CSRA RESEARCH ROADMAP

CSRA CONSTRUCTION SAFETY RESEARCH ALLIANCE



#1 Work Zone Management

Editors

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EXECUTIVE SUMMARY

The CSRA is a community of industry leaders and academic experts who collaborate to create and share new safety knowledge. The CSRA has set the vision to eliminate serious injuries and fatalities (SIFs) in the construction industry through transformative research and defendable science.

This Research Roadmap is the final product of the CSRA's STKY Challenge on Work Zone Management held at the University of Colorado, USA in 2024.

Grounded in the theory of energy-based safety, high-energy hazards are the 'Stuff that Kills You' (STKY). High-energy STKY hazards require direct controls to keep workers safe and protected from SIFs.

Work Zones represent a SKTY Challenge for construction safety management. No direct controls are available to protect workers from the high-energy hazards found within work zones, resulting in around 60 construction worker deaths each year on US roads (OSHA Roadway Work Zone Alliance 2024).

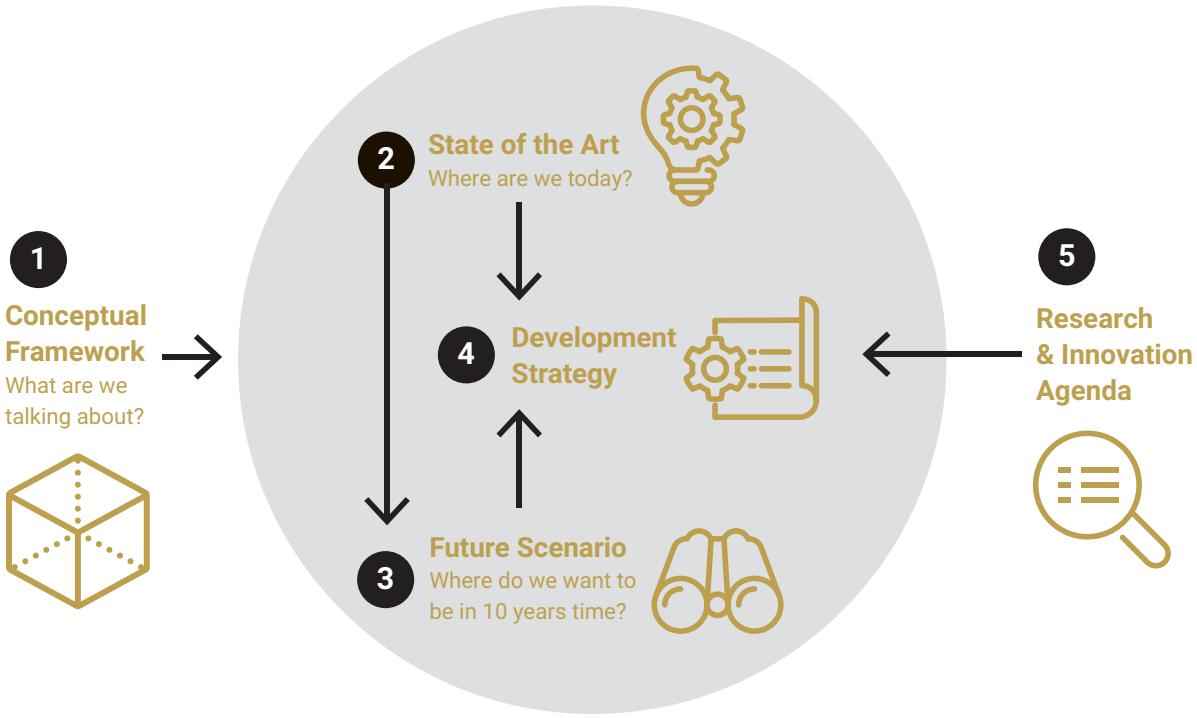
This report lays out a research roadmap for future research and innovation focused on enhancing worker safety within work zones to meet this STKY Challenge. To that end, it is intended for information purposes only. It does not in any way influence or substitute current responsibilities for Work Zone Management to comply with all regulations and standards, nor supplement or amend the current Manual on Uniform Traffic Control Devices (MUTCD).



