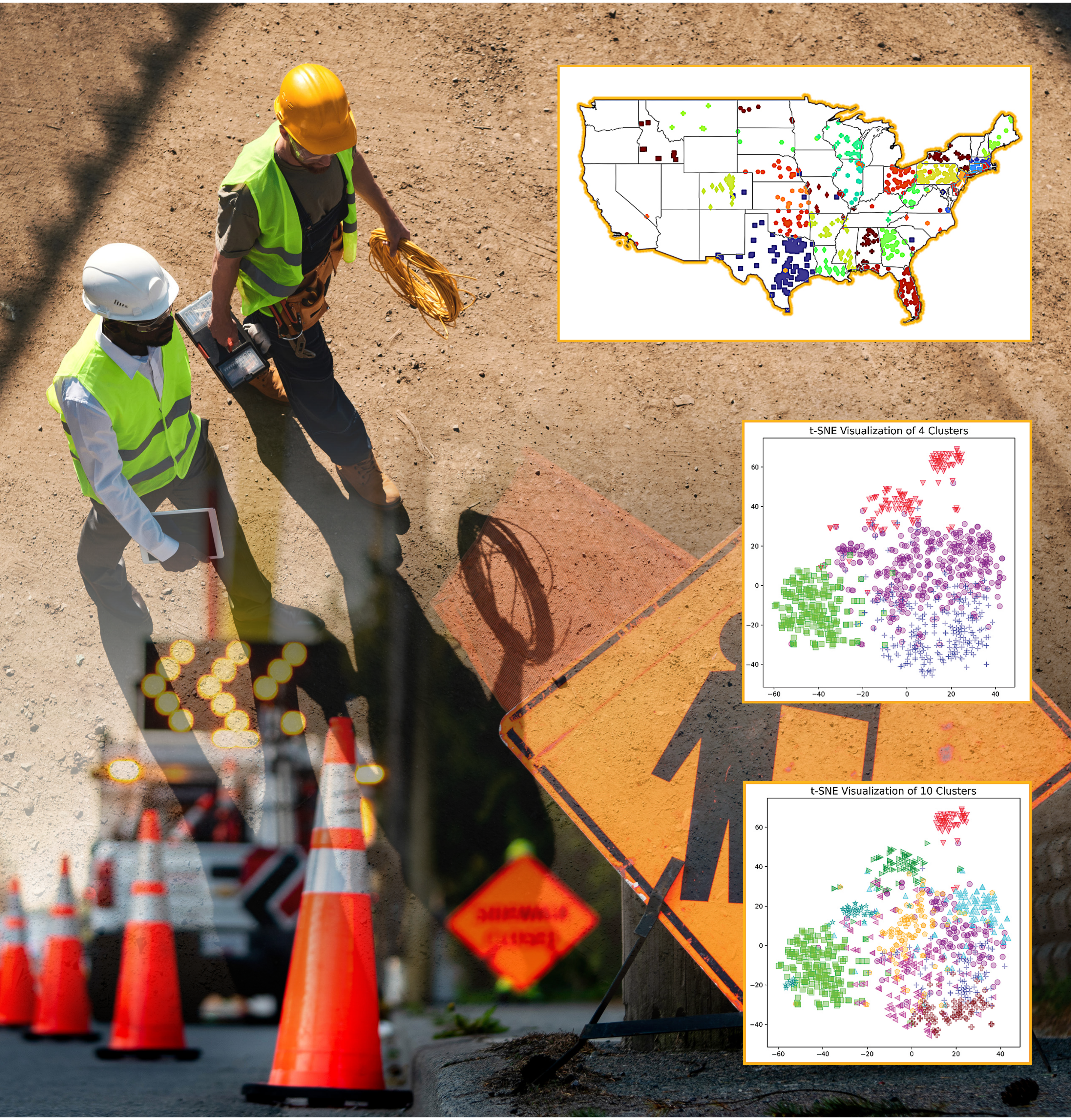

FINAL REPORT

IRISE-23-P22-01-01 | SEPTEMBER 2023

Identifying Major Causes of Construction Accidents

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CENTER FOR IMPACTFUL RESILIENT INFRASTRUCTURE SCIENCE & ENGINEERING

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16. Abstract

This study delves into the safety challenges inherent in the highway construction industry, acknowledging significant risks posed to worker safety by factors such as high-speed traffic, heavy equipment, and extreme environmental conditions. Faced with a construction industry accounting for a considerable share of worker fatalities, the imperative for thorough accident analyses is evident. The study's objective was to pinpoint major accident causes in highway construction, particularly in Pennsylvania, employing historical data analyses and extensive reviews of existing construction safety research. Initially planning a safety perception survey, the study pivoted to a more focused exploration of existing incident databases facilitated by the emergence of Large Language Models (LLMs), offering impactful insights into accident causation. The comprehensive literature review and LLM database analysis revealed crucial concerns in Pennsylvania's pavement, bridge, and rehabilitation projects, proposing further LLM integration to aid safety personnel. The study consolidates findings by exploring LLM applications, particularly the gpt-3.5 turbo model, for efficient text analysis in accident reports, showcasing their capability to streamline tasks and enhance incident categorization. The study concludes with a proposal for the "AI Safety Officer Assistant" in the highway construction sector, leveraging natural language processing (NLP) to streamline incident reporting, hazard communication, and safety planning. While acknowledging initial setup costs, the proposal emphasizes the long-term benefits, envisioning cost reduction, heightened productivity, and improved safety practices, aligning with transportation agencies' objectives for accident minimization and worker well-being.

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IRISE

Identifying Major Causes of Construction Accidents

Final Report

Lev Khazanovich, Mason Smetana, and Lucio Salles de Salles

Pittsburgh, September 2023

Report Outline

This report is designed to present varying levels of detail related to the IRISE project, "Identifying Major Causes of Construction Accidents.", as indicated below:

Section 1: Report Summary

> This section offers a high-level view of research activities, including a summary of the literature review, analysis of the Large Language Model (LLM) accident database, the "AI Safety Officer Assistant" proposal, and preliminary project results.

Section 2: Extended Report

> In addition to the overview, this provides more in-depth information not covered in the report, benefiting those seeking additional insights.

Section 3: Appendices

> Finally, all appendices with comprehensive details for each activity are available:

- Appendix A offers an extensive literature review, providing a thorough understanding of highway construction accidents and the current state of prevention techniques in the United States.
- Appendix B explores the innovative use of LLMs for data analysis in accident databases, delving into the details of clustering and summarizing major causes of accidents.
- Appendix C provides information about the proposal resulting from this IRISE project, introducing an application of LLMs as a new AI tool for safety personnel in daily work activity planning and future incident reporting.
- Appendix D includes additional LLM database analysis results not covered elsewhere.

All data utilized in this study is either available publicly, or upon request. For instance, the OSHA Severe Injury Reports database was sourced here. All other results that are not presented in any of the appendices may be available upon further request.

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IRISE

Identifying Major Causes of Construction Accidents

Section 1: Report Summary

1. Identifying Major Causes of Construction Accidents Overview

The highway construction industry is vital for infrastructure development but poses substantial risks to worker safety due to work zone hazards like high-speed traffic, heavy equipment, material movement, and extreme environmental conditions. In 2014, the construction industry accounted for 20.5% of worker fatalities in the United States (Kazan & Usmen, 2018). With over 44% of U.S. highways in poor condition, maintenance and rehabilitation projects are expected to increase, underscoring the need for comprehensive accident analyses in the industry (Das, Dutta, & Brewer, 2020).

Previous studies have identified common causes of construction fatalities, including struck-by accidents, falls, caught-in/between incidents, electrical shocks, and others. Work zone characteristics and human factors, such as worker behavior and ergonomics, significantly influence accidents. Despite safety improvements, injuries and fatalities persist, necessitating more comprehensive safety measures.

The objective of this study was to determine the major causes of accidents in the highway construction industry, with a focus of accidents occurring in Pennsylvania, using historical data analyses and through the dissemination of existing research related to construction safety. Originally the study would have included an additional survey to assess the current status of safety perception in the industry through the delivery and correspondence of various contractors and subcontractors on a local Pennsylvania level. However, due to the emergence of Large Language Models (LLMs) and their presence in various scientific fields, the focus of this study shifted to a more detailed analysis of existing incident databases pertaining to the highway construction industry. Consequently, the survey was considered less valuable, as the new focus provided more impactful insights into the major causes of accidents.

Of the various tasks performed in this project, the comprehensive literature review and database analysis provided substantial information and insights necessary to improve a local understanding of the major causes of accidents in the highway industry. While much of the existing literature was focused on vehicle intrusion accidents rather than work-zone related accidents, the limited articles pertaining to highway construction accidents was thoroughly examined to serve as a basis of understanding of the current status of accident causation and modern preventative measures. Building upon this foundation, the LLM database analysis carried out in this project further emphasizes critical areas of concern in pavement, bridge, and rehabilitation projects across Pennsylvania.

With access to the wealth of information and knowledge pooled together in this study, stakeholders may be able to make further decisions and directives to improve preventative methods in specifically targeted concentrations. As an auxiliary result of this study, further development of leveraging LLMs in construction safety has been proposed. Utilizing this novel artificial intelligence can significantly assist safety personnel in making informed decisions in future applications.

2. Literature Pertaining to Accidents in Highway Construction

The main objective of the primary task was to present a literature review regarding the current status of accident prevention and causation in highway safety. The construction industry is known for its high number of fatalities and injuries, accounting for a significant portion of total fatalities reported in any industry. Despite efforts to improve safety practices, highway construction continues to be considered one of the most dangerous fields. This report provides a summary of accident characteristics, current practices, and past and new technologies in construction safety. The findings of this technical review provide a foundational understanding of safety in a highway work zone and identify potential gaps in research related to safety practices. See Appendix A for the complete and extensive literature review.

The construction industry has made considerable strides in bolstering safety practices across its diverse sectors, yet the highway construction industry continues to grapple with persistent and unique challenges, notably when juxtaposed against other high-risk industries such as mining. Additionally, this review highlights the need for a more nuanced approach to safety within highway construction, necessitating in-depth, site-specific research to pinpoint unique activities and associated risks inherent to this specialized context. By conducting such targeted investigations, the industry can develop precise and effective safety measures tailored to the distinct challenges encountered on highway construction sites.

The literature review extended to the identification of accident causation models within the construction safety domain. These models have outlined key categories:

- Unsafe equipment
- Jobsite conditions
- Unsafe methods
- Human Elements
- Management failures
- Etc.

While these categories provide valuable insights into the leading causes of accidents, there exists room for more comprehensive research. This could involve delving deeper into the physiological and psychological dimensions of worker injuries, as well as examining the role of demographic factors in influencing accident frequency. Such detailed investigations can lead to a more nuanced understanding of the multifaceted causes of accidents in the construction industry.

In the realm of data collection, the review highlighted the imperative to refine the process, particularly in the context of the Occupational Safety and Health Administration's (OSHA) Integrated Management Information System (IMIS) database, and other databases alike. It was recommended that leading indicators such as near-miss incidents be incorporated into standard accident reports. Given that many companies currently do not report near-miss incidents due to a lack of OSHA requirements, a substantial amount of potentially useful information remains excluded from the database. Furthermore, metrics like the Injury-Ratio Assessment (IRA), as reported by the Korean Occupational Safety and Health Administration (KOSHA), could be integrated into the database to facilitate more structured assessments of accident severity (Kim, Ryoo, Kim, & Huh, 2013). This improved data collection can significantly enhance our understanding of construction safety and inform more effective preventative measures (Guo, Li, & Li, 2013; Zhou, Li, Mi, & Qian, 2019).

Education and training programs emerged as a pivotal focal point of the existing literature. While it is well-recognized that worker skills are essential, we also acknowledged the significance of addressing worker attitudes and behavior. Beyond improving the technical competencies of workers, there is a clear need to refine their safety consciousness and responsiveness. However, it was noted that there is limited information available on how to enhance safety programs at the management level. To truly effect positive change, this knowledge gap must be bridged. Additionally, the incorporation of preventative technologies into training programs warrants further exploration, ensuring that workers are not only skilled in their operation but are also proficient in utilizing these technologies effectively (Guo, Li, & Li, 2013).

In conclusion, the extensive literature review underscores the urgency of addressing these research gaps to fortify the foundations of construction safety, particularly within the dynamic context of highway construction. Through targeted, site-specific research, augmented data collection practices, and enhanced education and training programs, the construction industry can markedly reduce accidents and fatalities. By doing so, it can foster a culture of safety that not only safeguards the well-being of its workforce but also advances the industry as a whole, promoting efficiency, productivity, and sustainable growth.

3. Accident Database Analysis

The application of large language models (LLMs), particularly the gpt-3.5 turbo model, for text analysis in the highway construction industry, specifically in the context of accident analysis, is explored in this study. These language models, developed by OpenAI, have the capacity to streamline textual analysis tasks across various domains. The gpt-3.5 turbo model stands out due to its proficiency in zero-shot and few-shot learning scenarios, allowing it to understand and execute tasks with minimal guidance (Brown, et al., 2020). See Appendix B for a full description of all associated processes and results for the following analysis.

By leveraging the language model's capabilities, data-driven analysis of accident reports and incident narratives can be conducted more accurately and comprehensively. The model's ability to process and interpret instructions with precision opens up new possibilities for automating incident categorization and identifying contributing factors in highway construction accidents.

A database sourced from OSHA, namely the Severe Injury Reports (SIR) database, was extensively explored in this study. Pennsylvania was found to be the third highest contributor to this database with 93 cases (approximately 10% of all reported accidents), emphasizing the criticality of investigating major causes of accidents on a local scale. The dataset provided crucial incident details, including accident date, employer information, hospitalizations, amputations, and more, with a significant emphasis on textual descriptions in the final narrative, enhancing safety analysis.

With the database, the final narratives were isolated to calculate dense numerical vectors (1,536 dimensions) of textual embeddings that are crafted to withhold contexts and semantic meanings of individual incidents. Clustering these embeddings is essential for dissecting major accident causes, and machine learning algorithms like K-means are employed for this purpose. Additionally, techniques like t-Distributed Stochastic Neighbor Embedding (t-SNE), are utilized to visualize this high-dimensional data into two dimensions effectively and reveal clusters within complex datasets (van der Maaten & Hinton, 2008). The ideal number of clusters was found to be six clusters in this study, as shown in Figure 1, which also demonstrates the application of the t-SNE algorithm.

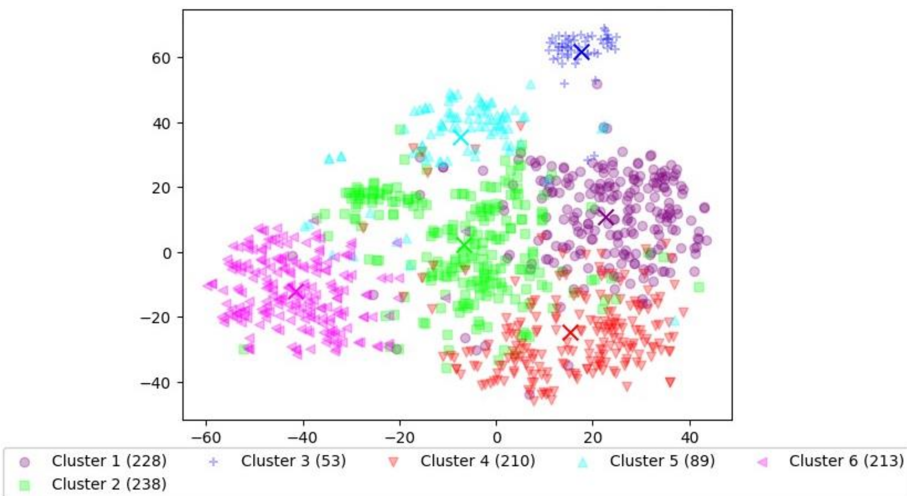

Figure 1: Example K-Means clustering of incidents (6 clusters)

Additionally, the study delves into the technical aspects of using language models, including prompt refinement and manual response evaluation, to summarize clusters and identify major causes of accidents. This approach revealed six major causes of accidents, a breakdown of national to state level cluster percentages is presented in Figure 2:

- Cluster 1: Stuck by Vehicle or Heavy Equipment
    - 228 cases | 99.6% Hospitalization | 1.8% Amputations
- Cluster 2: Contact with Objects or Equipment
    - 238 cases | 95.8% Hospitalization | 8.4% Amputations
- Cluster 3: Heat Related
    - 53 cases | 100% Hospitalization | 0% Amputations
- Cluster 4: Falling Objects or Personnel
    - 210 cases | 99% Hospitalization | 1% Amputations
- Cluster 5: Heated Materials or Equipment
    - 89 cases | 100% Hospitalization | 1.1% Amputations
- Cluster 6: Upper Limb Injuries
    - 213 cases | 49.8% Hospitalization | 72.3% Amputations

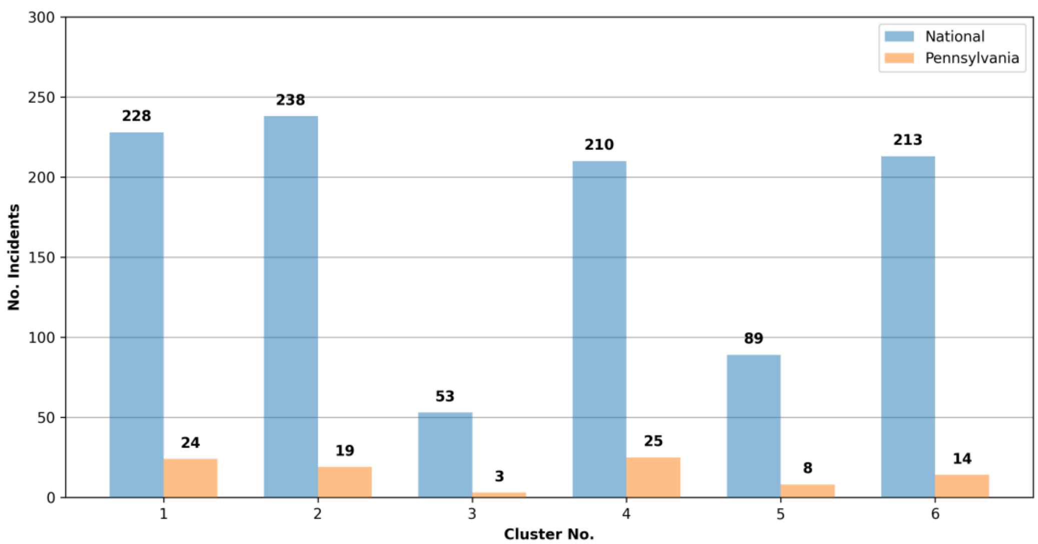

Figure 2: National vs. Pennsylvania cluster percentages

An example LLM generated summary for cluster three "Heat Related" is as follows:

LLM: All of the listed incidents involve employees working in road construction who suffered from heat-related illnesses or dehydration. Many employees were hospitalized due to symptoms such as heat exhaustion, cramping, and dehydration. The incidents occurred during hot weather conditions, with some employees working in temperatures as high as 86 degrees. The affected employees were performing a variety of tasks, including paving, welding, shoveling, and flagging. The incidents highlight the importance of proper hydration and heat safety measures in road construction work.

Additionally, the following top three causes were also identified by the LLM for cluster three:

1. **Heat exposure:** Many of the incidents were caused by heat exposure, which can lead to heat exhaustion, heat stroke, dehydration, and other heat-related illnesses.
2. **Lack of training and safety protocols:** Some incidents were caused by a lack of training and safety protocols for working in hot conditions.
3. **Physical exertion:** Many of the incidents were caused by physical exertion, such as shoveling, lifting heavy objects, or operating heavy machinery.

The language model was also employed for incident classification using specific fields from the OSHA SIR database. Evaluation metrics such as accuracy, recall, specificity, precision, and F1Score were utilized to assess the model's performance in various classification scenarios, as shown in Figure 3.

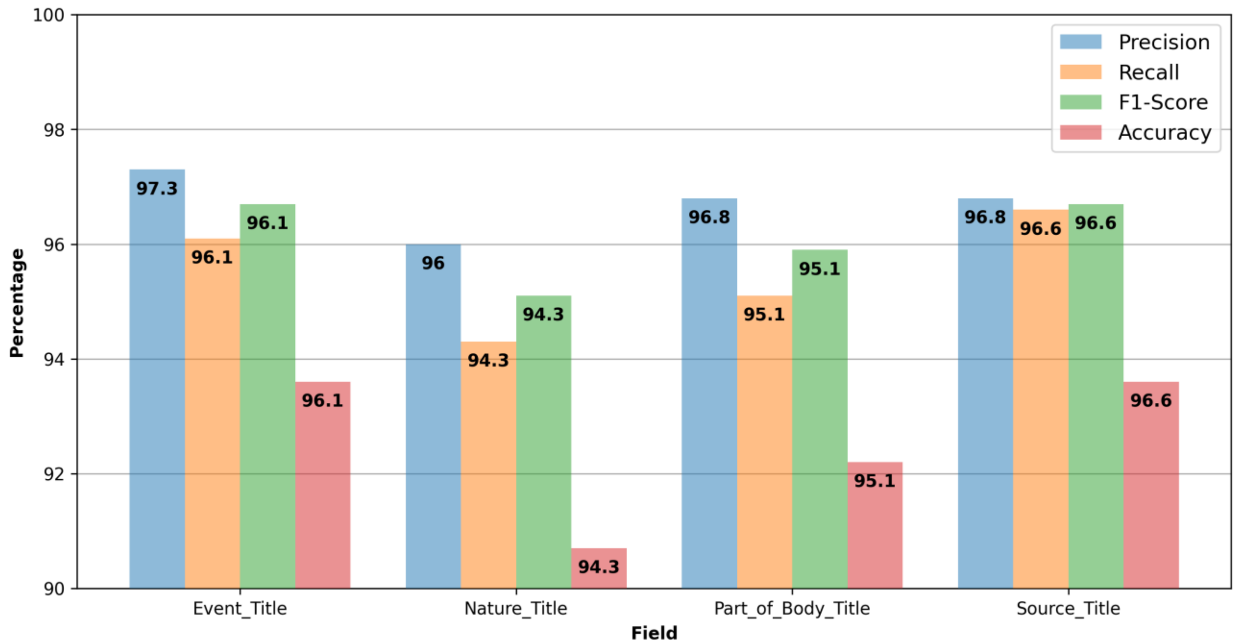

Figure 3: Evaluation metrics of LLM classification

The utilization of large language models (LLMs) in this study has significantly improved the analysis of safety incidents within the highway construction industry. These LLM-generated summaries offer insights similar to manual analysis, focusing primarily on accident causes, thus eliminating the need for laborious individual case iterations. Some of the identified causes align with common safety practices, while others are specific to incidents within the cluster. This analysis can enhance safety training by emphasizing specific issues based on the frequency of cases within the cluster. The LLM's classification of multiple fields within the OSHA database was evaluated, with the few-shot mode generally outperforming the zero-shot mode, particularly when classifying the event title.

The approach of leveraging LLMs has broadened the scope of accident analysis by identifying general trends in major accident categories and their causes, offering valuable insights into safety incidents in highway construction and paving the way for improved prevention and intervention techniques. This optimized approach provides datasets that illuminate accident causes, offering a more holistic perspective on highway construction safety.

4. AI Safety Officer Assistant Proposal

This study culminated in a proposal for the implementation of the "AI Safety Officer Assistant" within the highway construction industry. The proposal aims to address the persistent issue of high accident rates and fatalities in this sector, which pose financial and safety risks. The AI Safety Officer Assistant utilizes natural language processing to streamline incident reporting and hazard communication and generation of daily work activity plans with a focus of safety, enabling efficient analysis of unstructured data. It offers the potential to reduce costs, improve productivity, and enhance safety management practices, aligning with transportation agencies' objectives to minimize accidents and ensure worker well-being. While there are initial setup costs, the long-term benefits are expected to outweigh these expenses, making it an economically viable solution.

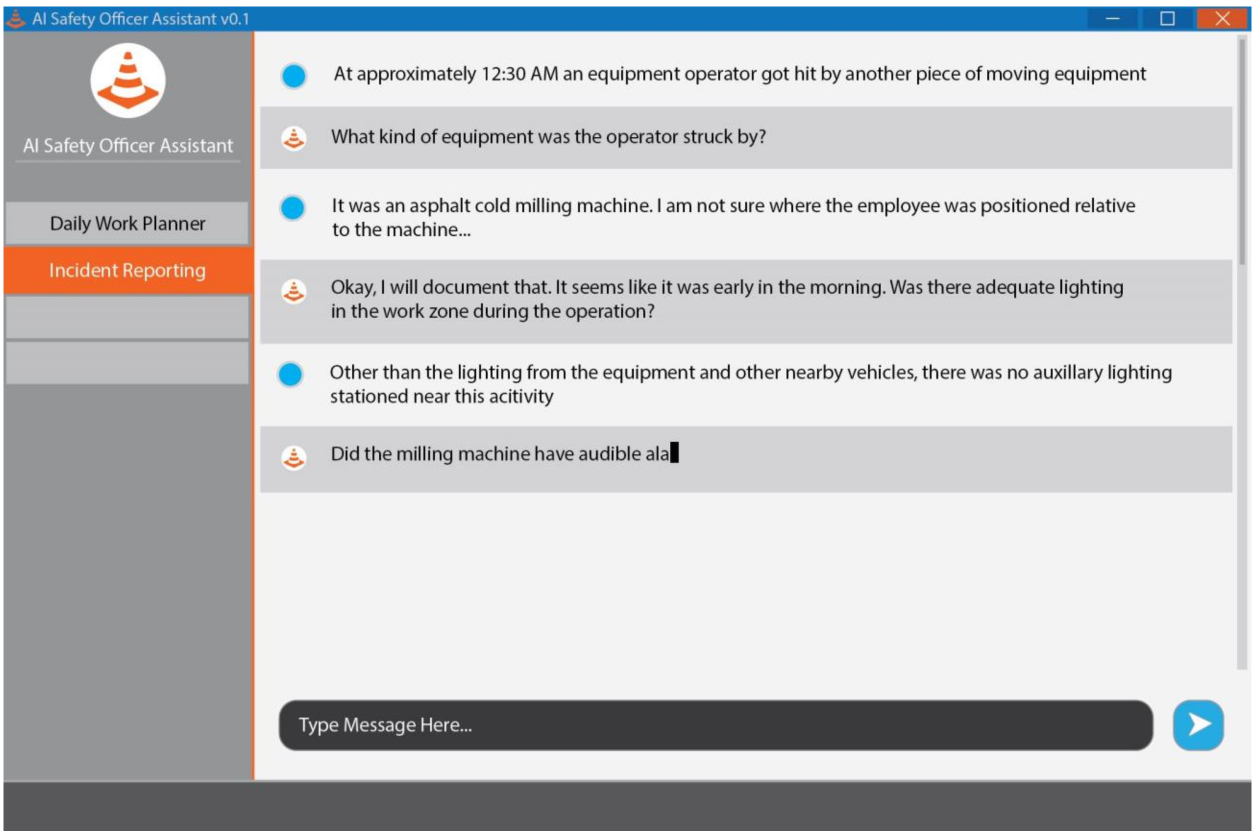

Figure 4: Mock user interface of AI Safety Officer Assistant program

5. Preliminary Conclusions

This study offers critical insights into safety concerns in highway construction, highlighting the value of innovative technologies like computer vision and AI in improving worker safety and work-zone conditions. The study emphasizes the prevalence of major accident categories, including struck-by accidents, falls, caught-in/between incidents, and electrical shocks, in these work zones. It underscores the importance of implementing preventative measures like proximity detection systems and addressing less common safety concerns such as heat exhaustion and fatigue. Understanding accident causes is crucial, and various contributing factors, including technical, human, and organizational aspects, have been explored, with a focus on unsafe equipment, inadequate lighting, and human factors like misjudgment and lack of awareness.

Moreover, the study introduces a groundbreaking approach that leverages Large Language Models (LLMs) to comprehensively analyze accident databases, providing valuable insights into accident causes and outcomes. It advocates for improved data quality in safety databases and proposes the AI Safety Officer Assistant, an AI-powered solution that can automate incident reporting, hazard identification, and safety management, offering economic benefits and aligning with the goals of transportation agencies. Overall, this study highlights the importance of a holistic approach to enhancing safety in highway construction through technological advancements and data-driven insights.

IRISE

Identifying Major Causes of Construction Accidents

Section 2: Extended Report

1. Summary of Literature on the Nature of Accidents

1.1 Accident Characteristics

To advocate for improving preventative measures in the construction industry and enhancing occupational health and safety, it is essential to understand all aspects of an accident, including its type, cause, and result. Without this foundational knowledge of potential hazards leading to accidents, it becomes challenging to formulate effective prevention strategies. A thorough exploration of an accident's result and the utilization of a well-constructed accident causation model can offer valuable insights for preventing future accidents.

Construction sites, often characterized by outdoor operations, working at heights, complicated on-site plants, and equipment operation by workers, present a complex challenge in addressing hazards. Safety managers employ various safety devices, including PPE and safety guardrails, to manage risk factors. However, construction operations are rapidly changing, and the roots of accidents vary dynamically with each process (Kim, Kim, & Kim, 2016). The following sections provide basic characteristics of accidents, including the types of accidents, potential causes, and ultimately common results of the major types of accidents. For a complete breakdown of the accident characteristics, types, and causes see Appendix A: section 2.

1.1.1 Types

Struck-by accidents, falls, caught-in/between incidents, electrical shocks, and various other hazards contribute significantly to fatalities and injuries within the construction (BLS, 2013). Moreover, accidents involving vehicles and equipment within work zones, as well as incidents involving pedestrians and workers in or on vehicles or equipment, present substantial risks (Bryden & Andrew, 1999). Addressing these risks and implementing effective safety measures is imperative for safeguarding construction sites and highway work zone personnel.

Struck-by accidents represent a significant concern in the construction industry, with studies revealing that a substantial portion of these accidents occurs within work zones and involves collisions between workers and vehicles or heavy equipment. Pratt et al. (2001) highlighted that a considerable number of vehicle-related fatalities were due to worker-vehicle collisions, with over half of struck-by injuries occurring within work zones (Pratt, Fosbroke, & Marsh, 2001). Similarly, more recent research by Marks & Teizer (2013) reported that heavy vehicle struck-by collisions on construction sites accounted for a notable percentage of fatalities. Moreover, Kim et al. (2019) emphasized the persistent increase in struck-by fatalities, underlining the need for further research and investment in preventative measures like proximity detection systems (Kim, Liu, Lee, & Kamat, 2019).

Traffic vehicular accidents in highway construction, particularly those involving flagging work and traffic control, present inherent risks due to high-speed vehicles. These accidents are responsible for a significant portion of vehicle-related fatalities, with passing cars and trucks being the main contributors (Pratt, Fosbroke, & Marsh, 2001).

On-site vehicular and equipment accidents, typically occurring away from high-speed traffic, involve heavy construction vehicles and equipment, contributing to a majority of struck-by accidents. Research has shown that the effectiveness of safety systems like backup alarms and sensors varies, with malfunctions and lack of proper installation playing a role in accidents (Kazan & Usmen, 2018). The direction of vehicle travel also affects accident likelihood, with vehicles traveling in reverse being associated with a higher fatality rate (Hinze & Teizer, 2011).

Falls, while more common in general construction, remain a critical concern in highway construction. Efforts to automate hazard detection and enhance safety planning have been explored. Misplacement of safety screening and scaffolding contributes to falling accidents (Guo, Li, & Li, 2013).

Lastly, while electric shock, caught-in/between, and other categories exist as safety concerns in the construction industry, they do not represent the leading causes of accidents in highway construction. Further research is needed to analyze these accident types and identify potential preventative measures. Additionally, there is a gap in the literature regarding physiological-related injuries such as heat exhaustion and fatigue in highway construction (Eusebio, 2020).

1.1.2 Results

Despite notable improvements in safety practices within the construction industry, the goal of achieving zero fatalities remains elusive. Preventing injuries, of any severity, not only saves lives and enhances productivity but also substantially reduces associated costs. Nearly 91% of total medical costs are attributed to expenses stemming from illnesses, injuries, and fatalities (Kim, Ryoo, Kim, & Huh, 2013). These costs could be significantly reduced through increased investment in accident prevention during project development. Through the analysis of the OSHA IMIS database, it becomes evident that a substantial proportion of accidents could have been prevented through suggested preventive measures, with OSHA safety standards potentially averting an additional 60% of reported accidents (Hinze, Huang, & Terry, 2005). The lack of adherence to OSHA standards and the potential for preventive measures underscore the importance of more rigorous hazard detection efforts to decrease fatalities in highway construction sites.

Near-miss incidents, which narrowly avoid resulting in injuries or illnesses, are increasingly recognized as crucial for preventing serious accidents in construction. Recent studies suggest that near-miss incidents share similar root causation models with accidents, differing primarily in the consequences due to opportunity factors (Zhou, Li, Mi, & Qian, 2019). Collecting and analyzing information about near-miss incidents can lead to a lower accident rate and more effective safety efforts in construction. Near-miss incidents, such as stumbling and the risk of being crushed by heavy machinery, are prevalent during the earthmoving and foundations stage (Cambraia, Saurin, & Formoso, 2010). Additionally, falling materials and equipment pose a significant risk during the erection of structures (Cambraia, Saurin, & Formoso, 2010). These near-miss incidents highlight the potential for serious accidents if proper safety measures are not in place.

Regarding fatal injuries/illnesses in construction, statistics reveal that struck-by accidents are a significant contributor to fatalities in highway construction, followed closely by other typically prescribed accident types (Hinze, Huang, & Terry, 2005). While these broad categories provide valuable insights into the causes of construction injuries and fatalities, further research may be required to identify specific leading indicators in highway construction projects. Equipment and on-foot worker contact collisions and caught-in/between accidents have also been identified as major causes of construction fatalities (Teizer, Allread, Fullerton, & Hinze, 2010).

The majority of fatalities occur when workers are engaged in their regularly assigned tasks (Kazan & Usmen, 2018). This suggests that even experienced workers are susceptible to accidents, emphasizing the need for ongoing safety training and awareness. Construction work-area accidents, such as being struck or pinned by large equipment, falls from elevated areas, contact with electrical or gas utilities, and being struck by moving or falling loads, contribute to the high number of fatalities and injuries (Kim, Ryoo, Kim, & Huh, 2013). These accidents result in significant costs and highlight the need for improved safety measures.

Even inspection staff, who have lower exposure to construction operations, face the risk of fatal accidents (Bryden & Andrew, 1999). Falls and contact with tools, materials, or equipment are the most common causes of accidents in the construction industry (Bryden & Andrew, 1999).

1.1.3 Causes

Identifying the causes of accidents in the construction industry is essential for improving safety measures. Accident causation theories have been developed to categorize contributing factors. Kazan and Usmen (2018) proposed a classification of technical, human, and organizational variables, while Hamid, Majid, and Singh (2008) suggested six factor categories, including unsafe equipment, jobsite conditions, unique nature of the industry, unsafe methods, human elements, and management failures. Toole (2002) also highlighted factors like inadequate training, safety enforcement deficiencies, and the absence of personal protective equipment. These categorizations aim to enhance safety training and procedures, ultimately improving jobsite safety.

Unsafe equipment is a significant contributor to accidents in highway construction, with equipment type playing a crucial role. Earthmoving equipment, including backhoes and dump trucks, has been associated with a high frequency of fatalities. Equipment accidents, including overturns, collisions, and being caught in running equipment, pose a risk to workers (Pratt, Fosbroke, & Marsh, 2001). Proximity to equipment and vehicles, equipment misuse, and faulty equipment also contribute to accidents. Equipment misuse, such as inappropriate operations of heavy construction equipment, is another factor that leads to accidents (Li, Yi, Chi, Wang, & Chan, 2018).

Visibility-related factors, such as excessive or insufficient lighting and visual obstructions, are critical in accident causation, with visibility-related construction fatalities accounting for nearly 5% of all construction fatalities from 1990 to 2007 (Hinze & Teizer, 2011). Vision-related fatalities in construction equipment operations are frequently caused by blind spots and obstructions (Hinze & Teizer, 2011). Glare is another visibility impairment that can lead to accidents, and measures such as increasing safety margins and wearing eye protection are necessary to prevent them. Lack of awareness among workers and noise on construction sites can also contribute to accidents (Ferreira, Kumar, & Abraham, 2017; Hinze & Teizer, 2011).

Blind spot detection and analysis in construction equipment operations is a critical area of research due to the high risk of accidents caused by limited visibility. Construction activities often involve repetitive tasks, leading to decreased awareness among workers (Pratt, Fosbroke, & Marsh, 2001). Blind spots around construction equipment are prevalent and can result in accidents when operators fail to identify workers or objects in close proximity (Teizer, Allread, Fullerton, & Hinze, 2010).

