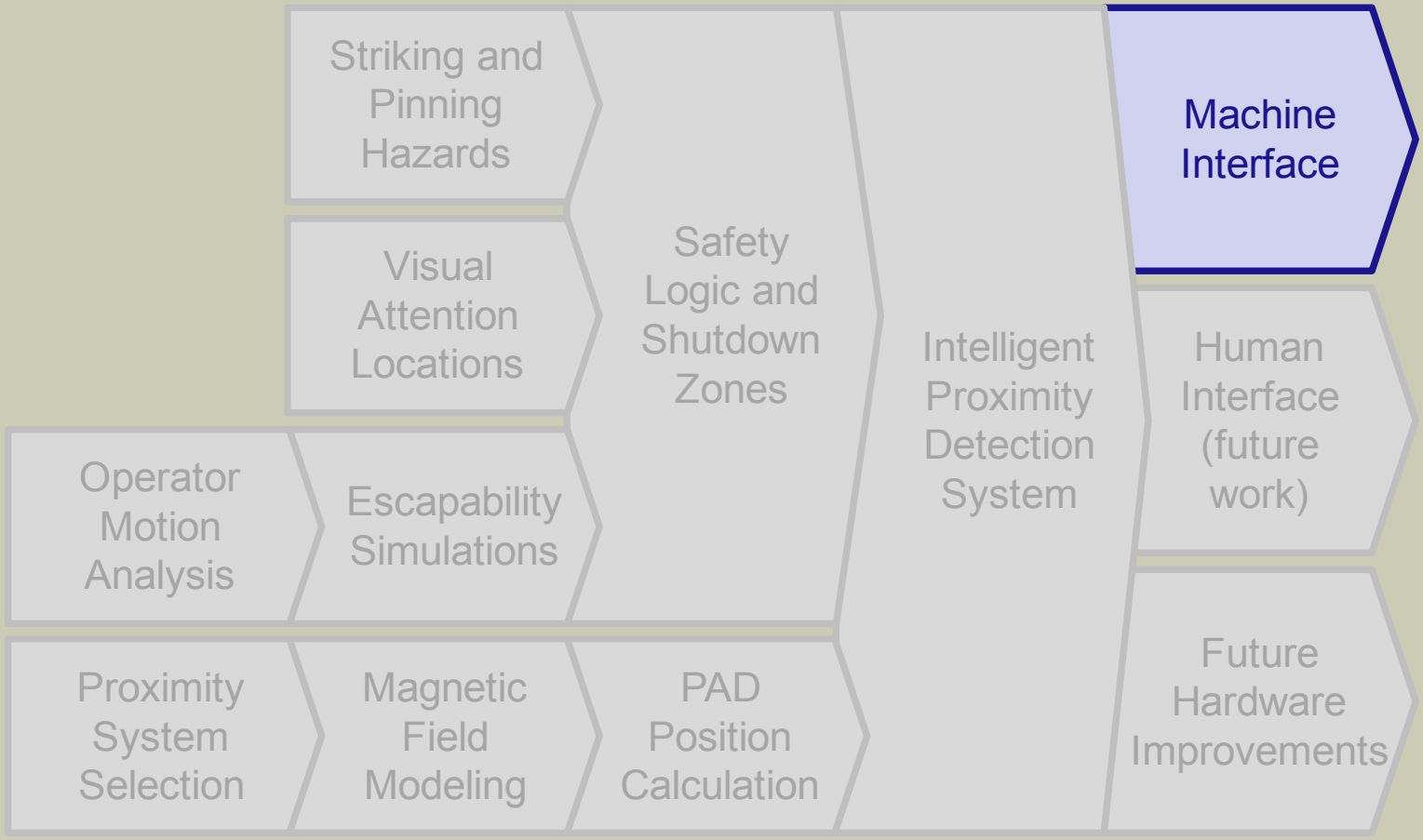
- Installed and tested on a Joy 14CM
- The intelligent proximity detection system determines triangulated position of miners near the machine



Intelligent Proximity Detection

- Situation-specific alarms are issued
- Specific machine functions are blocked
- The warning and shutdown zones are dynamic and programmable