INTRODUCTION

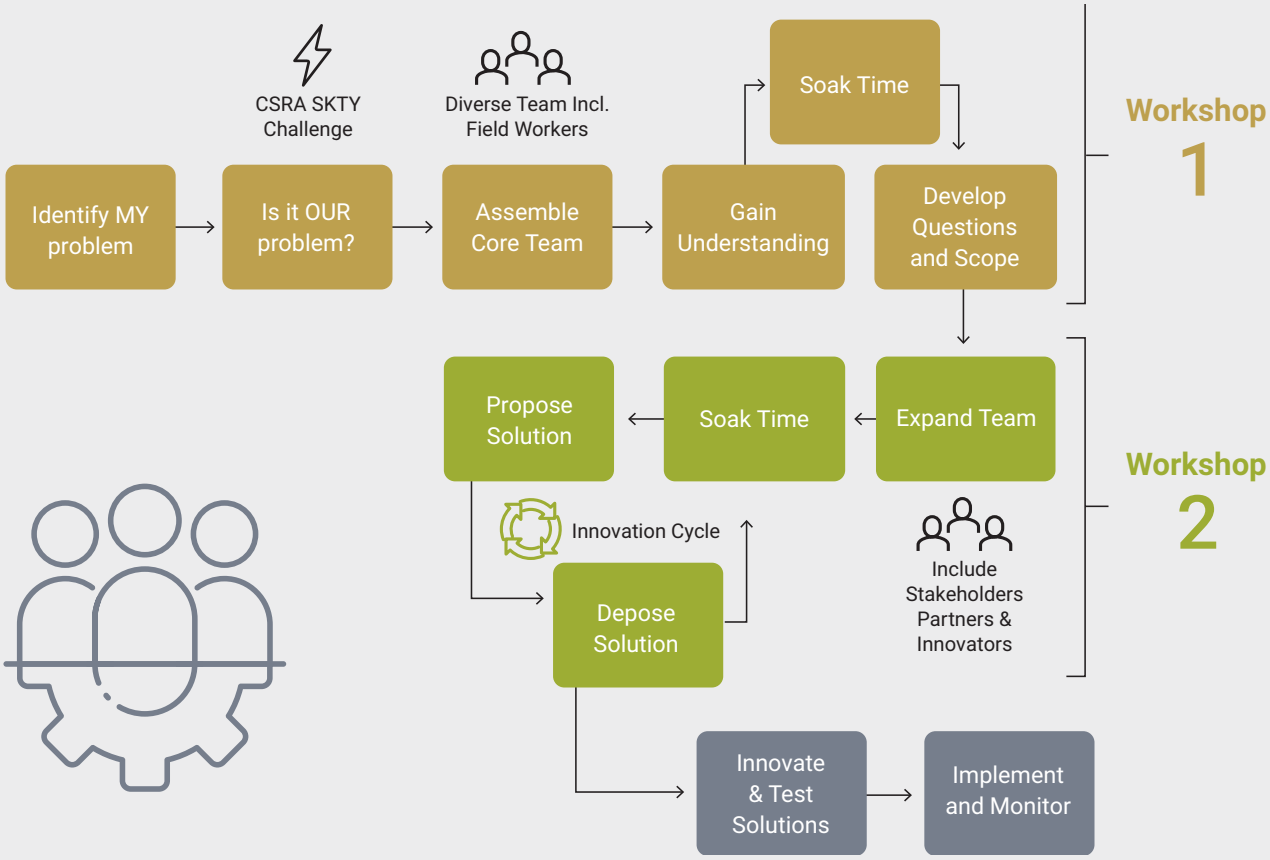
This document lays out a research roadmap to help resolve the STKY Challenge of Work Zone Management. The framework for this research roadmap can be seen in Figure 1.

Figure 1
CSRA Research Roadmap (After Finneran and Gibb 2013)



To facilitate the development of this Research Roadmap, two Industry Level Learning Teams were held by the CSRA on the University of Colorado Boulder's campus. The process for the operation of this team can be seen in Figure 2.

Figure 2
The Industry Level Learning Team Process



The first workshop was held on April 25th, 2024, with the aim of unpacking Work Zone Management from energy-based safety perspectives. The inclusion of field workers and safety professionals within the team guaranteed the details and problems shared and discussed had direct relevance to the situation, and that they were framed and explained by those who have to manage work zone safety in the field as part of their day-to-day work. This first workshop resulted in a holistic and in-depth understanding of the problem, as well as an early list of potential areas in which research and innovation could provide novel solutions.

The second workshop was held on August 15th, 2024, with the team expanded to include regulators, innovators, safety solutions providers, and other interest groups. The aim of this workshop was to further unpack the details of the problem outlined in the first workshop. Specifically, the team used the information gathered from the front-line supervision to explore existing, emerging, and potential solutions. The team also carried out an exercise to highlight where research and innovation could make a meaningful contribution to the problem in the near future, resulting in a research and innovation roadmap.

Detailed membership of the research team can be found at the end of this report.

CONCEPTUAL FRAMEWORK

Energy-Based Safety

This work is grounded in the theory of energy-based safety (Hallowell et al 2017).

Accidents and incidents are caused by the release of or lack of control of energy, the magnitude of which often dictates the severity of the outcome. An energy magnitude of up to 500 joules typically results in a first-aid incident, whilst energy levels between 500 and 1,500 joules are associated with medical cases. In situations where the energy levels are over 1500 joules, the outcome is often a serious injury or fatality (SIF). These are termed high-energy hazards and on jobsites can be referred to as 'Stuff That Kills You' or STKY situations.

To address high-energy hazards the concept of a direct control was developed (Hallowell 2023).

A direct control has 3 components:

1. It must specifically target the high energy.

2. It must effectively mitigate exposure to the high energy source when installed, verified and used properly.

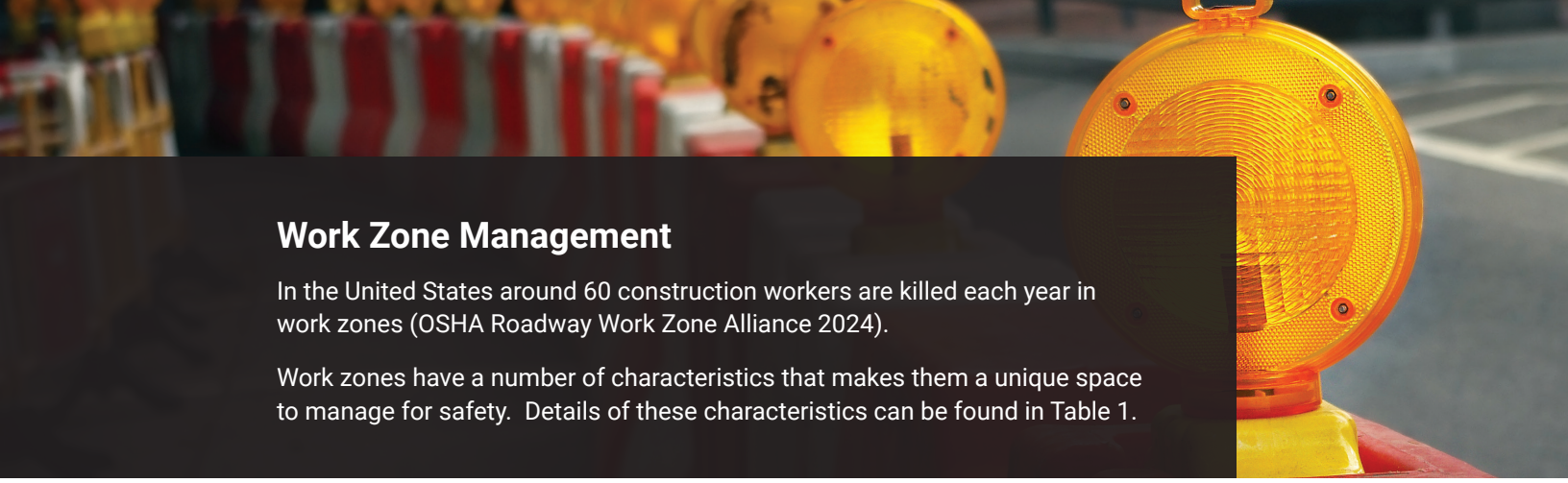
3. It cannot be vulnerable to human error and remain effective even if someone makes a mistake.

Examples of direct controls include lockout/tagout systems, machine guarding and fall prevention systems. Direct controls do not include training, signage, or basic PPE.

All activities involving high-energy should have a direct control to protect workers and keep them safe. However, there are a large number of construction activities that have no direct control. These activities create what has been termed STKY Situations.

One such STKY Situation is Work Zone Management.





Work Zone Management

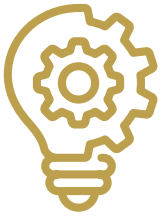
In the United States around 60 construction workers are killed each year in work zones (OSHA Roadway Work Zone Alliance 2024).

Work zones have a number of characteristics that makes them a unique space to manage for safety. Details of these characteristics can be found in Table 1.

Table 1
Characteristics of Work Zone Construction

Characteristic	Details
Governance	• Despite the MUTCD some aspects of Work Zone Management differ across the USA. • Different governance across the USA lacking consistency. • Differs between county, city, state. • Can be politically influenced. • In some places, exceeding minimum requirements to try to keep workers safe can be a violation of the contracted works. • In some work zones, no traffic control, inadequate traffic control, and/or illegal traffic control is used.
Work Types	• Overhead utilities (e.g., surveys, repairs, inspections, installations etc.). • Underground utilities (e.g., surveys, repairs, inspections etc.). • Highway infrastructure works (e.g., repairs, milling, paving, bridge work etc.) including internal work zones. • New highway installations (e.g. for new residential developments etc.) including internal work zones. • Vertical/Horizonal construction (e.g., site works, building footprints to highways, cantilevers, stores, deliveries, logistics etc.). • Emergency repair work (e.g., to utilities, highways infrastructure etc.).
Consistency	• Every work zone is different for both workers and drivers/pedestrians. • Pre-planning is critical and can be undertaken well in advance of the work. • Clients can dictate requirements – e.g., color of PPE etc.
Delivery	• Lack of traffic control plans when not required by the project. • Poor training of the workforce can lead to inadequate work zone management installations and controls. • Traditional production pressures can lead to distractions and lack of focus on work zone management.

Characteristic	Details
Geography	• Jobs range from 1-pole repair work to miles of construction activity. • Longer highway work moves zones as the work progresses. • Long term closures/large projects can create internal work zones.
Timescales	• Scheduled work ranges from minutes to years.
Motivations	• Zone set up focuses on keeping the public safe and traffic moving – not on construction worker safety. • Zone set up must be designed to minimize impact to the local area (public, businesses etc.) – not on construction worker safety.
The Public	• Human error occurs. • People will drive through cones and barriers. • Pedestrians will walk through cones and barriers. • People work in the roadways (e.g., window washing) • Complacency grows with long duration work, leading to lack of focus. • Drivers are distracted (which can be made worse by reflective PPE) • Drivers can be impaired (e.g., DUI) • Drivers exceed the speed limits. • Drivers get road rage. • There can be language barriers for signage and other communications.



STATE OF THE ART

Applying the theory of energy-based safety to Work Zone Management, it rapidly becomes evident that there are no direct controls available. Barriers, such as concrete Jersey barriers with mesh toppings, provide the nearest equivalent to a direct control. They form a physical barrier with the goal of stopping/mitigating the high energy of a car collision. Traffic detours with hard barriers also fall into this category. However, neither meet the full requirements of a direct control as they can be compromised by the weight and speed of a vehicle – they remain vulnerable to human error.