Human elements, including lack of awareness, human error, worker demographics, and management failures, play pivotal roles in accidents, with inadequate training and education being a notable concern. Lack of awareness and accident frequency are also contributing factors, with misjudgment of hazardous situations and inappropriate choice or use of equipment or methods being common causes (Kazan & Usmen, 2018).

Weather, time, crowdedness, and the dynamic nature of the construction industry further influence accident occurrences. The harsh outdoor environment of construction sites, combined with the repetitive nature of tasks, can cause workers to lose focus and awareness (Pratt, Fosbroke, & Marsh, 2001).

1.2 Current Practices of Accident Prevention

The current status of accident prevention in highway construction highlights the persistent challenge of reducing fatalities in the construction industry. While overall safety has improved, highway construction still records a high number of fatalities compared to other industries with high-risk activities. Existing research often fails to isolate highway construction from the broader construction industry, limiting its ability to address site-specific tasks and risks associated with highway projects.

Regulatory organizations like OSHA, NIOSH, and FHWA play crucial roles in enforcing safety regulations and guidelines. OSHA, for example, provides numerous safety standards for the construction industry. However, some gaps in these regulations still exist, particularly concerning certain activities like preventing contact collisions between workers and heavy equipment.

1.2.1 Existing Practices and Methods

Existing practices in construction safety, particularly accident reporting and education/training, reveal both strengths and areas for improvement. The OSHA IMIS database serves as a valuable resource for safety officials, but some limitations hinder its full potential. The database lacks detailed information about accidents, making it challenging to understand the nature of incidents fully (Hinze, Huang, & Terry, 2005). To enhance its effectiveness, entries should include a more comprehensive description of work, accident classification, demographic details of injured personnel, possible causes, and preventive measures pursued. Moreover, reporting near-miss incidents is essential for improving safety, but OSHA's guidance on this aspect is limited. Workers often hesitate to report near misses due to concerns about penalties or complexity in the reporting process. Integrating near-miss information into databases like IMIS, coupled with additional metrics like the injury-ratio assessment (IRA), could aid in better accident prevention by facilitating data analysis (Cambraia, Saurin, & Formoso, Identification, analysis and dissemination of information on near misses: A case study in the construction industry, 2010; Kim, Kim, & Kim, 2016).

Education and training are crucial for construction safety, but there's room for improvement. Inadequate training is a significant factor in many OSHA-reported citations (Kazan & Usmen, 2018). Implementing site-specific training programs has shown promise in enhancing safety practices (Marks & Teizer, 2013). However, the effectiveness of safety education is also influenced by worker behavior and attitudes, which can be challenging to manage. Workers' safety awareness and their ability to identify and respond to jobsite hazards are strongly connected to the quality of training they receive (Guo, Li, & Li, 2013). Additionally, workers often respond better to informal means of communication, such as oral communication, rather than relying solely on written documentation. To enhance safety training, further research into how workers engage with training procedures and their attitudes towards safety is essential, potentially leading to more effective training methods (Cambraia, Saurin, & Formoso, Identification, analysis and dissemination of information on near misses: A case study in the construction industry, 2010; Li, Yi, Chi, Wang, & Chan, 2018).

Static hazards, such as physical hazards, are inherent in construction designs. Current safety regulations require passive safety devices, such as personal protective equipment (PPE) and safety guardrails. However, these devices do not provide real-time alerts during hazardous situations. Therefore, there is a need for effective communication on accident prevention methods to reduce the number of injuries and fatalities on construction sites (Hinze, Huang, & Terry, 2005). Significant accidents involving construction workers often occur due to exposure to various environmental hazards and poor safety management. Safety policies implemented at the corporate level can influence safety performance at the project level. Therefore, safety needs to become the responsibility of every employee within an active work zone (Kim, Ryoo, Kim, & Huh, 2013).

1.2.2 Implemented Technologies

Existing preventative technologies and measures in construction safety encompass various approaches, each with its strengths and considerations. Manual observation and inspection are fundamental practices for identifying hazardous conditions on construction sites. Frequent safety inspections are considered vital for evaluating jobsite safety, but their effectiveness can be hampered by limited safety personnel and the potential for biased assessments (Zhou, Irizarry, & Lu, 2018; Irizarry, Gheisari, & Walker, 2012).

Traffic control devices and plans, including Internal Traffic Control Plans (ITCPs), play a crucial role in highway construction safety. Initially focused on minimizing collisions between highway traffic and workers, these plans have evolved to prevent internal vehicular and equipment-related collisions within construction sites (Pratt, Fosbroke, & Marsh, 2001). Personal Protective Equipment (PPE) mandated by OSHA is another essential aspect of construction safety, although it is considered passive in that it does not provide real-time hazard alerts to workers and equipment operators (Marks & Teizer, 2013; Teizer, Allread, Fullerton, & Hinze, 2010).

Automated Flagger Assistance Devices (AFADs) have shown promise in improving safety during highway construction. Studies have yielded varying results depending on different control measures, but a significant percentage of respondents found AFADs more effective and understandable than human flaggers alone (Brown H. , 2017; Debnath, Blackman, Haworth, & Adinegoro, 2017). However, it's worth noting that AFADs do not entirely replace the need for human flaggers, and trained workers should be available in case of device malfunction or driver intrusion (American Traffic Safety Services Associates, 2012). Combining AFADs with Changeable Message Signs (CMS) and Truck Mounted Attenuators (TMA) has further improved safety by enhancing operator awareness and providing additional protection (Ferreira, Kumar, & Abraham, 2017; Qing, Zhang, Brown, & Sun, 2019).

1.3 Innovative Technologies

1.3.1 Modern Applications

In recent years, the construction industry has witnessed the integration of wearable technologies, sensors, and radio frequency identification (RFID) technology into proximity detection and alert systems, with the aim of enhancing construction safety. These real-time systems hold the potential to prevent accidents by promptly warning workers and equipment operators about potential hazard (Kim, Ryoo, Kim, & Huh, 2013). In particular, blind spots in construction equipment operations, known to pose significant risks to workers, can be effectively addressed through automated tools designed for blind spot detection, which offer rapid and objective analysis (Li, Yi, Chi, Wang, & Chan, 2018).

To further improve safety, remotely operated traffic control devices, such as portable traffic lights and automated flagger assistance devices (AFADs), have been introduced to improve flagger safety in one-lane work zones (Brown H. , 2017). Monitoring construction activities in real time is crucial for preventing safety accidents and hazards, and computer vision-based (CVB) technology offers a promising solution for this purpose (Cambraia, Saurin, & Formoso, 2010). Unmanned Aerial Systems (UAS) and Virtual Reality/Augmented Reality (VR/AR) technologies have also shown potential in improving construction practices and enhancing jobsite safety (Pratt, Fosbroke, & Marsh, 2001).

Proximity detection and alert systems have gained significant attention in the construction industry due to their potential to prevent accidents and improve safety. These systems utilize wearable technologies, sensors, and RFID technology to provide real-time warnings and alerts to personnel working in hazardous proximity situations (Teizer, Allread, & Mantripragada, 2010). The integration of multiple sensor types in wearable devices offers complementary benefits, ensuring a comprehensive approach to safety. Environmental sensors and tracking-based systems can also be employed to provide early warnings in hazardous proximity situations.

In the pursuit of effective proximity detection and alert systems, ultrasound technology has been explored as a viable option. Ultrasound sensors offer precise measurement capabilities and exhibit good resistance to background noise (Awolusi, Marks, & Hallowell, 2018). They are energy-efficient, simple in design, and relatively low-cost; however, ultrasound sensors may still respond erroneously to loud noises and have slower response times compared to other technologies (Awolusi, Marks, & Hallowell, 2018).

Future research in proximity detection and alert systems for construction safety should focus on improving proximity estimation accuracy, addressing implementation challenges, enhancing RFID technology, investigating factors influencing system effectiveness, developing construction-specific wearable devices, and advancing neural network-based approaches (Kim, Ryoo, Kim, & Huh, 2013; Marks & Teizer, 2013; Chae & Yoshida, 2010). Additionally, the evaluation of various candidate technologies, such as ultrasound and UWB, is crucial to determine the most suitable solutions for proximity detection and alert systems in construction safety (Awolusi, Marks, & Hallowell, 2018).

CVB technology offers significant advantages in automating safety monitoring in construction sites. By fusing tracking information from remote sensing data and leveraging deep learning techniques, CVB systems can provide real-time monitoring, proactive hazard identification, and improved safety measures (Teizer & Cheng, 2015). Numerous studies demonstrate the effectiveness of CVB technology in automatic monitoring of struck-by hazards, nonintrusive monitoring, and interpreting the construction site context (Cambraia, Saurin, & Formoso, Identification, analysis and dissemination of information on near misses: A case study in the construction industry, 2010).

Furthermore, the construction industry has also shown interest in utilizing Unmanned Aerial Systems (UAS) and Virtual Reality/Augmented Reality (VR/AR) technologies for construction project management (Zhou, Irizarry, & Lu, 2018). UAS technology, in particular, has been adopted to collect real-time data within the dynamic and complex context of construction project management (Zhou, Irizarry, & Lu, 2018). These technologies have the potential to improve safety management by providing accurate and up-to-date information on construction sites, allowing for better decision-making and risk assessment (Zhou, Irizarry, & Lu, 2018).

1.4 Identification of Research Gaps

Several research gaps in existing literature related to construction safety, especially in highway construction projects, have been identified. Firstly, there is a need for more research that specifically focuses on site-specific activities found in highway construction. A lack of detailed research on these activities hampers statistical analysis and the development of targeted safety measures for this context. To improve safety in highway construction, it's essential to identify and thoroughly review the specific activities and risks associated with them.

Secondly, in the realm of accident causation models, the existing literature may not cover all potential causes comprehensively. While the reviewed literature identifies categories such as unsafe equipment, jobsite conditions, human elements, and management failures as leading causes of accidents, there's room for more in-depth exploration. For instance, there's limited mention of the physiological and psychological relationships between workers and injuries. Further research into the demographic factors affecting accident frequency could provide valuable insights into accident causation.

Thirdly, improving the collection of injury and accident data, particularly in databases like OSHA's IMIS, is crucial for accident prevention. Incorporating leading indicators like accident precursors and near-miss incidents into accident reports can enhance the database's utility. Additionally, metrics such as the Injury-Ratio Assessment (IRA) used by KOSHA could be integrated into the database to better organize the severity of reported accidents (Zhou, Li, Mi, & Qian, 2019).

Lastly, education and training programs require further investigation and enhancement, especially in terms of management-level safety programs and procedures. A more comprehensive approach to improving worker education and training should be explored, considering factors like worker attitudes and behavior. Moreover, research should focus on enforcing the maintenance and mandates of preventative technologies as part of training programs (Guo, Li, & Li, 2013; Cambraia, Saurin, & Formoso, Identification, analysis and dissemination of information on near misses: A case study in the construction industry, 2010). Addressing these research gaps can contribute to a safer construction industry, particularly in highway construction.

2. Leveraging Large Language Models for the Analysis of Accident Databases

Data-driven decision-making is crucial for safety incident analysis (Al-Shabbani, Sturgill, & Dadi, 2018). However, current methods have limitations, and few studies have explored the potential of using databases like OSHA's Integrated Management Information System (IMIS) for in-depth analysis (Chokor, Naganathan, Chong, & Asmar, 2016). Natural language processing (NLP) techniques have been used to extract information from accident narratives, but machine learning approaches face challenges in explaining the relationship between contributing factors and injury severity (Valcamonico, Baraldi, Amigoni, & Zio, 2022; Chokor, Naganathan, Chong, & Asmar, 2016).

Large language models (LLMs), like OpenAI's GPT-3.5, have transformative potential in automating textual analysis tasks across domains (Chen, Fu, Wang, Meng, & Lv, 2022). In the construction industry, NLP can streamline inspections, extract information from unstructured data, and classify textual data. GPT-3.5's proficiency in understanding and generating human-like text can complement accident report analysis. The study proposes using GPT-3.5 for a comprehensive analysis of textual narratives in injury reports from the highway construction industry, aiming to enhance data-driven accident analysis and improve safety measures. For a more detailed investigation, refer to Appendix B.

2.1 Methodology

2.1.1 Database Acquisition

The data was sourced from the Occupational Safety and Health Administration (OSHA) Severe Injury Reports (SIR) database. While other OSHA datasets were available, the SIR database was chosen due to its textual richness and comprehensiveness in multiple fields. The dataset covered the period from 2015 to 2021 and included over 70,000 entries spanning various industries under the North American Industry Classification System (NAICS). The study focused on NAICS Code 237310, representing Highway, Street, and Bridge Construction, which accounted for 1.5% of the total severe injury reports (1032 cases) and ranked among the top 10% of contributors to such injuries. Notably, Pennsylvania was one of the states with the highest contributions to this database, being the third highest contributor with 93 cases.

The dataset provided details about each incident, including accident date, employer information, hospitalizations, amputations, and more. Particularly important for safety analysis were related to the incident's nature, body part affected, event description, and source. The final narrative contained text-based descriptions of accidents, often offering valuable information not obtainable from traditional statistics. The study opted to use national data for further analysis due to its larger sample size and similarity to Pennsylvania's behavior.

2.1.2 Calculating Embeddings

Modern text embedding models, which are based on the transformer architecture, have gained popularity for their content-awareness and high performance in classification and clustering tasks (Muennighoff, Tazi, Magne, & Reimers, 2023). Unlike traditional word embedding models, these models capture semantic meaning and contextual information effectively. Previous research, including studies by Fang et al. (2020), Heidarysafa et al. (2018), and Jeon et al. (2021), has extensively used word and sentence embedding models for analyzing roadway incidents and extracting textual specifications.

Recent advancements in these modern text embedding models, such as OpenAI's Ada Embedding model (text-embedding-ada-002), have demonstrated superior performance in benchmark tests like the Massive Text Embedding Benchmark (METB) conducted by Muennighoff et al. (2023). This makes the Ada model particularly valuable for clustering safety-related incidents, as part of the project's objectives. In the study, text embeddings were generated from the final narrative field of the SIR database. The text was tokenized into smaller units called tokens and then processed by the embedding model to create dense numerical vectors representing semantic meaning and contextual information for each token.

2.1.3 Clustering Incidents and Dimensionality Reduction

Clustering text embeddings derived from safety-related incident narratives is a crucial step in dissecting the major causes of accidents in the highway construction industry. These embeddings, produced by the text-embedding-ada-002 model, result in high-dimensional vectors with 1,536 dimensions. To effectively cluster such high-dimensional datasets, machine learning algorithms like K-means are employed, as they are capable of statistically grouping data points based on their similarity (Yassin, 2020). K-means clustering relies on measuring the distance of each data point from cluster centroids. This technique has been successfully applied in various accident clustering studies (Chokor, Naganathan, Chong, & Asmar, 2016; Deng, Gu, Zeng, Zhang, & Wang, 2020; Ma, Mei, & Cuomo, 2021; Yassin, 2020).

Visualizing high-dimensional data in two or three dimensions can be challenging, but t-Distributed Stochastic Neighbor Embedding (t-SNE), as proposed by van der Maaten and Hinton (2008), provides an effective solution for dimensionality reduction. This technique addresses issues related to crowding and optimization, capturing both local and global structures, and revealing structures at various scales, making it particularly suitable for uncovering clusters in complex datasets (Dhalmahapatra, Shingade, Mahajan, Verma, & Maiti, 2019; van der Maaten & Hinton, 2008).

2.1.4 Large Language Models and Prompt Engineering

Large Language Models (LLMs) like GPT-3, have revolutionized natural language processing (NLP) and offer substantial potential in various industries, including construction. LLMs have been trained on enormous amounts of text data and have significantly outperformed previous language models, thanks to their advanced Transformer architecture (Vaswani, et al., 2017). One of the standout features of models like GPT-3 is their ability to perform zero-shot or few-shot learning, allowing them to understand and execute tasks with minimal guidance, which is highly valuable for applications that require clear and concise instructions (Brown, et al., 2020).

In the highway construction industry, the power of LLMs like GPT-3 can be harnessed for accident analysis. These models excel in understanding and generating human-like text, enabling more accurate and comprehensive analysis of accident reports and incident narratives. They can process and interpret instructions with remarkable accuracy, automating incident categorization and identifying contributing factors in highway construction accidents. This represents a significant advancement in leveraging cutting-edge NLP techniques to enhance safety and decision-making processes in the industry.

The Transformer architecture introduced by Google in 2017 has simplified traditional neural networks by relying on attention mechanisms, allowing it to capture global dependencies in input and output data (Vaswani, et al., 2017). Models like GPT-3, which use unsupervised distribution estimation from a set of examples, have opened up possibilities in various scientific fields, including textual narrative analysis (Radford, et al., 2018). GPT-3's large-scale training corpus and model parameters have enabled unique abilities such as summarization and question answering. Its few-shot learning capabilities mean that it can perform tasks with minimal examples or specific instructions, outperforming traditional NLP models that require extensive pretraining and fine-tuning for domain-specific tasks (Brown, et al., 2020). Despite the complexity of interacting with these models through natural language prompts, they offer the potential to return accurate responses without the need for additional training or weight updates.

2.2 LLM Clustering, Summarization, and Classification

In the analysis, the GPT LLM, specifically gpt-3.5 turbo, was employed for the tasks of summarizing clusters and identifying major causes of accidents. The process involved refining prompts through iterations and manually evaluating the model's responses. The final prompts were designed to allow the model to iterate over the entire dataset, providing it with a few entries at a time until all entries were evaluated. From this process, summaries and the top three causes for each cluster were generated.

Furthermore, the language model was utilized for classifying incidents based on specific fields extracted from the OSHA SIR database, including "EventTitle," "NatureTitle," "Part_of_Body_Title," "SourceTitle," "Hospitalized," and "Amputation." For each incident, the model was prompted to determine the most appropriate entry for each of these fields. Both few-shot and zero-shot prompting techniques were applied to evaluate the model's performance. Few-shot learning involved providing examples of existing classes in the prompt, while zero-shot learning relied solely on the list of unique entries. Evaluation metrics such as accuracy, recall, specificity, precision, and F1Score were used to assess the model's classification performance, with F1Score serving as a balanced measure of precision and recall in multi-class classification scenarios where binary classification was not applicable (Ma, Mei, & Cuomo, 2021; Yassin, 2020). These evaluations aimed to comprehensively gauge the model's classification capabilities in various fields within the OSHA database.

2.2.1 Clustering Results

Selecting the optimal number of clusters (n) for the K-Means algorithm proved challenging as there was no clear inflection point in the average sum of square errors (SSE) to indicate the ideal cluster count, as demonstrated in Appendix B: Section 3. This approach involved considering both quantitative and visual aspects to determine the most suitable cluster count for the K-Means algorithm, ultimately leading to the selection of the ideal number of clusters for further investigation. Consequently, six clusters (Figure 5) were chosen for further analysis as they struck a balance, occupying distinct regions with minimal overlap and demonstrating a notable shift in average SSE.

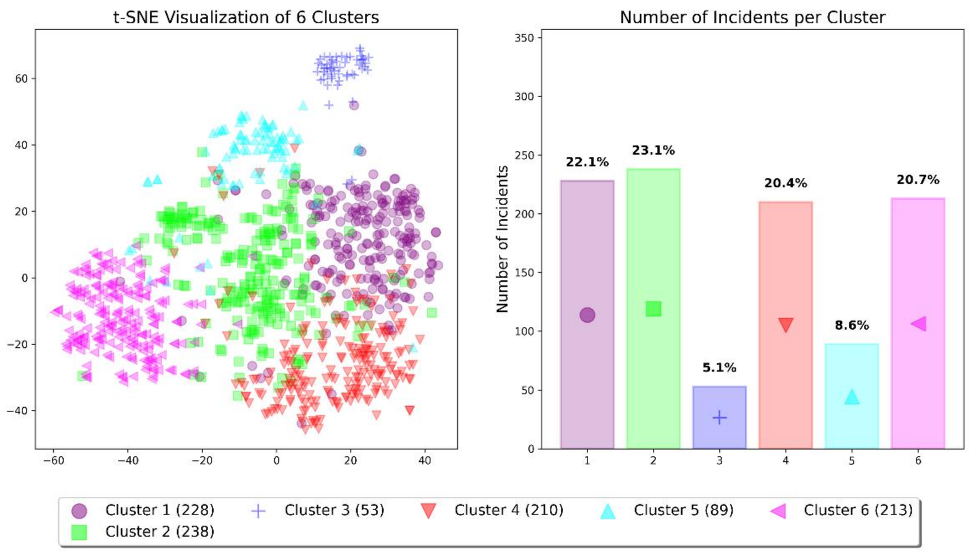

Figure 5: Example incident clustering (6 clusters) and associated percentages

2.2.2 LLM Generated Summaries and Causes

The iterative process for generating cluster summaries using the GPT-3.5 model is outlined in Appendix B. In the refine prompt, the previously generated summary is presented to provide additional context for newly introduced road construction incidents. It's important to note that the model does not retain a history of previous requests, generating summaries based solely on the current iteration of incidents. Table 1 presents an overview of the final responses generated by the language model for each cluster summary and cause identification, with manual analysis indicating that the six clusters consistently produced more well-defined summaries compared to other cluster quantities. Additionally, this table presents national statistics for each cluster with respective to state level (Pennsylvania) statistics.

Table 1: Overview of LLM generated summaries and cuases

Cluster	Categorization of LLM Summary	Identified Potential Cause Titles
Cluster 1 US: 228/1032 PA: 24/93	Struck by Vehicle or Heavy Equipment (22.1% National – 25.8% PA)	1. Inadequate traffic control measures 2. Inadequate training and supervision 3. Failure to follow safety procedures
Cluster 2 US: 238/1032 PA: 19/93	Contact with Objects or Equipment (23.1% National – 20.4% PA)	1. Inadequate hazard assessments 2. Lack of proper equipment, maintenance, inspection, and training 3. Failure to follow established safety procedures and inadequate training
Cluster 3 US: 53/1032 PA: 3/93	Heat Related (5.1% National – 3.1% PA)	1. Heat exposure 2. Lack of training and safety protocols 3. Physical exertion
Cluster 4 US: 210/1032 PA: 25/93	Falling Objects or Personnel (20.4% National – 26.9% PA)	1. Inadequate fall protection 2. Insufficient equipment training maintenance 3. Failure to follow established safety procedures
Cluster 5 US: 89/1032 PA: 8/93	Heated Materials or Equipment (8.6% National – 8.6% PA)	1. Inadequate handling of hot materials and lack of PPE 2. Lack of proper equipment maintenance and inspection 3. Inadequate communication and training
Cluster 6 US: 213/1032 PA: 14/93	Upper Limb Injuries (20.7% National – 15.1% PA)	1. Pinch points 2. Lack of guarding 3. Inadequate communication

Through manual analysis of the clusters, various insights can be derived. For example, cluster four was centered around incidents that were related to falling (either worker or an object) from a certain height, with a majority of cases involving a worker falling from a height. Some incidents were related to objects or equipment parts falling onto workers. To emphasize the model's performance, the following summary for cluster four was generated:

LLM Generated Summary: The road construction incidents involved a variety of tasks and equipment, resulting in a range of injuries from falls, being struck by falling objects, being caught in between objects, and tripping. Safety equipment was not always used properly or was unhooked at the time of the incident, and employees were not always using proper equipment or following proper procedures. Many of the incidents resulted in hospitalization and required emergency surgery, with injuries ranging from broken bones to electrical burns and partial amputations. The new incidents highlight the importance of proper safety equipment use and following proper procedures to prevent serious injuries, such as fractures, head injuries, lacerations, and crushing injuries. Commonalities between the incidents include falls from heights, being struck by falling objects, and improper use of equipment or failure to follow proper procedures.

The LLM-generated summaries provided insights similar to manual analysis, eliminating the need for laborious individual case iterations. These summaries predominantly focused on accident causes, with occasional mentions of affected body parts. While some causes identified by the LLM aligned with common safety practices like "inadequate training or communication," others were specific to incidents within the cluster. This analysis has the potential to enhance safety training by emphasizing the importance of addressing particular issues, such as the need for equipment guarding to reduce upper limb injuries, based on the frequency of cases within the cluster. See Appendix B: Section 3 and D for complete results of the model output for various cluster numbers.

2.2.3 Classification Results

After summarization and causation analysis, the LLM's classification of multiple fields within the OSHA database was evaluated. Generally, the few-shot classification mode outperformed the zero-shot mode, achieving the highest accuracy of 93.7% accuracy when classifying the event title. In contrast, the zero-shot mode's highest accuracy was 62.5% when classifying the nature title, potentially due to a limited selection of entries. The hospitalization and amputation fields were assessed alongside the four major fields using a classification prompt, as detailed in Appendix B: Section 3.

These queries performed well in both few-shot and zero-shot modes, likely because they were not reliant on previous field coding. Interestingly, their classification performances varied when presented in different field contexts, possibly influenced by the inherent probability and randomness of the LLM itself. For reference, the following table presents the performance of the classification of various database columns in the few-shot context:

Table 2: LLM few-shot classification of SIR database columns

Column	Precision	Recall	F1Score	Accuracy
Event Title	97.4	96.1	96.7	93.7
Nature Title	96.0	94.4	95.2	90.8
Part of Body Title	96.8	95.1	96.0	92.2
Source Title	96.8	96.6	96.7	93.6

Given the generally high accuracy of LLM classification, manual assessment of instances where LLMs provided different classifications can offer valuable insights into the adequacy of the initial incident coding. The following database entry exemplifies the LLMs capacity to classify incidents with more subtle nuances. More examples of the LLMs performance in classification can be found in Appendix B: Section 3.

Incident ID: 31

Field: Amputation

Final Narrative: “On February 15, 2017, at about 9:30 AM, an employee was using an excavator to push a concrete pipe together when his right forefinger was partially amputated above the fingernail, requiring surgery.”

SIR Database Classification: No Amputation

LLM Classification: Amputation

In this specific example of incident #31, the narrative clearly indicates that he incident involved an amputation, whereas the original database entry indicates that no amputation was presented in the incident. In many cases, the LLM was able to classify the incidents in a more illusive fashion, highlighting potential for discoveries and disconnections between what was originally coded and what the LLM identified. These models can now be utilized to reconsider entries in the database for a more representative dissemination of findings for statistical purposes.

As an auxiliary classification, classifying incidents related to concrete work activities, the LLM identified 121 cases related to concrete work, accounting for 13.3% of all cases. Cluster 2, which involves contact with objects or equipment, contributed significantly to cases related to concrete pavements, likely due to the heavy equipment needed in large-scale concrete construction projects. Overall, the LLM performed well in determining whether incidents were connected to concrete pavements, identifying the equipment involved, and providing concise accident descriptions, although some challenges were noted. For instance, the model occasionally associated terms like "concrete piping" with concrete pavement incidents and struggled with precise equipment identification due to sentence context challenges.

In the context of heat exposure incidents, a slight disparity emerged when comparing manual assessments with LLM results. Initially, ten cases in Cluster 3 were linked to heat exposure during concrete procurement, but the LLM's classification recognized only six clusters related to heat exposure. While the LLM excelled in summarizing tasks, there is room for improvement in classification accuracy. Enhancements could involve refining prompts or incorporating traditional machine learning metrics like accuracy, precision, and recall to provide a more comprehensive and quantifiable evaluation of the LLM's incident classification performance, facilitating further improvements in its capabilities.

Following the implementation of LLM classification, the top entries in each database field for the respective cluster were derived (Table 3), aiding in the evaluation of LLM summarization performance (see Appendix B: Section 3 for a full breakdown). These categories effectively reflect in their corresponding summaries without disclosing any previously coded information, offering conclusive results that were previously unattainable. For instance, cluster one's summary, focusing on vehicle struck-by accidents, predominantly consisted of cases labeled "Pedestrian struck by forward-moving vehicle in work zone" in the event title field, demonstrating the LLM's consistent and distinctive relationship between clusters and their corresponding fields.

Table 3: Top entries for each cluster with LLM classification

Cluster	Event Title	Nature Title	Part of Body Title	Source Title
Cluster 1 Stuck by Vehicle or Heavy Equipment	Pedestrian struck by forward-moving vehicle in work zone	Fractures	Nonclassifiable	Highway vehicle, motorized, unspecified
Cluster 2 Contact with Objects or Equipment	Injured by slipping or swinging object held by injured worker	Fractures	Legs, unspecified	Saws-powered, except chainsaws
Cluster 3 Heat Related	Exposure to environmental heat	Effects of heat and light	Body systems	Heat-environmental
Cluster 4 Falling Objects or Personnel	Struck by falling object or equipment	Fractures	Multiple body parts	Bridges, dams, locks
Cluster 5 Heated Materials or Equipment	Contact with hot objects or substances	Heat (thermal) burns, unspecified	Multiple body parts	Paving asphalt, asphaltic cement
Cluster 6 Upper Limb Injuries	Compressed or pinched by shifting objects or equipment	Amputations	Fingertips	Nonclassifiable

3. Dissemination, Findings, and Suggestions

3.1 LLM Database Analysis and Future Applications

The emergence of large language models (LLMs) in the field of artificial intelligence represents a significant advancement with far-reaching applications, including automation, data analysis, and transportation research. In the context of highway construction safety, which is characterized by its dynamic and unpredictable nature, harnessing the vast textual information within accident databases is crucial. Traditional descriptive statistics often fall short when dealing with text-heavy accident report databases. To address this challenge, a cutting-edge approach was proposed in this study, leveraging LLMs to comprehensively analyze such databases. By surpassing the limitations of conventional methods, this approach offers valuable insights into the causes, characteristics, and outcomes of accidents, ultimately enhancing our understanding of safety incidents in highway construction and paving the way for improved prevention and intervention techniques.

The approach was applied to the OSHA Severe Injury Reports database, acknowledged for its rich textual information. Unlike traditional descriptive analysis, which may limit insights to specific niche situations, this approach broadens the scope of accident analysis by identifying general trends in major accident categories and their causes. The use of LLMs for clustering, summarization, cause identification, and classification enriches safety-related insights, avoiding the need for labor-intensive manual analysis. Additionally, LLM classification brings out crucial details from narratives that were not evident in previous field entries, highlighting the model's capacity to reevaluate incidents based on narrative context. This optimized approach to data clustering provides datasets that illuminate accident causes, such as environmental heat or specific body part involvement, offering a more holistic perspective on highway construction safety.

3.2 Resulting Proposal

As a result of this study, a proposal was crafted to pursue continued use of LLMs in the area of highway construction safety. The proposal centers around the development and implementation of an innovative AI-powered Language Model (LLM) known as the "AI Safety Officer Assistant" within the context of the highway construction industry. The primary problem this proposal addresses is the persistently high rate of accidents and fatalities within this sector, resulting in significant financial losses and jeopardizing worker safety. This challenge underscores the urgency of investing in a solution that enhances safety practices and mitigates risks.

The proposed innovation, the AI Safety Officer Assistant (Appendix C), is designed to revolutionize safety management practices in highway construction. It employs natural language processing algorithms to streamline incident reporting and hazard communication processes, enabling comprehensive analysis of unstructured data. Unlike existing practices, this tool can rapidly process large volumes of incident reports, identify potential hazards, and provide actionable recommendations for hazard mitigation. Moreover, it automates routine tasks, freeing up safety officers to focus on higher-level safety management strategies and proactive measures.

Economically, the proposal suggests that while there are initial setup costs, the long-term benefits are expected to outweigh these costs. The technology promises increased operational efficiency, reduced downtime, lower medical costs, decreased legal expenses, and improved worker productivity. This aligns with the goal of transportation agencies to minimize construction accidents and ensure the safety of their crews. The proposal also emphasizes the economic and social-economic benefits, including cost savings and improved worker well-being, as significant drivers for the adoption of this innovative solution.

3.3 Study Conclusions and Suggestions

This study provides critical insights into safety concerns within the highway construction industry, emphasizing the persistence of major accident categories. Innovative technologies, such as computer vision and advanced artificial intelligence, have demonstrated their efficacy in enhancing work-zone conditions and worker safety. Additionally, technologies like UAVs and wearables offer potential for specific intervention techniques and hazard mitigation. While pinpointing precise accident causes remains challenging, new data analysis and knowledge discovery methods can aid in this endeavor.

Highway work zones present a multitude of safety hazards, resulting in injuries and fatalities, with struck-by accidents, falls, caught-in/between incidents, and electrical shocks being primary concerns. Worker-vehicle collisions within work zones highlight the importance of preventative measures, such as proximity detection systems. Vehicular accidents, especially during flagging work, are aggravated by high-speed traffic, and on-site accidents involving construction vehicles are prevalent. Falls, often attributed to safety screening misplacement, remain a critical issue. Addressing less common safety concerns and investigating physiological-related injuries like heat exhaustion and fatigue are equally vital. Effectively implementing safety measures is crucial for safeguarding personnel in these challenging environments.

Understanding the causes of accidents in highway construction is essential for improving safety protocols. Various theories categorize contributing factors, encompassing technical, human, and organizational variables, unsafe equipment, jobsite conditions, unsafe methods, and management failures. In highway construction, the risk is exacerbated by unsafe equipment, such as earthmoving machinery, and factors like proximity, misuse, and faulty equipment. Visibility-related issues, such as inadequate lighting and visual obstructions, significantly contribute to fatalities. Human elements, encompassing awareness, error, training, and management failures, play pivotal roles, with common causes including misjudgment and improper equipment choices. Detecting blind spots in construction equipment operations is vital due to limited visibility, while vision-related fatalities often result from glare and a lack of awareness, highlighting the need for comprehensive safety measures. Overall, accident causation in construction is influenced by cognitive abilities, awareness, concentration, and undetected blind spots, underscoring the importance of holistic safety strategies.

Furthermore, effectively utilizing the wealth of textual information within accident databases is paramount. This task report introduces an innovative approach, leveraging LLMs to comprehensively analyze such databases. By surpassing the limitations of conventional statistical methods, this approach offers valuable insights into the causes, characteristics, and outcomes of accidents, ultimately enhancing our understanding of safety incidents in highway construction and paving the way for improved prevention and intervention techniques.

Deeper investigation and efforts to improve the quality of narratives within safety databases may provide more accurate and higher-quality results of major causes in future data-driven analysis. These efforts could involve refining data collection procedures, encouraging more detailed incident reporting, and enhancing the comprehensiveness of narratives to ensure that crucial contextual information is captured. Such improvements in data quality can significantly benefit the accuracy and reliability of safety assessments, leading to more effective safety measures and strategies in the highway construction industry.

In conclusion, this study advocates for the development and deployment of the AI Safety Officer Assistant to address the pressing safety issues in the highway construction industry. This innovation leverages advanced AI and LLM technology to provide actionable insights and automation capabilities that current practices cannot achieve. It is economically feasible, aligns with the goals of transportation agencies, and promises substantial benefits, making it a compelling solution for enhancing safety in highway construction.

Section 3: Appendices

IRISE

Identifying Major Causes of Construction Accidents

Appendix A: Comprehensive Literature Review

1. Introduction

This document reports activities performed for the first task of the project entitled "Identifying Major Causes of Construction Accidents". The main objective of this task was to present a literature review regarding the current status of accident prevention and causation in highway safety.

Construction industry work has been known to be one of the most dangerous occupations for a plethora of reasons. According to Zhou et al. (2019), the construction industry only employs about 7% of the world's labor force, yet it is accountable for 30-40% of the total fatalities reported in any industry. Due to the high frequency of accidents that occur in construction, further research and development in jobsite safety must be conducted to improve current practices. Any loss of life is tragic and this level of fatalities during pavement construction is unallowable. Action needs to be taken to save the lives of construction workers, reduce the hazards of this career, and remove the potential trauma from workers and their families.

Safety has been a topic of research in construction for a long time in an effort to reduce injuries and death. However, there has been limited research on highway construction safety specifically and despite efforts to improve practices, it continues to be considered one of the most dangerous fields.

The following report provides a summary of accident characteristics, current practices, and past and new technologies in construction safety. The findings of this technical review will provide an understanding of safety in a highway work zone and the potential gaps in research related to safety practices.

2. Accident Characteristics

In order to properly introduce methods of improving occupational health and safety and advocate for the improvement of preventative measures within the construction industry, a more detailed description of all elements encapsulated in an accident is pertinent.

It is paradoxical to understand how to prevent an accident from occurring without having a foundation of understanding the potential hazards that cause an accident. An accident is described by the type, cause, and result. To effectively review accidents that have occurred or will occur, a detailed description of the accident result and a well-developed accident causation model may provide useful insights in the prevention of future accidents.

2.1 Types of Accidents

Currently the U.S. Occupational Safety and Health Administration classifies the type of fatal accidents into four categories: falling, struck-by, electric shock, and caught in/between, (Bureau of Labor Statistics 2013). These categories allow for the classification of fatal accidents in terms of reporting; however, they limit an analysis of existing data to broad categories. Each category is broad, and it can be difficult to understand effective preventative measures without more important details about the accident. For example, an OSHA incident report shows a worker who was injured from being struck by a flying object. This example offers minimal facts about the accident and fails to provide specific details about how the accident occurred, making it harder to prevent similar accidents in the future.