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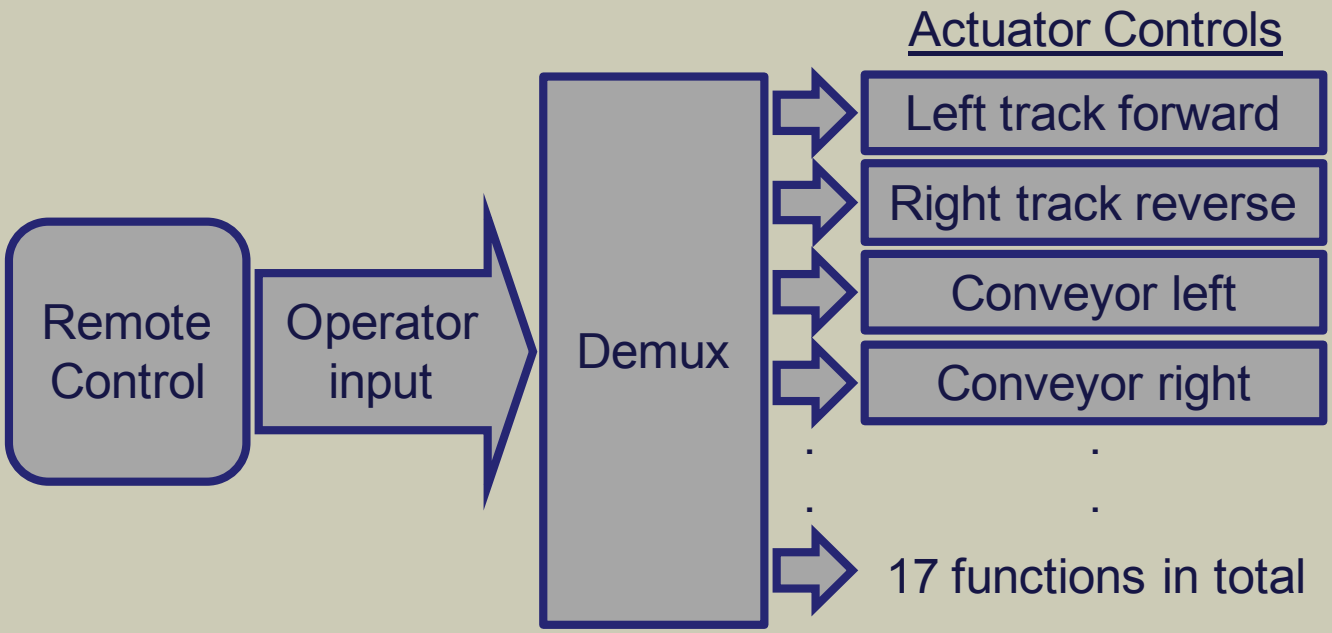
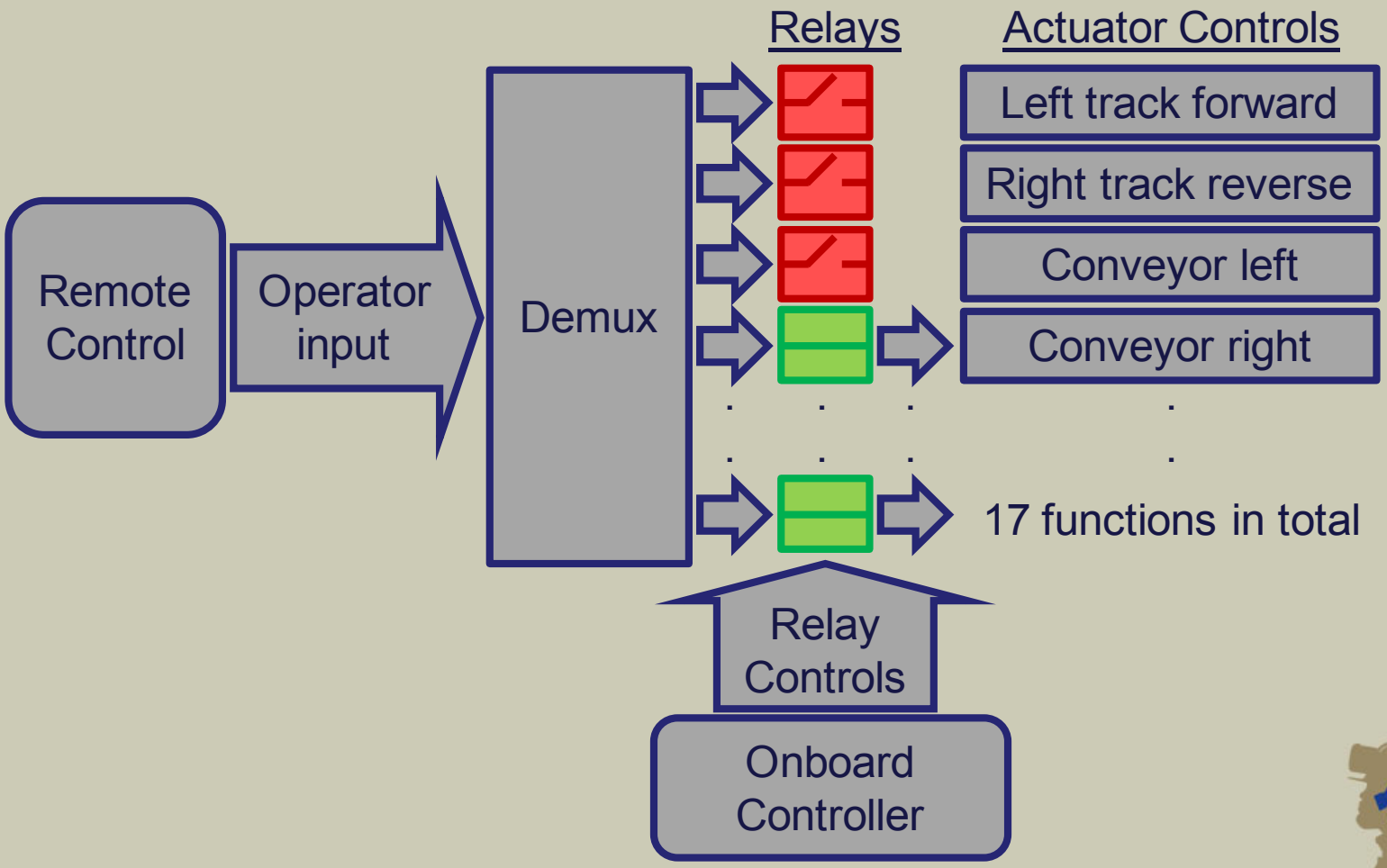
Machine Control Interface:
Normal Operation



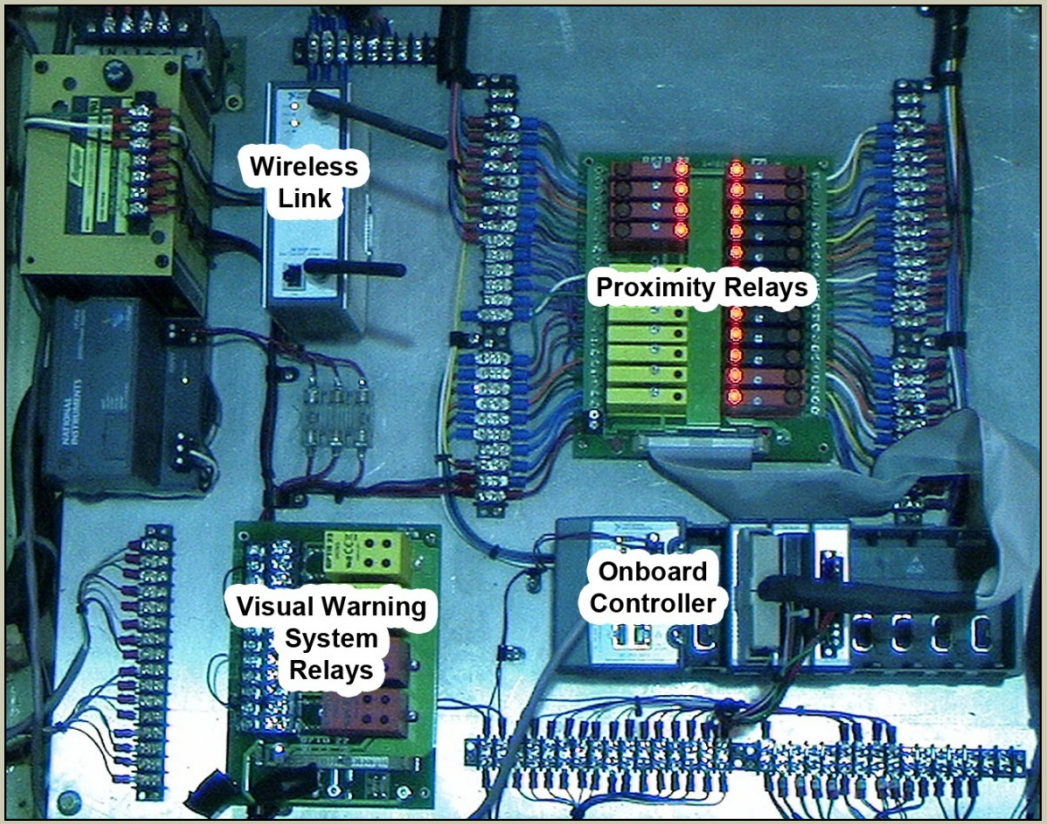
Machine Control Interface:

Intelligent Proximity Detection

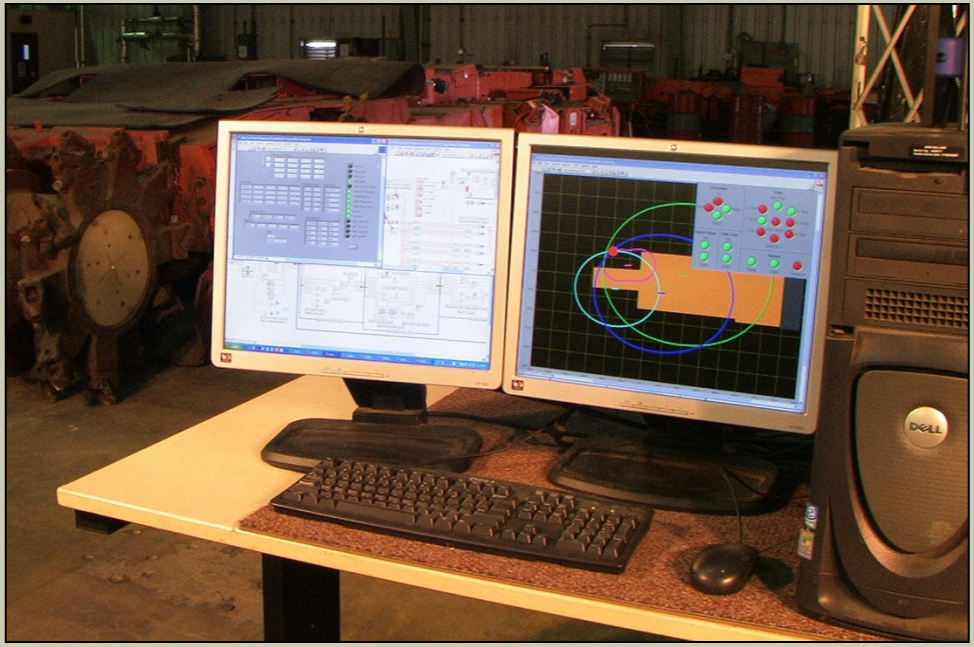


Machine Control Interface:
Prototype Hardware as Installed

- Onboard controller runs intelligent proximity software
- Proximity relays block machine functions
- Visual warning system relays will control LED warning lights
- Wireless link communicates data to a Host PC



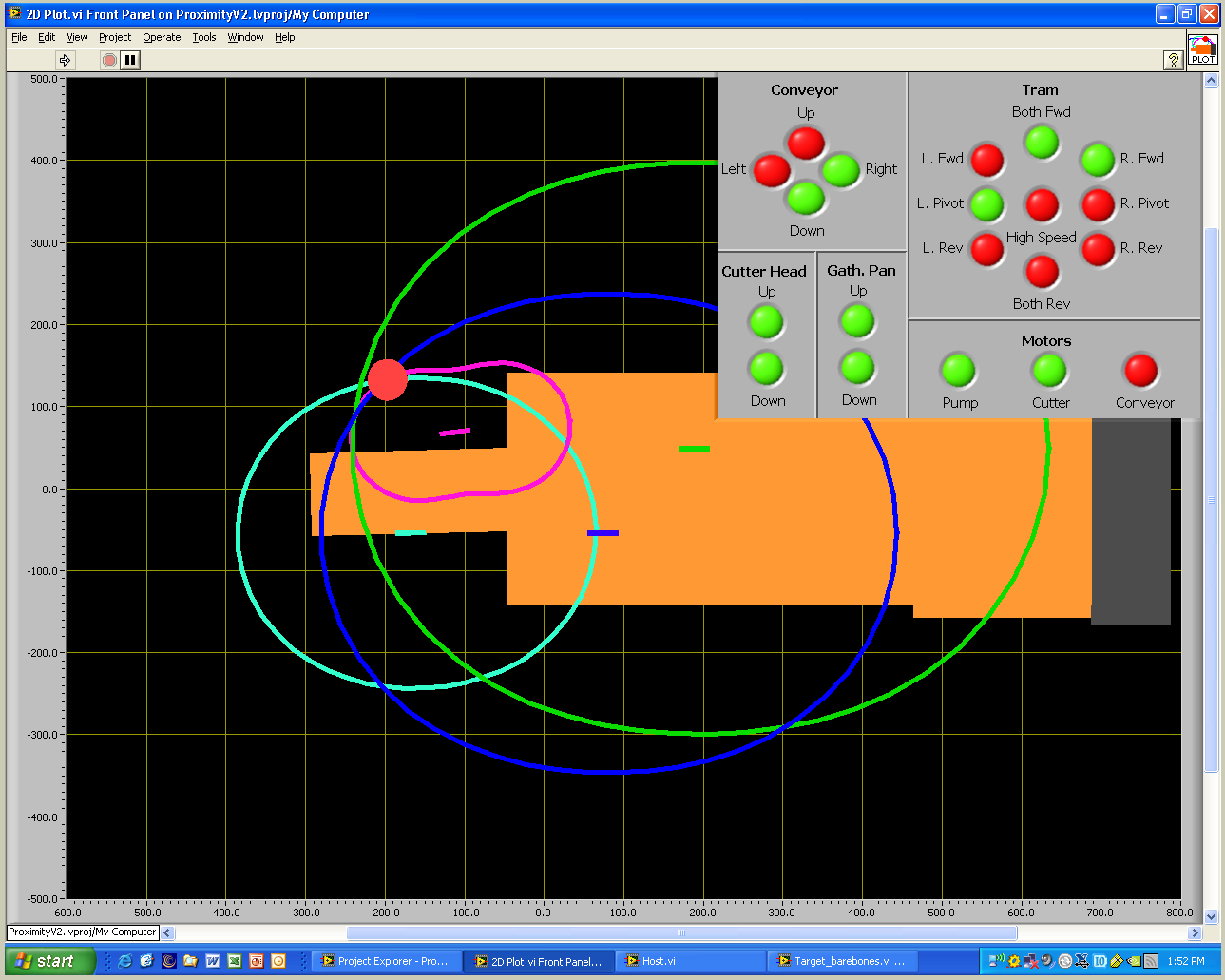
Machine Control Interface:
Hardware as Installed