There are a number of alternative controls available for use in work zones, as listed in Table 2. However, even when used in as a part of a layered approach they are unable to provide the coverage of a direct control.

Table 2
Alternative Controls for Work Zone Management

Cones	Flaggers (for the traffic – but very vulnerable to harm)
Speed Bumps	Spotters (for the workers – but very vulnerable to harm)
Barriers (e.g., water-filled)	Highway patrol/traffic control
Signage (metal and illuminated)	Proximity alarms for workers
Lights (freestanding or cone topper)	Geofencing for work zones with alarms for workers
Truck-Mounted Attenuators (TMA) able to project different messages	PPE – incl. reflective elements
Automated Flagger Assistance Devices (AFADS)	Public education signage – e.g., 'Please go slow, my mommy works here'
Alerts on GPS and radios warning the public of roadworks ahead	LED lights for hard hats

Specifically, which, and how many, alternative controls from Table 2 will be adopted in any work zone situation inevitably depends on the precise nature of the work to be undertaken. Federal DOT laws set certain requirements under the Federal Register and MUTCD.

In addition, commercial decisions will inevitably be taken that will also impact the alternative controls included in any bid, to ensure it remains competitive. Client education can help enhance bid evaluation processes to ensure selected bids incorporate appropriate evaluations of proposed controls.



Other aspects of the work will also need to be taken into consideration including but not limited to:

- Any permits or governance requirements.
- Space available – the road width is finite, so there may be only 6" between workers and live traffic.
- Duration of the work (ranging from 1 minute – 1 hour – 1 day – 1 year).
- Budget available for the work.
- Setup might be by just one worker – time/weight/practicality of the controls then becomes relevant.
- Acceptable risk transfer between workers and flaggers.

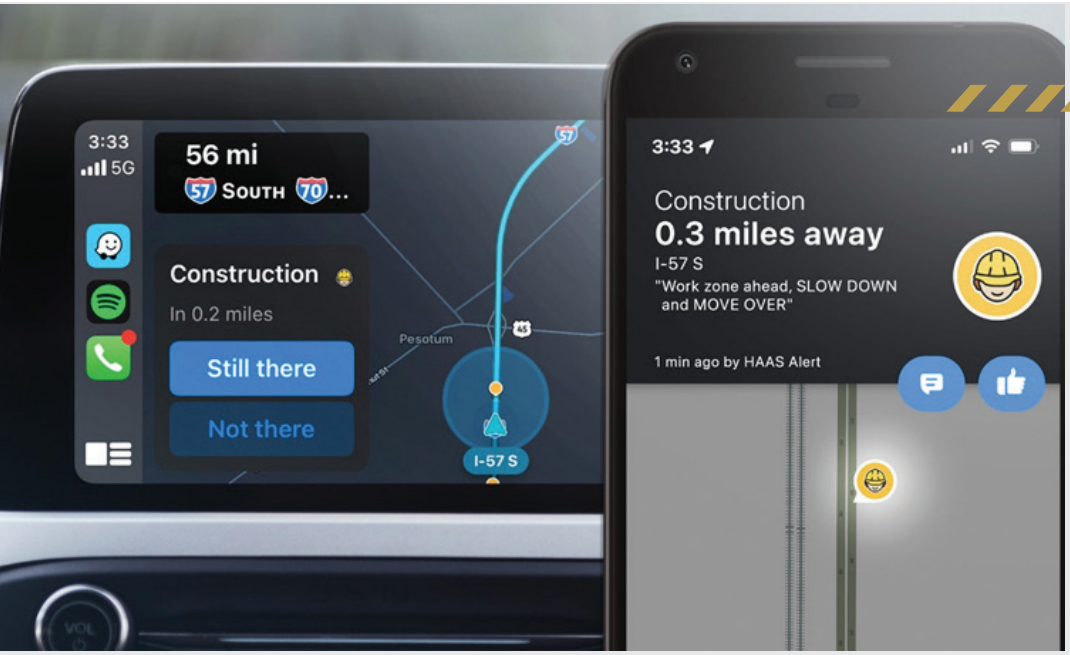
There have been a number of innovations in recent years within Work Zone Management. Notably these have leveraged new technologies to enhance safety in work zones. Despite such innovations, and the reductions in incidents they have been demonstrated to deliver, there is still room for improvement in other aspects of Work Zone Management.



pi-lit® Ground Truth Technology: Enhancing safety through guidance and digital warning



Personnel, and vehicles, on the side of the road are in danger. Existing signage, triangles or cones provide little advance warning or on-scene guidance. *pi*-lit® technology replaces these passive devices with cloud mapping alerts and sequential on-scene visual guidance. Sequential flashing lamps, easily deployed and linked to Waze, Apple Maps, and modern vehicle dashboards, are recognized by the Federal Motor Carrier Safety Administration (FMCSA) as an alternative to other required warning devices. Work zones should not come as a surprise to drivers. *pi*-lit® technology brings advanced warning (miles upstream) and local "follow-me" visual guidance to oncoming traffic, helping both drivers and workers stay safe.



HAAS Alert Safety Cloud

Safety Cloud® by HAAS Alert lets responders and roadway workers digitally alert drivers for safer roads. Drivers receive these alerts through compatible in-vehicle infotainment centers and through leading navigation apps like Waze.