Table 4: Accident type and brief description

Accident Type	Description
Struck-by	A contact collision between a worker and other moving or stationary objects. Some examples include being struck by falling objects, getting hit by a vehicle, or being hit by other equipment or tools on site.
Falls	Workers are at risk when performing work on elevated surfaces. It can be a result of insufficient fall protection equipment, lack of leading edge delineation, among others.
Electric Shock	An accident in which a worker is physically injured in the form of contact with high voltage carrying devices.
Caught In/Between	Situation in which a worker is immobilized due to being positioned within a "pinch point" or for example other areas such as confined spaces with cave-ins.
Other	Other accidents that may occur on a construction site were not mentioned as most common in OSHA. For example: proximity to hazardous materials, fatigue illness, heat exhaustion (environmental), etc.

In the focus of highway construction, there are additional types of accidents that can result in fatalities that were found based on existing research pertaining to construction safety and prevention. Table 4 provides an overview of accident types found on a construction site, a majority of which are identified by OSHA, and it includes a brief description of each accident type. The addition of on/off-site vehicular/traffic accidents and heavy equipment accidents was necessary in this literature review due to the high frequency of occurrences on highway construction projects. The various types of accidents identified were reviewed as a part of this literature review and serve to provide foundation to identify potential causes and preventative measures necessary to mitigate worker's risk. Figure 6 shows a distribution of the most common accidents to occur.

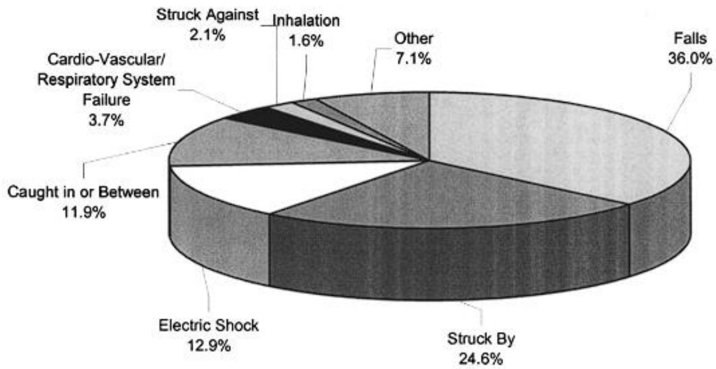

Figure 6: Type of construction injuries 1997-2000 (Hinze, Huang, & Terry, 2005)

2.1.1 Struck-by

Struck by accidents have been a major cause of fatalities in the construction industry. In many cases, accidents involving heavy construction equipment internally in a work zone are as hazardous as accidents caused by traffic moving through highway construction projects. There has been a significant amount of studies recently involving the nature of struck by accidents in construction. Pratt et al. (2001) reviewed historical data reported by the Census of Fatal Occupational Injuries (CFOI) between 1992 and 1998. This report showed that out of 465 vehicle and equipment related fatalities, 318 of them involved collision of an on-foot worker with a vehicle. Of the reported struck by injuries, 51% occurred within the work zone rather than exposure to moving traffic outside of the work zone (Pratt, Fosbroke, & Marsh, 2001).

The common conception from industry personnel is workers are more likely to get involved in a fatal accident due to moving traffic, however many studies have found that many fatalities still occur within the confines of a work zone (Bryden & Andrew, 1999). Hinze et al. (2005) showed from OSHA's IMIS database (from 1980, 1985, and 1990) that 70% of fatal struck-by accidents were reported as follows "Struck by a falling object; struck by a crane, boom, or load;

struck by a trench cave in; and workers being run over by heavy equipment or private vehicles" (Hinze, Huang, & Terry, 2005). Hinze et al. (2011) also provided some insight on other types of struck-by accidents that do not involve moving equipment (e.g., workers being hit by material being lowered) (Hinze & Teizer, 2011).

More recent studies, which include updated data, still report similar findings in struck-by accidents despite improvements in safety mechanisms. According to the Bureau of Labor Statistics (BLS) of 818 reported fatalities, 18% were a result of an on-site heavy vehicle struck by collisions with workers (Marks & Teizer, 2013). Kim et al. (2019) studied remote proximity monitoring and highlighted that struck-by fatalities increased by 34% from 2010 to 2015. This is more than twice as much as all other industries combined (Kim, Liu, Lee, & Kamat, 2019). There is a need for more research and investment in preventative measures such as proximity detection to reduce the number of injuries and accidents as a result of struck by incidents. Further investigation in the causation models of on-site struck-by accidents may improve future prevention effectiveness.

2.1.1.1 Traffic Vehicular

Highway workers are in areas where vehicles travel at high speeds, which inherently contains associated risks and injuries with any work activity. This type of accident is specifically dangerous for flagging work, repairing the roadway, or setting up traffic control devices (TCDs) where a worker must be placed in very close proximity to the moving vehicles. These types of accidents only make up approximately half of the vehicle-related fatalities. It was found that of reported traffic vehicular accidents, 43% were caused by passing cars and 47% were caused by passing trucks as shown in Figure 7 (Pratt, Fosbroke, & Marsh, 2001).

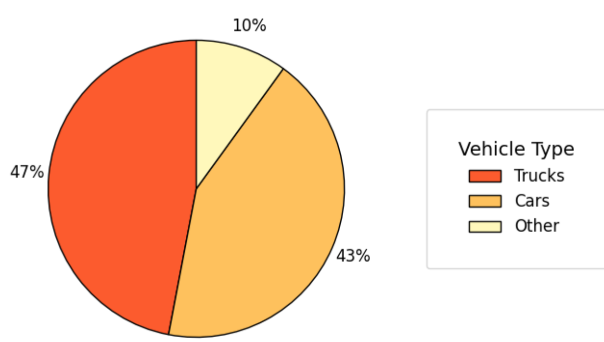

Figure 7: Traffic accident by vehicle type (Pratt, Fosbroke, & Marsh, 2001)

2.1.1.2 On-Site Vehicular and Equipment (Heavy Vehicle)

A majority of struck-by accidents are within the proximity of the work zone, away from high-speed traffic, due to contact collisions with private construction vehicles and heavy construction earthmoving equipment (such as backhoes, bulldozers, excavators, and scrapers). Existing research focused on reducing accidents involved with highway vehicular traffic, whereas few recent studies have sought to investigate visibility related fatalities with construction equipment (Ferreira, Kumar, & Abraham, 2017).

Hinze and Teizer (2011) further dissected OSHA reported accidents involving on-site equipment and workers. The data shown in Figure 8 relate the percentage of equipment accidents to the type of accident. Struck-by equipment or vehicle in the work-zone is a leading cause of accidents related to equipment (Hinze & Teizer, 2011).

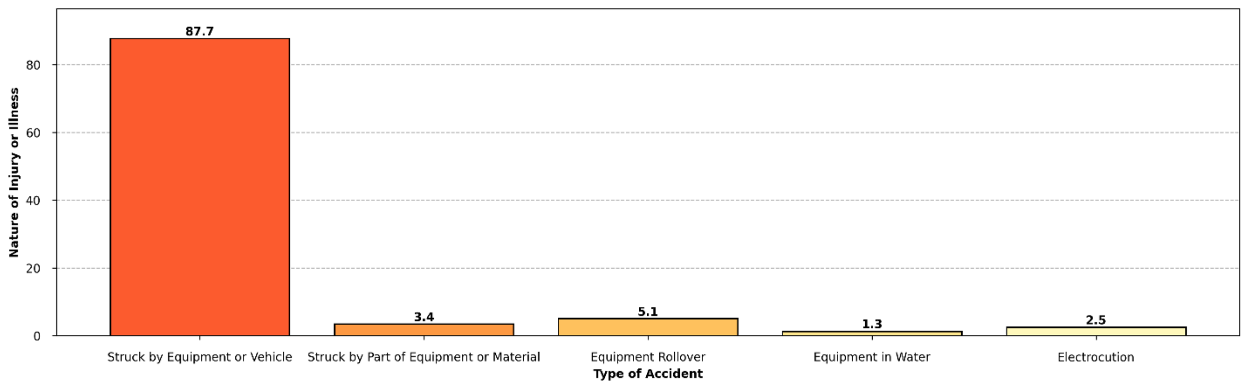

Figure 8: Percent of equipment accidents vs. type of accident (Hinze & Teizer, 2011)

Many preventative systems used to alert workers and operators of potential collisions such as back-up alarms, sensors, and cameras have been implemented in modern equipment to assist the driver in a lack of visibility situations. Some researchers studied the effectiveness of these preventative systems. In many cases where an accident occurred, these systems were either completely out of service or malfunctioning. According to Kazan and Usmen (2018), in roughly 19% of reported cases the protective systems were not working properly and in 15% there were no systems installed (Kazan & Usmen, 2018). Additionally, the travel direction of a vehicle can affect the chance of an accident occurring. In Hinze and Teizer (2011), of 431 visibility related cases, vehicles travelling in reverse resulted in almost four times as many fatalities as those travelling in the forward direction as demonstrated in Figure 9 (Hinze & Teizer, 2011). Having functioning back up alarms and sensors may provide both the worker and operator with sufficient warning and allow for the prevention of an accident before it occurs.

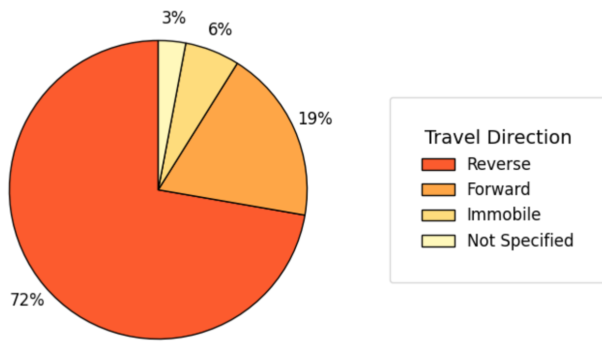

Figure 9: Percent of fatalities based on vehicle travel direction (Hinze & Teizer, 2011)

According to Hinze, Huang, and Terry (2005), private vehicles were involved in a majority of reported struck by accidents and over 90% were fatal (Hinze, Huang, & Terry, 2005). In addition to having functioning warning systems implemented in heavy vehicles, it may also be necessary to implement on site traffic control devices – akin to those found on highway construction projects.

2.1.2 Falls

When compared to all other industries, 51% of reported falls in the United States are in the construction industry (Eusebio, 2020). This statistic is misleading in the highway construction sector and is more applicable to construction that involves elevated heights (e.g., building construction or reconstruction). In highway construction, workers are typically at an elevated surface, with the exception of bridge construction, yet falling accidents have drawn the focus of many researchers.

There have been efforts to automate the detection of hazardous activities that could result in a falling accident. Detecting activities that have elevated risks such as identifying worker location, suggesting preventative planning, and the automation of guardrail installation can be performed automatically with an algorithm. In many cases the lack of more detailed hazard identification and misplacement of safety screening and scaffolding is a significant factor in workers involved in falling from height accidents (Guo, Li, & Li, 2013).

2.1.3 Electric Shock, Caught-In/Between and Other

The other categories highlighted by OSHA (electric shock, caught-in/between, and other) were not found to be the leading cause of accidents in highway construction. A further investigation of these accident types may provide useful insight on possible preventative measures. The literature also lacked a deep analysis of any physiological related injuries such as heat exhaustion or fatigue that could be identified in the review literature.

2.2 Result of Accidents

Although the construction industry has significantly improved upon their safety methods, the overall number of fatalities has not reached the goal of net zero. Avoiding injuries of any caliber does not only save lives and improve productivity, but it also significantly lowers any associated costs. Additional costs accrued from illnesses, injuries, and fatalities account for nearly 91% of total medical costs (Kim, Ryoo, Kim, & Huh, 2013). This expense could be minimized if there was more investment in accident prevention during project development.

An accident will result in a non-fatal injury/illness, a fatal injury/illness, or potentially a near miss incident. From a review of the IMIS database provided by OSHA, it was reported that 66% of the cases could have been prevented based on suggested preventative measures documented by the authors. Also from this review, OSHA safety offices agreed that compliance with OSHA standards could have prevented an additional 60% of reported accidents (Hinze, Huang, & Terry, 2005). The lack of conformity to OSHA standards and clear indication of possible preventative techniques proves that more rigorous pre-injury hazard detection will reduce the number of fatalities within a highway construction site.

2.2.1 Non-Fatal and Fatal Injuries/Illnesses

According to an OSHA report of data collected between 1985 and 1988, the percent of fatalities in the construction industry, based on accident type, are shown in Figure 10 (Hinze, Huang, & Terry, 2005).

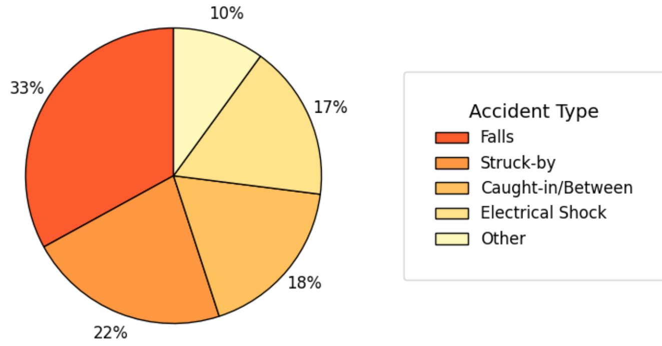

Figure 10: Construction fatalities by accident type (Hinze, Huang, & Terry, 2005)

This figure also shows the overall spread of fatal accidents per each OSHA derived category. In highway construction, the falls category is not fully applicable to regular pavement construction or rehabilitation (due to the lack of activities performed at elevated heights). Struck-by accidents are the second largest contributor to construction fatalities followed by the other prescribed accident types. This data can be useful in the future prevention of fatalities and other construction injuries and illnesses. It motivates researchers to focus on broad types of accidents, however more detailed research may be required per accident category to determine leading indicators in highway construction projects. Further investigation of OSHA's IMIS database suggested other major causes of construction fatalities were related to equipment and on-foot worker contact collisions and caught-in/between accidents (Teizer, Allread, Fullerton, & Hinze, 2010).

2.2.2 Near-Miss Incidents

A near-miss incident occurs when an accident does not result in an injury or illness, which means an incident was close to a failure but was avoided (Zhou, Li, Mi, & Qian, 2019). Many recent studies conclude that gathering more information about near-miss incidents may be beneficial in the prevention of serious injuries.

In a study conducted by Zhou et al. (2019), the researchers suggest that the only difference between a near-miss, and an accident is the consequence due to opportunity factors whereas they both have similar root causation models (Zhou, Li, Mi, & Qian, 2019). The ability for construction management to gather and use information about near-misses may procure an overall lower accident rate and promote more effective safety efforts.

2.3 Cause of Accidents

It is not always trivial to identify the cause of an accident. Since a construction site constitutes dynamic moving parts and some events occur strictly due to randomness, there is always an uncertainty in the cause of an accident. There have been some developments in identifying the causation of accidents that include the categorization of factors that can contribute to an accident.

For example, Kazan and Usmen (2018) proposed a new method of forming accident causation theories by considering accident causes according to contributing factors and devised three main categories for classification: technical, human, and organizational variables. Additionally, in their study they built upon a fishbone model presented by Hamid, Majid, and Singh (2008), which include six factor categories: unsafe equipment, jobsite conditions, unique nature of the industry, unsafe methods, human elements, and management failures (Kazan & Usmen, 2018). A study conducted by Toole (2002) suggested additional factors that contribute to the occurrence of accidents such as: lack of proper training, deficiencies in the enforcement of safety, personal protective equipment (PPE) not being provided, unsafe methods in sequencing, among a few others (Irizarry, Gheisari, & Walker, 2012).

Categorizing and isolating more specific factors that cause accidents on a construction site will help safety organizations devise more improved safety training procedures and methods. Having a more refined accident causation model promotes the improvement of jobsite safety. In the context of the literature reviewed for this project, the following sections summarize the most significant causes of accidents within a construction site. These categories can be general but serve the purpose of being elaborated on in future studies that seek to improve accident causation models in highway construction projects.

2.3.1 Unsafe Equipment

2.3.1.1 Equipment Type

The type of equipment used in highway construction plays a role in the frequency of accidents and the outcome or severity of an accident. Due to the nature of highway construction and reconstruction, many activities include earthmoving equipment to prepare the site. The four most common types of earthmoving equipment are the backhoe, bulldozer, excavator, and scraper. It was found that a majority of earthmoving equipment accidents will result in a fatal condition, with the highest frequency of fatalities when the backhoe is involved in the scope of work (Kazan & Usmen, 2018). Of the investigated types of equipment, the dump truck results in the most frequent number of fatalities – shown in Figure 11 (Hinze & Teizer, 2011).

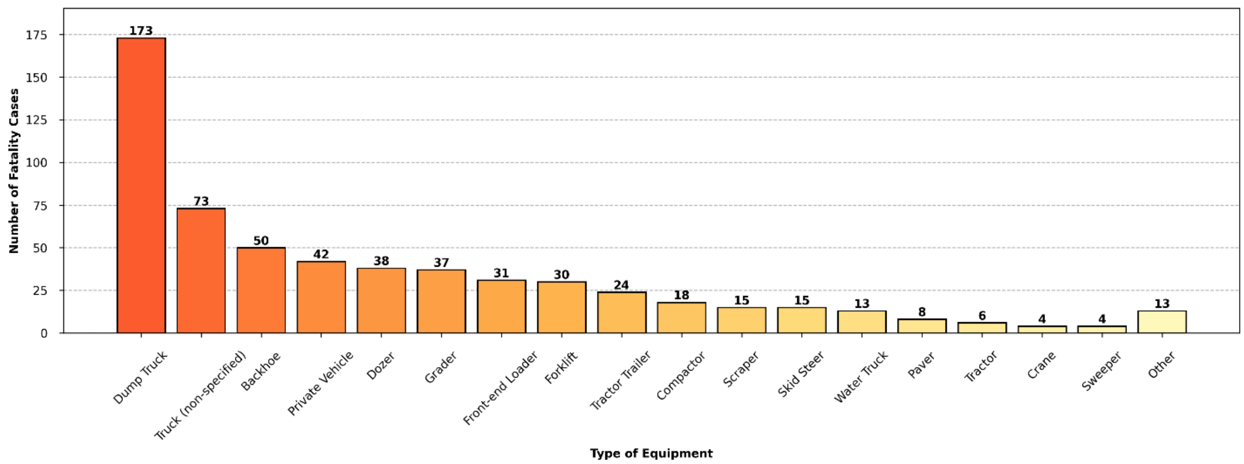

Figure 11: Number of fatal cases by equipment type (Hinze & Teizer, 2011)

2.3.1.2 Proximity of Worker to Equipment and Vehicles

Workers are in close proximity to highway vehicular traffic, internal jobsite vehicular traffic, and heavy equipment operation which poses a high risk of contact collisions and struck-by accidents that often lead to fatalities. While Teizer et al. (2010) studied the automation of blind spot measurement of construction equipment, their findings showed that there has not been much improvement of the prevention of contact collision fatalities in the industry. This study mentions how even though there has been an extensive amount of research efforts in proximity detection, injury statistics still show that proximity related accidents remain one of the most prevalent causes of accidents in the industry (Teizer, Allread, & Mantripragada, 2010). Another study to assess proximity detection and alert technologies in construction equipment operation conducted by Marks et al. (2013) suggests similar findings on the lack of effectiveness of the current proximity detection methods (Marks & Teizer, 2013).

2.3.1.3 Equipment Misuse

Since equipment typically requires the use of a human operator, improper usage of equipment is a product of human nature. Seatbelts are an example of a commonly misused safety device in human operated vehicles and heavy equipment. The act of fastening seatbelts reduces the operator's chance of accident during rollover and overturing during operation (Kazan & Usmen, 2018). While seat belt usage is an important exposure for an operator, it has no relation to reducing accidents that could include on-foot workers.

2.3.1.4 Faulty Equipment

If various types of equipment used on a construction site are not inspected on a regular basis, future accidents that could have been avoided may be more prevalent. From a study of visibility-related fatalities with construction equipment, it was found that 56 out of 69 cases of struck-by vehicle/equipment related cases involved a back-up alarm that was either broken or malfunctioning (Hinze and Teizer (2011)). This study also found five cases where it was reported that the back-up alarm was not heard due to other noises.

The effectiveness of a functioning back-up alarm is also dependent on other pieces of equipment operating in the area, which potentially can drown out the alarm (Hinze & Teizer, 2011). Kazan and Usmen (2018) found similar results in their study of worker safety related to earthmoving equipment accidents. In approximately 56% of the struck-by equipment cases observed, a functioning back-up alarm failed to alert workers while travelling in the reverse direction (Kazan & Usmen, 2018).

2.3.2 Jobsite Conditions

2.3.2.1 Noise

Due to the proximity of highway construction projects to other highways, the loud sounds generated by the usage of heavy equipment, and other contributions from regular operations it can be difficult for workers to hear alerts from other workers/systems that would potentially remove them from a dangerous scenario. Kim et al. (2016) discussed a study conducted by Fernandez et al. (2009) where the typical level of noise can be greater than 85 dBA in a construction zone. These large magnitudes of sound require the usage of hearing-protection devices that could also lead to the reduction of worker awareness (Kim, Kim, & Kim, 2016). The large generation of sounds within the construction environment could result in a situation where a worker does not have an adequate perception of warning sounds – ultimately increasing the frequency of accidents.

2.3.2.2 Visibility

Of the factors that influence the cause of accidents, visibility related accidents have been studied in many recent research papers to assess the implementation of back up cameras and sensors. Hinze and Teizer (2011), investigated OSHA's reported visibility related accidents. The lack of visibility that vehicle and equipment operators may encounter significantly impacts safety on a jobsite, accounting for 5% of fatalities in the construction industry from 1990 to 2007 (Hinze & Teizer, 2011). Table 5 shows visibility-related accident factors identified in that study.

Table 5: Visibility-related accident factors

Factor	Description
Excessive Lighting	Too much lighting can cause the operators visible range out of vehicle/equipment cabin to be limited. This is typically a problem during daytime operations.
Insufficient Lighting	It is hard to see objects/personnel without sufficient amount of light (even with the use of proper reflective PPE). This factor is more common during nighttime operations.
Visual Obstruction	Any object that is blocking an operator's field of view.
Blind Spots	Certain areas of an operator's field of view where the operator does not have any view of obstructions or personnel. Blind spots are unique to the equipment/vehicle that is being used and often times cannot be treated.

Excessive or insufficient lighting both can increase the chance of accident occurrences. Of the devised factors, blind spots and obstruction were the most prominent cause of vision related fatalities – accounting for 56.1% and 23.2% of all construction fatalities as show in Figure 12 (Hinze & Teizer, 2011).

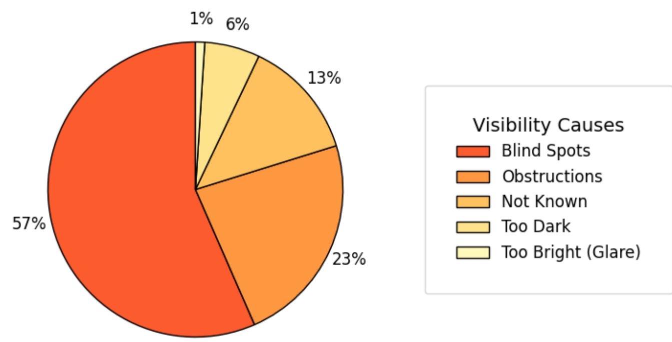

Figure 12: Visibility-related cause of accidents (Hinze & Teizer, 2011)

Sensors and back-up cameras sought to combat common blind spots on vehicles. Some excavators have significantly large blind spots, some of which obstruct 50% of the field of view (Hinze & Teizer, 2011). Contrary to the traditional procedure of reporting these types of accidents as struck-by accidents, Hinze and Teizer suggest these types of accidents should be classified as vision impairments due to their dominance in the cause of fatalities within the construction industry.

2.3.2.3 Weather and Temperature

Environmental factors, such as weather and temperature, have had limited investigations in the literature reviewed. Kim et al. (2013) further investigated weather as part of their study of major accident factors in a case study of highway construction on a project in Korea. The results of this study indicated weather and temperature does not directly affect the occurrence of accidents, but still must be included when considering its impact on workers psychological and physiological contributions to jobsite safety (Kim, Ryoo, Kim, & Huh, 2013).

2.3.2.4 Time

The time of day contributes to the frequency of other types of accidents occurring. This is prevalent in the various types of vision related accidents (i.e., the excessive illumination during high sun or the lack of illumination during the nighttime). Figure 13 depicts vision related fatalities with the corresponding time of day they were reported.

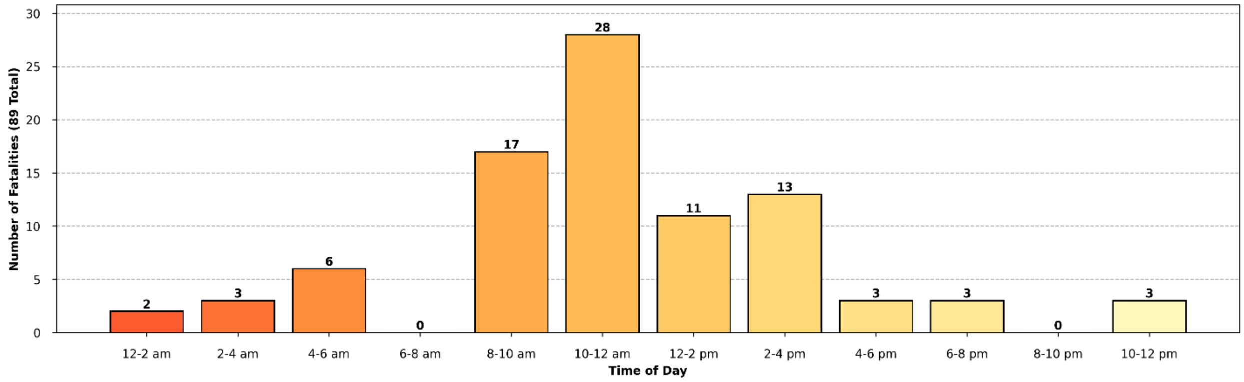

Figure 13: Number of vision-related fatalities at various times (Hinze & Teizer, 2011)

The data from this study shows that from 10:00 A.M. to 12:00 A.M. resulted in the greatest number of fatalities (Hinze & Teizer, 2011). An additional study by Hinze et al. (2005) on the nature of struck-by accidents using OSHA data from 1997 to 2000 resulted in the highest frequency of struck-by fatalities at both 9:00 A.M. and 1:00 P.M. as shown in Figure 14 (Hinze, Huang, & Terry, 2005). Although these studies included data from different years, there is a consensus that more accidents occur during peak hours of construction.

The time of year and day of the week also have an influence on the frequency of accidents. A study concluded that October had the highest frequency of accidents as shown in Figure 15 (Hinze et al. (2005)). Another study suggested specific days of the week are safer for construction (Kim, Ryoo, Kim, & Huh, 2013). Accident frequency is correlated to accident time based on the results discussed in this section, however improving this factor may require additional study.

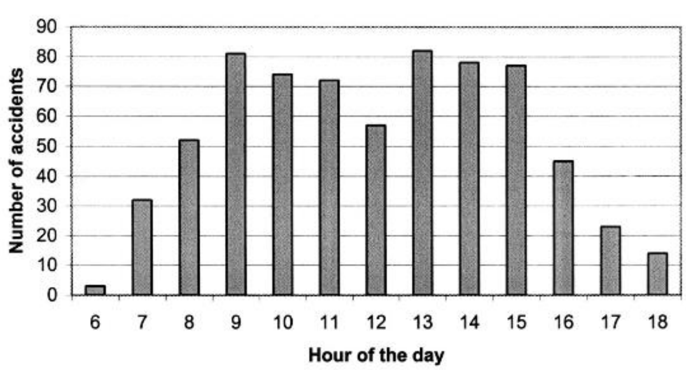

Figure 14: Number of struck-by accidents by hour of the day (Hinze, Huang, & Terry, 2005)

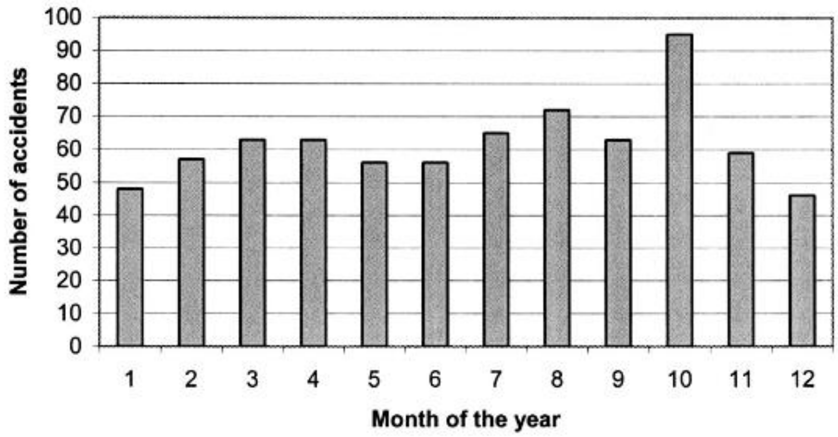

Figure 15: Number of struck-by accidents by month of the year (Hinze, Huang, & Terry, 2005)

2.3.2.5 Crowdedness

A construction site typically consists of many moving parts and is a conglomerate of on-foot workers, heavy equipment, vehicles, materials, waste, among many other objects. When the matrix of these objects is confined to limited work zone spaces, a site can become a very crowded space. When considering a worker's proximity to all of the other objects present on a jobsite the more tightly packed objects are together, the harder it may be for workers to navigate around the site. The crowdedness of the site directly impacts the frequency of proximity related accidents.

Kim et al. (2016) assessed the crowdedness of a jobsite by defining a variable to describe the level of crowdedness in a defined area of a work zone: in this case it is the number of workers and of pieces of objects within 18 m of each other (Kim, Kim, & Kim, 2016). This research convoluted to the idea that noise is also correlated with the crowdedness of a jobsite. The more crowded the activity, the louder a jobsite may become. The increased crowdedness and level of noise negatively influences a worker's ability to recognize where equipment is located – ultimately lowering the worker's awareness and increasing the frequency of accidents (Kim, Kim, & Kim, 2016).

2.3.2.6 Nature of the Construction Industry

The construction industry innately has higher health and safety risks associated with work activities in comparison to some other industries. The high-risk nature of construction is a biproduct of the external environmental factors (such as weather and temperature), the associated hazardous chemicals and wastes, the dangerous heavy equipment, among many other factors. It is also complex, dynamic, and unpredictable which leads to a higher order of error in some of the related tasks (Zhou, Li, Mi, & Qian, 2019). There is a general consensus that the chaotic and dynamic environment of construction, in conjunction with the large number of activities that take place, pose high risk to any personnel working in the work zone – as mentioned in many of the articles as reviewed in this study (Awolusi, Marks, & Hallowell, 2018), (Zhu, et al., 2016), (Zhou, Li, Mi, & Qian, 2019).

2.3.3 Unsafe Methods

Unsafe methods in highway construction may contribute to the high percentage of fatalities in the industry. In the current review there was limited information that addressed this potential cause of accidents – further investigation and research may be required to identify major contributions. The unsafe methods category must have more available data on the work activities that are specific to highway construction activities and their associated risks. Some of the information that may be investigated are as follows:

- Activity type and equipment involved
- Hazards to due to a specific work activity
- Lack of activity specific hazard prevention
- Level of exposure of hazards to a worker during the activity

2.3.4 Human Elements

2.3.4.1 Lack of Awareness

A worker is subjected to many external distractions and hazards during typical daily endeavors within the jobsite. In efforts to build a safer work zone, Pratt et al (2001) studied measures and methods used to prevent worker injuries on highways. This study mentioned how the common involvement of repetitive tasks that construction workers participate in may lead to a decreased overall awareness. Additionally, external environmental factors can lead to workers to lose focus and awareness during their tasks (Pratt, Fosbroke, & Marsh, 2001). Teizer et al. 2010 also contributed to the concept of lack of awareness due to fatigue and task repetition (Teizer, Allread, Fullerton, & Hinze, 2010).

2.3.4.2 Human Error

Due to the primary involvement of personnel responsible for executing the activities of highway construction, human error must be accounted for in analyzing construction safety information. Chae and Yoshida (2010) deduced that safety management can be improved with the evaluation of human error since it has been shown to be a major contributor to accidents (Chae & Yoshida, 2010). Humans require 0.2 to 2.4 seconds of reaction time in a dangerous situation . Many hazardous incidents may occur in this human reaction time which makes it significantly more important to have systems that respond quicker or shut down before an incident could occur.

2.3.4.3 Worker Demographic

Many researchers attempt to categorize fatal incidents in the construction industry by the demographic of those involved. A study from Kazan and Usmen (2018) indicated there was a higher frequency of accidents in victims that were non-union. In their analysis of the OSHA IMIS database 76.6 % of victims involved in accidents were non-union workers. It also appeared that non-union workers had a higher fatality frequency of 55% of recorded fatalities (out of a total of 919 non-union workers from the database) (Kazan & Usmen, 2018).

These results provide insight into the type of worker that has a higher probability of being involved in a fatal accident. However, it is important to note that according to the Bureau of Labor and Statistics (BLS) there are more non-union workers on a construction site than union workers. From this finding it may be important for safety management to provide additional training to non-union workers since they may not receive as much training. Non-union workers may have a higher frequency of accidents because there are typically more of them found on a jobsite, which may require additional analysis.

In addition to this classification, further study on the age of a worker can impact the likelihood of an accident. The nature of struck-by accidents the distribution of frequency of injuries/fatalities by age is shown in Figure 16 (Hinze et al. (2005)).

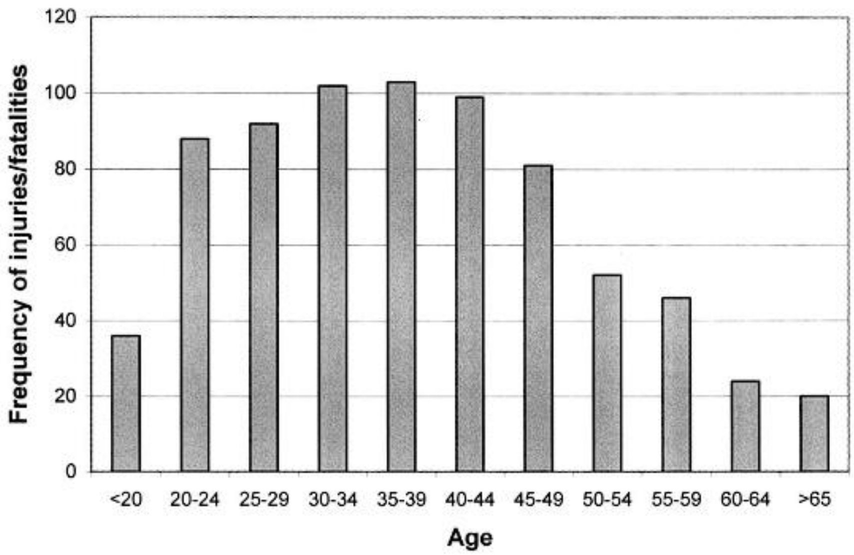

Figure 16: Frequency of struck-by accidents by age (Hinze, Huang, & Terry, 2005)

From this distribution, it is shown that workers within the age of 30 to 44 have a higher frequency of injuries/fatalities than others. This finding indicates that middle aged workers are more likely to be involved in an accident, which may lead to younger and older workers to be more precocious in their activities. Workers who are within the range of higher frequency accidents may have had less recent training which could accompany the higher frequency of incidents, yet more research is required to make any significant conclusions.

2.3.5 Management Failures

2.3.5.1 High Productivity Expectations

The construction industry intrinsically procures strict deadlines and limits the durations of activities to maintain profitability – which will lead to the overall expectation of workers to complete tasks at high productivity rates. Ferreira et al. (2017) comments on these high expectations and discusses how the workers are expected to meet these expectations while staying alert to other environmental factors such as traffic and heavy equipment – which is not a trivial task when considering a workers fatigue and the effects of human error in awareness and focus (Ferreira, Kumar, & Abraham, 2017). Similarly, Teizer and Cheng (2015) commented on the need of workers to meet construction schedules amidst being in close proximity to many jobsites hazardous conditions (Teizer & Cheng, 2015). Many firms will have to assess their implementation of safety in scheduling and production to improve the overall performance of preventative measures and reduce the number of injuries.

2.3.5.2 Incorrect Placement and Inspection of Safety Devices

The lack of quality checking and assurance of the placement of safety devices, such as safety screens or scaffolding, can lead to unforeseen incidents that could have been prevented otherwise. For example, when safety screening is used in fall protection, incorrectly placing the screen could be the cause of a potential fall accident. However, it can be arduous for safety officers and project managers to assure that the correct placement of these devices is feasible at the design stage of a construction project (Guo, Li, & Li, 2013). Along with incorrect placement, the inspection of safety devices can also lead to overseen yet preventable injuries.