- The Host PC is used for programming and viewing data in real-time
- ALL system calculations are performed by the onboard controller

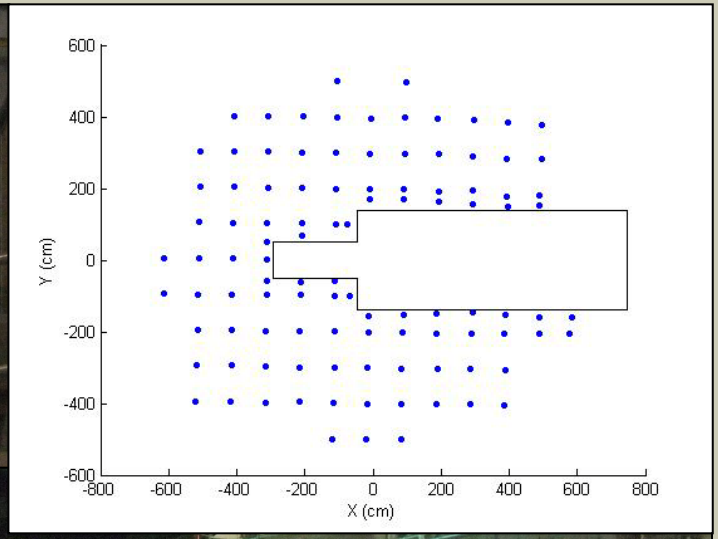
Machine Control Interface:

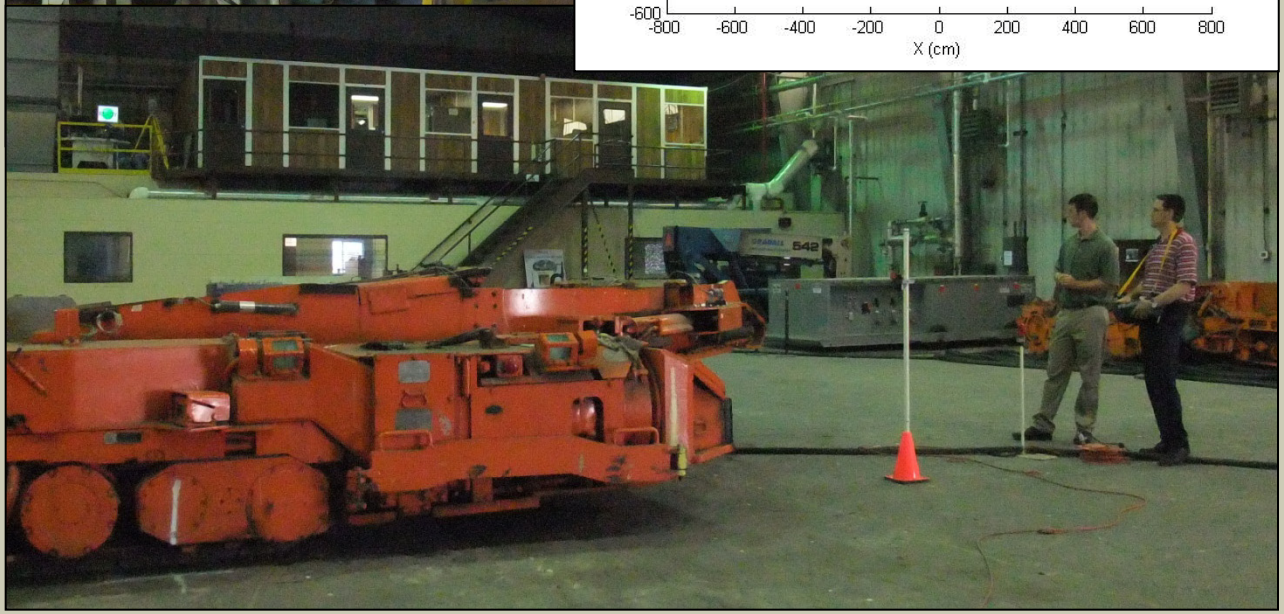
Software



- Algorithms tested first in simulation then installed on the Joy 14CM
- Real-time display allows for on-the-fly testing and modification