Digital alerts have been proven to help prevent distracted driving and better protect those working along the road, like construction crews. Purdue University published a study to determine the impact of digital alerting-equipped vehicles on hard-braking events. Their results showed that advanced warning systems, like Safety Cloud like digital alerting, decreased hard braking events by 80 percent. Road construction crews are at constant risk of near-misses and struck-by collisions. The extra protection from Safety Cloud digital alerting helps every construction crew member gets to go home safely at the end of every day.



FUTURE SCENARIO

The ideal future scenario is one in which workers are fully protected in work zones by direct controls, and the annual rate of worker serious injuries and fatalities is reduced to zero.

Here, three timescales are proposed for research and innovation to influence positive action to improve worker safety in work zones:

Now

Existing research and innovations already offer potential for improvement and could be actioned now:

1. Insurers to require work zone alert technology within vehicles and on driver phones as a condition of insurance, with rebates/ incentives for use.
2. Prevention through design (PtD) leveraged in new highway/utility infrastructure designs to reduce the need for workers to carry out activities in roadways and adjacent to live lanes.
3. Novel barrier designs that better meet operational requirements.
4. Ongoing empirical research to determine and validate the most appropriate combinations and layers of controls for Work Zone Management as innovations/changes occur. This work should include an ROI point to enable applications to work of various scopes.



1 – 5 Years from Now

Within the short-to-medium term, and given the pace of innovation at present, there is the potential for:

1. Enhanced work zone alter technologies to optimize geofencing precision to provide better alerts for both the public and workers and reduce redundant notifications.
2. Speed control technology in new vehicles including haptic feedback that automatically engages in work zones, limiting the vehicle speed safely. A reduction in speed reduces the potential for human error and reducing the level of energy for the driver. This would also enhance journey consistency for drivers as it will also facilitate ease of travel through work zones.
3. Standardization and enhanced consistency of Work Zone Management regulatory requirements across the United States. This approach could set a consistent high standard to ensure optimal requirements are set across the country. Consistency will also better familiarize workers and drivers with best practices.
4. Improved construction machine design and operational requirements to eliminate the need for workers having to work within or close to live lanes.
5. Improved work vehicle design to enhance their use as a defensive barrier when workers are undertaking short-term or emergency works.

6. Increased use of automatic flagging systems where possible. Templates for automatic flagging system specifications should be circulated for widespread use for uniformity and consistency. Enhanced training and career opportunities for traditional flaggers to develop the role into a higher-skilled safety occupation with due recognition, cognizant of the need to avoid simply transferring risk from the worker to the flagger.
7. Client education to ensure clients are specifying the most appropriate controls for their work zone projects, to ensure whoever secures the work protects their workers to the best of their ability.
8. Worker education specifically focused on roadway working fundamentals, to equip and empower them with the awareness and knowledge to speak up and/or challenge poor work zone setups when they are in the field.

5 – 10 Years from Now

In the longer term, yet still achievable given the rate of technological innovations, there is the potential for:

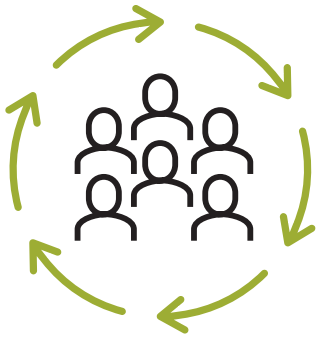
1. Infrastructure to be developed to enable autonomous driving in work zones to be reliable and safe.
2. Fully autonomous driving within work zones to automatically implement speed controls (taking the public out of driving) made a legislative and insurance requirement in new vehicles.



Workshop 2

DEVELOPMENT STRATEGY

Strategically, the ambitions set out as future scenarios will require collaboration and the cooperation of a number of very different stakeholders:



- Federal and local agencies (Governance)
- Insurers
- Vehicle manufacturers
- Safety technology innovators
- Construction firms
- Construction machinery manufacturers
- Clients
- Designers
- The public

A notable strategic point of interest is the comparison that can be made between work zones and school zones. In the latter, drivers generally behave better than in work zones. This is due to a number of factors – school zones are fixed, there are large penalties for speeding or overtaking school buses, and there is a large social stigma involved for violations. Unfortunately, work zones are not seen in the same way by drivers. Work Zones cause traffic jams, they are populated by adults not children, and there is no stigma associated with violations. In fact, drivers are often frustrated by work zones and see them a hindrance to their daily lives.

However, the construction workforce is working in work zones for the public good. They are working to improve journeys and ensure vital infrastructure is operational. When combined with the desire to prevent people from getting seriously hurt or killed at work, work zone safety should not be a hard sell!



Education of the public will be necessary to improve safety in work zones and the development of social stigma around violations. Although there may be constraints on personal freedoms, stopping highway workers from getting seriously injured and killed should be something everyone is happy to support.

Details of how each stakeholder group can support the ideal future scenario laid out in this research roadmap are addressed in the following section.

RESEARCH & INNOVATION AGENDA

A large number of different stakeholders have the potential to be involved in the process of enhancing Work Zone Management to optimize worker safety.