2.3.5.3 Lack of Proper Education/Training

A study found that 45.4% of reported OSHA cases the workers were not provided with adequate safety training and/or workers were working out of compliance with safety regulations (Kazan & Usmen, 2018). The lack of proper education and/or training has contributed to the increase in frequency of fatalities in the construction industry. Marks and Teizer (2013) elaborated on this issue and also found that some workers and equipment operators were subjected the following conditions:

- Outdated policies
- Policies that were never implemented
- Lack of knowledge of activity specific hazards

These conditions contribute to the concept that some management on a construction site have not or only partially included the proper training and education in their organization. In many cases activity specific training and education is not adequately provided for, which increases the potential for workers to be operating in hazardous conditions without understanding all of the associated risks.

2.3.5.4 Additional Contributions to Management Failures

Some other aspects of management failures have not been fully addressed in the reviewed literature. These can include topics such as infeasible construction sequences and insufficient traffic control. An infeasible construction sequence, procured at early stages of the design, may lead to overlooked potential hazards. Additionally, insufficient traffic control (or traffic control devices) automatically imposes more threat to workers subjected to working closely to heavy traffic on a highway.

3. Current Status of Accident Prevention in Highway Safety

Although improvements to jobsite safety have been prevalent in the construction industry as a whole, the number of fatalities in the industry are still significantly higher compared to other industries with high risk activities (such as the mining industry). An assessment of the current safety mechanisms of construction provides insight into features that could be used for improvement, and this improvement begins with additional research and development.

Previous studies do not isolate highway construction from the entire industry which may be why fatality reduction or accident prevention has remained relatively stagnant (Kim, Ryoo, Kim, & Huh, 2013). Having sufficient research in the entire construction industry will benefit safety mechanisms, however these findings do not necessarily contribute to site specific tasks found on highway construction projects. Current research has focused on the identification of accident types in hopes to improve the planning phase, but it is thus far limited. Furthermore, existing research overlooks correlations between accident causation models including environmental factors and other factors that can be extracted from existing accident data (Kim, Ryoo, Kim, & Huh, 2013). Additional research provided more information about existing organizations, practices, and technologies being used in the construction industry as discussed in the following sections.

3.1 Regulatory Organizations and Regulations

The following organizations have influenced the enforcement of safety management practices and methodology in the industry (among others):

- The Occupational Safety and Health Administration (OSHA)
- The National Institute for Occupational Health and Safety (NIOSH)
- The Federal Highway Administration (FHWA)

These organizations have restrictions and regulations in place for accidents and accident prevention, and yet there are some limitations or gaps in their effectiveness and enforceability. Overall compliance with such regulations is important but in some cases the regulations established do not provide comprehensive guidance for workers to follow (Pratt, Fosbroke, & Marsh, 2001). In an effort to identify potential gaps in these regulations, the NIOSH reviewed fatality/injury data along with current and existing research in safety (Pratt, Fosbroke, & Marsh, 2001). An example of one of these gaps include the lack of federal or state statutes that require equipment operators (other than crane operators) to be certified by a recognized body (Kazan & Usmen, 2018). Nonetheless, each organization recognized in this review has managed to provide useful documentation and resources accessible to industry personnel.

3.1.1 OSHA

Many researchers have used the OSHA Integrated Management Information System (IMIS) enforcement database to conduct deeper research into finding connections and correlations between accident causes and injury occurrences. This tool has been proven useful in many cases, but still lacks detailed descriptions of the exact type of accident and specific factors that may have led to a fatal accident.

Other than the IMIS database, OSHA provides many standards and safety regulations that are essential guidelines for safety in the construction industry with the exception of some grey area where the regulations do not provide specific information for some activities. There are no standards or regulations established by OSHA to prevent contact collisions between workers and heavy equipment (Marks & Teizer, 2013). There has been no assessment of the adequacy of OSHA standards and compliance in the prevention of struck-by accidents (Hinze, Huang, & Terry, 2005).

OSHA has tried to address the operation of vehicles and heavy equipment in the construction industry. A majority of the related construction industry related regulations can be found in 29 CFR 1926. More specifically, motor vehicles and mechanized equipment regulations can be found in 29 CFR 1926 Subpart O. Within 1926 Subpart O, there is a lack of specific regulations that address the related hazards for site specific heavy equipment (Kazan & Usmen, 2018). OSHA 29 CFR 1926 Subpart O does provide various safety aspects for general equipment under various regulations (which are not specific to a certain type of equipment):

- 29 CFR 1926.600: Equipment
- 29 CFR 1926.601: Motor Vehicles
- 29 CFR 1926.602: Material Handling Equipment
- 29 CFR 1926.604: Site Clearing
- 29 CFR 1926.651: Specific Excavation Requirements

OSHA investigates any event that results in hospitalization or death to ensure that all fatal accidents are documented and eventually placed into the database for further statistical analysis (Kazan & Usmen, 2018). This ensures that every fatality is accounted for but does not necessarily represent all of the injuries and accidents that occur on a jobsite. Near-miss accidents are not required to be reported to OSHA by any law enforcement which allows a large amount of useful information on accidents to be discarded.

3.1.2 FHWA

The Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), developed by the FHWA, contains specifications temporary and permanent traffic devices commonly used in highway construction projects across the United States. There has not been any mention of the effectiveness of the MUTCD imposed devices in the literature reviewed. Nonetheless, it remains important that safety officers ensure that the MUTCD requirements are set in place and inspected on a regular basis. Additional safety measures may be improved and practiced in the field.

3.2 Existing Practices in Construction Safety

3.2.1 Accident Reporting

3.2.1.1 OSHA IMIS Database

One useful tool commonly used among safety officials in the industry is the database created by OSHA, also known as the Integrated Management Information System (IMIS). Some researchers have conducted studies relating to the usefulness of the IMIS database. Hinze et al. (2005) investigated the level of detail that is coded into the database and found that with the amount of useful information the database could provide, it still had limited information about what had actually occurred during the accident. Much of the information is provided in the form of a single paragraph abstract. It was also concluded that many abstracts were not written in a useful manner, which makes it difficult to understand the nature of an accident (Hinze, Huang, & Terry, 2005).

Kazan and Usmen (2018) also reviewed the database structure and noted that only a small fraction of nonfatal injuries was included. Ultimately this database has the potential to be a valuable resource for improving safety measures on a construction site, however more detailed information should be coded in every report. To enforce the effectiveness of the database each entry should include a description of work, classification of the accident, demographic of injured personnel, possible causes of accident, and any preventative measures pursued (Chae & Yoshida, 2010).

3.2.1.2 Near Miss Reporting

OSHA currently requires all injuries and fatalities be reported the instant they occur, however there is little to no guidance on reporting near miss incidents. In many cases a near miss will fail to be reported, and this is partially due to the idea that a construction worker is concerned about a penalty after reporting an incident. Unfortunately, a worker may not be familiar with the reporting process or believe that the reporting process is too complicated (Zhou, Li, Mi, & Qian, 2019). This leads to a huge discrepancy in the collection of useful near-miss data. Since near-miss information has the potential to improve the prevention of accidents, it could be very beneficial to document as many incidents as possible.

Cambraia et al. (2010) suggests integrating near-miss information into a system such as the OSHA IMIS database and additionally include information on unsafe act/conditions and any adaptations to safety methods during regular working conditions (Cambraia, Saurin, & Formoso, Identification, analysis and dissemination of information on near misses, 2010). In Korea, the Korean Occupational Safety and Health Administration (KOSHA) implemented an additional metric known as the injury-ratio assessment (IRA), which indicates both frequency and intensity of accidents (Kim, Kim, & Kim, 2016). Incorporating additional metrics akin to the IRA into future or existing accident reports could aid in later statistical analyses related to stored data on fatalities in the industry.

3.2.2 Education and Training

In many cases, improper education or training of construction workers can induce negative consequences with regards to jobsite safety performance. Few studies have been conducted to evaluate the current safety training programs and their effectiveness in practice. 45.4% of OSHA reported citations involved a worker who did not have adequate safety training, which originates in the lack of planning from higher management personnel (Kazan & Usmen, 2018). Site specific training programs typically resulted in better safety practices (Marks and Teizer (2013)).

Many companies are looking into implementing the "Design for Safety" concept, which could improve the lack of front-end planning failures (Marks & Teizer, 2013). Even though worker education is commonly used in the industry, the actual implication of its effectiveness is swayed due to the behaviors and attitudes of workers not being easily manageable (Kim, Kim, & Kim, 2016). The enforcement of training education and application may not be managed properly in the field setting, and this could pertain to another factor of the accident causation models.

Human unsafe behavior due to the lack of safety awareness or training has shown to affect the occurrence of accidents (Guo, Li, & Li, 2013). Another study conducted coincides with the conception of lack of training and how it could be correlated to workers being less capable of identifying and reacting to jobsite hazards (Li, Yi, Chi, Wang, & Chan, 2018). Even with a sufficient amount of training, workers may still have negative attitudes towards safety. In order to effectively improve safety training and education methods in the industry, a closer study on a construction worker will participate in training procedures may need to be conducted. Workers more effectively through informal means, such as communicating easier orally as opposed to written documentation and other educative procedures (Cambraia, Saurin, & Formoso, Identification, analysis and dissemination of information on near misses, 2010).

3.3 Existing Preventative Technologies and Measures

3.3.1 Manual Observation and Inspection

Safety managers are currently required to continuously monitor a construction site and identify potentially hazardous conditions as the standard of safety management, prevention, and inspection. The manual observation process is comprised of the following characteristics: frequency of observation, directness of observations, and direct interaction with workers (Irizarry et al. (2019)).

Frequent safety inspections are considered one of the current most important preventative measures to evaluate jobsite safety (Irizarry, Gheisari, & Walker, 2012). However, observations and inspections can be restrained if there are not enough safety personnel employed as they can be time consuming and labor intensive (Zhou, Irizarry, & Lu, 2018). Often times manual safety inspections and observations are performed randomly with minimal information and end up resulting in a biased assessment of safety risks (Teizer & Cheng, 2015). A review of the applied tactics in manual observation and inspection may be undertaken in future studies to evaluate their effectiveness.

3.3.2 Traffic Control Devices and Plans

In a general review of regulations regarding highway construction safety, Pratt et al. (2001) elaborates on the development of internal traffic control plans (ITCP's) used on highway construction sites. Prior to focus on ITCP's on site, a majority of the industry's concern was to minimize collisions between highway traffic motorists and workers that were in close proximity to this traffic (Pratt, Fosbroke, & Marsh, 2001). While this concern is still in effect, as many workers are subjected to this risk, additional investigations have been proceeded to develop more effective ITCP's to prevent internal vehicular and equipment related collisions.

3.3.3 Personal Protective Equipment (PPE)

The use of various types of personal protective equipment (PPE) are mandated by OSHA requirements and are dependent on the type of activity being performed. Although these devices have been effective in preventing certain injuries (i.e., hard hats reducing the impact of falling objects), these devices are still considered to be passive safety devices – meaning they do not provide real time hazard alerts to construction workers and equipment operators. One example of this could be shown through the use of high visibility safety vests. Regardless of the ability of a vehicle operator to see an on-foot worker with the proper PPE in a struck-by accident event, the worker is not provided with any generated warning to the potential of a proximity related collision. Additional information related to PPE can be found in the following literature: (Marks & Teizer, 2013; Teizer, Allread, Fullerton, & Hinze, 2010; Zhu, et al., 2016).

3.3.4 AFAD and Changeable Message Sign (CMS)

Many highway construction projects rely on the use of flaggers to redirect sections of traffic during road closure activities. Since these workers are subjected to a higher risk of contact with high-speed vehicular traffic, the use of Automated Flagger Assistance Devices (AFAD's) has been effectively improving safety in many applications. There are a number of studies that have investigated the usage of AFAD's in specific applications. Some of the studies alluded to conflicting views – mainly due to the fact that there were different control measures in place:

- A flagger and an AFAD
- A standalone AFAD
- An AFAD mounted to a TMA with a CMS
- An AFAD combined with a CMS

There is not a clear optimal safety design. A questionnaire was developed for drivers after they were subjected to the use of AFAD's in a work zone (Brown H. , 2017). It was found that approximately 67% of respondents believed that the AFAD was more effective and more understandable than the flagger alone. Furthermore, the vehicle approach speed was significantly reduced from 27.4 mph to 23.2 in the study (Brown H. , 2017).

In another study, it was suggested that not all drivers were completely able to understand some of the signals provided by the AFAD, however, they did not consider human flaggers (Debnath et al. (2017)). The American Traffic Safety Services Associates (ATSSA) acknowledge the use of AFAD's do not entirely remove the need for human flaggers and suggest that trained workers be available in case of device malfunction or driver intrusion (American Traffic Safety

Services Associates, 2012). Additionally, the ATTSA's enforce that AFAD's only be used when there is only one lane of traffic to be controlled, as they are not to be used as traffic control signals (American Traffic Safety Services Associates, 2012).

A Changeable Message Sign (CMS) has been used in conjunction with AFAD's and/or a Truck Mounted Attenuator (TMA) (Ferreira, Kumar, & Abraham, 2017; Brown, 2017; Qing, Zhang, Brown, & Sun, 2019). The TMA improves the safety of a flagger by removing a worker from the heavy traffic exposure (Brown H. , 2017). Qing et al. (2019) simulated the usage of the various configurations (standalone AFAD, AFAD with CMS, AFAD used in conjunction with TMA and CMS). The use of CMS improved full stop and first brake locations as well has the addition of TMA providing additional operator safety (Qing, Zhang, Brown, & Sun, 2019).

4. Innovation in Preventative Technologies and Methods

The construction industry has yet to employ more advanced information and communication technologies (ICT) relative to other labor-intensive industries (Zhou, Irizarry, & Lu, 2018). There has been some effort to improve the innovative techniques used within the field, however the industry remains significantly dangerous. An overview of various innovative technologies that can be applied to highway construction safety can be found in Table 6. They could be implemented into highway construction projects with additional research and development in each of these technologies.

Table 6: Overview of innovative technologies

Technology	Description	References
Computer Vision	The usage of computer aided vision systems that enable jobsite automation in proximity detection and hazard identification. This type of technology is often in the form of video cameras, LIDAR, and proximity detection and alert systems.	(Azhar, 2017), (Ferreira, Kumar, & Abraham, 2017), (Hinze & Teizer, 2011), (Kim, Liu, Lee, & Kamat, 2019), (Kim, Kim, & Kim, 2016), (Li, Yi, Chi, Wang, & Chan, 2018), (Marks & Teizer, 2013), (Teizer, Allread, & Mantripragada, 2010), (Teizer, Allread, Fullerton, & Hinze, 2010), (Yan, Zhang, & Li, 2020), (Zhu, et al., 2016)
UASs/UAVs	Unmanned ariel systems of vehicles that are able to be remotely operated by safety personnel. These systems allow safety officials to have instantaneous access to various areas around a work zone, including areas that are not easily reachable.	(Zhou, Irizarry, & Lu, 2018), (Gheisari & Esmaeili, 2016), (Yan, Zhang, & Li, 2020), (Irizarry, Gheisari, & Walker, 2012), (Kim, Liu, Lee, & Kamat, 2019)

Technology	Description	References
Wearables	Wearable technology that can physically mount onto a worker. This technology may proactively detect when a person is in or near immediate danger. Some devices include smartwatches, ECG's, RFID tags, among others.	(Antwi-Afari, et al., 2019), (Awolusi, Marks, & Hallowell, 2018)
AR/VR	Augmented, virtual, or mixed realty. These systems allow workers and safety management officials to review training procedures and identify hazards without putting anyone in a harmful situation.	(Li, Yi, Chi, Wang, & Chan, 2018), (Azhar, 2017)
Virtual Prototyping (VP)	A method of simulating jobsite operations before they are implemented.	(Guo, Li, & Li, 2013)

4.1 Types of Innovative Technologies

4.1.1 Computer Vision

The assistance of computer vision in practical applications of proximity and object detection in construction has been investigated in numerous studies. In many other industries, such as the mining industry, they have been able to successfully implement proximity detection in their operations (Marks & Teizer, 2013). In terms of construction site safety, proximity detection has been effectively introduced by many researchers, more specifically to mitigate the risk of struck-by accidents. Much of the recent research promotes the use of two-dimensional computer vision methods rather than the use of three-dimensional computer vision methods. 3D sensing devices have limited feasibility in the conditions of an outdoor construction site (Kim, Liu, Lee, & Kamat, 2019). 3D stereo vision is a common technique used to map a construction site and reproduce a three-dimensional model, yet the current research has only been applied to static scenes which does not suite the dynamic features of a typical construction site (Zhu, et al., 2016).

Although there have been few studies, proximity detection can be simplified to two-dimensional computer vison with everyday closed-circuit video camera systems and an autonomous processing program. This type of computer vision-based technology is generally more affordable than others as it does not require additional remote technologies to be tagged to the various objects on a construction site (Zhu, et al., 2016). The proximity of objects is estimated by the number of pixels between two objects. However, there is significant distortion of the actual distance between 3D objects due to the projection of a 2D spatial relationship (Yan, Zhang, & Li, 2020). In addition to the potential distortion from the two-dimensional projection to 3D, there are other concerns with the accuracy of this method of proximity detection. Since construction equipment (heavy vehicles) have relatively large sizes, there exists an inevitable self-occlusion where the 2D image of the equipment overlaps itself. This self-occlusion ultimately effects the accuracy of proximity detection (Yan, Zhang, & Li, 2020).

Figure 17: Various annotations of workers and equipment from CVB method (Yan, Zhang, & Li, 2020)

To improve these proximity detection techniques, the video feed can be paired with deep learning or neural network algorithms. In order to combat self-occlusion distortion (as demonstrated in Figure 17), it is important for computer vision based technologies to detect additional projections of the vehicles faces with a neural network to accurately describe a vehicles geometry (Yan, Zhang, & Li, 2020). Convolutional Neural Networks (CNN's) or Deep Neural Networks (DNN's) are neural networks that use an input image and weigh its important features to differentiate objects from each other. Neural networks can also be paired with other forms of automation related technologies. Training a network may allow for faster hazard identification and improved proximity detection. They have been used in the construction industry for multiple purposes - including a recent study to monitor proximity based on 2D video frames from drone footage (Yan, Zhang, & Li, 2020). Other studies also indicate the implementation of DNN's have had successful detection performance in the construction industry (Kim, Liu, Lee, & Kamat, 2019).

4.1.2 Unmanned Aerial Systems (UAS's)

The use of Unmanned Aerial System/Vehicle (UAS/UAV) has been incorporated into civil engineering in many applications such as : traffic surveillance, structural health monitoring, bridge inspections, safety inspection, site monitoring, and construction progress monitoring (Gheisari & Esmaeili, 2016). Widespread use of UAS in the industry has prompted research to investigate its potential in the realm of construction site safety and monitoring.

UAS has been shown to be effective in monitoring site conditions autonomously as the operator does not have to be physically present across different areas (some of which may be hard to access on foot). Table 7 represents the effectiveness, frequency, and importance factor for various hazards common in the construction industry (Gheisari & Esmaeili, 2016).

Table 7: Importance factor of UASs for various hazards (Gheisari & Esmaeili, 2016)

Hazardous situations or safety related activities	Effectiveness		Frequency		Importance Factor
	Median	Average Rating	Median	Average Rating	
Working in proximity of boomed vehicles/cranes	5	4.50	3.5	3.55	15.95
Working near unprotected edge/opening	5	4.27	4	3.73	15.93
Working in blind spot of heavy equipment	5	4.24	3	3.50	14.83
Conducting post-accident investigation	4	3.77	4	3.67	13.83
Using boom vehicles/cranes in proximity of overhead power lines	4	4.00	4	3.38	13.52
Inspecting house keeping	3.5	3.82	3	3.45	13.19
Inspecting proper usage of fall protection systems	4	3.81	3	3.36	12.81
Working at unprotected trench	4	3.55	4	3.24	11.48
Working in proximity of hazardous materials	3	3.67	3	3.20	11.73
Inspecting proper usage of PPE on the site	4	3.64	2	2.91	10.58
Inspecting confined space entry	3	3.45	2.5	2.82	9.74
Inspecting requirements for ladder/ scaffold	3	3.14	3	3.05	9.57
Inspecting at-risk rigging operation	2	2.82	2	2.41	6.79
Inspecting requirements for guarding machinery	2	2.55	2	2.27	5.79
Inspecting ergonomics requirements	2	2.27	1	1.95	4.44
Appropriate usage of tag out/lock out	1	1.74	1	1.76	3.06

When compared to other means of transportation, a drone is far less bulky and easier to maneuver. Some other benefits to UAS include its relatively low cost and fast speeds (Zhou, Li, Mi, & Qian, 2019). In addition to the ease of use that UAS can provide no additional equipment may be necessary, other than recharging and maintenance, which can influence its adoption in the industry (Gheisari & Esmaeili, 2016). Currently, drones do not have an extensive battery life that could be used to monitor construction tasks that have longer durations (Zhou, Irizarry, & Lu, 2018). An additional concern is the negative perception of public safety. Drones typically fly at relatively low altitudes which can be perceived as an invasion of privacy to the public (Zhou, Irizarry, & Lu, 2018). The benefits of UAS in a construction site further promote the effectiveness of this type of technology, assuming the disadvantages of using drones in a public or private setting can be mitigated.

General use of UAS in field conditions is limited (Zhou, Li, Mi, & Qian, 2019). In order for the industry to accept this technology, disregarding the dislocated knowledge of UAS, further assessment of its usability is necessary. If UAS becomes simplified, it could become an efficient safety device (Irizarry, Gheisari, & Walker, 2012). A safety managers efficiency can be increased by 50% with the use of a UAS in conjunction with daily duties (Zhou, Li, Mi, & Qian, 2019).

4.1.3 Wearables

The recent development of microcomputers in telecommunication devices has allowed for advanced health monitoring systems that are mounted to personnel and provide physiological metrics. Wearable systems have only recently been introduced to the construction industry with limited documentation of implementation (Awolusi, Marks, & Hallowell, 2018). These wearables have the potential to collect real-time data pertaining to all personnel on a jobsite, with the goal of identifying precursors to a proximity-based accident and other health related hazards.

A few possible types of wearables that can be used to improve safety are Radio-Frequency Identification (RFID), Global Positioning System (GPS), ultrasonic sensors, accelerometers, gyroscopes, many of which are already found in smart devices (e.g., smartphones or smartwatches). An example of a useful application of wearables is their ability to prematurely detect falling potential. Some algorithms have already been developed for smartphones that use the devices accelerometers to have fall detection capabilities (Awolusi, Marks, & Hallowell, 2018). Table 8 below provides an overview of which metrics can be monitored by wearable devices and their associated construction site hazards. Table 9 demonstrates which type of sensor can be used for the various safety and health metrics.

Table 8: Safety performance metrics for construction safety (Awolusi, Marks, & Hallowell, 2018)

	Construction site hazards		Metrics
	Safety hazards	Health hazards	
Physiological monitoring	Slips, trips, and falls from height.	Stress, heat, cold, strain injuries (carpal tunnel syndrome, back injuries), skin diseases (absorption), cuts (injection), breathing or respiratory diseases, toxic gases.	Heart rate, heart rate variability, respiratory rate, body posture, body speed, body acceleration, body rotation and orientation, angular velocity, blood oxygen, blood pressure, body temperature, activity level, calories burn, and walking steps.
Environmental sensing	Slips, trips, fire and explosions.	Chemicals (paints, asbestos, solvents, chlorine), molds, noise, heat, cold, radiation, vibration, toxic gases.	Ambient temperature, ambient pressure, humidity, noise level, light intensity, air quality.
Proximity detection	Caught-in or -between, Struck-by moving vehicle or equipment, electrocution.	Chemicals (paints, asbestos, solvents, chlorine), molds, noise, heat, cold, radiation, vibration, toxic gases.	Object detection, navigation, distance measurement, and proximity detection.
Location tracking	Caught-in or -between, struck-by, confined spaces, cave in, electrocution.	Hazardous chemicals (paints, asbestos, solvents, chlorine), molds, noise, heat, cold, radiation, vibration.	Worker location tracking, materials tracking, and vehicle/ equipment location tracking.

Table 9: Sensors and systems for monitoring construction safety (Awolusi, Marks, & Hallowell, 2018)

Construction Site hazards	Metrics	Sensing technology
Falls from height	Body posture	Gyroscope, accelerometer, magnetometer
Slips and trips	Body posture, body speed, body rotation and orientation	Gyroscope, accelerometer
Stress	Heart rate, blood pressure, respiratory rate	ECG/EKG, infrared, radar
Heat or cold	Body temperature	Thermistor
Fire and explosions	Smoke and fire detection	Infrared
Noise	Noise level	Noise sensor
Caught-in or -between	Proximity detection	RFID, UWB, infrared, radar, Bluetooth
Struck-by object	Proximity detection, location tracking	RFID, UWB, infrared, radar, Bluetooth, GPS
Electrocution	Proximity detection, location tracking	RFID, infrared, radar, Bluetooth, GPS, RFID, UWB
Cave in	Location tracking	GPS, RFID, UWB

Some of the advantages of wearables include (Alwolusi et al. 2018):

- Small enough to be fit an asset without interruption
- Accurate and precise data collection (relative to traditional methods)
- Low implementation and maintenance costs
- Flexibility of rugged designs (for harsh environmental conditions)
- The same publication presents as disadvantages of wearables the following: Need for extreme power efficiency

- Sweat production and build up for wrist mounted wearable devices
- Magnetic field interference
- Relative need for close proximity to signal collection devices

The devices in the construction industry have significantly high levels of accuracy in terms of proximity detection (Figure 18) as well as relatively lower costs – aside from RFID (Figure 19).

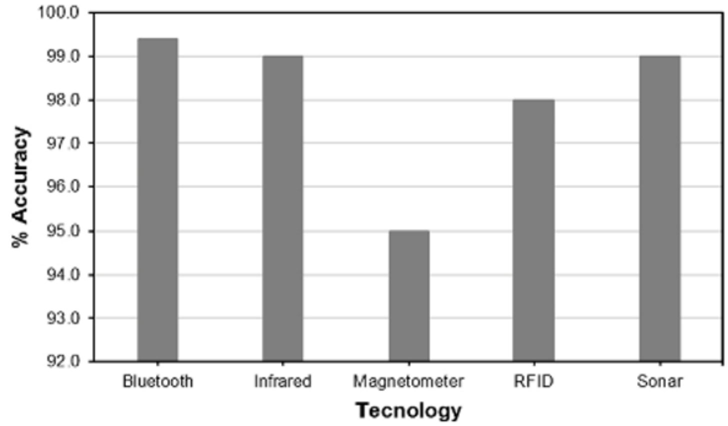

Figure 18: Accuracy of selected proximity detection wearables (Awolusi, Marks, & Hallowell, 2018)

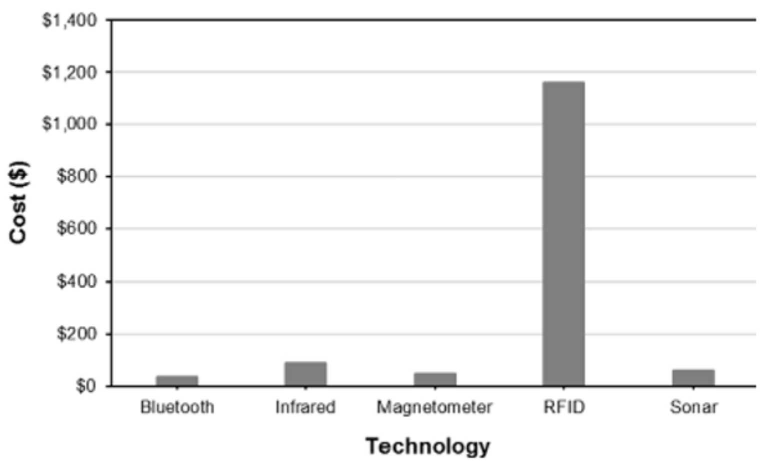

Figure 19: Cost of selected proximity detection wearables (Awolusi, Marks, & Hallowell, 2018)

It has been recommended that multi-modal sensors (or devices that integrate two or more sensors) are to be used in the application of construction site safety (Awolusi, Marks, & Hallowell, 2018). It is beneficial to include multiple sensors in a wearable device to be able to measure more than one metric at once.

4.1.4 Augmented/Virtual Reality

There has been a significant increase in the number of publications regarding the use of Virtual Reality (VR) and Augmented Reality (AR) in the application of construction safety (Figure 20). More specifically, many publications have been produced in the United States regarding VR/AR applications (relative to other countries). Safety planning, training, and education are common applications of VR/AR (Li, Yi, Chi, Wang, & Chan, 2018).

Virtual reality allows a worker to experience life-like scenarios without being in hazardous situations. In some cases, workers assigned to specialized tasks may have little to no real-world/hands on experience of a task and its associated risks. The use of VR/AR in this application allows them to simulate hands-on experiences off of the site (Li, Yi, Chi, Wang, & Chan, 2018).

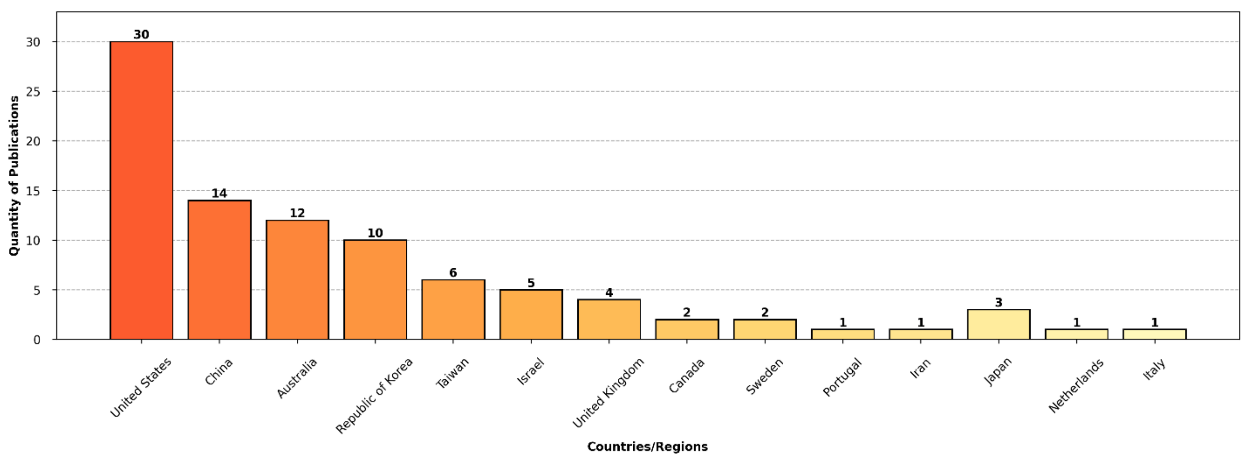

Figure 20: Number of VR/AR publications based on country (Li et al. 2018)

Workers who participate in VR/AR training typically completed assessments related to jobsite activities in shorter times with higher average success rates and ultimately improved onsite communications (Li, Yi, Chi, Wang, & Chan, 2018). In addition to these improvements, VR training was more effective in retaining workers' attention and concentration. Aside from these results, there were some cases where kinesthetic vision and dizziness affected some of the users during the training which could potentially impact their performance when operating the actual equipment (Li, Yi, Chi, Wang, & Chan, 2018). The highlighted improvements of VR training and education should be further investigated in future studies to be able to have a more widespread implementation in the industry.

4.1.5 Virtual Prototyping (VP)

Virtual prototyping allows safety officials to simulate work zones in large-scale construction projects (Figure 21). Many hazards may be misidentified or misjudged during the design phase of a construction project. By virtually prototyping a jobsite prior to execution, it is now possible to identify associated risks and hazards much earlier in the construction process. A framework for this type of technology is shown in Figure 22.

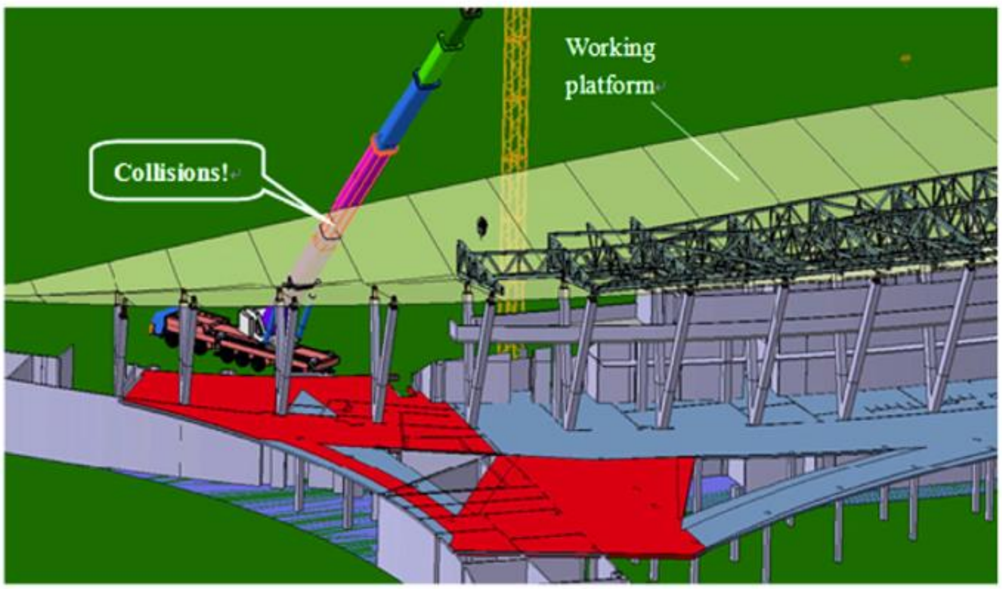

Figure 21: Example VP produced collision detection (Guo, Li, & Li, 2013)

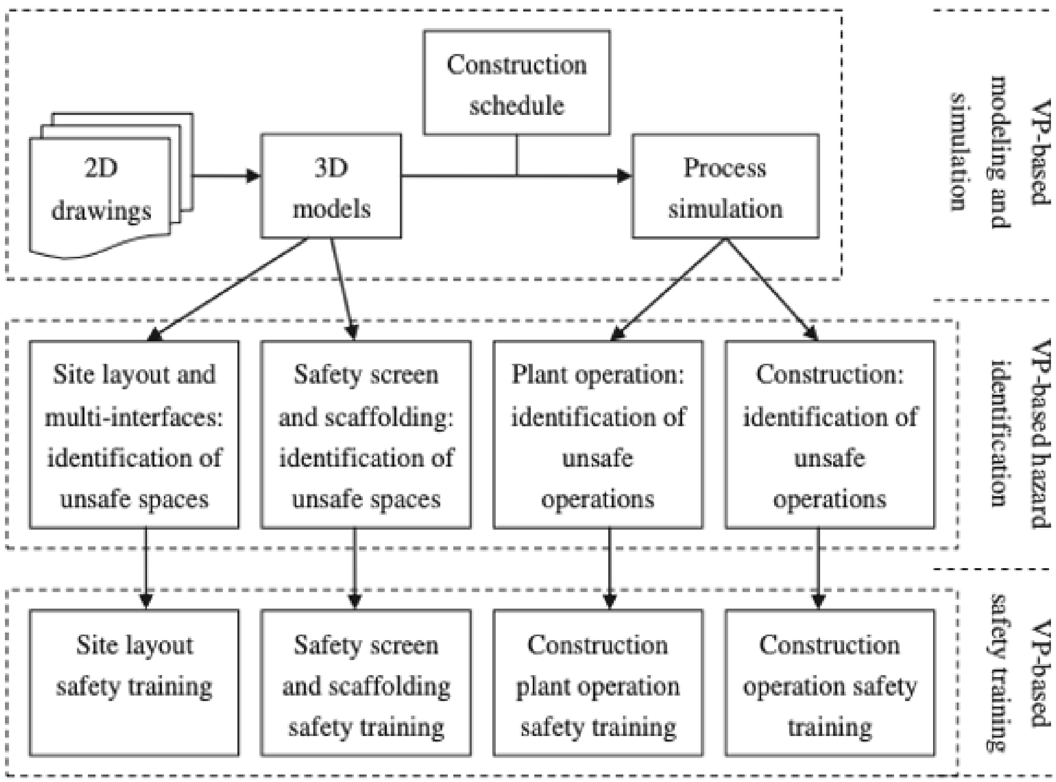

Figure 22: Conceptual framework for VP (Guo, Li, & Li, 2013)

In this framework, models can procure a virtual site that allows for deeper inspections and simulations of jobsite procedures and activities. Potential hazards can either be manually or automatically detected in the simulation, as defined by safety personnel (Guo, Li, & Li, 2013). This type of technical framework is usually limited to the available software that engineers and designers have available. In many cases this software can be costly.