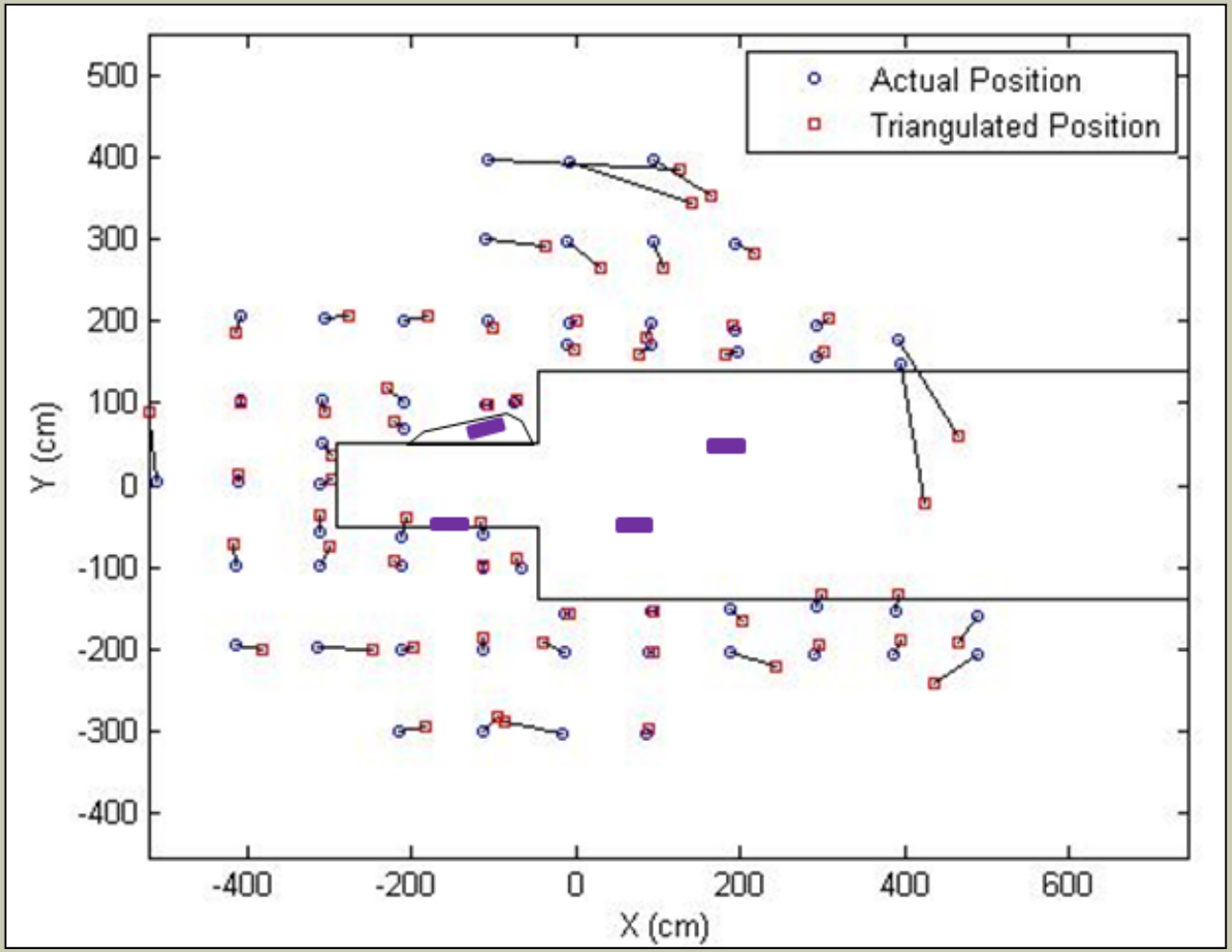
Testing System as Installed on Joy 14CM





- Data collected with PAD on a 1-meter grid around the CM
- Various PAD heights
- Various machine poses

Testing System as Installed on Joy 14CM



- Triangulation requires signal from at least 2 generators
- Generators are concentrated near the tail, resulting in good accuracy in that area

Testing System as Installed on Joy 14CM

Proximity system should perform properly regardless of:

- Pad elevation
  - Low (16”)
  - Mid (44”)
  - High (48”)
- Conveyor elevation
  - Down
  - Up
- Conveyor swing
  - Left
  - Center
  - Right

Testing System as Installed on Joy 14CM

Proximity system should perform properly regardless of:

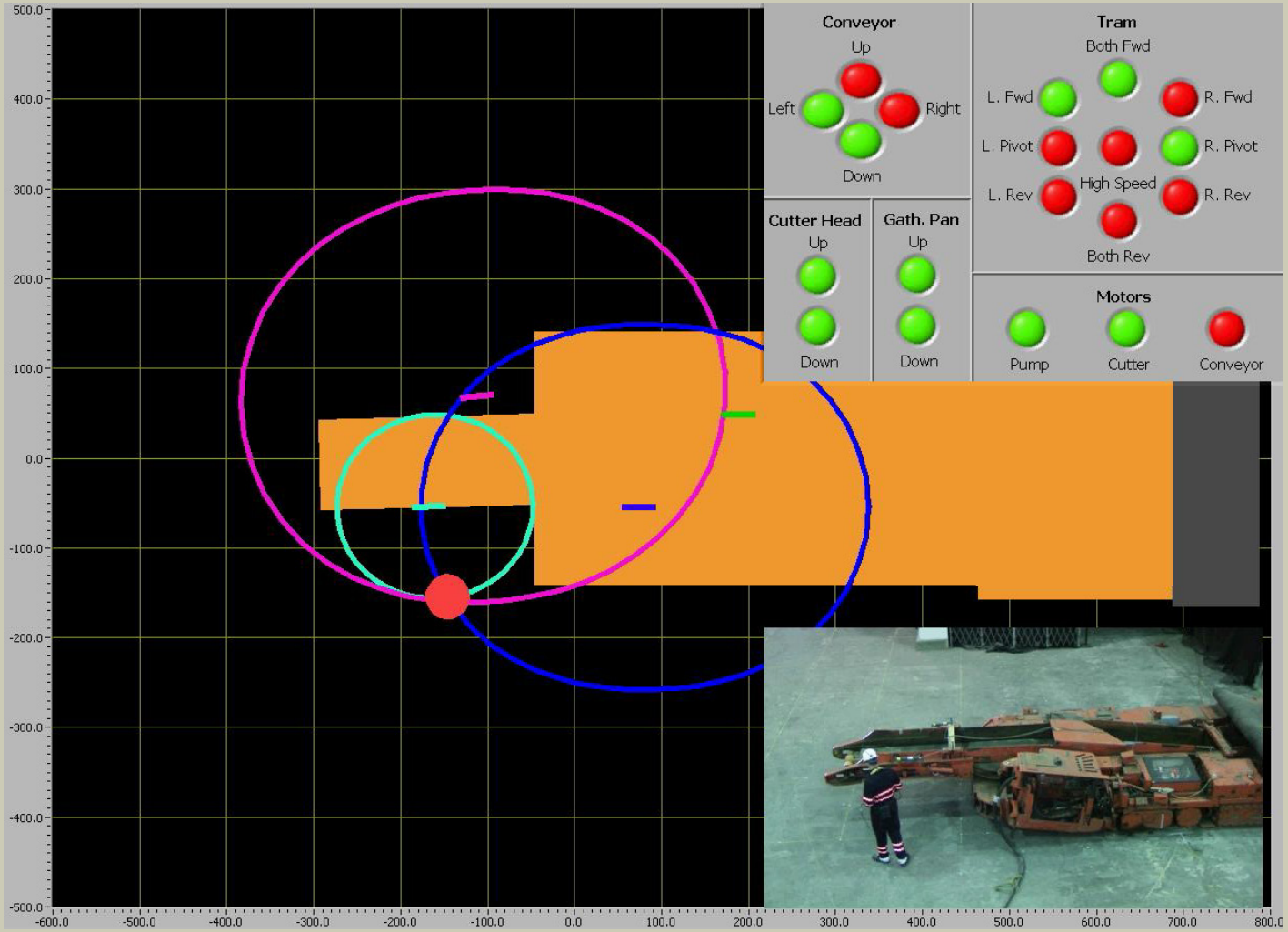
- Cutter head position
  - Down
  - Up
- Trailing cable
  - On floor
  - Draped over tail
- Hydraulic pump / conveyor / cutter motors
  - On
  - Off