Governance



- Consistency between national-state-county is required to support best practices.
- The ability for a work zone speed limit to suit the design of the work to be undertaken would be beneficial – at present in some places the speed can only be dropped 10mph below the posted limit, which is inadequate. A work zone speed setting and management standard is needed.
- Driving tests could be a stronger learning point – asking folks to stand by the side of the road and 'feel it' as part of the test. This should also form part of renewals.
- Legislation to mandate vehicles with self-driving technologies to automatically (but safely) reduce speed within work zones.
- Legislation to require drivers to use smart alerts to inform of work zones ahead – alongside the smart alter technology ensuring 100% accuracy to avoid complacency caused by old notifications etc.
- Use of fines/tickets in work zones is not popular, however can make a difference. Work zone-specific traffic cameras generating e-tickets may be an option. Pilot work is currently being undertaken in this area in Colorado starting Spring 2025.

Insurers

Insurers are a powerful voice in this space. They have the potential to shape driver behaviors, but also to bring pressure on vehicle manufacturers to develop vehicles that minimize work zone incidents.

- Insurers to require work zone alert technology within vehicles and on driver phones as a condition of insurance.



- Potential to offer rebates/incentives for manufacturers and customers who buy cars with automatic speed/control management for work zones as a standard feature.
- Potential to reduce insurance costs for active use of work zone technologies and automatic speed restriction in work zones, thus financially incentivizing drivers to comply.

Vehicle Manufacturers



Given the recent innovations in car manufacturing, including self-driving, haptic feedback for automatic lane control etc. it is possible to build-in speed management systems to new vehicles. As drivers are human and therefore will make mistakes, it would be beneficial for decision making in work zones to be automated where possible.

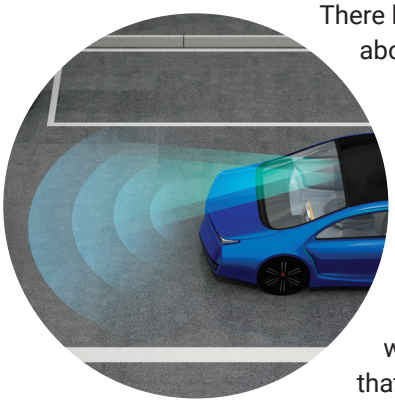
Drivers are most concerned with consistency of journey. The below technologies can help keep traffic flowing through works zones as well as support rerouting as necessary through the same alert and speed-control technologies. If work zone safety is bundled in with journey optimization and reduced insurances (see below) there is the potential for such options to become a desirable feature for drivers.

- Technology to automate speed reduction in work zones could be built into the self-driving systems of new cars.
- Lane departure technology could be leveraged to better control vehicles in work zones.
- Collision avoidance technology could be further developed to operate within work zone set ups.
- Smart alert work zone technology should be included as a matter of course in in-vehicle navigation systems.
- Truck manufacturers could develop vehicles specifically to be used as defensive barriers in short-duration work zones, these could be built into fleets.

Safety Technology Innovators

Any proposed practical research and innovation tool must consider the necessary requirements for any direct or alternative control for work zone. These requirements, depending on the nature of the control, include but are not limited to:

- **Quick to install/use**
- **Cost-effective**
- **Mobile**
- **Can be installed by 1-2 workers**
- **Durable**
- **Flexible**
- **Modular**
- **Compact**
- **Weatherproof**
- **Useable night and day**



There have been a number of recent innovations in this space, as the case studies above show, however there is still potential for improvement in existing areas.

For example, *barriers* have remained unchanged for many years, but they also form a hazard in and of themselves. Currently, barriers provide positive protection by redirecting the vehicle, but this can still cause both drivers and construction workers harm. Furthermore, Jersey barriers are impractical for short-duration work and other alternatives are needed. There remains the potential for a new barrier to be developed that is mobile, lightweight yet robust, and that could still offer protection for driver and worker through, for example, a novel core design or similar. This is a space that has yet to be thoroughly explored.

Construction Firms



There is not necessarily a desire to remove all workers from work zone operations. Construction work can be good work and it provides good employment for many. However, flaggers and spotters are very vulnerable within work zones. In some cases, they should be replaced by automatic devices, thus removing the person from the high energy (traffic) but human interactions will still be required for many work zone activities.

An alternative would be to enhance the role of the flagger/spotter. It should become a recognized job role with prospects for career development in the future. Flagging as a first step to a trades progression will lead to a focus from the crew on work zone protection. The Colorado DOT is currently developing an apprenticeship for flaggers, which will ensure they are well-trained and have the skills necessary to undertake hazardous work safely.

Construction Machinery Manufacturers



Machinery should be developed to optimize worker/operator safety. At present, most paving/milling machines do not allow some safety measures to be adopted due to the nature of their operation. Machine design can require workers to be located on the screed to operate the controls needed to adjust the depth of material which requires constant checking. However, this places workers with their back to live traffic in a highly exposed and vulnerable area should a vehicle enter the work zone. Most newer machines still require some interaction on the live side of the machine. Although wired remotes can enable workers to move to less vulnerable positions behind the machine, they are still adjacent to live traffic. There is the potential for redesign of such machinery to eliminate the need for any workers to be adjacent to live roadways during paving operations.

Enhanced GPS systems could also be developed to help reduce re-work. At present around 40% of concrete paving carried out using GPS requires rework due to the low quality of the outputs. This requires workers to revisit work zone spaces and be placed at risk a second time.