5. Preliminary Conclusions

There are numerous dangerous scenarios prevalent in construction. Based on the literature reviewed here, a majority of accidents occur within the work zone. This primarily includes being struck by or caught between construction equipment, improper use of safety equipment, and incorrect use of construction equipment. Further sources of accidents include struck by passenger vehicles, falls, and others established in this report.

It is clear that there can be improvement to the practices of safety on highway construction sites – either by improving existing practices or by incorporating the use of modern/innovative technologies. There are numerous gaps or discrepancies in the past research that needs to be resolved to effectively improve the current status of safety. By conducting additional research in these topics, the industry can improve upon existing preventative measures.

Due to a lack of scientific evaluation of modern innovative technologies in the industry, the technologies presented in this review may have yet to be implemented in the field. Unfortunately, it is not trivial to change a company's safety culture with the emergence of these potentially effective technologies – additional case studies and deeper analyses of the presented technologies are essential in order to promote successful adoption. Within each of the technologies outlined by this literature review, there exist additional gaps in research that could be halting their implementation.

5.1 Research Gaps in Existing Literature

5.1.1 Highway Construction Safety

There should be further research conducted on site specific activities found on typical highway construction projects. In order to effectively improve safety within highway construction projects, it is important that specific highway construction activities, and their associated risks, be identified and reviewed. There is limited research available on these specific activities, which inhibits statistical analysis of these accidents.

5.1.2 Accident Causation Models

The identified accident causes in this literature review may not fully encapsulate all possible causes in construction. The general categories presented were unsafe equipment, jobsite conditions, nature of the industry, unsafe methods, human elements, and management failures. Although each category had significant information regarding leading causes of accidents, improvement of each category can aid in future reporting and prevention techniques. For example, there were few mentions of physiological and psychological relationships between workers and injuries in the reviewed literature. Further breakdown between the relationship of worker demographic and accident frequency may provide additional insight into the cause of accidents.

5.1.3 OSHA IMIS Database and Near-Misses

Improving the collection of injury and accident data will benefit the prevention of future accidents. Leading indicators such as accident precursors and near miss incidents should be implemented in a typical accident reported to this database. Since some companies fail to report all near-miss incidents, as they are not required by OSHA, a significant amount of useful information is left out of the database. Additionally, other metrics such as the IRA (as reported by KOSHA) could be incorporated into the database to organize the severity of reported accidents.

5.1.4 Education and Training

By improving education and training in the field, workers may be subjected to less accidents. There was little information or suggestions as to how to improve management level safety programs and procedures in the industry. Further enforcement of the maintenance and mandates of the presented preventative technologies should also be investigated and implemented into training programs.

IRISE

Identifying Major Causes of Construction Accidents

Appendix B: Analysis of OSHA SIR Accident Database

1. Introduction

This document reports activities performed for the second task of the project entitled "Identifying Major Causes of Construction Accidents". The main objective of this task was to present the analysis of an accident database using a novel approach with Large Language Models (LLMs).

Safety incidents in various industries necessitate effective categorization and analysis to understand their causes, attribute accidents to worker behavior, and improve safety programs (Al-Shabbani, Sturgill, & Dadi, 2018; Cambraia, Saurin, & Formoso, Identification, analysis and dissemination of information on near misses: A case study in the construction industry, 2010). Data-driven decision making is widely acknowledged as a crucial approach to informed decision making based on safety incident analysis (Al-Shabbani, Sturgill, & Dadi, 2018). However, there exist some limitations in the current methods employed for incident analysis, highlighting the need for further advancements in the field.

While incident databases offer valuable insights for case studies, only a few researchers have explored the potential of utilizing databases such as the OSHA IMIS database to gain deeper insights into safety incidents and their underlying causes. For example, Chokor et al. (2016) addressed this gap by utilizing the OSHA injury reports database along with machine learning techniques, emphasizing the time-consuming and expensive nature of manual analysis (Chokor, Naganathan, Chong, & Asmar, 2016). Studies of such nature highlight the limited exploration and utilization of incident databases in data-driven analysis.

Furthermore, the analysis of accident narratives has been recognized as an important approach. Researchers have employed various techniques, such as text classification and mining, to extract valuable information from accident narratives. Machine learning algorithms, including support vector machines (SVM), random forests, and logistic regression, have been utilized to classify and predict accident severity levels (Jeon, Xu, Zhang, Yang, & Cai, 2021). Additionally, deep-learning approaches have been explored to classify safety incidents, with a particular focus on understudied areas like near-misses (Fang, et al., 2020).

Despite advancements in analyzing accident severity, there are still significant limitations that need to be addressed. One key limitation is the lack of explanation for the relationship between contributing factors and severity (Fang, et al., 2020). While machine learning algorithms can predict severity levels, understanding the underlying mechanisms and causal relationships remains a challenge, necessitating further research and development.

2. Methodology

This section describes the source of data and research methodology. The general workflow of this process, as shown in Figure 23, was created to be reproducible for any further studies. The first step in the analysis is obtaining and processing an appropriate database, with a target of having a full dataset of incidents pertaining to highway construction safety. The project mainly focuses on using language models to derive calculated textual embeddings to be clustered for further analysis – i.e., using LLMs to assist in a data-driven analysis. After the textual embeddings are clustered, these clusters can then be used in LLM prompting to derive human-like generated text that is useful for summarizing, identifying causes, and classification of individual cases. To further visualize the clusters, dimensionality reduction techniques are applied to produce two-dimensional plotting which can be more easily investigated. Figure 23 also highlights the various models and algorithms that were selected to achieve many of the steps. For example, the k-means algorithm was selected for clustering, which was particularly applicable for this general workflow.

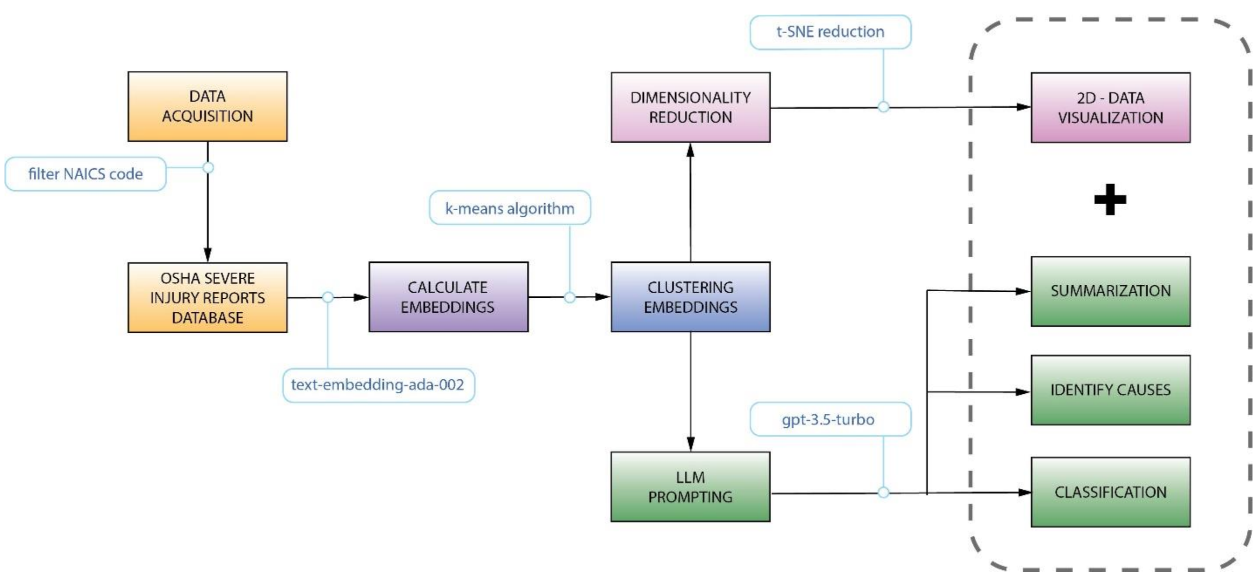

Figure 23: Data processing, visualization, and LLM usage workflow

A python script was developed by the research team to calculate, cluster, and visualize embeddings. The calculated embeddings, and GPT API interface were implemented using OpenAI's python library. K-means Clustering and t-SNE dimensionality reduction was carried out using scikit-learn libraries. Additional plotting and data processing was also carried out in the python script with packages such as Matplotlib, NumPy, and pandas.

2.1 Accident Database

For this part of the project, data from the Occupational Safety and Health Administration (OSHA) Severe Injury Reports (SIR) database was used. OSHA requires employers to report all severe work-related injuries, defined since January 1, 2015. Alternative datasets were available such as the Reports of Fatalities and Catastrophes (archive), Establishment Specific Injury and Illness Data, and the Integrated Management Information System (IMIS). Given the completeness and heavy concentration of textual information of the SIR database, it was selected over other publicly available datasets from OSHA. Additionally, the OSHA IMIS database has already been investigated by a few researchers, which adds to the appeal of analyzing the SIR database to gain new insights that were not previously explored (Hinze, Huang, & Terry, 2005; Kazan & Usmen, 2018; Kim, Ryoo, Kim, & Huh, 2013).

The OSHA SIR database, covering data from 2015 to 2021, has over 70,000 entries considering all the industry codes from the North American Industry Classification System (NAICS). NAICS Code 237310, which refers to Highway, Street, and Bridge Construction was investigated in this task report. This code encompasses a range of activities from conventional paving to airport runaway construction and painting of traffic lines. A total of 1032 accidents with severe injuries were reported to code 237310, making up about 1.5% of the total OSHA SIR database, which ranks the highway construction industry among the top 10 percent of contributors to severe injuries relative to all other industries. Figure 24 demonstrates the distribution of incidents across the United States. Overall, the top three states reporting severe injuries were Texas, Florida, and Pennsylvania with 18.5%, 14.3%, and 9% of contributions, respectively.

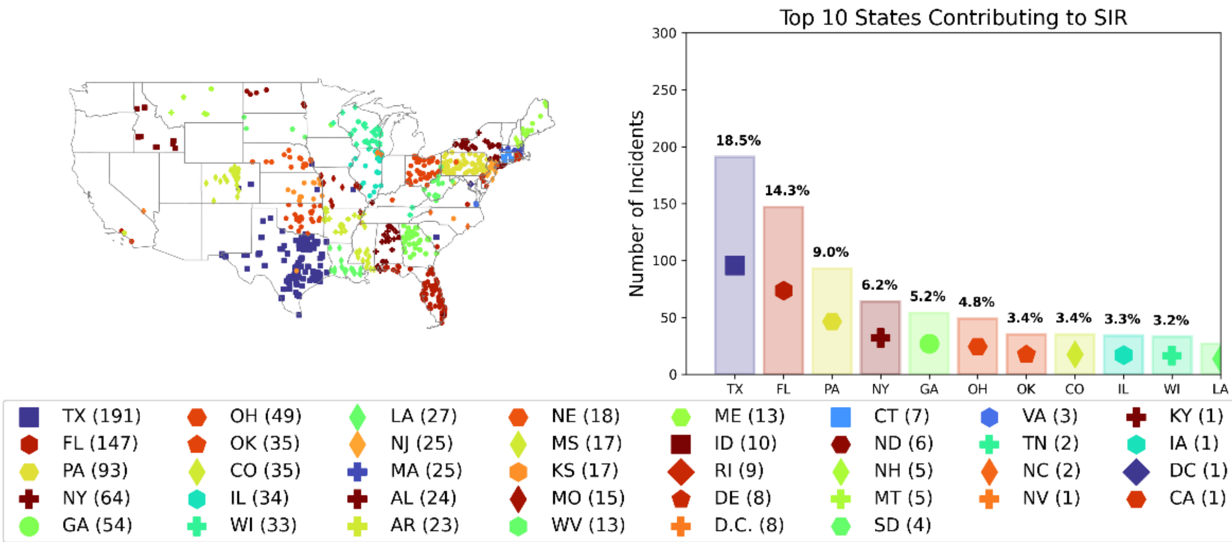

Figure 24: Map of OSHA SIR incidents with highway construction NAICS code

The database has 26 columns with descriptive information on each incident. Data is included regarding the accident date, employer name and address, accident address and coordinates, number of hospitalizations, amputations, and others. For code 237310, 90.2% of accidents resulted in hospitalization while 17.5% of cases involved an amputation. From the perspective of safety training and accident prevention, the columns containing the final narrative, the accident nature, part of the body involved, event title, and source are the most interesting data. Aside from the final narrative, these columns were coded in accordance with the Occupational Injury and Illness Classification Manual (OIICS) developed by the Bureau of Labor Statistics (BLS).

The nature category describes the type of injury or illness suffered by the worker. The part of the body category indicates where the injury was located. The event title provides a more quantifiable description of the accident than the final narrative. Several of the event titles fall into classic accident types such as struck-by, fall, etc. The source identifies the main source of the accident either being a vehicle, specific objects, equipment, etc. The database also contains a column named "second source" which identifies a potential secondary source. The majority (695) of the 1032 accidents do not present a secondary source. However, given the plethora of information from these fields, it is difficult to derive useful statistics to contribute to identifying major causes of accidents. Table 10 defines the top entries for each of the columns. Since these injuries are coded to adhere to the OIICS, selecting the appropriate entry may be too fine-grained. As shown in Table 10, columns such as the source of injury have been coded to 1,407 different categories, with 230 selected for the 237310 code.

In contrast, the final narrative is comprised of a heavily text-based description of the accident and appears to guide the other characterizations. The final narrative can be a description of the accident with several sentences or only a single sentence – significantly varying in the level of detail prescribed. In many cases there is very useful information found within these narratives that cannot be derived from traditional descriptive statistics, which further emphasizes the beneficial usage of natural language processing tools and large language models.

Table 10 also shows the national behavior is similar to PA so national data was chosen for the remaining analysis due to the larger number of observations.

Table 10: OSHA SIR characterization and top entries for the highway industry

Column	Unique Values		Top 5 for Code 237310	Frequency (1032 Reports)	Top 5 for Code 237310 in PA	Frequency (93 Reports)
	All OSHA SIR	Only Code 237310				
Nature of Injury or Illness	503	58	Fractures	35%	Fractures	34%
			Amputations	18%	Soreness, pain, hurt-nonspecified injury	13%
			Soreness, pain, hurt-nonspecified injury	8%	Amputations	13%
			Cuts, lacerations	7%	Heat (thermal) burns, unspecified	6%
			Heat (thermal) burns, unspecified	3%	Crushing injuries	5%
Part of the Body Affected	166	82	Multiple body parts, n.e.c.	9%	Multiple body parts, n.e.c.	11%
			Leg(s), unspecified	7%	Leg(s), unspecified	10%
			Fingertip(s)	7%	Lower leg(s)	8%
			Finger(s), fingernail(s), n.e.c.	6%	Finger(s), fingernail(s), n.e.c.	5%
			Body Systems	6%	Fingertip(s)	4%
Event or Exposure	342	160	Compressed or pinched by shifting objects or equipment	8%	Compressed or pinched by shifting objects or equipment	6%
			Injured by slipping or swinging object held by injured worker	5%	Struck by falling object or equipment, n.e.c.	5%
			Pedestrian struck by forward-moving vehicle in work zone	5%	Pedestrian struck by forward-moving vehicle in work zone	4%
			Exposure to environmental heat	5%	Other fall to lower level, unspecified	4%
			Other fall to lower level, unspecified	4%	Struck by object or equipment, unspecified	3%
Source of Injury or Illness	1407	230	Highway vehicle, motorized, unspecified	5%	Truck-motorized freight hauling and utility, unspecified	6%
			Heat-environmental	5%	Highway vehicle, motorized, unspecified	6%
			Nonclassifiable	4%	Beams-unattached metal	4%
			Saws-powered, except chainsaws	3%	Floors, walkways, ground surfaces, unspecified	4%
			Dump truck	3%	Dump Truck	3%

2.2 Natural Language Processing

The field of construction requires efficient extraction and processing of information from various documents, such as inspection reports and regulatory requirements. Natural Language Processing (NLP) techniques, including word embeddings and topic modeling, provide valuable tools for analyzing safety incidents. Word embeddings capture contextual relations within texts and enable the analysis of word similarity and syntactical meaning, playing a fundamental role in NLP applications (Dhalmahapatra, Shingade, Mahajan, Verma, & Maiti, 2019; Dieng, Ruiz, & Blei, 2019). Popular word embedding models like Word2Vec and GloVe create high-dimensional vectors to capture word relationships and meaning. Pre-trained models like BERT have also gained popularity in various NLP tasks (Reimers & Gurevych, 2019). On the other hand, topic modeling extracts topics or themes from textual documents, providing high-level summaries and facilitating document search and grouping (Dhalmahapatra, Shingade, Mahajan, Verma, & Maiti, 2019). This is typically achieved through techniques such as Latent Dirichlet Allocation (LDA) or Non-negative Matrix Factorization (NMF).

In high-dimensional data analyses, dimensionality reduction and clustering techniques are essential for visualizing and understanding complex datasets. Traditional techniques like Principal Component Analysis (PCA) and classical multidimensional scaling (MDS) have limitations (van der Maaten & Hinton, 2008). To overcome these limitations, t-Distributed Stochastic Neighbor Embedding (t-SNE) can be employed for visualizing high-dimensional data while maintaining original integrity and facilitating a better understanding of relationships between incidents (Dhalmahapatra, Shingade, Mahajan, Verma, & Maiti, 2019; van der Maaten & Hinton, 2008)

Accident severity classification using text representation is a critical area of research. Various approaches have been explored, including combining TFIDF with machine learning classifiers, utilizing the K-means clustering algorithm for data mining, and employing feature analysis through descriptive statistics and graphical techniques (Chokor, Naganathan, Chong, & Asmar, 2016). Term Frequency-Inverse Document Frequency (TFIDF), a traditional method in text analytics, quantifies word importance in a document. However, TFIDF has limitations in capturing word similarity and accurately reflecting token importance (Valcamonico, Baraldi, Amigoni, & Zio, 2022). Traditional machine learning approaches also have limitations in explaining the relationship between contributing factors and injury severities, highlighting the need for further research and improved methods (Chokor, Naganathan, Chong, & Asmar, 2016).

2.3 Advanced Language Models

Language models and NLP techniques hold tremendous potential for automating various textual analysis tasks across different domains. In the construction industry, NLP approaches can streamline inspection practices, extract pertinent information from unstructured data, and classify textual data (i.e., project requirement sentences). Among the advanced language models, Large Language Models (LLMs) like GPT-3 have emerged as a game-changer in NLP, demonstrating exceptional performance and revolutionizing downstream tasks (Chen, Fu, Wang, Meng, & Lv, 2022).

LLMs, such as GPT-3, have been trained on vast amounts of text data, boasting an impressive size of over 175 billion parameters (Brown, et al., 2020). The underlying and novel Transformer architecture in these advanced models has significantly elevated their performance, outshining previous language models (Vaswani, et al., 2017). The remarkable scale and capacity of these models have unveiled unforeseen capabilities, further enhancing their usefulness and effectiveness (Wei, et al., 2022).

One notable advantage of the GPT-3 model is its ability to generate results compared to human performance through instruction based on in-context learning. Unlike earlier NLP systems that struggled with tasks requiring few examples or simple instructions, GPT-3 excels in zero-shot or few-shot learning scenarios (Brown, et al., 2020). This means that the model can comprehend and execute tasks based on minimal guidance, making it particularly suited for applications where clear and concise instructions are vital.

In the highway construction industry, one application where the power of LLMs like GPT-3 can be harnessed is accident analysis. By leveraging the capabilities of GPT-3, data-driven analysis in accident analysis can be significantly enhanced. The model's proficiency in understanding and generating human-like text allows for a more accurate and comprehensive analysis of accident reports, incident narratives, and related textual data. Its ability to process and interpret instructions with remarkable accuracy opens up new possibilities for automating incident categorization and identifying contributing factors in highway construction accidents. The utilization of GPT-3 as an advanced language model in this context represents a significant advancement in leveraging cutting-edge NLP techniques for improving safety and decision-making processes in the industry.

2.4 Embeddings – Clustering and Dimensionality Reduction

Text embeddings models like SBERT and various GPT models are constructed using the transformer architecture akin to LLMs. Unlike the predecessor of Glove and Word2Vec, which are referred to as word embedding models, these text embedding models are now considered content aware and tend to perform very well in classification and clustering tasks (Muennighoff, Tazi, Magne, & Reimers, 2023). The word and sentence embedding models have been used extensively in past research regarding the analysis of roadway incidents and extraction of textual specifications (Fang, et al., 2020; Heidarysafa, Kowsari, Barnes, & Brown, 2018; Jeon, Xu, Zhang, Yang, & Cai, 2021).

New and improved text embedding models such as OpenAI's Ada Embedding model (referred to as text-embedding-ada-002) have been shown to perform very well among other models as conveyed in Muenninghoff et al.'s (2023) Massive Text Embedding Benchmark (METB), making the Ada model particularly useful for clustering safety related incidents in this part of the project.

2.4.1 Calculating Embeddings

The text embeddings derived in this study pertain to the final narrative field from the SIR database. The sentences first get tokenized by effectively chunking the text into smaller, manageable units called tokens. These tokens are then fed into the embedding model, where they are transformed into dense numerical vectors representing the semantic meaning and contextual information of each token, as demonstrated in Figure 25.

In order to train a text embeddings model to produce embeddings, the Transformer Encoder E maps inputs x and y to embeddings vectors, v_x and v_y respectively, and the similarity between these inputs is quantified by cosine similarity between their embeddings, v_x and v_y (Neelakantan, et al., 2022), as provided in Eqs. (1) – (3).

$$v_x = E([SOS]_x \oplus x \oplus [EOS]_x) \tag{1}$$

$$v_y = E([SOS]_y \oplus y \oplus [EOS]_y) \tag{2}$$

$$Sim(x, y) = \frac{v_x \cdot v_y}{\|v_x\| \cdot \|v_x\|} \tag{3}$$

Where,

$[SOS]$ and $[EOS]$ – special tokens appended to the start and the end of a sequence

$\oplus$ is a concatenation of two strings together

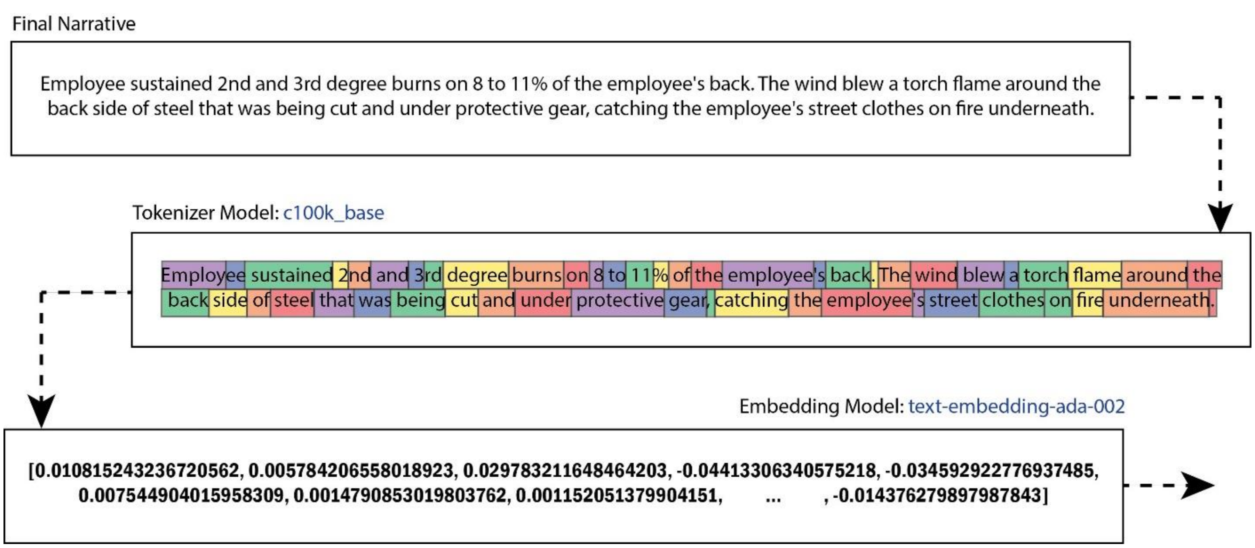

Figure 25: Flowchart - Narrative to embedding vector

2.4.2 K-Means Clustering

Clustering the calculated text embeddings into categories based on their similarities allows for further dissection of major causes of accidents in the highway construction industry. The text-embedding-ada-002 model results in relatively high dimensional vectors of 1,536 dimensions. The use of machine learning (ML) algorithms, such as the unsupervised K-means technique utilized in this report, enables the ability to statistically cluster high-dimensional datasets (Yassin, 2020).

The K-means algorithm is based on each data points distance from cluster centroids, and has been successfully evaluated in various studies pertaining to accident clustering (Chokor, Naganathan, Chong, & Asmar, 2016; Deng, Gu, Zeng, Zhang, & Wang, 2020; Dhalmahapatra, Shingade, Mahajan, Verma, & Maiti, 2019; Ma, Mei, & Cuomo, 2021; Yassin, 2020). The Euclidean distance (d) in n-dimensional space is defined by Eq. (1), which is a measure of the true straight line distance between two points (p, q) in Euclidean space.

$$d(p,q) = \sqrt{(p_1 - q_1)^2 + \cdots + (p_i - q_i)^2 + \cdots + (p_n - q_n)^2} \tag{4}$$

One Method of evaluating cluster performance is the elbow technique, where the average sum of square errors (SSE), Eq. (2), is plotted against the number of clusters (n). The kink-point where rate of change is most drastic is typically selected as the optimal number of clusters.

$$SSE = \sum_{i=1}^{p} \sum_{j=1}^{n} \left| x_i - \bar{X}_j \right|^2 \tag{5}$$

Where,

p = total number of points in cluster

x = data point location

X¯ = cluster centroid

2.4.3 Dimensionality Reduction

Visualizing this high-dimensional dataset to two or three dimensions can be a trivial task. The use of t-Distributed Stochastic Neighbor Embedding (t-SNE), proposed by van der Maaten and Hinton (2008), reveals a powerful technique to dimensionality reduction compared to traditional techniques such as Principal Component Analysis (PCA). The t-SNE technique overcomes the challenge of employing heavy-tailed distributions in a low dimensional space of SNE, which reduces crowding and optimization techniques, captures both local and global structure, and reveals structures at different scales to uncover the presence of derived clusters (Dhalmahapatra, Shingade, Mahajan, Verma, & Maiti, 2019; van der Maaten & Hinton, 2008).

2.5 Leveraging LLMs

A novel network architecture in language processing, the Transformer, was introduced by Vaswani et al. in 2017. This architecture simplifies traditional recursive neural networks (RNNs) by eliminating the need for convolutional layers and relies on what is defined as attention mechanisms, which are able to derive global dependencies between input and output (Vaswani, et al., 2017) The model is comprised of an encoder, decoder, and attention mechanism that work together allowing it to process and generate text (Brown, et al., 2020; Das, Dutta, & Brewer, 2020). GPT's approach in language modeling is unsupervised distribution estimation from a set of examples $(x_1, x_2, \cdots, x_n)$, each being variable length symbol sequence $(s_1, s_2, \cdots, s_n)$ by factorizing the joint probabilities over symbols as the product of conditional probabilities (Radford, et al., 2018):

$$p(x) = \prod_{i=1}^{n} p(s_n | s_1, \cdots, s_{n-1}) \tag{6}$$

Based on this architecture, several notable models have since evolved. These include e Google's BERT, Microsoft's Turing-NLG, Stanford's Alpaca, Meta's LLaMA, and OpenAI's GPT. Due to the sheer upscaling of the massive training corpus (45 TB) and the model parameters (175 billion) that are encapsulated within OpenAI's GPT-3 (Generative Pre-trained Transformer) model, unique abilities have appeared that are not present in smaller models: namely summarization, question answering, etc. (Wei, et al., 2022). These abilities provoke usage in various scientific fields, making it vital for the textual narrative analysis conducted in this part of the project. GPT-3 now lies among the state-of-the-art large language models compared to traditional natural language processing models. Traditional approaches to NLP tasks require extensive pretraining and fine-tuning for specific domains. The introduction of LLMs few-shot learning abilities allow for only few examples or specific instructions to complete similar tasks with improved or better performance to traditional NLP tasks (Brown, et al., 2020). On the other hand, zero-shot learning may still be carried out without providing the model with examples – anticipating lower quality responses in some cases.

The most common way of interacting with these models is through prompting: where the LLM completes a response based on a given prompt without further fine-tuning and/or training (Brown, et al., 2020; Wei, et al., 2022). However, using natural language within these models can become complex relative to other statistical machine learning models that primarily rely on numerical data. Altering user prompts drastically affect the quality of responses since the prompt guides the model to return a probabilistic response. Taking advantage of the few-shot learning capabilities of these models can return accurate responses without the need for weight updates or further training (Brown, et al., 2020).

2.5.1 Incident Summarization and Classification

The ChatGPT large language model, which is the product of OpenAI's largest language model: GPT-3, was selected for the summarization and classification of clusters and incidents. More specifically, the gpt-3.5 turbo (snapshot: gpt-3.5-turbo-0613) model was used to interface user prompting and model generated responses. To perform the tasks of summarizing clusters and identifying major causes of accidents, iterations of prompt refinement and manual response performance evaluation were conducted. The final version of the initial prompt and refinement prompts resulted in a process to iterate over the entire dataset, providing the model with a few entries at a time, until all entries were evaluated. From this process, generated summaries and the top three causes are derived that pertain to each cluster.

Additionally, using the LLM to classify incidents was carried out in the analysis. The following fields found in the OSHA SIR database were isolated from the original dataset:

- “EventTitle”
- “NatureTitle”
- “Part_of_Body_Title”
- “SourceTitle”
- “Hospitalized”
- “Amputation”

By compiling a list of unique entries for each of these fields, the language model was prompted to determine the most applicable entry for each individual incident. Both modes of few-shot and zero-shot prompting were applied to each field to further evaluate the LLM’s performance. In the scenario where few-shot learning was applied, the existing class was provided in the prompt to demonstrate examples for the model. Alternatively, zero-shot learning was not provided with these examples, only the list of unique entries. The following metrics, Eqs. (3) – (7), were used then to evaluate the LLM classification of the fields within the OSHA database: accuracy, recall, specificity, precision, and F1Score (Ma, Mei, & Cuomo, 2021; Yassin, 2020).

$$Accuracy = \frac{TP + TN}{TP + FP + FN + TN} \tag{7}$$

$$Recall = \frac{TP}{TP + FN} \tag{8}$$

$$Specificity = \frac{TN}{FP + TN} \tag{9}$$

$$Precision = \frac{TP}{TP + FP} \tag{10}$$

$$F1Score = 2 * \frac{(Precision * Recall)}{(Precision + Recall)} \tag{11}$$

Where,

TP = True Positive: predicted class is equal to actual class, and is true in binary classification

TN = True Negative: predicted class is equal to actual class, and is false in binary classification

FP = False Positive: predicted class is not equal to actual class, predicted true when actual class is false in binary classification

FN = False Negative: predicted class is not equal to actual class, predicted false when actual class is true in binary classification

In scenarios where binary classification was not applicable, such as in cases other than hospitalization and amputation columns, accuracy, recall, and precision can be used to assess the classification capabilities of the LLM. Accuracy provides an overall measure of correctness in the model's predictions. Recall and precision, on the other hand, focus on the model's ability to correctly classify positive instances. In multi-class classification, specificity cannot be utilized since there are no technically defined true negative instances. To comprehensively evaluate the model's performance, the F1Score combines precision and recall into a single metric, striking a balance between the two aspects.

2.5.2 Additional Classification Queries

Expanding upon the previous utilization of LLM for summarization and classification, the LLM was also employed for individual accident classification using a zero-shot approach. The primary goal was to automate the identification of accidents connected to concrete pavement activities.

The GPT-3.5 model demonstrates remarkable transfer learning capabilities, enabling it to tap into the context of individual accidents, even in a zero-shot context. This contextual awareness was crucial in enabling the model to make precise determinations regarding their relevance to specific scenarios, particularly any activities associated with concrete pavements. This heightened context awareness empowered the model to classify accidents with a high degree of accuracy, aligning perfectly with the objective of pinpointing those linked to concrete work.

Beyond the classification of concrete operations, this approach also opened up opportunities for querying additional valuable data points, including information about the equipment involved and concise descriptions of each incident. Consequently, the utilization of LLMs transcended the realm of summarization, delivering additional insights and data to facilitate a more comprehensive analysis of safety-related incidents within the highway construction industry.

3. Results and Discussion

3.1 Clustering Embeddings

Selecting the optimal number of clusters (n) for the K-Means algorithm does not have innate relationships to the provided dataset. By evaluating the average sum of square errors (SSE) of each cluster there was no obvious kink-point or elbow in Figure 26 where the rate of change of error drastically changes.

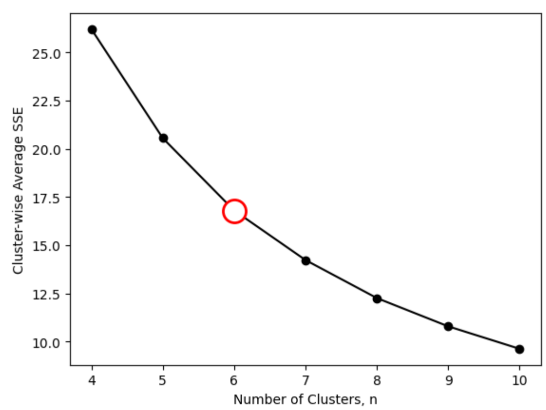

Figure 26: Cluster-wise average SSE and elbow technique for optimal number of clusters

Thus, this elbow technique had to be coupled with visual and manual investigation of the resulting clusters. Figure 27 and Figure 29 demonstrate the edge cases for the number of clusters, four and ten clusters, respectively. Visually, the four clusters have too much spread, and are much less centric than the ten clusters, which is key to a centric based algorithm such as K-Means. Alternatively, ten clusters appears to be too fine-grained or too specific. As the number of clusters increases, the convoluted Cluster 1 and 3 in Figure 27 get further distinction, showing that the incidents in these cluster originally had a lot of overlap (based purely on the representative embeddings). Ideally, the six clusters presented in Figure 28 were selected for further analysis. These clusters have distinct regions that they occupy while maintaining minimal overlap, and there appears to be a relatively significant shift in average SSE.