Testing System as Installed on Joy 14CM

Proximity system should perform properly regardless of:

- Presence of other metallic objects
  - Shuttle cars
  - Mine infrastructure
- Interference from RF signals
  - Communication

Testing System as Installed on Joy 14CM



- Real-time position tracking
- Dynamic safety zones

Testing System as Installed on Joy 14CM

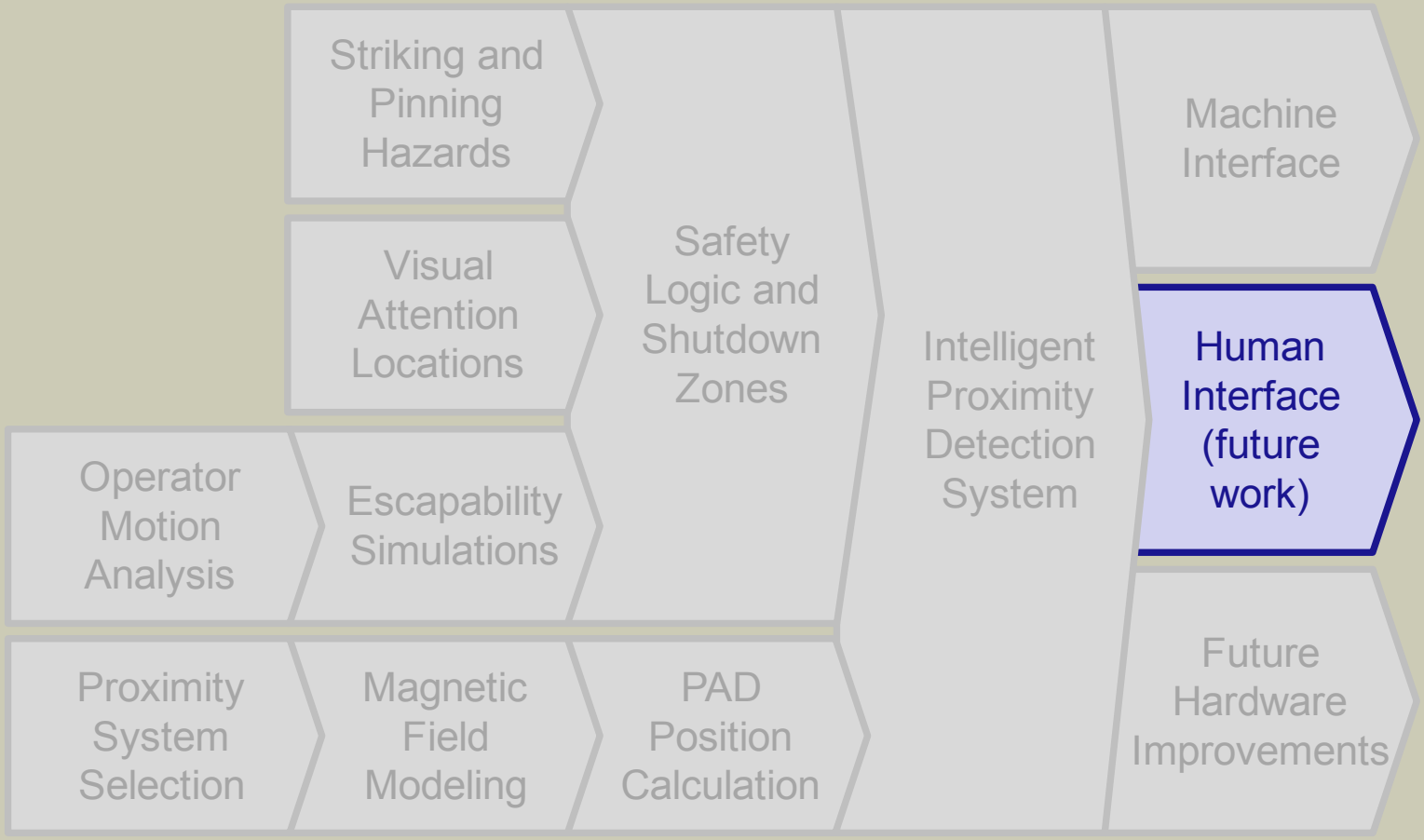
- Forward tram is allowed
- Reverse tram is not allowed within 3 feet