Clients

- Clients will require education to ensure their enhanced support specifically for work zone safety.
- Under OSHA they have a legal responsibility to provide a workplace free from serious recognized hazards and to comply with standards, rules and regulations issued under the OSHA Act.
- They should be aware of the need to price in safety to their works and avoid lowest-price bidding when placing contracts. The scope of the work will inevitably inform the need to ensure the work is as safety as reasonably practicable, however worker safety should be prioritized as a first principle. For example, lone working is not acceptable, and teams should be sized appropriately for the work, and the client be prepared to pay for such accommodations.



Designers



Prevention through design could be better leveraged to reduce the need for Work Zone Management at all:

- Pigging line entries/receivers should be placed off-road, e.g. in parks etc. for safer operations.
- Utility vaults should not be placed in roadways and should be accessible without the need for a work zone. This is already happening in some new developments but could be legislated.
- Anything requiring maintenance and not vital for highway operations should be relocated away from the highway.

The Public

The public are already becoming more aware of how technology can assist their journeys through smart alert technologies that automatically communicate with their navigation systems, either built-into their vehicles or via their smart phones. This could be further encouraged by insurers making the use of smart alerts a condition of insurance.



For the benefits of more advanced technologies such as automatic driving to be able to impact work zone safety, the public need to buy vehicles with such capabilities, and willingly engage with automatic speed reduction controls, lane control, collision avoidance and even full self-driving within work zones. Again, this could be incentivized through rebates on such vehicles, or via insurers providing reduced costs for the active use of such technologies within work zones.

The benefits of improved journey consistency through work zones should be leveraged to encourage public engagement, alongside financial benefits realized through vehicle subsidies and insurers.

SUMMARY

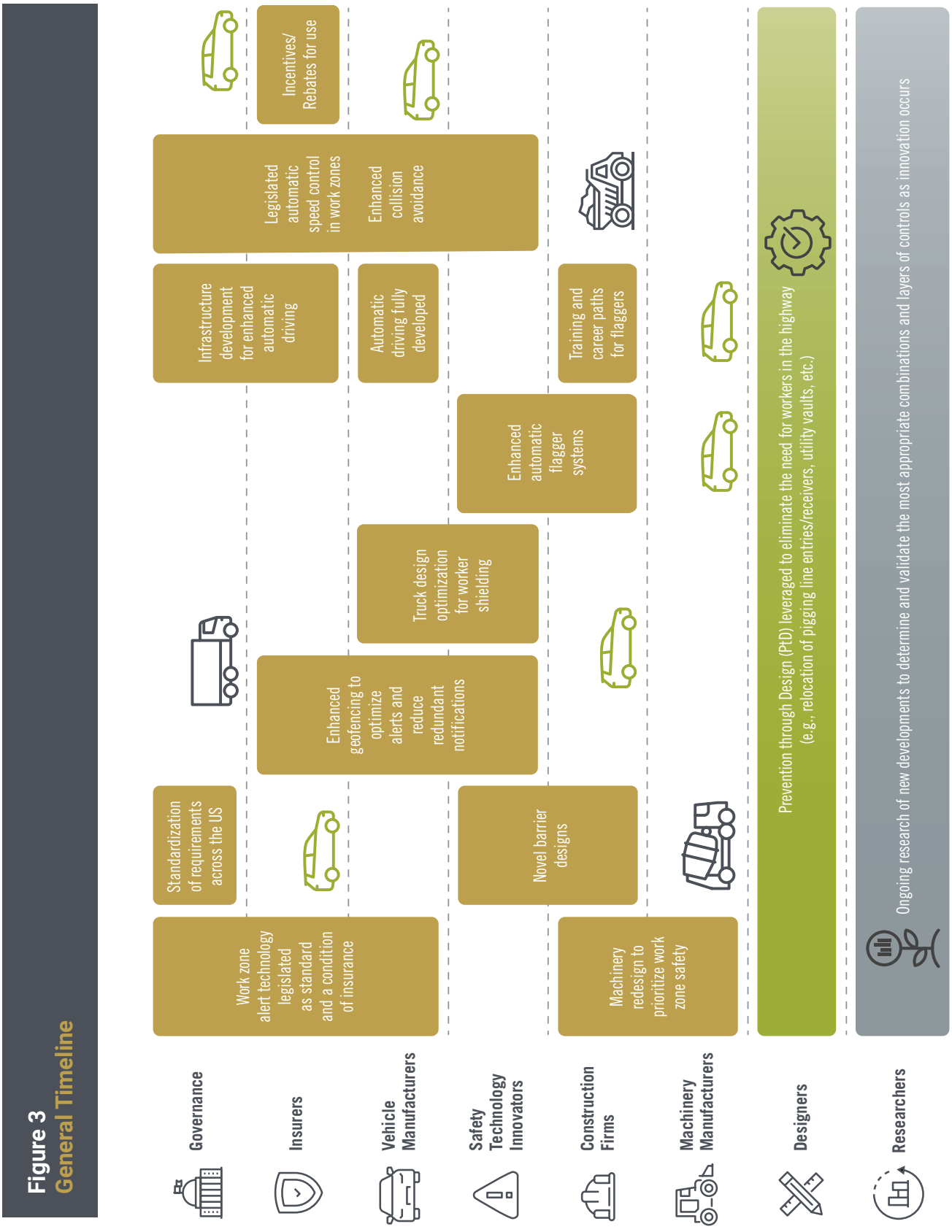


In recent years there has been considerable improvement in the controls available for Work Zone Management, including leveraging new technologies. However, there is still room for improvement.