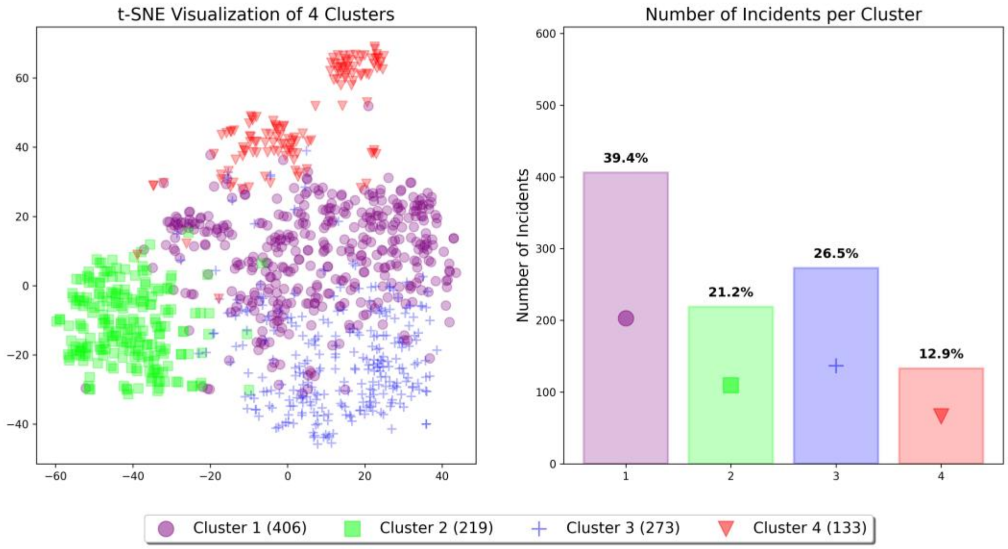

Figure 27: Four clusters identified in road construction incidents (t-SNE)

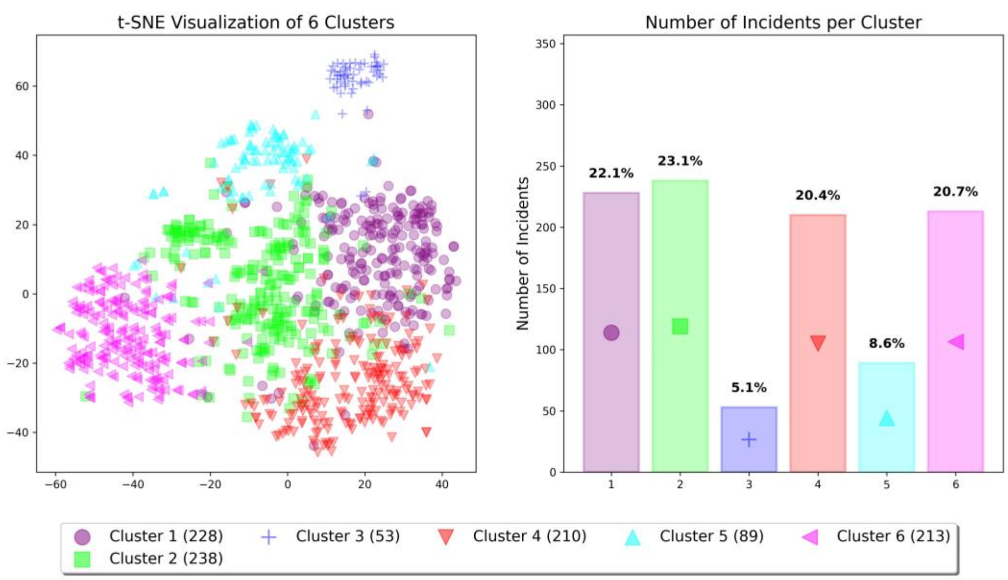

Figure 28: Six clusters identified in road construction incidents (t-SNE)

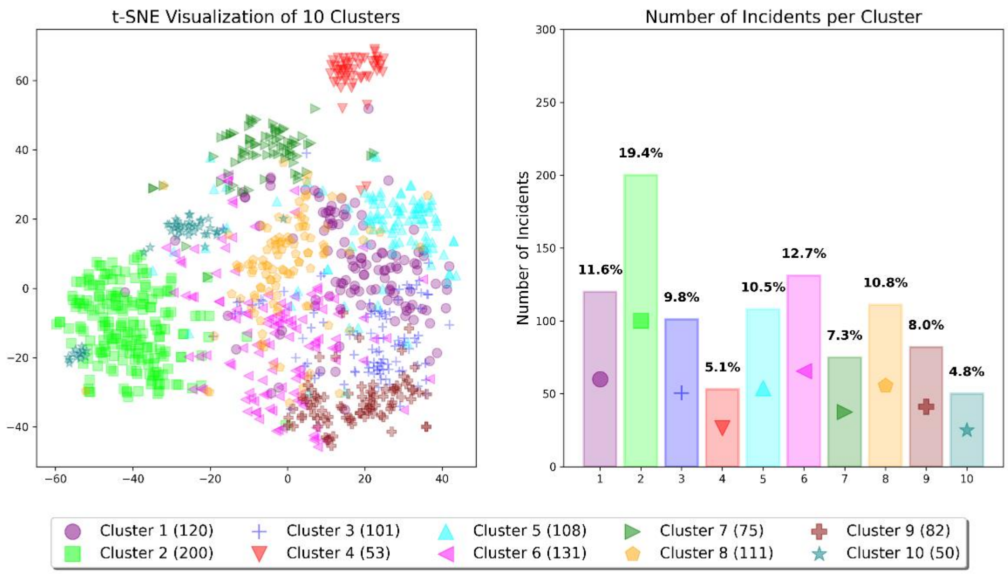

Figure 29: Ten clusters identified in road construction incidents (t-SNE)

3.2 LLM Summarization and Cause Identification

The prompt template conveyed in Figure 30 demonstrates the iterative process of initial prompt and refine prompt for cluster summarization. Within these prompt templates, it was important to emphasize that the model temperature was set to zero. Maintaining a zero temperature when continuously prompting the GPT-3.5 model ensures that the response is more probabilistic and statistically relevant while reducing the creativity of the model.

Also, in the refine prompt, the previously generated summary for the model is presented to contribute more information to newly introduced road construction incidents. The model does not hold a history of previous requests; therefore, it would only create a summary based on the next iteration of incidents inherently disregarding the previous iteration.

Table 11 provides the final LLM generated responses for the summary of each cluster. Based on a manual dissemination of various number of clusters and their resulting summaries, the six clusters tended to create more well-defined summaries than others. The following manual analyses of the clusters were conducted:

Cluster 1 pertained to incidents mostly related to moving vehicles or equipment. Most of these vehicles are passenger vehicles, vans, and SUVs indicating issues with traffic control at the work-zone. It unclear if the trucks involved in the accidents are passing traffic or construction trucks. Issues within the work zone were observed as well with 18% of accidents involved construction equipment such as pavers, rollers, scrapers, and others.

Cluster 2 mainly consisted of incidents resulting in contact with objects, equipment, or equipment parts. Most accidents in this cluster involve struck-by accidents between an object/equipment/equipment part and a worker. These incidents seem to happen inside the work-zone and are not related to passing passenger traffic.

Cluster 3 was almost entirely comprised of heat-related incidents. Some incidents (3 of the 53 cases) are related to heart attacks that do not seem directly heat-induced.

Cluster 4 was clustered around incidents that were related to falling (either worker or an object) from a certain height, with a majority of cases involving a worker falling from a height. Some incidents were related to objects or equipment parts falling onto workers.

Cluster 5 was mostly related to incidents where a worker suffers burns from heated materials or equipment, also including incidents related to electrical hazards

Cluster 6 incidents consisted of cases where workers suffer injuries to upper limbs – including damage to hands, fingers, or arms. These accidents are less severe in consequence with about half of accidents requiring some level of hospitalization. However, these accidents tend to result in permanent upper limb damage with most accidents requiring amputation procedures.

The resulting LLM-generated summaries were able to provide similar insights to manual analysis, without the need for iterating through individual cases manually. For most of the derived clusters, the summaries focused on the causes of the accidents, with some summaries also alluding to information about the body parts affected.

Similar to the prompt template for LLM summarization, Figure 31 was the final version of the template for identifying the top three major causes within the cluster. The resulting major causes were exemplified for clusters 1-6 in Table 12. While some of the causes pointed out by the LLM are common safety approaches such as "inadequate training or communication", several of the causes are quite specific to the incidents inside the cluster. This type of analysis can help improve safety training to avoid certain incidents, for example, emphasizing how the number of cases regarding the lack of guarding on equipment may be impactful in reducing upper limb injuries.

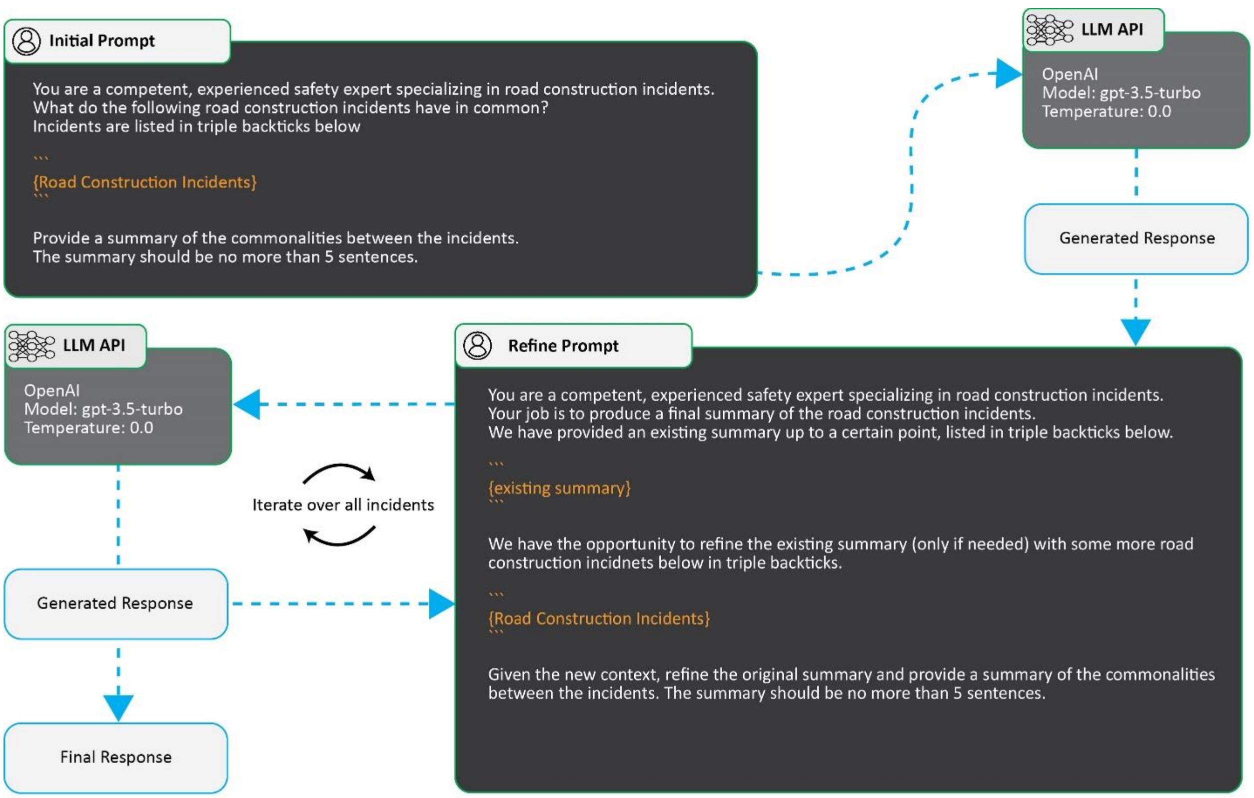

Figure 30: LLM summary prompt template

Table 11: LLM summarization of incidents (clusters 1-6)

Cluster Number	Summary
Cluster 1	The road construction incidents listed involve a wide range of injuries, including fractures, head injuries, and back injuries, with many employees requiring hospitalization. The incidents highlight the importance of proper safety protocols, such as wearing seat belts and using proper equipment, to prevent accidents and injuries on road construction sites. The incidents also demonstrate the need for ongoing safety training and vigilance in the road construction industry. The incidents involve employees being struck by vehicles or equipment, either while working alongside the road or while performing tasks such as loading or unloading equipment. The incidents emphasize the need for increased safety measures and awareness in the road construction industry to prevent further accidents and injuries, including the importance of proper traffic control and the dangers of distracted driving. The incidents also show the importance of proper footwear, the dangers of working in close proximity to moving vehicles, and the need for proper maintenance of equipment. The additional incidents highlight the importance of being aware of one's surroundings, the dangers of working at heights, and the need for proper training and supervision. Commonalities between the incidents include the importance of proper safety protocols, ongoing safety training, and vigilance in the road construction industry to prevent accidents and injuries.
Cluster 2	The additional incidents in road construction work highlight the ongoing need for proper safety protocols and equipment maintenance. The incidents range from employees being struck by objects or run over by equipment to suffering severe lacerations and fractures, resulting in hospitalization and surgery. Many incidents involve the use of heavy machinery, while others involve slips and trips on uneven surfaces or debris. The incidents emphasize the importance of prioritizing safety in the workplace through ongoing safety training, awareness, supervision, communication, and hazard identification to ensure a safe work environment for all employees. Commonalities between the incidents include employees being struck by equipment, suffering fractures and lacerations, and being hospitalized for their injuries. The incidents also highlight the importance of proper clothing and equipment maintenance, as well as the need for caution when working in trenches or around heavy machinery.
Cluster 3	All of the listed incidents involve employees working in road construction who suffered from heat-related illnesses or dehydration. Many employees were hospitalized due to symptoms such as heat exhaustion, cramping, and dehydration. The incidents occurred during hot weather conditions, with some employees working in temperatures as high as 86 degrees. The affected employees were performing a variety of tasks, including paving, welding, shoveling, and flagging. The incidents highlight the importance of proper hydration and heat safety measures in road construction work.
Cluster 4	The road construction incidents involved a variety of tasks and equipment, resulting in a range of injuries from falls, being struck by falling objects, being caught in between objects, and tripping. Safety equipment was not always used properly or was unhooked at the time of the incident, and employees were not always using proper equipment or following proper procedures. Many of the incidents resulted in hospitalization and required emergency surgery, with injuries ranging from broken bones to electrical burns and partial amputations. The new incidents highlight the importance of proper safety equipment use and following proper procedures to prevent serious injuries, such as fractures, head injuries, lacerations, and crushing injuries. Commonalities between the incidents include falls from heights, being struck by falling objects, and improper use of equipment or failure to follow proper procedures.
Cluster 5	The road construction incidents involve a range of injuries, including burns from hot materials such as asphalt and oil, exposure to chemicals like battery acid and gasoline, and electrical hazards. Many incidents occur while employees are working on or near machinery and are injured due to equipment malfunctions or accidents. Other incidents involve employees being struck by vehicles or falling from heights. The new incidents highlight the importance of proper safety protocols, training, and equipment maintenance in the road construction industry. Employers must ensure that employees are aware of the potential hazards and are equipped

	with the necessary protective gear to prevent injuries. Commonalities between the incidents include hot materials causing burns, equipment malfunctions leading to accidents, and employees being exposed to hazardous materials.
Cluster 6	The road construction incidents continue to involve hand and finger injuries, with many resulting in amputations. The injuries were caused by a variety of tools and equipment, including saws, forklifts, cranes, and excavators. Many of the incidents involved pinch points or kickbacks, where the worker's hand or finger was caught between two objects or pulled into a dangerous area. The new incidents highlight the ongoing need for proper training, safety protocols, and equipment maintenance in preventing hand and finger injuries in road construction. The commonalities between the incidents include the use of heavy machinery, pinch points, kickbacks, and human error, emphasizing the importance of proper training, safety protocols, and equipment maintenance to prevent these types of injuries.

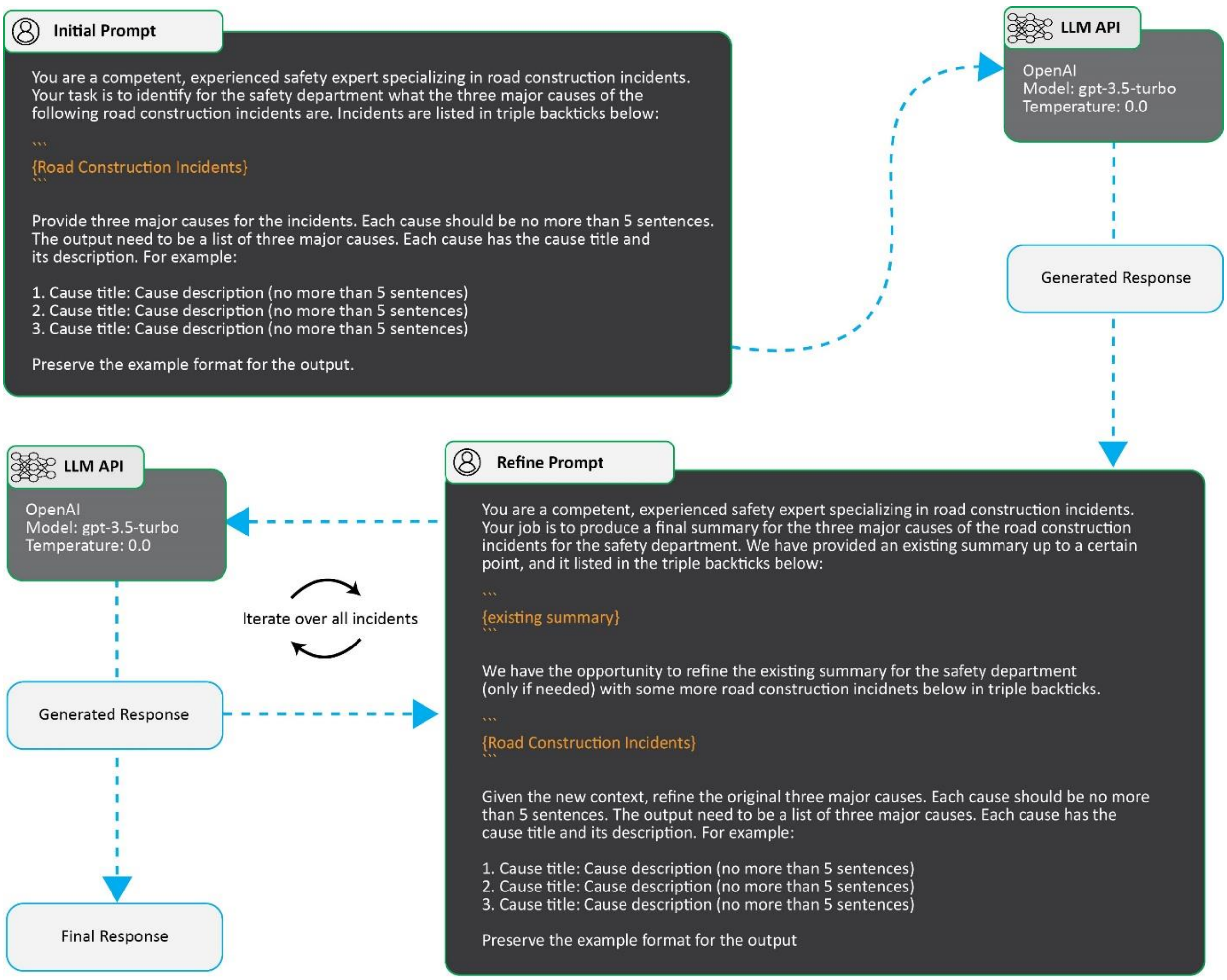

Figure 31: LLM major cause identification prompt template

Table 12: LLM major causes of incidents (clusters 1-6)

Cluster Number	Major Causes
Cluster 1 Stuck by Vehicle or Heavy Equipment	**1. Inadequate traffic control measures:** The majority of incidents involved employees being struck by passing vehicles, indicating a lack of proper traffic control measures such as warning signs, barriers, or flaggers. **2. Inadequate training and supervision:** Several incidents involved employees being injured while performing tasks such as loading or unloading equipment or working with heavy machinery. **3. Failure to follow safety procedures:** Many of the incidents involved employees being injured while performing tasks that are known to be hazardous, such as working with heavy machinery or working in close proximity to traffic.
Cluster 2 Contact with Objects or Equipment	**1. Inadequate hazard assessments:** Many of the incidents were caused by hazards that were not properly identified or addressed, such as falling objects, collapsing trenches, and unexpected equipment movements. **2. Lack of proper equipment maintenance, inspection, and training:** Several incidents were caused by equipment malfunctions or failures, such as saw blades kicking back, rigging slipping, and machinery grabbing onto employees. **3. Failure to follow established safety procedures and inadequate training:** Many incidents were caused by employees not following established safety procedures, such as not wearing appropriate personal protective equipment, not properly securing materials, and equipment, and not following proper operating procedures.
Cluster 3 Heat Related	**1. Heat exposure:** Many of the incidents were caused by heat exposure, which can lead to heat exhaustion, stroke, dehydration, and other heat-related illnesses. **2. Lack of training and safety protocols:** Some incidents were caused by a lack of training and safety protocols for working in hot conditions. **3. Physical exertion:** Many of the incidents were caused by physical exertion, such as shoveling, lifting heavy objects, or operating heavy machinery.
Cluster 4 Falling Objects or Personnel	**1. Inadequate fall protection:** Many of the incidents involved falls from heights, such as falling off of formwork or aerial lifts. In several cases, employees were not wearing appropriate fall protection equipment, such as harnesses or guardrails, which could have prevented or minimized their injuries. **2. Insufficient equipment training and maintenance:** Some of the incidents occurred because employees were not properly trained in how to use equipment safely or were using equipment that was not properly maintained. **3. Failure to follow established safety procedures:** In several incidents, employees were injured because established safety procedures were not followed. Additionally, some incidents occurred because employees were not following established procedures for working at heights or in confined spaces.

Cluster 5 Heated Materials or Equipment	**1. Inadequate handling of hot materials and lack of personal protective equipment:** The incidents involving hot materials highlight the need for proper personal protective equipment and training on how to handle hot materials. **2. Lack of proper equipment maintenance and inspection:** Equipment failure or malfunction was a major cause of incidents. Lack of proper maintenance and inspection of equipment contributed to these incidents. **3. Inadequate communication and training:** Many incidents were caused by employees attempting tasks without proper training or safety procedures in place. Lack of communication between workers and with other contractors on the site also contributed to incidents.
Cluster 6 Upper Limb Injuries	**1. Pinch points:** Many incidents involved workers' fingers getting caught in pinch points, such as between equipment and materials, resulting in partial or full amputations of fingers. **2. Lack of guarding:** Several incidents involved workers using power tools, such as saws and table saws, without proper guarding. Additional incidents involving lack of guarding include an employee's finger being amputated while installing a soil/cave protection system, an employee's finger being smashed by a T-post driver, and an employee's fingers being crushed by an excavator bucket. **3. Inadequate communication:** In some incidents, workers were injured due to miscommunication or lack of communication between coworkers. Additionally, incidents involving loading and unloading equipment onto trailers resulted in finger amputations due to lack of communication between workers.

3.3 LLM Classification

Following summarization and causation analysis, the LLM classification of multiple fields within the OSHA database was conducted and performance was evaluated as shown in Table 13. In almost all scenarios, the few-shot mode of classification tended to outperform the zero-shot mode, achieving the highest accuracy of 93.7% accuracy with the event title. The highest accuracy the zero-shot mode was able to achieve was only 62.5% with the nature title, which may be due to the fewer entries to select from.

Both hospitalization and amputation fields were assessed with each of the four major fields, as shown in the prompt template for classification (Figure 32). These queries performed very well in both few-shot and zero-shot modes because they were not dependent on what was previously coded in the field. However, it is interesting to note that they were classified with varying performances when given in the context of different fields. This phenomenon could be partly explained by the probable and statistical randomness of the LLM itself.

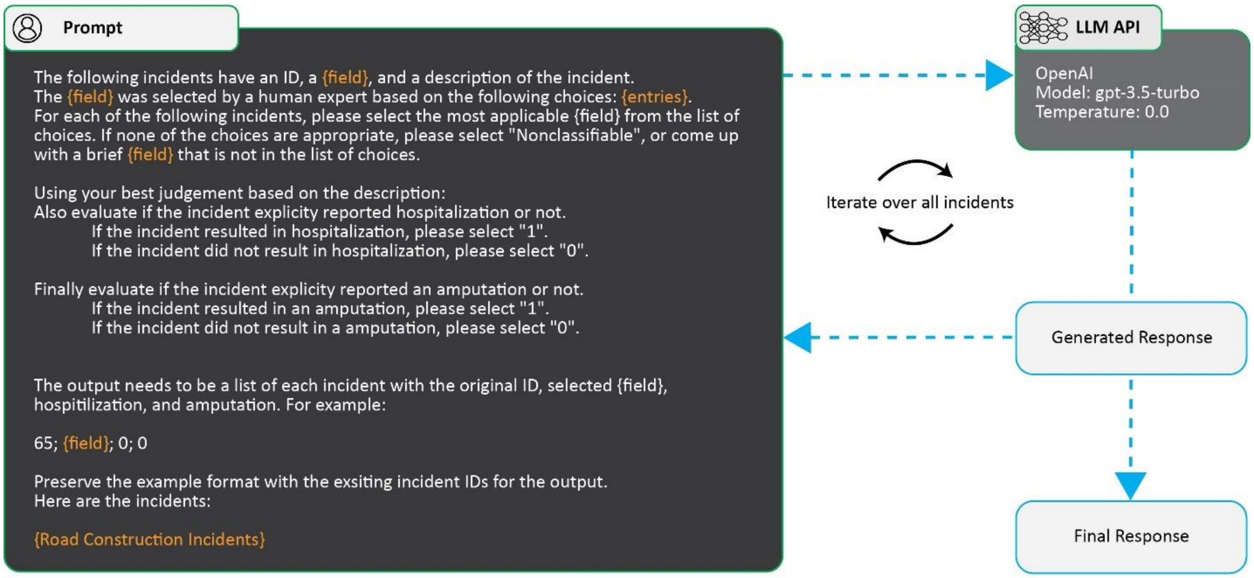

Figure 32: LLM classification prompt template

Table 13: Performance of few-shot and zero-shot LLM classification

Field		Few-Shot				Zero-Shot			
		Precision	Recall	F1Score	Accuracy	Precision	Recall	F1Score	Accuracy
EventTitle		97.4	96.1	96.7	93.7	46.8	34.1	39.4	24.6
NatureTitle		96.0	94.4	95.2	90.8	80.3	73.8	76.9	62.5
Part_of_Body_Title		96.8	95.1	96.0	92.2	57.0	55.0	56.0	38.9
SourceTitle		96.8	96.6	96.7	93.6	62.9	63.5	63.2	46.2
In Context with EventTitle:	Hospitalized	89.2	85.4	87.3	78.0	88.0	81.7	84.7	74.0
	Amputation	88.4	92.3	90.3	96.5	86.9	95.0	90.8	96.6
In Context with NatureTitle:	Hospitalized	88.2	77.8	82.7	71.2	86.9	68.4	76.5	62.9
	Amputation	95.6	95.6	95.6	98.4	96.6	94.5	95.5	98.4
In Context with Part_of_Body_Title:	Hospitalized	88.0	84.1	86.0	75.8	90.0	73.8	81.1	69.5
	Amputation	91.5	95.0	93.2	97.6	94.5	94.5	94.5	98.1
In Context with SourceTitle:	Hospitalized	89.5	88.7	89.1	80.8	88.4	84.4	86.4	76.4
	Amputation	84.5	93.4	88.7	95.8	88.2	95.0	91.5	96.9

With the high accuracy of the LLM classification in most cases, manually assessing where LLMs classified the incidents differently also provides some valuable insight as to whether the incidents were originally coded sufficiently. Error! Reference source not found.Figure 33 demonstrates the LLM's ability to classify incidents in a more allusive fashion. The human classification in these examples refer to was originally reported in the database.

Incident ID: 259

Field: Event Title

Road Construction Incident: An employee was replacing a motor when an asphalt plant component fell and hit the lift platform, knocking the employee to the ground. He suffered a back vertebrae injury.

Human Classification: Other fall to lower level, unspecified

LLM Classification: Struck by falling object or equipment, unspecified

Incident ID: 31

Field: Hospitalization

Road Construction Incident: An employee was hooking a trailer up to a truck with a coworker. The hitch got stuck; while attempting to unhook the hitch, the employee placed his hand on the hitch. The coworker lowered the trailer, and the employee's right, third fingertip got amputated after getting caught between the hitch and trailer. He was hospitalized.

Human Classification: Not Hospitalized

LLM Classification: Hospitalized

Incident ID: 313

Field: Amputation

Road Construction Incident: On February 15, 2017, at about 9:30 AM, an employee was using an excavator to push a concrete pipe together when his right forefinger was partially amputated above the fingernail, requiring surgery.

Human Classification: No Amputation

LLM Classification: Amputation

Figure 33: Examples of LLM classification different from the original coding

Even with a few examples provided, among many more derived from the analysis, new insights in evaluating the existing database entries can be determined. Both incidents #31 and #313 in Figure 33 are clear examples of where the narrative explicitly states that the incident involved a hospitalization or amputation whereas the field entry insinuated that they were not present in the accident. Additionally, as exemplified in incident #259, the incident resulted in a fall. However, the cause of the accident in this case was more likely contributed to the worker being struck by a falling object. These discoveries and disconnections between the narrative and what was coded in the original database demonstrate the model’s ability to reevaluate entries for more representative dissection and findings for statistical purposes.

3.3.1 Auxiliary Classification – Concrete Work

The following prompt was used to generate the subsequent results presented in Table 14.

System: "You are a competent, experienced safety expert specializing in road construction incidents

User: "The following incidents have an ID and a description of the incident. Using your best judgment based on the description, first evaluate if the incident explicitly involved concrete pavements. If the incident involved a concrete pavements, please select "1". If the incident did not involve a concrete pavement, please select "0".

Next, also evaluate if any type of equipment was involved. If no equipment was involved, select "None". Otherwise list the type of equipment.

Finally, evaluate what activity was being performed during the incident. If you can't detect the type of activity or use the context of the incident, select "Nonclassifiable". Otherwise create a title for activity in 3-5 words.

The output needs to be a list of each incident with the original ID, concrete pavement involvement, equipment used, and title of activity.
For example: 65; 1; concrete paver; Nonclassifiable

Preserve the example format with the existing incident IDs for the output.

Here are the incidents: {injected incidents}"

Table 14 presents a breakdown of the cases identified by the LLM as being related to concrete work activities. Out of the total cases examined, which amounted to 121, accounting for 13.3% of all cases, the LLM's automated assessment pinpointed them. This figure exhibits a slight variance when compared to the manual assessment, which recognized only 81 incidents. It's worth noting that Cluster 2, encompassing incidents involving contact with objects or equipment, notably contributed the highest number of cases related to concrete pavements. This can be attributed to the consistent requirement for heavy equipment in large-scale concrete construction projects.

When evaluating the LLM's classification performance, in most cases, the model adeptly identified whether the incident was connected to concrete pavements. Moreover, it accurately recognized the type of equipment involved and furnished a succinct description of the accident. An illustrative example is provided:

Road construction incident (ID = 318)
“An employee was paving a highway road and was struck by a cement truck. The truck ran over the employee's left leg.”

LLM concrete pavement classification
1 *(yes)*
LLM identified equipment
Cement truck
LLM identified activity
Paving highway road

Nevertheless, it's important to acknowledge that there were instances where the model's performance fell short. In some cases, the LLM incorrectly associated terms such as "concrete piping" with concrete pavement incidents, as demonstrated in the following response. Additionally, there were situations where the model struggled to correctly identify the type of equipment used due to potential sentence context challenges. Similar difficulties were observed in capturing concise activity descriptions.

Road construction incident (ID = 399)
“An employee was guiding an underground concrete pipe in a trench when the pipe fell off its cable and hit his right leg, breaking it.”

LLM concrete pavement classification
1 (yes)
LLM identified equipment
Cable
LLM identified activity
Guiding concrete pipe

These instances, represented by cases 319 and 399, among others, highlight both the strengths and limitations of employing LLMs for automated incident classification in the context of concrete pavement-related activities.

Table 14: LLM concrete work classification (clusters 1-6)

Cluster Info	Summary
Cluster 1 *Struck by Vehicle or Equipment* <u>Concrete Cases</u> 23/228 (10.1%)	**Equipment:** concrete truck, broom tractor, backhoe, work trailer, cement truck, loader truck, front-end loader, line striping truck, concrete mixer, heavy equipment, shoulder widener paving machine, spray truck, semi-trailer, dump truck **Activities:** pinned between concrete form and truck, cleaning up after concrete chipping, spotting for broom tractor, pouring concrete, struck by concrete debris, struck by motor vehicle, resurfacing interstate, paving highway road, maintenance, work zone setup, rear-end collision, driving a concrete mixer, moving paving machine, road shoulder sweeping, working on concrete spacer, directing truck
Cluster 2 *Contact with Objects or Equipment* <u>Concrete Cases</u> 34/238 (14.3%)	**Equipment:** concrete paving saw, weber machine, paver, track hoe, rubber track excavator, excavator, ready-mix truck, paving machine, cable, cut-off saw, concrete barrier, string line reel, tube float, material loader, mechanic truck, remote-controlled guillotine concrete breakers, skid steer, road paver, road roller machine, track excavator, rubber-track mini excavator, rubber-tracked placer, chop saw, rock drill **Activities:** run over by tire on weber machine, loading paver onto truck, struck by concrete barrier, struck by excavator, placing concrete barrier rail and crash cushions, walking back to paver, guiding concrete pipe, cutting concrete, positioning a barrier, operating part of the paving machine, rolling up string line used in concrete paving operations, cutting chamfer on concrete curb, sweeping debris into trench, finishing the edge of a concrete pour, operating guillotine concrete breakers, cutting concrete pipe, adjusting width on skid swing arm, cutting concrete piles, grinding concrete curb, spotting for road paver, removing top part of retaining wall, crushing old concrete, dismounting excavator from lowboy trailer, walking towards work area, pouring culvert, cleaning concrete placer, cleaning rubber-tracked placer, concrete cutting, concrete drilling
Cluster 3 *Heat Related* <u>Concrete Cases</u> 6/53 (11.3%)	**Equipment:** hydraulic excavator, concrete pad, backhoe **Activities:** operating hydraulic excavator, installing concrete pad, developing heat-related illness, finishing concrete
Cluster 4 *Falling Object or Personnel* <u>Concrete Cases</u> 28/210 (13.3%)	**Equipment:** backhoe, concrete form, paving machine, concrete pour forms, flatbed truck, ladder, jackhammer, concrete finishing machine, rebar column, concrete platform **Activities:** securing concrete wall panel, stripping concrete form work, moving concrete cure deck bridge, struck by concrete form, going down into trench, moving concrete, concrete finishing activities, working on concrete pour forms, loading concrete, painting bridge, dismantling forms from a bridge column, cleaning and cutting rebar, juking concrete pile, standing on top of concrete road barrier, climbing ladder, jackhammering concrete deck, moving generator on concrete finishing machine, installing supports for concrete base, falling from concrete platform, tripping and falling on concrete anchor bolts, cleaning concrete chute
Cluster 5 *Heated Materials or Equipment* <u>Concrete Cases</u> 5/89 (5.6%)	**Equipment:** paver, distributor truck, concrete pump truck, high-pressure washing equipment **Activities:** paving roadway, spray bar cleaning, verbal altercation, pouring concrete in drill shafts, inspecting recently casted concrete segments
Cluster 6 *Upper Limb Injuries* <u>Concrete Cases</u> 25/213 (11.7%)	**Equipment:** track-hoe, forklift, excavator, paving machine, hammer drill, concrete plow, drill, concrete truck chute, backhoe, crane, concrete pump hopper, paver box, hammer, pneumatic chipping gun **Activities:** covering hole with steel plate, forks dropping unexpectedly, moving concrete form, measuring inside trench box, setting concrete lid, placing concrete barriers, pushing concrete pipe, adjusting conveyor belt, pouring concrete, drilling holes in a concrete column, inspecting concrete against existing header, removing a concrete barrier wall, removing concrete form, cleaning concrete, placing concrete slab, replacing joint on bridge, riding on paver box, instructing employee to secure load of pipe, driving a wooden stake into a concrete form, chipping concrete

In the context of incidents associated with heat exposure, we observed discrepancies when comparing the results of the manual assessment conducted prior to utilizing the LLM. In the initial analysis, ten cases within Cluster 3 were identified as being linked to heat exposure during the concrete procurement process. However, the LLM's classification identified only six clusters related to heat exposure. While the LLM demonstrated remarkable proficiency in summarizing tasks, there appears to be room for improvement in classification accuracy. This potential enhancement could be achieved through prompt refinement or by incorporating evaluation metrics like accuracy, precision, recall, and others commonly employed in conventional machine learning applications. The utilization of these metrics would offer a more comprehensive and quantifiable evaluation of the LLM's performance in incident classification, facilitating further refinements in its capabilities.

3.3.2 Top Entries in Database after Classification

After implementing the LLM classification, Table 15 summarizes the top 3 entries in each field for the respective cluster. These categories also assist in evaluating the performance of LLM summarization. The top entries in each field are effectively represented in their corresponding summaries, without providing any information about what was previously coded (and only providing the final narrative). Other than the manual evaluation of the clusters, this could not be previously performed with such conclusive results.

To demonstrate the LLM’s abilities, the summary of cluster 1 pertained to vehicle struck-by accidents, and the coded event title comprised a majority of cases labeled “Pedestrian struck by forward-moving vehicle in work zone” (21.9%). All other clusters and corresponding fields also appear to relate to the summary in this distinguishing manner.