Testing System as Installed on Joy 14CM

- Tail swing left is allowed
- Tail swing right is not allowed within 3 feet

Testing System as Installed on Joy 14CM

- Pivot right is allowed
- Pivot left is not allowed within 3 feet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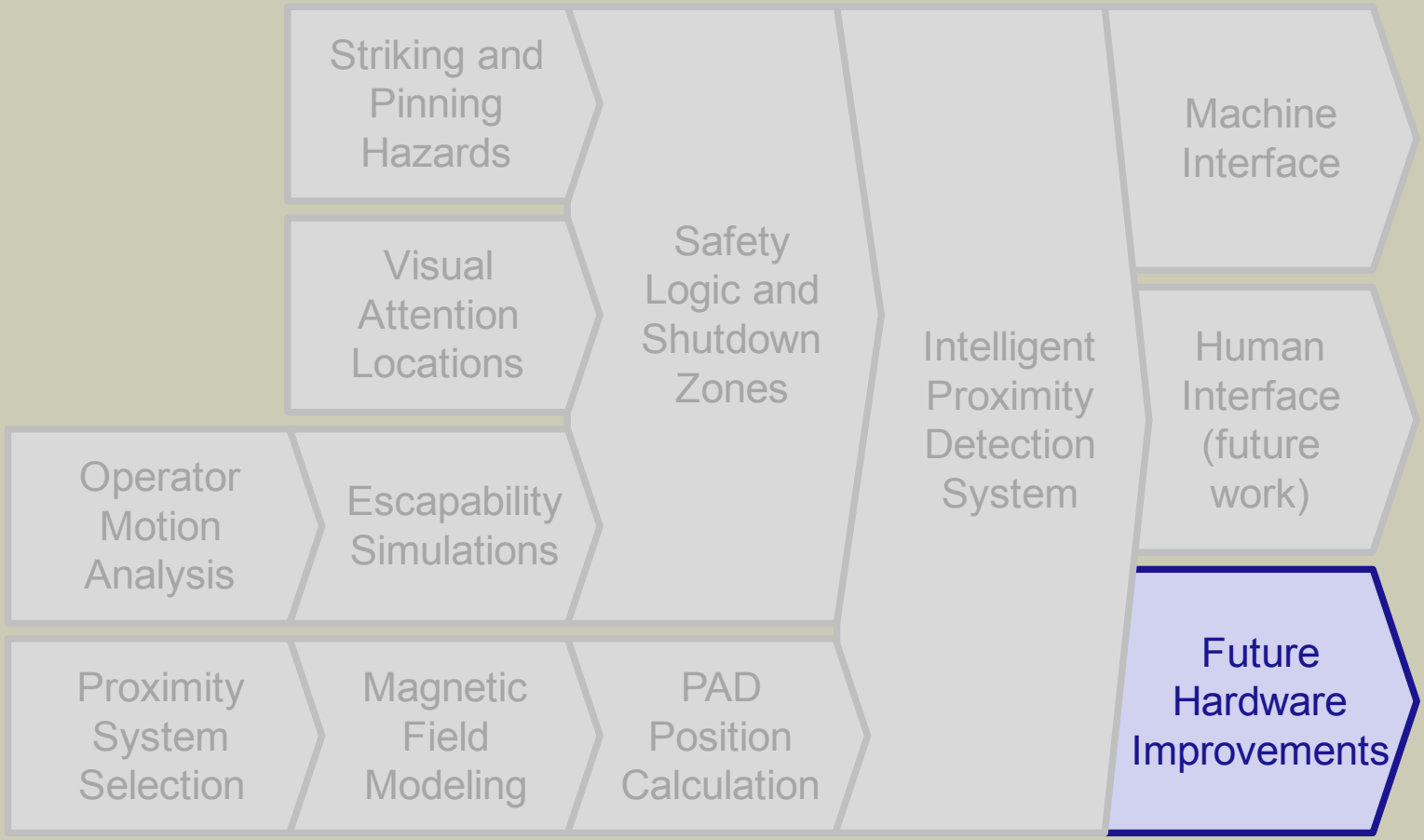
Human Interface:
Alarm System

- Several methods of providing alarms (audible and visual) to the operator will be tested
  - NIOSH-developed LED Visual Warning System
- The alarms need to clearly convey meaning to the operator – for example:
  - Person detected near left rib
  - Reverse tram disabled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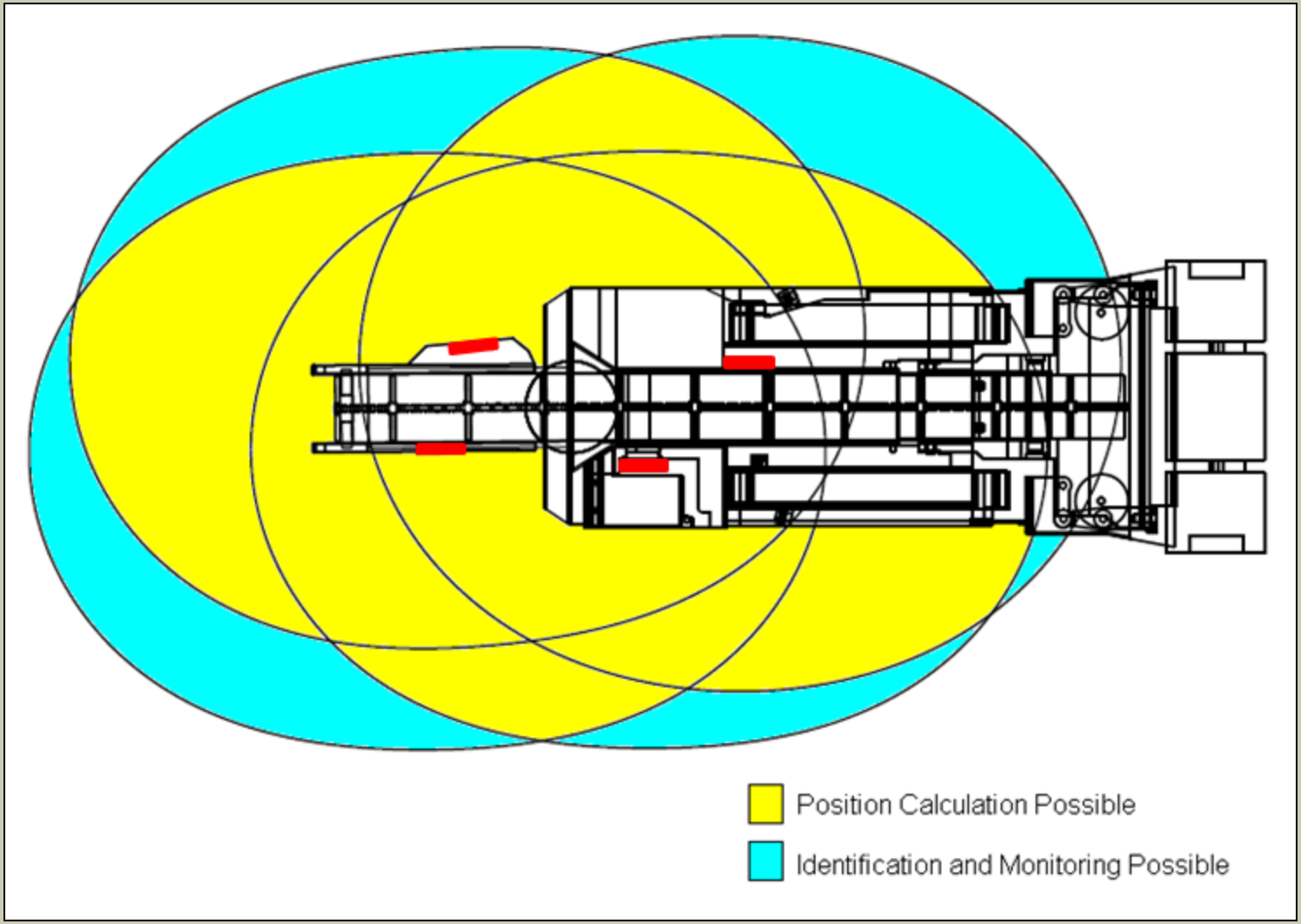
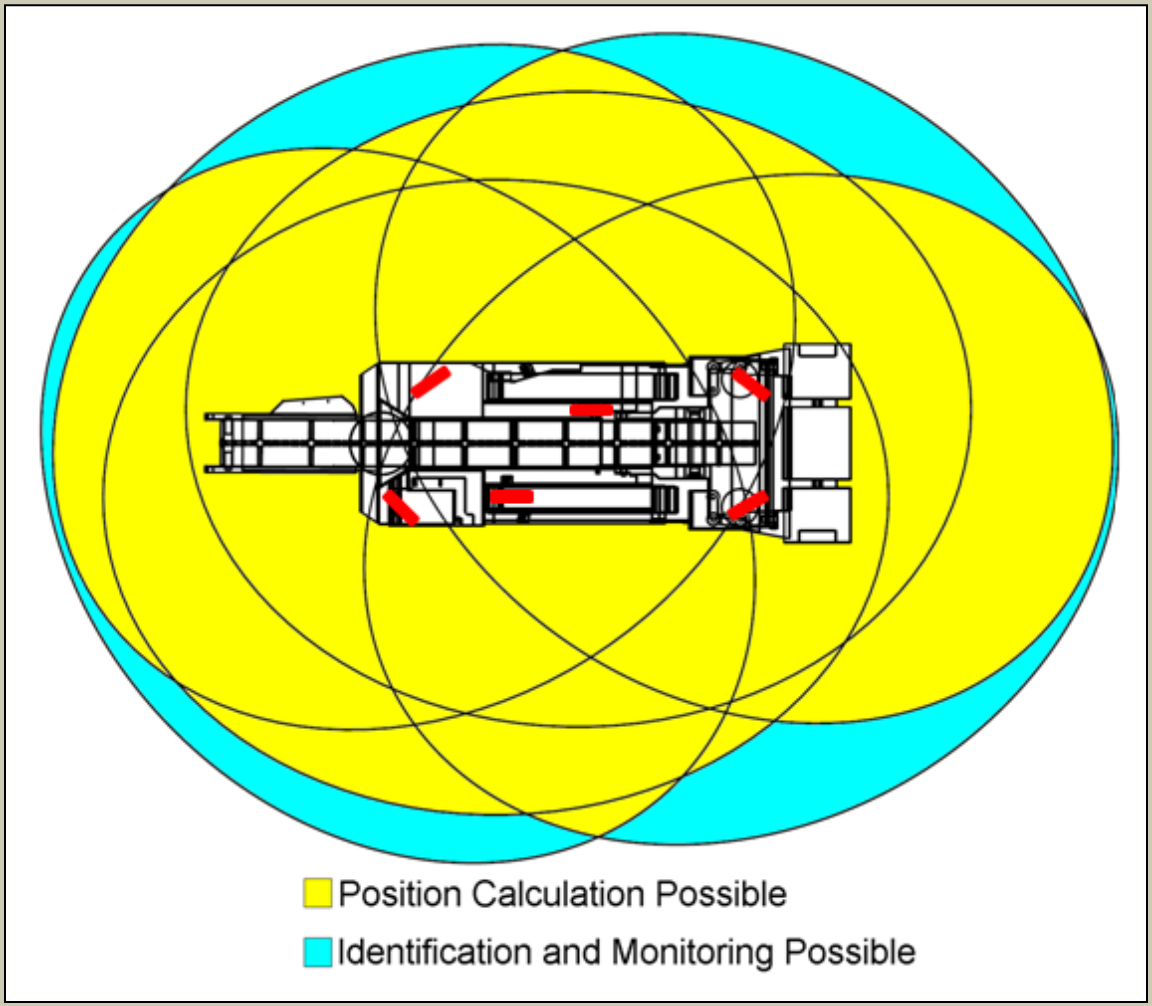
Current Four-Generator System