This research roadmap lays out the current state of the art, including recent innovations that are already helping reduce serious injuries and fatalities in work zones. The roadmap goes a step further to highlight the key stakeholders that will be required to make a difference in the future.

There is the potential for research and innovation to deliver significant improvements in work zone safety from various perspectives. This roadmap will help all the stakeholders in work zone protection look at how they can take action going forward.

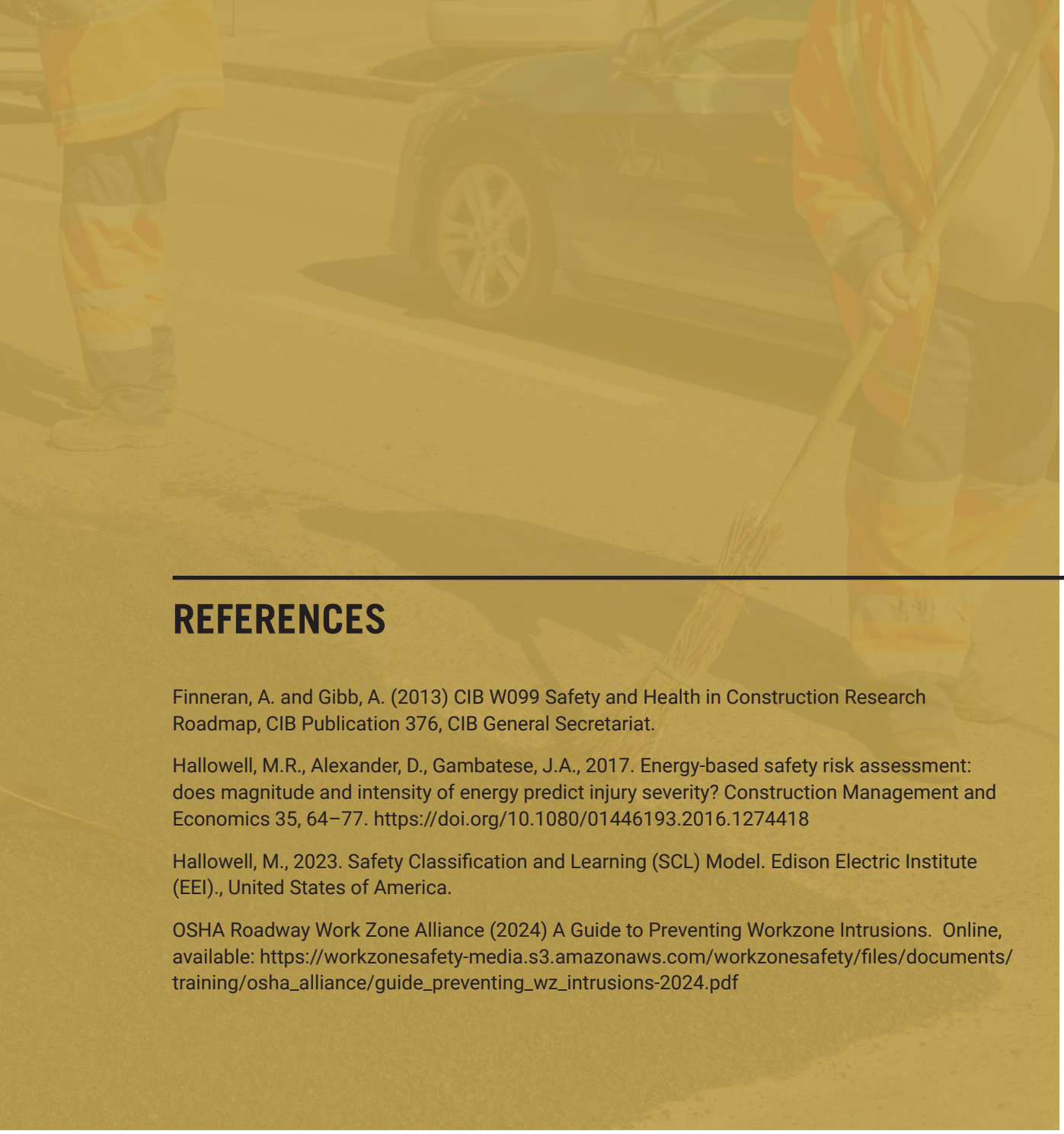
Many of the potential areas for future focus overlap between these key stakeholder groups. These overlaps and the potential direction of travel are illustrated in Figure 3.



TEAM MEMBERSHIP & ACKNOWLEDGEMENTS

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REFERENCES

Finneran, A. and Gibb, A. (2013) CIB W099 Safety and Health in Construction Research Roadmap, CIB Publication 376, CIB General Secretariat.

Hallowell, M.R., Alexander, D., Gambatese, J.A., 2017. Energy-based safety risk assessment: does magnitude and intensity of energy predict injury severity? Construction Management and Economics 35, 64–77. https://doi.org/10.1080/01446193.2016.1274418

Hallowell, M., 2023. Safety Classification and Learning (SCL) Model. Edison Electric Institute (EEI)., United States of America.

OSHA Roadway Work Zone Alliance (2024) A Guide to Preventing Workzone Intrusions. Online, available: https://workzonesafety-media.s3.amazonaws.com/workzonesafety/files/documents/training/osha_alliance/guide_preventing_wz_intrusions-2024.pdf

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