Table 15: Top fields in each cluster after LLM classification

Cluster	EventTitle	NatureTitle	Part_of_Body_Title	SourceTitle
Cluster 1	**Pedestrian struck by forward-moving vehicle in work zone (21.9%)**	**Fractures (49.1%)**	**Nonclassifiable (11.8%)**	**Highway vehicle, motorized, unspecified (24.6%)**
	Pedestrian struck by vehicle in work zone, unspecified (9.6%)	Traumatic injuries and disorders, unspecified (7.5%)	Multiple body parts, n.e.c. (10.1%)	Dump truck (9.2%)
	Other fall to lower level, unspecified (7.0%)	Internal injuries to organs and blood vessels of the trunk (6.1%)	Leg(s), unspecified (10.1%)	Truck-motorized freight hauling and utility, unspecified (8.8%)
Cluster 2	**Injured by slipping or swinging object held by injured worker (9.7%)**	**Fractures (49.6%)**	**Leg(s), unspecified (14.7%)**	**Saws-powered, except chainsaws (10.5%)**
	Pedestrian struck by vehicle in non-roadway area, unspecified (6.7%)	Cuts, lacerations (17.2%)	Lower leg(s) (11.8%)	Excavating machinery, unspecified (9.7%)
	Struck by falling object or equipment, n.e.c. (5.9%)	Amputations (8.0%)	Foot (feet), unspecified (10.9%)	Milling machines, cold planers, and road profilers (3.8%)
Cluster 3	**Exposure to environmental heat (90.6%)**	**Effects of heat and light, n.e.c. (37.7%)**	**BODY SYSTEMS (90.6%)**	**Heat-environmental (90.6%)**
	Fall on same level, n.e.c. (1.9%)	Effects of heat and light, unspecified (26.4%)	Heart (5.7%)	Floors, walkways, ground surfaces, unspecified (1.9%)
	Fall through surface or existing opening less than 6 feet (1.9%)	Heat exhaustion, prostration (13.2%)	Head, unspecified (1.9%)	Nonclassifiable (1.9%)
Cluster 4	**Struck by falling object or equipment, n.e.c. (10.0%)**	**Fractures (68.6%)**	**Multiple body parts, n.e.c. (11.4%)**	**Bridges, dams, locks (12.9%)**
	Other fall to lower level, unspecified (9.5%)	Soreness, pain, hurt-nonspecified injury (6.2%)	Leg(s), unspecified (10.5%)	Structural elements, n.e.c. (6.2%)
	Other fall to lower level less than 6 feet (8.6%)	Internal injuries to organs and blood vessels of the trunk (4.8%)	Lower leg(s) (8.6%)	Beams-unattached metal (5.7%)
Cluster 5	**Contact with hot objects or substances (23.6%)**	**Heat (thermal) burns, unspecified (25.8%)**	**Multiple body parts, n.e.c. (25.8%)**	**Paving asphalt, asphaltic cement (18.0%)**
	Ignition of vapors, gases, or liquids (9.0%)	Second degree heat (thermal) burns (16.9%)	Nonclassifiable (11.2%)	Nonclassifiable (10.1%)
	Exposure through intact skin, eyes, or other exposed tissue (5.6%)	Third or fourth degree heat (thermal) burns (11.2%)	Leg(s), unspecified (6.7%)	Gasoline, diesel fuel, jet fuel (9.0%)
Cluster 6	**Compressed or pinched by shifting objects or equipment (34.3%)**	**Amputations (71.4%)**	**Fingertip(s) (32.9%)**	**Nonclassifiable (8.9%)**
	Injured by slipping or swinging object held by injured worker (10.3%)	Cuts, lacerations (9.4%)	Finger(s), fingernail(s), n.e.c. (29.6%)	Saws-powered, except chainsaws (4.7%)
	Caught in running equipment or machinery during regular operation (8.5%)	Fractures (5.2%)	Finger(s), fingernail(s), unspecified (26.3%)	Cranes, unspecified (4.7%)

4. Summary

The recent advent of large language models (LLMs) in artificial intelligence represents a significant advancement, providing a wide array of innovative tools applicable to automation, data analysis, and other transportation research areas.

In the context of the dynamic and chaotic nature of highway construction safety, investigating the wealth of textual information within accident databases is crucial for enhancing our understanding of accidents. However, heavily textual accident report databases pose significant challenges. To address this, the present task report proposed a cutting-edge approach that leverages LLMs to analyze these databases, gaining valuable insights into the causes, characteristics, and outcomes of accidents, and enabling the identification of patterns and underlying factors contributing to safety incidents. By surpassing the limitations of conventional descriptive statistics, which often fall short when dealing with primarily textual databases, this task report provides a comprehensive understanding of the data. The findings of this part of the project emphasize specific areas of interest in highway construction safety, serving as a foundation for further investigations to enhance prevention and intervention techniques.

The approach was applied to the OSHA Severe Injury Reports database, selected for its rich textual information presented in the reports. A conventional descriptive analysis of the database reveals numerous accident sources and characteristics that often confine and limit the scope of accident analysis and potentially overlook general incident details, resulting in insights relevant only to niche situations. However, by employing the proposed approach, the project significantly enhances the breadth and depth of identifying general trends in major accident categories and their causes, such as accidents related to burns from heated materials or equipment. This utilization of the narratives provided valuable information: extracting meaningful insights and augmenting what could not be otherwise derived from traditional descriptive statistics.

Through global clustering of the incidents based on their narrative content, refined visualization, and pattern discovery in high-dimensional data become possible. Utilizing LLMs for summarization, cause identification, and classification further enriches safety-related insights without the need for laborious manual analysis. LLM classification also identified many cases in which the narrative provided crucial details that were not obvious in the previously reported field entries. The ability to uncover such disconnections demonstrates the model's ability to reevaluate entries by using narrative context, leading to more accurate and comprehensive statistical outcomes. The optimized approach to data clustering yields datasets that indicate accident causes, such as environmental heat or the involvement of specific body parts (e.g., upper limbs).

IRISE

Identifying Major Causes of Construction Accidents

Appendix C: NCHRP IDEA Proposal – AI Safety Officer Assistant

1. Preliminary Questions

1.1 Specific Innovation and Addressing High Priority Needs

What is the specific innovation? Does it address a high priority need of state highway agencies?

The innovation is the AI Safety Officer Assistant, an AI/LLM (Artificial Intelligence and Large Language Model) tool designed to assist highway construction safety officers in enhancing safety management practices within the highway construction industry. This innovation addresses a high priority need of state highway agencies of highway and worker safety by providing an advanced technology solution for work planning with a focus on safety and streamlines incident reporting. The tool utilizes AI-driven natural language processing (NLP) algorithms to generate safety insights, provide hazard communication recommendations, and efficiently process incident reports. By automating and optimizing these tasks, the innovation aims to significantly improve the efficiency and accuracy of safety management practices, ultimately contributing to safer construction environments and reduced accidents.

1.2 Current State of Practice and the Limitations

How could this innovation affect the current state of practice? What will it do that the current practice cannot do?

The implementation of the AI Safety Officer Assistant could revolutionize the current state of practice in the highway construction industry. This innovation addresses a critical objective of transportation agencies: minimizing construction accidents on their projects and ensuring the safety of their construction and maintenance crews. The tool offers several advancements that current practices cannot achieve. Its unique ability to generate actionable insights from unstructured data sets it apart from traditional methods, empowering safety officers to make informed decisions based on comprehensive analyses. By automating routine tasks and providing valuable insights, the innovation frees up personnel to focus on higher-level safety management strategies and proactive measures. The AI/LLM tool can rapidly process and analyze large volumes of incident reports, enabling timely identification of potential hazards and recommendations for hazard mitigation to specific construction and inspection activities.

1.3 Economic Feasibility

Compared with current practice, is the proposed innovative solution economically feasible and easy to use?

Compared to the current practices, the AI Safety Officer Assistant offers economic feasibility and ease of use. Although initial setup costs are involved, the AI Safety Officer Assistant offers long-term advantages by streamlining hazard communication and incident reporting, leading to increased operational efficiency and reduced downtime. Moreover, the tool's ability to proactively communicate hazards associated with daily work activities and inspections can result in substantial economic benefits, including lower worker compensation and medical expenses. These benefits, combined with improved job satisfaction and enhanced transportation infrastructure safety, underscore the solution's positive impact on both the economy and social equity among workers.

2. Summary of Concept and Application for Practice

The highway construction industry has made significant strides in adopting modern technologies to boost productivity and workers' safety. Nonetheless, it still confronts the persistent challenge of being one of the leading contributors to workplace accidents. Highway maintenance and construction, with its distinctive set of risks, are hindered by seemingly fewer directly applicable safety standards, regulations, and programs when compared to the broader construction industry (Al-Shabbani, et al., 2018). While common safety practices such as actively communication potential hazards during daily work activities and inspections as well as analyzing historical incident databases have shown promise in preventing accidents and enabling swift interventions, there is ample room for further improvement and innovation in their implementation.

The current approach to reporting incidents involves manually curated textual narratives of a critical event by field personnel, providing valuable insights into specific accident causes and facilitating future analysis and the dissemination of crucial information. However, the quality of these narratives can vary significantly depending on factors such as the expertise of the personnel involved, level of detail provided, and consistency of the reporting process.

Additionally, many safety management teams have implemented a form of daily huddles between safety officers and laborers. These huddles serve as an interactive platform where all parties involved come together to discuss the day's work plans and their associated hazards. Alongside historical incident databases, these huddles enable safety officers to gather firsthand information from field personnel about accidents and near-miss incidents, as well as allowing them to provide insight into what activities pose certain risks. The chaotic and dynamic nature of construction, in conjunction with the vast number of niche activities that take place, increase the risk to any personnel in the work zone (Awolusi, et al., 2018; Zhu, et al., 2016). Without clear communication and detailed insights, it is difficult to proactively mitigate these potential risks.

By engaging in proactive communication and collaboration, all parties involved gain a comprehensive understanding of potential risks, allowing for timely adjustments to the work process and implementation of necessary safety precautions. Yet the information that safety officers transmit to the field may be limited to their understanding of certain site-specific construction activities and their associated risks, which could be potentially overlooked. This is especially true for newly contracted unexperienced workers.

Despite the highway industry's exploration of innovative technologies, the utilization of artificial intelligence (AI) in safety management has been constrained. Nevertheless, recent progress in cutting-edge natural language processing (NLP) methodologies, particularly employing advanced large language models (LLMs), has exhibited a growing capacity to handle tasks involving extensive textual data. This becomes particularly relevant to the construction sector where NLP approaches can streamline inspection practices, extract pertinent information from unstructured data, and classify textual data (i.e., project requirement sentences) (Jeon, et al., 2021). Leveraging these transformative technologies offers distinct advantages for safety-related tasks within construction, notably in addressing the discrepancies in the quality of incident narratives.

The research team at the University of Pittsburgh's Department of Civil and Environmental Engineering is proposing an AI/LLM tool to aid safety personnel in the highway construction industry. The tool will focus on two primary tasks: firstly, it will assist in procuring daily work activity plans with a safety focus, aiding safety management in communicating specific hazards associated with various activities and inspection practices. Secondly, as an auxiliary feature, the tool will serve as a data entry tool to improve the quality of accident reporting, filling any knowledge gaps that new employees might have, and enhancing future analysis and safety data dissemination. By incorporating innovative NLP techniques, this tool can help ensure more accurate and comprehensive incident reports, overcoming the limitations of manually curated narratives.

The main deliverable of this innovative approach is a prototype of a user-friendly chat-like software interface, the AI Safety Officer Assistant. The software will guide safety personnel in curating daily work plans, inspection checklists, and populating incident reports by gathering inferences and providing follow-up clarification questions. This guidance will ensure the creation of high-quality safety reports, highlighting activity-specific details that might otherwise be overlooked. Integrating AI-powered tools with daily huddles between safety officers and laborers can further improve incident reporting and risk assessment processes, enabling proactive safety measures.

2.1 Potential Payoff for Practice

By embracing state-of-the-art NLP techniques and LLMs, the AI Safety Officer Assistant holds tremendous potential to revolutionize safety-related tasks in the construction industry, offering a range of significant benefits to transportation agencies and other stakeholders. The implementation of the use of innovative LLMs can lead to higher quality accident reports, enabling a more thorough and accurate analysis of incidents. This, in turn, will provide transportation agencies with a deeper understanding of work zone accidents and their underlying causes, paving the way for targeted interventions and proactive prevention strategies.

Through seamless integration with existing safety practices, transportation agencies can foster a safer work environment for their personnel, effectively mitigating potential hazards and minimizing on-site risks. This powerful approach will facilitate enhanced communication of hazards associated with specialized construction activities and inspections, empowering safety officers to effectively inform laborers about potential risks and preventive measures.

With an AI/LLM-driven data entry tool at their disposal, safety personnel can streamline the reporting process, ensuring that incident narratives are comprehensive and standardized. This unified knowledge basis will not only aid in recognizing safety-related information promptly but also support data-driven decision-making and resource allocation, ultimately optimizing safety management. In addition, the AI/LLM knowledge database can help fill in the expertise gap for newly contracted employers by helping with their training.

By harnessing the capabilities of AI-powered tools and leveraging real-time insights, transportation stakeholders can implement proactive measures, preventing accidents before they occur and creating a culture of safety that prioritizes the well-being of workers and avoid costs related to accidents. The potential payoff of this innovation, therefore, lies not only in reducing accidents and injuries but ensuring workers' health and safety while fostering increased productivity and improved operational efficiency.

2.2 Transfer to Practice

The comprehensive strategy for implementing the AI Safety Officer Assistant involves several interconnected elements that encourages industry adoption among transportation agencies, construction companies, safety officers, and other relevant entities. By fostering partnerships, prioritizing user needs, and effectively demonstrating the benefits of AI assisted tasks, the research team aims to facilitate a seamless transfer of this groundbreaking technology from research and development to practical implementation, ultimately making a substantial impact on safety-related tasks in the highway construction industry.

2.2.1 Collaborative Partnerships and Understanding Industry Needs

A cornerstone of this strategy is the establishment of collaborative partnerships with various stakeholders as per the letters of support attached to this proposal. These stakeholders encompass a construction company and a professional association. These partnerships serve as the bedrock for comprehending the nuanced challenges and needs specific to the industry. The insights gained from these collaborations ensure that the AI Safety Officer Assistant is precisely aligned with real-world requirements.

Embracing a user-centered design approach, the strategy involves engaging safety officers, field personnel, and laborers in the development process. Actively incorporating user feedback and preferences ensures that the tool caters directly to the practical demands of daily users.

Integral to the approach is continuous monitoring and evaluation. This iterative process enables the collection of valuable feedback, measurement of impact, and identification of areas for enhancement. By responding to evolving industry demands, the technology will remain effective and adaptive over time.

In a targeted effort, the Golden Triangle Construction Company will undergo testing of the tool, involving their team of safety officers. Simultaneously, the Constructors Association of

Western Pennsylvania (CAWP) will actively engage in seeking out partners to participate in prototype testing, all the while actively facilitating the gathering of critical data on prevailing incident reporting methods and safety training approaches within their network.

2.2.2 Training and Testing for Effective Utilization

To introduce the AI Safety Officer Assistant to prospective users, a series of training videos, tutorials, user manuals, and documentation will be provided. These resources will cover various aspects, ranging from understanding the AI/LLM technology's role in enhancing safety management to utilizing the tool for incident reporting, interpreting AI-generated analysis, and best practices for integration into existing safety management processes.

The partners will help identify contractors of varying sizes to test the tool directly in the field. Safety officers and workers with different levels of experience will provide continuous feedback that will be used to improve the tool.

2.2.3 Barriers and Proactive Measures

While the approach shows promise, addressing certain barriers is crucial for successful adoption. These challenges encompass resistance to change within established workflows, concerns about technology's learning curve, and doubts regarding the accuracy of AI-driven insights. Legal and regulatory issues, including liability for incidents, might also be perceived as adoption barriers. Clear communication, thorough training, and transparent demonstrations of capabilities will play pivotal roles in overcoming these challenges. Moreover, the financial investment required for implementation could be seen as an obstacle, particularly for smaller construction companies with limited budgets. To mitigate these concerns, comprehensive cost-benefit analyses and demonstrations of long-term advantages will be essential in highlighting the technology's potential for reducing accidents and enhancing safety measures.

2.2.4 Investment and Recoup

Significant investment is allocated to the initial development of the AI Safety Officer Assistant, including the creation of advanced natural language processing algorithms and intuitive user interfaces. Acquiring the necessary hardware and computing resources further bolsters the technology's infrastructure. The time it takes for an agency to recoup the costs associated with the initial adoption of the technology will depend on several factors, including the frequency and severity of accidents before and after implementation, the number of incidents prevented, and the associated cost savings. In addition, costs related to safety are not always straightforward but the emphasis on worker safety is a priority for all stakeholders involved. Typically, agencies can expect to see a return on their investment within a few years of adopting the technology, provided that the implementation is successful, and the tool is effectively utilized to enhance safety practices and accident prevention measures. The precise timeframe for recouping the costs will vary based on the specific circumstances and the extent of safety improvements achieved with the implementation of the tool.

The strategic implementation also considers the necessary equipment to support the technology's operation. High-performance computing infrastructure, data storage systems, communication and networking equipment, and user interface devices. It's important to note that the specific equipment requirements will depend on the scale and complexity of the AI/LLM tool and the deployment strategy. Additionally, as technology evolves, updates and upgrades may be required to keep the equipment aligned with the tool's ongoing needs and advancements.

3. Investigative Approach

The proposed investigative approach for this research project aims to systematically develop, validate, and demonstrate the effectiveness of the AI Safety Officer Assistant in enhancing safety management practices within the highway construction industry. The research will be carried out in three distinct stages

3.1 Stage 1: Concept Design/Inception and Specification Development

In this initial phase, the research team will focus on refining objectives and gathering requirements for the AI Safety Officer Assistant. Collaborative discussions with contractors and other stakeholders will inform the desired features and functionalities of the tool. The following tasks are proposed:

1. Requirement Gathering:
    - Conduct extensive consultations with stakeholders to identify functional and non-functional requirements for the assistant. Explore current approaches for accident

reporting and safety training based on accident reporting utilized by contractors in the highway construction sector.
  - Understand the needs and expectations of safety officers, users, and other potential beneficiaries of the tool.
2. Refining Objectives:
   - Engage in discussions with contractors, safety officers, and other related personnel to clarify and refine the objectives of the AI Safety Officer Assistant identifying key features and functionalities.
   - Determine the scope of the tool's capabilities and the specific tasks it should address within highway construction safety.
   - Determine how the tool can integrate seamlessly into existing workflows and augment safety-related tasks

3.2 Stage 2: Preliminary Development and Testing

During this stage, the research team will focus on the preliminary development and testing of the AI Safety Officer Assistant, integrating generative AI into highway construction safety workflows. The stage involves selecting a suitable LLM, designing natural language processing algorithms, prompt engineering, and in-house testing hosted by the research team. The following tasks are proposed for Stage 2:

1. Selecting a suitable LLM:
   - Evaluate available LLM candidates for their alignment with project goals and requirements.
   - Choose an LLM that can be fine-tuned to effectively address the safety needs of the highway construction industry.
2. Designing Natural Language Processing Algorithms:
   - Develop and refine algorithms that enable the AI Safety Officer Assistant to procure incident reports, generate safety insights, and provide hazard communication recommendations.
   - Create an architecture that prioritizes high-priority requirements and accounts for both functional and non-functional aspects.

- Ensure alignment with the objectives and user experience established in the previous stage.

3. Prompt Engineering:
   - Design specialized prompts that guide the assistant's responses toward the safety domain.
   - Develop prompts that procure clarifications or explanations from the assistant in cases of uncertain responses.
4. In-House Testing:
   - Develop a comprehensive set of test cases, test suites, and scenarios to thoroughly assess the tools functionality taking into consideration feedback from safety officers from different partners (Contractors and Associations)
   - Execute the developed test suites to identify any gaps and areas for improvement in the tool's performance.
   - Evaluate the accuracy and effectiveness of the natural language processing algorithms.
   - Assess the assistant's ability to provide relevant safety insights and hazard communication recommendations.

3.3 Stage 3: Field Deployment and Evaluation

In this final stage, the focus shifts to field deployment and real-world evaluation of the AI Safety Officer Assistant. The tool's functionality is iteratively implemented and refined, complying with requirements and the designed user experience (UX). Additionally, this stage includes a task to develop preliminary specifications for the future production of a final product. The following tasks are proposed for Stage 3:

1. Comprehensive Testing:
   - Deploy the AI Safety Officers to the field on projects of selected Contractors. This task will involve the training of safety officers in operating the tool for accident reporting and safety training.
2. Refinement based on Feedback:
   - Refine the assistant based on feedback received from early users and experts, addressing concerns, and incorporating valuable suggestions.

- Optimize the architecture and deployment setup of the LLM to ensure rapid and efficient inference.
- Implement techniques such as temperature scaling and top-k sampling to control the LLM's response randomness and diversity.

3. Documentation and Training Materials:
    - Document the newly implemented functionalities and UX enhancements, providing clear and accessible documentation.
    - Develop training materials, resources, or sessions to ensure that safety specialists can effectively utilize the AI Safety Officer Assistant.
4. Develop Preliminary Specifications for Future Product Employment
    - Identify requirements and considerations of future product employment in the format of a roadmap
    - Outline specifications for scalability, user accessibility, security, and other factors essential for the transition from the prototype to a commercial product

With proper execution of this final stage, the AI Safety Officer Assistant transitions from development to practical application, with a strong emphasis on refinement, optimization, testing, and collaboration. The feedback loop established with users and experts ensures that the tool's capabilities will evolve to meet the evolving needs of the highway construction industry. Training materials empower users to maximize the benefits of the assistant, fostering a culture of safety enhancement across the sector. Additionally, the task of developing preliminary specifications for future product employment ensures a clear path towards commercial viability and widespread adoption.

The research results will be evaluated at the completion of each stage to ensure the achievement of specific objectives and milestones. A comprehensive assessment will be conducted to validate the accuracy of the AI-driven insights, the effectiveness of hazard communication recommendations, and the overall enhancement of safety management practices within the highway construction industry.

4. Key Personnel and Facilities

4.1 Principal Investigator

Dr. Lev Khazanovich, Anthony Gill Chair Professor, Department of Civil and Environmental Engineering, University of Pittsburgh. Dr. Khazanovich is an internationally recognized expert in pavement design, structural modeling, performance prediction, as well as pavement construction and non-destructive testing. He has served as a Principal or co-Principal Investigator on numerous high-profile research projects sponsored by the Federal Highway Administration, Department of Energy, National Cooperative Highway Research Program, Strategic Highway Research Program, and state transportation agencies. Currently, he is serving as a Principal Investigator on the project 'Identifying Major Causes of Construction Accidents,' sponsored by the Impactful Resilient Infrastructure Science and Engineering (IRISE) consortium. This study utilizes a state-of-the-art large language model (LLM) to enhance text-based incident analysis sourced from OSHA's Severe Injury Reports (SIR) database

4.2 Co-PI

Dr. Lucio Salles de Salles, Assistant Professor, Department of Civil Engineering Technology, Environmental Management and Safety, Rochester Institute of Technology. For the past 10 years, Dr. Salles has worked in the field of transportation infrastructure engineering. He conducted research for several U.S. Departments of Transportation and has experience testing new technology directly in the field.

4.3 Research Assistants

Mason Smetana, Graduate Student, Department of Civil and Environmental Engineering, University of Pittsburgh. In 2022, Mason began his pursuit for a doctorate in advanced infrastructure under Dr. Khazanovich. He is currently conducting research pertaining to identifying major causes of accidents in highway construction and also classical finite element methods for the analysis of concrete pavements.

Dr. Igor Sukharev, Graduate Student, Department of Civil and Environmental Engineering, University of Pittsburgh. Dr. Sukharev earned a PhD in Electrical Engineering from Voronezh State Technical University, Russia. He has 20 years of experience as a Software Engineer and

Architect for various IT companies, including 15 years at IBM. Starting in 2023, he is pursuing a PhD in Civil Engineering under the supervision of Dr. Khazanovich.

4.4 Facilities

The University of Pittsburgh Center for Research Computing (Pitt CRC) has computing resources enabling hardware acceleration for LLMs development and experiments by providing access to the state-of-the-art GPU cluster (e.g., Nvidia A100 40/80GB GPUs).

5. Other Related Proposals

Dr. Khazanovich has proposed the development of a tool named 'pavementGPT,' which is an Artificial Intelligence (AI) model designed to process and generate natural language. This tool aims to provide answers to common questions in pavement engineering and construction. These questions include topics such as pavement design, mix design, specifications, best construction practices, pavement maintenance and rehabilitation, pavement management, pavement testing, and evaluation. The proposal for this project has been submitted for funding to the PITT IRISE consortium. It has received a recommendation for funding, starting from January 2024. If approved, it would create opportunities for synergistic activities, such as the selection of the LLM, as described in Stage 2, Task 1. These activities would benefit both projects.

Identifying Major Causes of Construction Accidents

Appendix D: LLM Results of Varying Cluster Numbers

1. Four Clusters

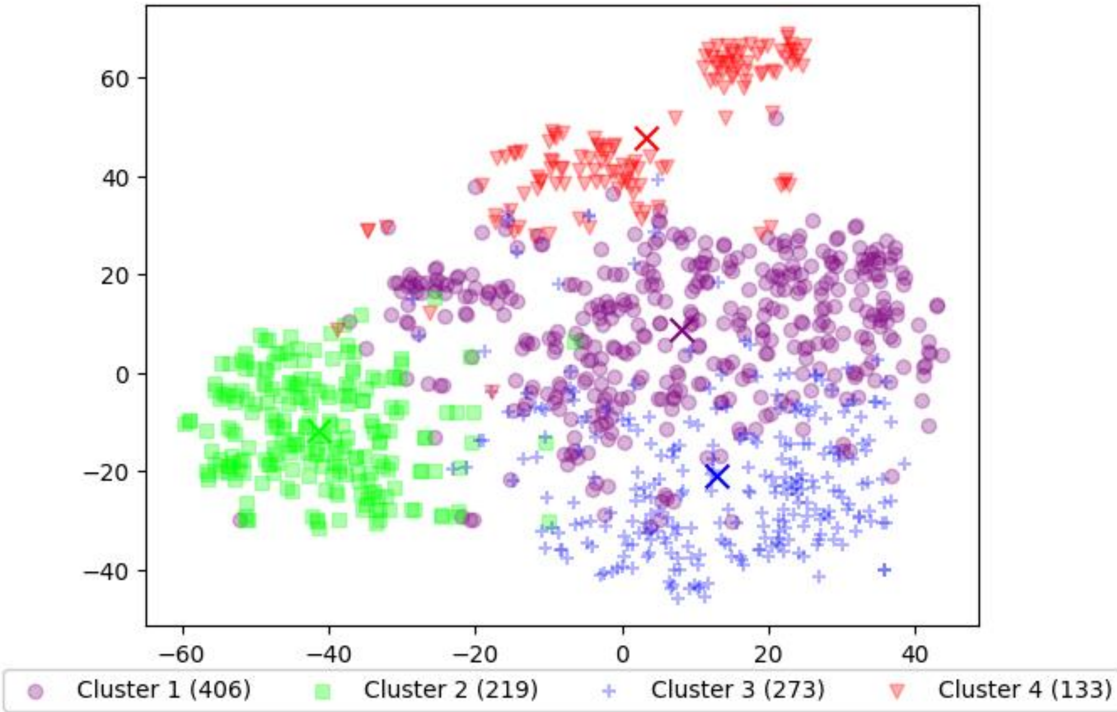

Figure 34: 4 clusters identified in road construction incidents (t-SNE)

Cluster 1 Summary:
All of these road construction incidents involve injuries to employees working on or near construction equipment or vehicles. The incidents also involve a variety of hazards, including falls, being struck by vehicles or equipment, being caught in machinery, and being injured by falling objects. These incidents highlight the importance of proper training, safety protocols, and equipment maintenance to prevent accidents and injuries on construction sites.

Cluster 1 top 10 major causes:
1. Employee's arm caught in conveyor belt while attempting to dislodge stuck material
2. Slip and fall from a bumper while checking water levels on a truck
3. Struck by two back wheels of a semi-trailer while repairing a filter fence
4. Struck by a semi-truck while performing milling work
5. Struck by a car that drove into the employee's work zone while pouring concrete
6. Slip and fall while getting out of a vehicle
7. Rolled over by a truck while hooking up wires beneath it
8. Roller rolled downhill and struck a parked work truck, causing injuries
9. Struck by a tractor-trailer that veered into the work zone while operating a truck behind a vehicle laying down road striping
10. Struck by a car while repairing/installing guardrails

Other causes include:
11. Struck by a piece of structural steel while inspecting demolition work
12. Lower right leg pinned and broken between a motorized concrete buggy and a fence

13. Dump truck backed into the employee, breaking the employee's leg while working on and near a concrete spacer
14. Fractured femur after falling out of a bulldozer and being run over by it
15. Fractured neck after being thrown out of the seat of a dozer
16. Struck by a security guard's vehicle while standing in a marked parking lot
17. Fractured skull after being hit in the head by a falling hopper gate
18. Legs run over by an asphalt roller
19. Foot bruised by a road grader
20. Fractured skull after being hit in the head by a pipe
21. Struck by a vehicle while cleaning out barricades inside a work zone
22. Struck by a food truck at the jobsite
23. Stabbed in the stomach by a homeless man on the jobsite
24. Fractured right hip and pelvic area after being backed over by a truck while working under the front of it
25. Laceration to left foot after it was caught between a flatbed trailer and a trackhoe
26. Struck by a third party vehicle in a construction zone
27. Intestinal injury after falling while cleaning the tracks of a bulldozer
28. Dislocated big toe after load shifted while picking up a steel cap
29. Struck by a vehicle while performing paving operations
30. Fractured vertebrae in lower back after bulldozer fell into an 8-foot pit
31. Broken right leg after being caught between a pickup truck and a dozer blade
32. Fractured femur and fibula after being struck by a motor vehicle while removing cones in a "closed lane"
33. Broken left ankle after a section of a trench caved-in while shoveling dirt around a gas main pipe
34. Fractures to left femur and both ankles after being pinned between a paving machine and a dump truck
35. Fractured right arm and kidney damage after being struck by a bucket that swung down from an excavator
36. Nose, knee, and wrist injuries after driving a gator vehicle into a block out
37. Shocked and burned after being in contact with a dump truck that contacted overhead electrical lines
38. Broken arm after arm was caught between rollers while using a hammer to clean accumulated material from a conveyor
39. Broken right foot, broken left collarbone, and burned right hand after being caught by a paving machine's front apron while cleaning its hopper with a shovel.

Records in cluster 1:
406 out of 1031 (39.38%)

Cluster 2 Summary:
All of these road construction incidents involve hand or finger injuries, many of which resulted in partial or complete amputations. These injuries were caused by a variety of equipment and tools, including excavators, air compressors, chop saws, concrete mixers, and forklifts. Many of these incidents also involved the employee's hand or finger getting caught in machinery or equipment, or being struck by a tool or object. These incidents highlight the importance of

proper training, safety protocols, and personal protective equipment to prevent hand and finger injuries in road construction.

Cluster 2 top 10 major causes:

1. Rotating equipment catching clothing or body parts
2. Striking body parts with hand tools
3. Crushing injuries from heavy equipment or machinery
4. Falling debris causing injuries
5. Pinching or amputating fingers while working with machinery or equipment
6. Injection injuries from ruptured hydraulic lines
7. Amputations from concrete mixers or other machinery
8. Partial amputations from heavy-duty jacks or other equipment
9. Getting caught in conveyor belts or other machinery
10. Pinching or amputating fingers while working with hand tools or equipment.

Records in cluster 2:

219 out of 1031 (21.24%)

Cluster 3 Summary:

All of the road construction incidents involve injuries to employees while performing construction work. The incidents involve falls from heights, being struck by falling objects, being caught in between objects, being struck by moving equipment, and other types of accidents. These incidents highlight the importance of implementing safety measures and providing proper training to employees to prevent such incidents from occurring.

Cluster 3 top 10 major causes:

1. Slips, trips, and falls
2. Struck by falling objects
3. Equipment failure
4. Collapse of structures
5. Improper use of equipment
6. Struck by moving equipment
7. Improper ladder use
8. Struck by heavy objects
9. Caught between objects
10. Electrical hazards

Records in cluster 3:

273 out of 1031 (26.48%)

Cluster 4 Summary:

All of these road construction incidents involve injuries or illnesses related to working in hot weather conditions, exposure to hot materials such as asphalt, or dehydration. Many of the incidents also involve burns from hot materials or equipment, such as welding equipment or hot liquid asphalt. It is important for road construction workers to take precautions to prevent heat-related illnesses and injuries, such as staying hydrated, taking breaks in shaded or air-conditioned areas, and wearing appropriate protective gear. Additionally, proper training and safety protocols should be in place to prevent accidents involving hot materials and equipment.

Cluster 4 top 10 major causes:

1. Tripping and falling while handling hot asphalt sealer cans
2. Heat exhaustion while working inside a tunnel pipe
3. Heat stress while performing bridge work in hot weather
4. Electrical burn due to wind blowing sheet metal into a powerline
5. Burns due to residual solvent fumes igniting while using welding equipment
6. Burns due to heated asphalt bubbling out of a pipe onto an employee
7. Burns due to hot liquid asphalt spraying onto an employee after a hose detached
8. Possible heart attack while shoveling snow
9. Dehydration while performing road work

Other causes include:

10. Stomach pain and hospitalization possibly due to heat stress while performing service work on paving equipment outdoors
11. Hospitalization for heat-related illness after welding pile splices and performing pile-driving work
12. Heat exhaustion while placing bricks and mesh for concrete slab pouring
13. Flash burns due to fumes/vapors igniting while fueling a push boat
14. Second degree burns due to tar/tack spraying onto an employee while cleaning out a tack truck
15. Dehydration and possible kidney failure
16. Flash vapor fire causing second degree burns while fueling a boat with gasoline
17. Hospitalization with stomach pains and possible heat-related injuries after working in the heat
18. Broken leg and burns due to falling on hot asphalt while paving a roadway
19. Hospitalization due to dehydration while finishing concrete
20. Hand and arm pain due to a fire caused by fuel spillage while refueling a job site crew boat
21. Burns to hand and shoulder due to contact with a live electrical line while holding onto a braided chocker line (wire)
22. Palm burn due to hot liquid asphalt shooting out of a pressurized pump while unclogging an asphalt distribution machine
23. Hospitalization for heat exhaustion and dehydration
24. Hospitalization for dehydration after performing highway construction
25. Hospitalization for heat exhaustion and dehydration after experiencing intense cramping while setting forms for pouring a concrete deck on a bridge
26. Third degree burns to legs due to gasoline catching fire after a powered saw exploded while cutting metal rebar
27. Second-degree burns due to 300-degree asphalt cement spraying out of a connection while unloading liquid asphalt cement from a semi-tanker
28. Second and third degree burns due to safety vest getting caught on an asphalt paver and being pulled in toward the auger
29. Burns to arms, chest, neck, and face due to an asphalt truck exploding while opening the door
30. Possible heat stroke causing an employee to become shaking and unresponsive after setting forms for concrete
31. Battery acid burns to the face while attempting to start an air compressor on the back of a service vehicle by boosting the battery with jumper cables
32. Hospitalization for heat exhaustion and dehydration after working on the deck of a barge

33. Hospitalization for dehydration after becoming dizzy while building forms along an interstate
34. Hospitalization for dehydration after feeling unwell while working outside on the bridge of a highway
35. Burns to arms and upper torsos due to an asphalt concrete unit exploding while preparing to unclog a jacketed hot oil line
36. Lacerations on the right palm due to abrasive water during a high-pressure washing operation while inspecting recently casted concrete segments
37. Hospitalization due to concussion and lacerations to the upper lip and left ear after an inflatable blow plug ruptured while being installed into a 30-inch ADS pipe
38. Cramps and hospitalization for heat stress symptoms.

Records in cluster 4:
133 out of 1031 (12.90%)

2. Five Clusters

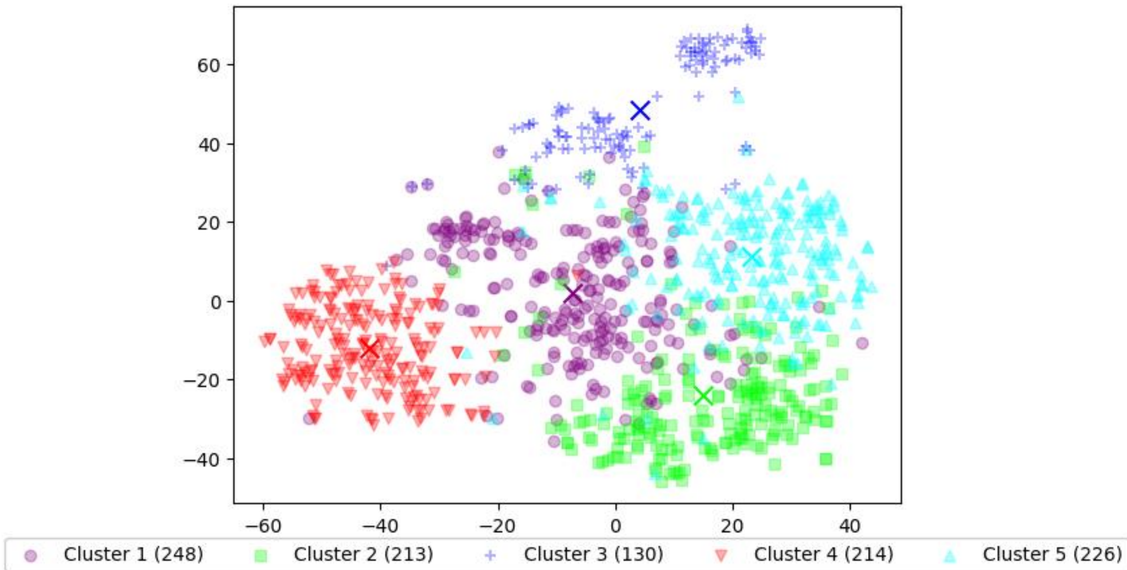

Figure 35: Five clusters identified in road construction incidents (t-SNE)

Cluster 1 Summary:
All of these road construction incidents involve injuries to employees while performing their job duties. The incidents involve a variety of equipment, including saws, excavators, and paving machines, and the injuries range from lacerations and fractures to amputations and more severe injuries requiring hospitalization and surgery. These incidents highlight the importance of proper training, equipment maintenance, and safety protocols to prevent accidents and injuries on road construction sites.