Future Work:
Expansion of System to Six Generators



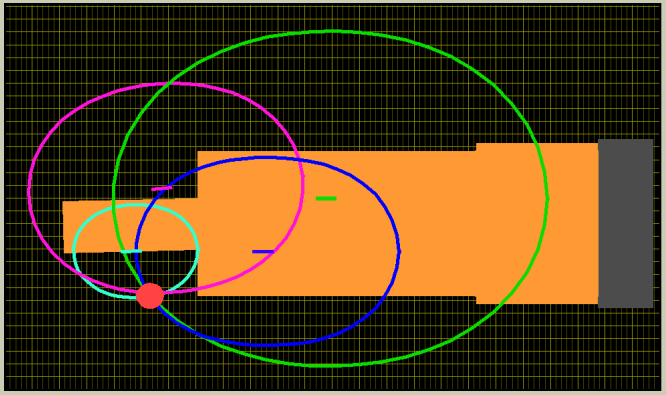
Future Work:
Further Laboratory Evaluation

- Future tests will include:
  - Triangulation accuracy
  - System reliability
  - Simulated mining tasks

- We are exploring partnerships to introduce this improvement to proximity detection technology to the mines

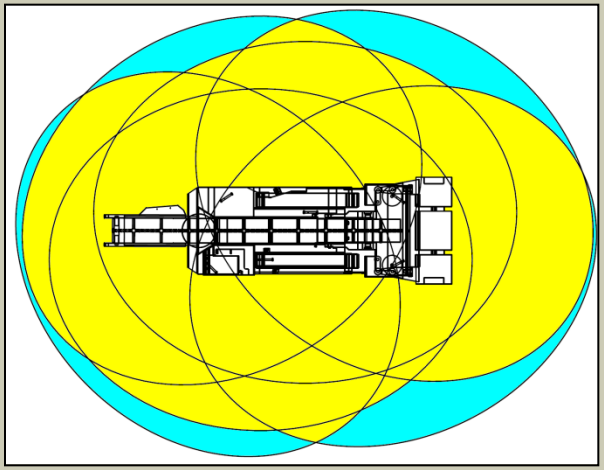
Summary

- Background work
  - Visual attention locations (VAL)
  - Operator motion analysis
  - Escapability simulations
  - Magnetic field modeling
  - Triangulation techniques



Summary

- Intelligent proximity detection system
  - Real-time tracking (2D or 3D position) of multiple people
  - Programmable, dynamic warning and shutdown zones



Thank you for your attention

CDC Workplace Safety and Health
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