Cluster 1 top 10 major causes:
1. Equipment failure (cut-off saw wheel exploded)
2. Struck by equipment (lower leg run over by Weber machine)
3. Struck by falling object (sheet piling hammer fell on employee)
4. Equipment kickback (saw kicked back and cut employee's face)

5. Caught in/between equipment (counterweight slid and pinned employee's arm)
6. Struck by equipment (drill bounced and struck employee's foot)
7. Struck by equipment (track on milling machine ran over employee's foot)
8. Struck by falling object (concrete barrier fell and amputated employee's toes)
9. Struck by falling object (pillar fell and crushed employee's toes)
10. Struck by falling object (metal pile pocket fell and hit employee's lower body)

Other causes include:

11. Struck by falling object (concrete bucket struck employee's head)
12. Struck by equipment (grab bar on dozer struck employee's face)
13. Caught in/between equipment (auger caught employee's leg and ankle)
14. Struck by falling object (rock fell onto employee's foot)
15. Electrical contact (dump truck contacted power line)
16. Struck by equipment (skid steer loader struck employee's chest)
17. Struck by falling object (concrete debris fell and struck employee's head)
18. Caught in/between equipment (tree shear attachment caught employee's arm)
19. Struck by equipment (gator vehicle drove into block out)
20. Caught in/between equipment (roller pinned employee's leg)
21. Struck by equipment (excavator struck employee's leg and ankle)
22. Caught in/between equipment (trench box swung and crushed employee's foot)
23. Struck by object (bar struck employee's face)
24. Laceration (razor knife cut tendons in employee's knee)
25. Struck by equipment (grab handle ruptured cyst in employee's abdomen)
26. Struck by equipment (paver struck employee's leg)
27. Struck by equipment (excavator struck employee's leg and foot)
28. Caught in/between equipment (trench box fell and crushed employee)
29. Struck by equipment (excavator struck employee's chest)
30. Struck by object (chip of steel punctured employee's arm)
31. Caught in/between equipment (foot caught between trailer and trackhoe)
32. Laceration (circular saw landed on employee's hand)
33. Struck by equipment (tire caught employee's legs and pinned him to the ground)
34. Struck by equipment (backhoe ran over employee's leg)
35. Amputation (chop saw blade struck employee's hand)
36. Struck by equipment (concrete barrier rolled onto employee's foot and leg)
37. Amputation (milling machine ran over employee's foot and ankle)
38. Struck by equipment (excavator struck employee's leg)
39. Laceration (chop saw kicked back and struck employee's shoulder and forearm)
40. Puncture/fracture (spud wrench went through employee's foot)

Records in cluster 1:

248 out of 1031 (24.05%)

Cluster 2 Summary:

All of these road construction incidents involve employees being injured while working on or around heavy equipment, machinery, or structures. Many of the incidents involve falls from heights, being struck by falling objects, or being caught in between equipment or structures. These incidents highlight the importance of proper training, safety protocols, and equipment maintenance in preventing accidents and injuries on road construction sites.

Cluster 2 top 10 major causes:
1. Failure of crane equipment and rigging
2. Contact with energized electrical wires
3. Scaffold failure
4. Slip, trip, and fall from height
5. Tripping on debris or equipment
6. Fall from height while working on a flatbed trailer
7. Fall from height while creating a temporary work surface
8. Collapse of a bridge
9. Struck by equipment or materials during disassembly
10. Slip, trip, and fall on uneven or broken surfaces

Records in cluster 2:
213 out of 1031 (20.66%)

Cluster 3 Summary:
All of the road construction incidents listed involve some form of injury or illness to the employees working on the construction site. Many of the incidents involve heat-related illnesses or injuries, such as heat exhaustion or heat stroke, which can be common in outdoor construction work. Other incidents involve burns, falls, or other accidents that can occur when working with heavy machinery or hazardous materials. Overall, these incidents highlight the importance of proper safety training and equipment for employees working in road construction, as well as the need for ongoing monitoring and evaluation of safety practices on construction sites.

Cluster 3 top 10 major causes:
1. Burns from torch while cutting steel on elevated expressway structure
2. Heat stroke while shoveling and raking asphalt
3. Falling on hot asphalt while stepping off a paver
4. Heat stress while performing bridge work in hot weather
5. Pinned between a dump truck and a laydown asphalt paver while laying hot asphalt
6. Dehydration/acute kidney failure while prepping the ground for a concrete sidewalk
7. Burns from a torch that exploded on a paver
8. Heat exhaustion while placing bricks and mesh for concrete slab pouring
9. Dehydration while building forms along an interstate
10. Heat-related illness and loss of consciousness while welding pile splices and performing pile-driving work.

Other causes include:
11. Electric shock from overhead power lines while pouring concrete in drill shafts
12. Stomach pains and possible heat-related injuries after working in the heat
13. Dehydration and muscle cramping while installing bridge beams on a hot, humid day
14. Skin burns/abrasions from getting caught while spraying a tacky solution onto the conveyor belt of a dump truck
15. Flash burns from ignited fumes/vapors while fueling a push boat
16. Heat-related muscular injury after waking up feeling ill in the middle of the night
17. Burns from falling into hot asphalt after being assaulted by a coworker
18. Electric shock from overhead power lines while sealing cracks in the highway
19. Burns from hot liquid asphalt shooting out of a pressurized pump while unclogging an asphalt distribution machine

20. Burns from a flame shooting out of a sealer container while heating up sealer on a seal coating sprayer
21. Dehydration and feeling weak and dizzy while finishing concrete
22. Collapsed lung, contusions, and neck pain from falling off a paint truck while securing tank caps
23. Eye injury from a piece of asphalt flying into the eye while using a small air-driven chisel to remove hardened asphalt
24. Heat-related illness and cramping while working outdoors
25. Heat exhaustion while rigging and walking around a construction site
26. Burns from hot tar after slipping and falling to the ground while operating a tar truck on the highway
27. Battery acid burns to the face while attempting to start an air compressor on the back of a service vehicle
28. Third degree burns to the legs from gasoline catching fire after a powered saw exploded while cutting metal rebar
29. Heat stroke while back-filling dirt along a newly installed silt fence
30. Frostbite and minor burns from propane spewing from lines and flaring back while hooking up propane lines for heat at a construction site
31. Dehydration while working outside on the bridge of a highway
32. Heat stress while performing masonry work on a manhole
33. Severe burns to the hands, neck, and face from a fire caused by sparks from concrete sawing igniting gasoline vapors while mixing two-cycle fuel for a concrete saw
34. Dehydration after feeling ill following work at an asphalt plant
35. Heat exhaustion while cutting 2x4's on a bridge
36. Burns from an exploding asphalt truck door
37. Second and third degree burns from a fire/explosion while transferring diesel fuel from the middle tank of a fuel truck to the forward tank using a barrel pump.

Records in cluster 3:
130 out of 1031 (12.61%)

Cluster 4 Summary:
All of these road construction incidents involve hand or finger injuries, and many of them involve amputations or fractures. They also involve a variety of equipment and tasks, such as hooking up trailers, operating machinery, and performing maintenance. These incidents highlight the importance of proper training, safety protocols, and personal protective equipment to prevent hand and finger injuries in road construction.

Cluster 4 top 10 major causes:
1. Pinch point incidents while hooking up trailers or equipment
2. Amputations caused by drilling rig equipment
3. Falling objects, such as concrete barriers, causing foot or finger amputations
4. Forklift accidents resulting in hand and arm fractures
5. Pinch point incidents while removing or adjusting concrete barriers
6. Amputations caused by sealant machine equipment
7. Finger amputations caused by machinery maintenance or repair
8. Hand caught in paving machine accidents

9. Finger amputations caused by mobile tool trailer accidents
10. Finger amputations caused by sledgehammer or barricade accidents

Records in cluster 4:

214 out of 1031 (20.76%)

Cluster 5 Summary:

All of these road construction incidents involve employees being injured while performing their job duties. The incidents range from falls, being struck by vehicles, being pinned between vehicles, being struck by falling objects, and suffering allergic reactions. These incidents highlight the importance of implementing safety measures and training for employees working in road construction to prevent accidents and injuries.

Cluster 5 top 10 major causes:

1. Struck by a vehicle while performing paving operations
2. Fell from a truck while getting out, suffering a possible broken hip
3. Slipped and fell while checking water levels on a truck, suffering a broken wrist
4. Fell from a striper truck, suffering head trauma
5. Fell off a flatbed trailer platform while unloading a tractor-trailer, suffering a broken skull and possible brain bleeding
6. Shocked and burned while spotting a dump truck carrying fill material that contacted overhead electrical lines
7. Rolled over by a tractor while backing up, suffering a back injury
8. Struck by a box truck while working on a state highway, suffering collapsed lungs, head injuries, lacerations, and fractures
9. Struck by a vehicle mirror while picking up traffic cones
10. Impacted by another truck while parked in the safety zone, suffering a broken pelvis

Other causes include:

11. Struck by a cement truck while paving a highway road, resulting in a crushed leg
12. Struck by a passing driver while setting up cones to define a control zone, resulting in non-life threatening injuries
13. Struck by a concrete screed that was hit by a semi-trailer, resulting in a fractured leg and head laceration
14. Pinned between a public driver's car and the rear end of the company's pickup truck while aligning highway cones, resulting in the amputation of a leg and possible amputation of the other leg
15. Struck by a tri-axle asphalt truck, suffering multiple injuries including lacerations to the liver and lungs, crushed ribcage, and vertebrae
16. Struck by a vehicle while setting up a work zone on a state highway, suffering rib fractures and a punctured lung
17. Pinned underneath the wheels of a tag trailer while washing down a truck, resulting in crushed lower body and pelvis
18. Sustained cracked ribs and a punctured lung and spleen after a dump truck went into a hole in a snow-covered area
19. Suffered ruptured vertebrae after slipping and being hit by falling plywood stencils
20. Struck by a vehicle while flagging traffic, suffering a broken pelvis and ribs
21. Struck by an automobile while setting up a work zone, suffering multiple broken ribs, a broken pelvis, several broken vertebrae, and multiple internal injuries

22. Hospitalized with a concussion after slipping off the steps of a cone trailer and hitting head on pavement
23. Sustained a head injury after being struck by a falling tree branch while clearing trees for an install project
24. Partially run over by a water truck after losing control while driving to spray a newly chipped road, resulting in a broken leg and pelvis
25. Sustained a soft tissue injury after being struck by a vehicle while flagging traffic
26. Fractured ankle after landing wrong while exiting a flatbed trailer
27. Suffered a broken ankle after slipping and having foot run over by a trailer tire while picking up traffic cones
28. Laceration to the head after hitting it on the inside of a truck door when the truck tumbled over while dumping sand
29. Orbital bone fractures, a broken collar bone, increased cranial pressure, spinal fractures, and respiratory problems after being struck from behind by a tractor trailer while operating a roller along the shoulder of a road
30. Broken leg, concussion, and laceration to the lower back after being hit by a pickup truck with a trailer while surveying joints and concrete inside a construction zone
31. Hospitalized with a broken ankle, two fractured/chipped vertebrae, minor cuts to the head, loss of skin from the back of one hand, and a small brain bleed after being struck by a passing car while crossing the street within a work zone
32. Pinned under a truck and suffering head injuries and broken bones after the truck rolled over the employee while he was hooking up wires beneath it
33. Run over by a dump truck after slipping on the curb while loading it on a median at an intersection
34. Hospitalized with a head injury, fractured ribs, and a fractured femur after being thrown from a pickup truck that was struck by a tractor trailer
35. Broken legs and ribs after being struck by a private vehicle while setting up flagging stations
36. Fractured ankle and broken wrists after slipping off the tire of a dump truck
37. Allergic reaction after being stung by an insect while placing traffic cones at a construction site
38. Broken right leg and left ankle after being struck by a vehicle while directing traffic as a flagger
39. Fractures to the right shoulder, lumbar spine, left leg, right finger, and ribs after a fuel truck flipped on a construction access road
40. Head injuries after being struck by a vehicle while painting street lines in a middle lane work zone.

Records in cluster 5:

226 out of 1031 (21.92%)

3. Six Clusters

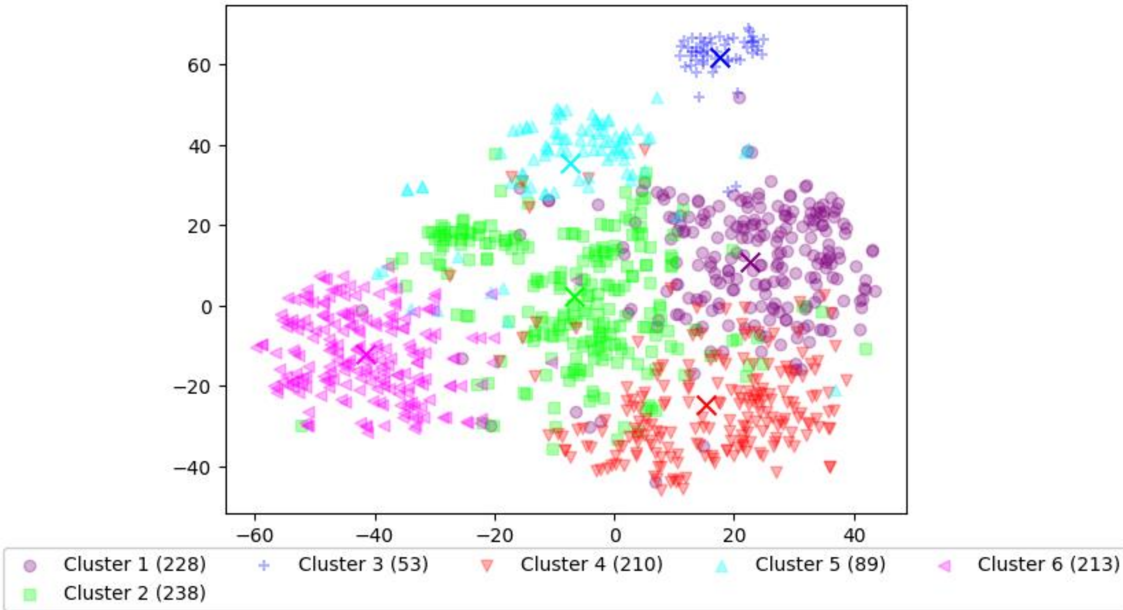

Figure 36: 6 clusters identified in road construction incidents (t-SNE)

Cluster 1 Summary:

All of these road construction incidents involve employees being injured while working in a construction zone. The incidents involve a variety of causes, including being struck by vehicles, falling, being caught between equipment, and being injured by equipment or materials. These incidents highlight the importance of proper safety protocols and training for employees working in construction zones, as well as the need for drivers to exercise caution and follow traffic laws when driving through work zones.

Cluster 1 top 10 major causes:

1. Vehicle intrusion into work zone
2. Drunk driving
3. Equipment malfunction
4. Vehicle intrusion into work zone
5. Struck by company vehicle
6. Caught between equipment and materials
7. Trip and fall
8. Slip and fall
9. Equipment malfunction
10. Equipment malfunction

Other causes include:

11. Vehicle collision with animal
12. Improper use of equipment
13. Slip and fall
14. Struck by vehicle
15. Struck by vehicle

16. Struck by vehicle
17. Struck by vehicle
18. Struck by vehicle
19. Struck by vehicle
20. Distracted driving
21. Equipment malfunction
22. Struck by falling object
23. Caught between equipment
24. Struck by falling object
25. Allergic reaction
26. Struck by vehicle
27. Slip and fall
28. Slip and fall
29. Struck by vehicle
30. Slip and fall
31. Struck by vehicle
32. Slip and fall
33. Vehicle intrusion into work zone
34. Slip and fall
35. Vehicle collision with parked truck
36. Slip and fall
37. Struck by vehicle
38. Equipment malfunction
39. Struck by vehicle
40. Struck by flying debris.

Records in cluster 1:

228 out of 1031 (22.11%)

Cluster 2 Summary:

All of these road construction incidents involve injuries to employees working on or near heavy equipment, machinery, or vehicles. The injuries range from fractures and lacerations to amputations and even fatalities. These incidents highlight the importance of proper training, safety protocols, and equipment maintenance to prevent accidents and injuries in road construction sites.

Cluster 2 top 10 major causes:

1. Slip and fall from loader
2. Struck by rubber track excavator
3. Crushed hand by concrete
4. Struck by publicly owned vehicle
5. Caught foot in rotomill track
6. Amputation from saw
7. Struck by pipe while stacking
8. Struck by concrete bucket
9. Struck by rolling clay/rock

Other causes include:
10. Pipe spool fell on foot
11. Tripped over pry bar and fell
12. Foot/leg run over by roadway tiller
13. Crushed by excavator swinging tail
14. Struck by falling pipe
15. Injured in gator vehicle accident
16. Foot caught between trailer and trackhoe
17. Fractured tibia and fibula from physical altercation
18. Pinned between paving machine and dump truck
19. Hand amputated by chop saw
20. Puncture to knee from bolt on paving machine
21. Struck by road grader
22. Struck by sheet piling hammer
23. Leg lacerated by roller machine
24. Slipped and fractured leg
25. Struck by excavator arm and bucket
26. ATV accident resulting in broken legs and amputation
27. Foot fractured by milling machine track
28. Anti-two-block device fell on employee
29. Struck in head by pipe
30. Struck by excavator bucket
31. Struck by paving machine
32. Struck by skid steer loader bucket
33. Leg pinched between motor grader and step
34. Struck by excavator bucket against trench box.

Records in cluster 2:
238 out of 1031 (23.08%)

Cluster 3 Summary:
All of these road construction incidents involve employees suffering from heat-related illnesses or injuries, such as heat exhaustion, dehydration, heat stroke, and cramping, while working in hot and humid conditions. These incidents highlight the importance of implementing effective heat stress prevention measures, such as providing adequate hydration, rest breaks, and shade, as well as training employees on the signs and symptoms of heat-related illnesses and how to prevent them.

Cluster 3 top 10 major causes:
1. Heat exhaustion and dehydration due to working in hot weather conditions
2. Heat stroke due to prolonged exposure to high temperatures
3. Heat stress while performing concrete work
4. Heat cramps and dehydration while stacking materials
5. Heat stroke while back-filling dirt
6. Dehydration due to working with concrete
7. Heat exhaustion while cutting 2x4's on a bridge
8. Heat exhaustion while rigging and walking around a construction site

9. Dizziness and loss of balance due to heat exposure while pouring concrete
10. Dehydration and possible kidney failure due to working in the heat.

Records in cluster 3:

53 out of 1031 (5.14%)

Cluster 4 Summary:

All of these road construction incidents involve some form of fall or impact injury. They also involve a variety of causes, including equipment failure, tripping hazards, collapsing structures, and electrical hazards. These incidents highlight the importance of proper safety protocols, training, and equipment maintenance in the construction industry.

Cluster 4 top 10 major causes:

1. Equipment failure (chain breaking)
2. Fall from height (working atop a horizontal whaler)
3. Tripping and falling (over the edge of a box scraper attachment)
4. Fall from height (stepping on the platform of a scaffolding system)
5. Struck by object (steel beam dropped unexpectedly)
6. Caught between objects (hydro platform truck rolled back and pinned employee)
7. Struck by object (steel beam slid and pinned employee)
8. Crush injury (foot wedged between crane load hook and block)
9. Fall from height (employee fell approximately 10 feet)
10. Crush injury (beam jostled loose and rolled over employee)

Records in cluster 4:

210 out of 1031 (20.37%)

Cluster 5 Summary:

All of these road construction incidents involve burns or electrical shocks to employees. The incidents also involve the use of heavy machinery, hot materials, and hazardous chemicals. Many of the incidents could have been prevented with proper safety training, equipment maintenance, and hazard identification and mitigation.

Cluster 5 top 10 major causes:

1. Torch cutting on a bolt
2. Cutting an abandoned cable
3. Vacuuming steel grit
4. Contact with overhead electric line
5. Slipping on wet road
6. Attempting to start an air compressor with jumper cables
7. Verbal altercation leading to assault and falling into hot asphalt
8. Pressurized pump causing hot liquid asphalt to shoot out
9. Rear of paving machine catching on fire
10. Puncturing an aerosol can of brake cleaner with a hot bolt or part of the frame pin

Other causes include:

11. Arm getting caught while spraying a tacky solution onto the conveyor belt of a dump truck
12. Electrical shock from possible arc flash
13. Hot thermoplastic coming through joints while heating up to open a pipe
14. Tack spray material landing on employee's shirt
15. Tripping and falling into hot tar or asphalt

16. Residual solvent fumes igniting while using welding equipment
17. Gasoline overflowing and igniting while refueling a water pump
18. Explosion of asphalt concrete unit while unclogging a jacketed hot oil line
19. Abrasive blasting material striking employee's leg
20. Falling while spreading hot asphalt
21. Tacky solution spraying onto employee
22. Foot getting pinched in a gate while cleaning an agitator truck
23. Minor burns from sparks in an auger hole
24. Electrical shock from overhead power line while pouring concrete in drill shafts
25. Fire while climbing the asphalt distributor tank
26. Explosion of drill casing used to load shot
27. Flash burns from ignited fumes/vapors while fueling a push boat
28. Burn to leg while fighting a fire at the shop
29. Lacerations from abrasive water during high-pressure washing operation
30. Burns from molten thermoplastic splattering onto employee
31. Burned while lighting a torch
32. Friction burns from arm getting caught in a conveyor belt
33. Second and third degree burns from safety vest getting caught on paver
34. Asphalt flying into employee's eye while using a chisel
35. Safety gate hitting employee in the head
36. Burned by heated asphalt bubbling out of a pipe
37. Splashed with hot asphalt while removing a hose
38. Falling on hot asphalt and breaking a leg.

Records in cluster 5:

89 out of 1031 (8.63%)

Cluster 6 Summary:

All of these road construction incidents involve hand or finger injuries, and most of them involve amputations or partial amputations of fingers. Many of these incidents also involve equipment or machinery, such as forklifts, cranes, and saws, and some involve heavy objects or materials, such as steel plates and concrete forms. Additionally, some of these incidents involve pinch points or getting caught between objects, while others involve cuts or lacerations. Overall, these incidents highlight the importance of proper training, safety protocols, and equipment maintenance in preventing hand and finger injuries in road construction work.

Cluster 6 top 10 major causes:

1. Hand caught between hitch and trailer during unhooking process
2. Pinched thumb between pipe and cab mounting bracket on forklift
3. Hand caught between cable and timber pile during crane operation
4. Hand caught between two steel plates while positioning steel plates
5. Hand caught in safe door while removing cash box
6. Finger caught in pulley and belt of compressor while repairing dump truck
7. Finger caught while changing tracks on a John Deere bobcat
8. Hand crushed while diagnosing a problem with a bump truck's steering
9. Finger caught between spud bar and truck body while chipping asphalt
10. Finger caught in manhole cover while attempting to lift it

Other causes include:

11. Finger caught between pipe and turnbuckle while adjusting concrete forms
12. Thumb lacerated by compressor fan while securing cover
13. Finger smashed by jackhammer against a structure
14. Finger amputated between ball of hitch and trailer during hooking process
15. Fingers caught and lacerated between averaging arm and milling machine
16. Finger amputated by concrete mixer while dislodging rock
17. Arm and hand fractured by falling fork attachment on boom forklift
18. Finger amputated by powered circular saw during wood cutting
19. Fingertips amputated by mobile tool trailer door
20. Hand pinned by tipped smooth drum roller
21. Hand caught between concrete barrier walls during installation
22. Finger lacerated by front end loader's bucket rotation
23. Finger fractured and soft tissue removed by face wire and kevel
24. Bone fractured by truck tailgate while cleaning
25. Fingertip amputated by catwalk on pavement marking vehicle
26. Fingers broken and fingertip amputated by lowering jumping jack into trench
27. Fingers amputated by crawler crane pulley shiv while inspecting
28. Femur fractured and ring finger lacerated by falling backhoe forks
29. Fingers amputated by crawler crane boom cable and sheave while lubricating
30. Finger partially amputated while moving a concrete form
31. Finger amputated and wrist fractured by unguarded drive pulley on asphalt silo
32. Multiple fingers amputated by chain while moving steel plate
33. Finger avulsion caused by air impact wrench slipping off nut
34. Thumb partially amputated by flange while bolting in pipe
35. Fingertip amputated by saw kickback while cutting lumber
36. Finger bitten by snake while removing it from work area
37. Finger injured by trailer hitch tongue during offloading of excavator
38. Finger smashed by T-post driver while driving post
39. Fingertip amputated by barricades while placing them in a row
40. Finger caught and amputated by auger handle while digging a hole for a sign.

Records in cluster 6:

213 out of 1031 (20.66%)

4. Seven Clusters

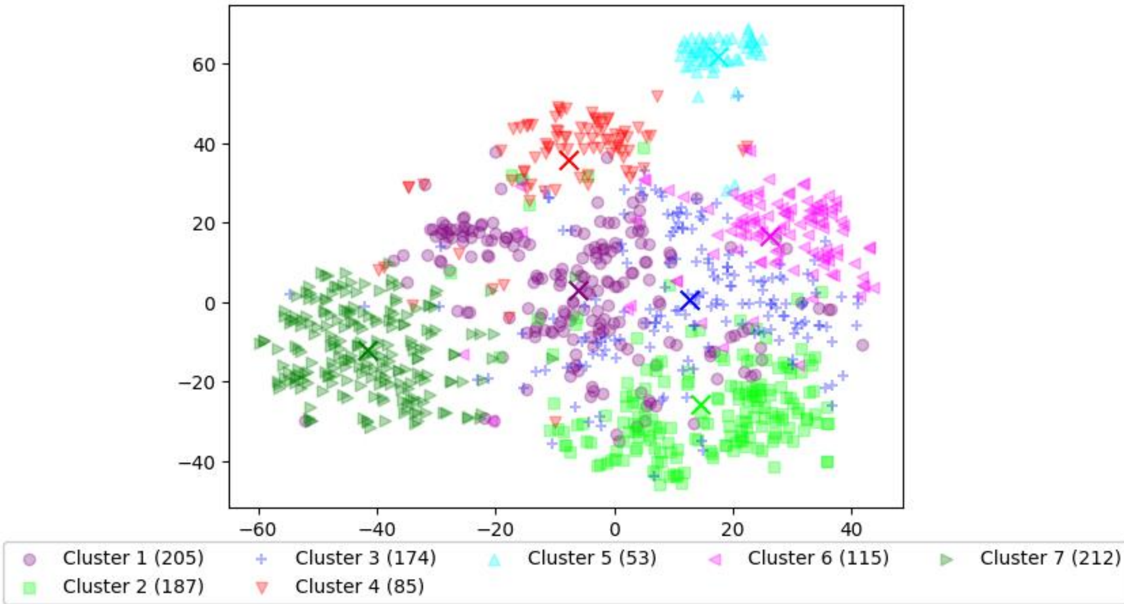

Figure 37: 7 clusters identified in road construction incidents (t-SNE)

Cluster 1 Summary:
All of these road construction incidents involve injuries to employees working on or near construction equipment or in excavations. The injuries range from broken bones to amputations and lacerations. Many of the incidents involve equipment malfunctions or operator error, while others involve hazards such as falling objects or collapsing excavations. These incidents highlight the importance of proper training, equipment maintenance, and hazard identification and mitigation in road construction safety.

Cluster 1 top 10 major causes:
1. Being struck by a piece of concrete barrier
2. Tripping and falling in a ditch
3. Being pinned between a roller and a paver
4. Being struck by a boulder
5. Being trapped in a collapsed excavation wall
6. Being struck by a dislodged drill bit
7. Being run over by an aggregate spreader
8. Tripping and falling over a pry bar
9. Being struck by a falling concrete pile
10. Being caught between an excavator and a tree

Other causes include:
11. Being struck by a road grader
12. Being struck by a moving concrete barrier
13. Being struck by an excavator bucket
14. Being struck by a barrel ring
15. Being injured by a saw

16. Being injured by a partner saw
17. Being injured by a portable saw
18. Being injured by a cut-off saw
19. Being crushed by a milling machine
20. Tripping over an elevated manhole
21. Being struck by a cast iron pipe
22. Being struck by a disconnected concrete pipe
23. Falling due to a broken chain
24. Being struck by a rubber track excavator
25. Being run over by an asphalt delivery truck
26. Being struck by a steel beam
27. Being run over by a road grader
28. Being struck by falling soil in a trench excavation
29. Being injured by a pipe saw
30. Having toes amputated by a milling machine drum
31. Being struck by a falling sheet piling hammer
32. Having a hand amputated by a chop saw
33. Being pinned between a ventilator wall and equipment
34. Being struck by a pipe attached to machinery
35. Having a leg broken by a motorized concrete buggy
36. Being run over by a large rubber-tired loader
37. Being struck by a falling tree section
38. Being struck by a milling machine

Records in cluster 1:

205 out of 1031 (19.88%)

Cluster 2 Summary:

All of these road construction incidents involve employees being injured while performing tasks related to construction work. The incidents involve a variety of causes, including falls, being struck by objects, being caught in between objects, and electrical shocks. Many of the incidents involve heavy equipment, such as cranes and scaffolding, and some involve working at heights. In all cases, the incidents resulted in injuries that required medical attention, including broken bones, fractures, and other serious injuries. These incidents highlight the importance of proper safety training and equipment, as well as the need for ongoing safety monitoring and risk assessment in road construction work.

Cluster 2 top 10 major causes:

1. Slip, trip, and fall hazards
2. Improper rigging and crane operation
3. Medical emergencies
4. Falling objects
5. Working at heights without proper fall protection
6. Entanglement hazards
7. Trench collapse
8. Scaffold collapse
9. Struck-by hazards
10. Electrical hazards

Records in cluster 2:
187 out of 1031 (18.14%)

Cluster 3 Summary:
All of these road construction incidents involve injuries or accidents that occurred while employees were performing their job duties. The incidents range from falls, being struck by vehicles or equipment, being electrocuted, and suffering from various fractures and injuries. These incidents highlight the importance of proper safety protocols and training for employees working in road construction to prevent accidents and injuries.

Cluster 3 top 10 major causes:
1. Lack of fall protection or safety measures for employees working on trucks or elevated platforms.
2. Failure to properly secure vehicles or equipment, leading to accidents and injuries.
3. Lack of proper communication and coordination between workers, leading to accidents involving moving vehicles.
4. Failure to clear snow and ice from work areas, leading to slip and fall accidents.
5. Lack of proper training and supervision for employees operating heavy machinery, leading to accidents and injuries.
6. Failure to properly secure loads or equipment, leading to accidents and injuries.
7. Lack of proper safety measures for employees working near or under heavy equipment, leading to accidents and injuries.
8. Failure to properly maintain equipment, leading to accidents and injuries.
9. Lack of proper safety measures for employees working near power lines, leading to electrical shocks and burns.
10. Lack of proper safety measures for employees working on or near elevated platforms, leading to falls and injuries.

Records in cluster 3:
174 out of 1031 (16.88%)

Cluster 4 Summary:
All of these road construction incidents involve burns or injuries caused by hot materials, chemicals, or electricity. Many of them also involve machinery or equipment malfunctions, improper handling of materials, or failure to follow safety procedures. These incidents highlight the importance of proper training, equipment maintenance, and adherence to safety protocols in road construction work.

Cluster 4 top 10 major causes:
1. Failure to close safety valve while unloading liquid asphalt cement from a semi-tanker
2. Battery acid burns due to improper use of jumper cables while starting an air compressor
3. Employee's fingers caught in a V-belt pulley while performing maintenance on a drum at an asphalt plant
4. Flash fire while attempting to open a gas cover/cap
5. Flame shot out while heating up sealer on a seal coating sprayer
6. Falling from the side of a paint truck while securing tank caps
7. Spark in an auger hole causing minor burns to the employee
8. Hot tar splashed onto the employee while helping to fill an asphalt tar kettle

9. Arm caught while spraying a tacky solution onto the conveyor belt of a dump truck
10. Insect sting while putting on gear to start welding

Other causes include:

11. Third degree burns on the back and lesser burns in the armpit area while torch cutting on a bolt
12. Hot asphalt splashed onto the employee's arms, torso, and neck while disconnecting an asphalt hose from a truck
13. Hot asphalt spilled on and burned the employee's left hand while sealing highway asphalt and tripping
14. Fire caused by sparks from concrete sawing while mixing two-cycle fuel for a concrete saw
15. Splashed with hot tar after a machinery malfunction
16. Stung numerous times by yellow jackets while operating a weed eater cleaning around guard rails
17. Slipped on tar and fell to the ground, contacting the 240-degree tar while operating a tar truck on the highway
18. Arm landed inside the cart, which was half full of asphalt while mopping hot tar
19. Hot oil splashed onto the employee while preparing to unload liquid asphalt from the tanker truck into the storage tank at the asphalt plant
20. Caught fire on the burners while fueling a tack distributor with gas
21. Electric shock from an overhead electric line while standing adjacent to an asphalt dump truck
22. Electrical shock from a possible arc flash while using a crane to load beams
23. Knocked unconscious inside the catch basin after an inflatable blow plug ruptured while installing it into a 30-inch ADS pipe
24. Pinched right forearm in a gate while cleaning his agitator truck with a hose
25. Fire in the rear of the paving machine while preparing to pave a road
26. Electric shock from an overhead electrical line while directing the operator of an excavator that made contact with the line
27. Flash vapor fire while investigating a clicking noise near the battery compartment while fueling a boat with gasoline
28. Hot tar burned 40 percent of the surface of the employee's hands after slipping on a wet road
29. Piece of asphalt flew into the employee's right eye while using a small air-driven chisel to remove hardened asphalt from the conveyor slats of a hot mix asphalt transfer device
30. Burns to the leg and arm from residual hot material left in the hose after a cavitation while disconnecting two adjoining 4" hoses from a slurry pump
31. Third degree burn to the right forearm between the wrist and elbow after hot rubber contacted the employee's skin while using a wheelbarrow to pour hot stone and rubber into a bridge plug joint
32. Flash fire caused by a positive wire from a battery coming into contact with a hydraulic hose while servicing a mill with a reported hydraulic leak
33. Hot liquid asphalt shot out and burned the palm of the employee's right hand while trying to unclog an asphalt distribution (spreading) machine
34. Falling into hot asphalt after tripping on the arm of a machine
35. Chemical burns on the left arm after oil remaining in the hose splashed back onto the employee while removing a hose from an asphalt truck
36. Chemical burns to the face due to a chemical reaction while mixing chemical products

37. Burns to the backs of the legs above the knees after gasoline overflowed out of the fuel tanks and ignited while refueling a water pump
38. Second and third degree burns to the body and arms after a fire/explosion occurred while transferring diesel fuel from the middle tank of a fuel truck to the forward tank using a barrel pump
39. Trouble breathing due to fumes produced from the mixture of bleach and toilet bowl cleaner while cleaning toilets at a rest stop
40. Burns on the hand, face, and upper torso after a fire occurred while climbing the asphalt distributor tank to take measurements.

Records in cluster 4:

85 out of 1031 (8.24%)

Cluster 5 Summary:

All of these road construction incidents involve employees suffering from heat-related illnesses or injuries, such as heat exhaustion, dehydration, heat stroke, and cramping, while working in hot and humid conditions. These incidents highlight the importance of implementing effective heat stress prevention measures, such as providing adequate hydration, rest breaks, and shade, as well as training employees on the signs and symptoms of heat-related illnesses and how to prevent them.

Cluster 5 top 10 major causes:

1. Heat exhaustion and dehydration due to working in hot weather conditions
2. Heat stroke due to prolonged exposure to high temperatures
3. Heat stress while performing concrete work
4. Heat cramps and dehydration while stacking materials
5. Heat stroke while back-filling dirt
6. Dehydration due to working with concrete
7. Heat exhaustion while cutting 2x4's on a bridge
8. Heat exhaustion while rigging and walking around a construction site
9. Dizziness and loss of balance due to heat exposure while pouring concrete
10. Dehydration and possible kidney failure due to working in the heat.

Records in cluster 5:

53 out of 1031 (5.14%)

Cluster 6 Summary:

All of the road construction incidents involve employees being struck by vehicles, either while working on the road or while setting up or taking down work zones. These incidents highlight the importance of proper traffic control measures and the need for drivers to be aware of their surroundings and exercise caution when driving through work zones. It is crucial for employers to provide adequate training and personal protective equipment to their employees to prevent such incidents from occurring.

Cluster 6 top 10 major causes:

1. Employee struck by a food truck - Lack of proper traffic control measures and signage, inadequate training of food truck drivers, failure to enforce safety protocols.
2. Roller rolling over employee's foot - Lack of proper safety equipment, inadequate training of employees, failure to enforce safety protocols.
3. Employee struck by a company truck - Lack of proper traffic control measures and signage,

inadequate training of company truck drivers, failure to enforce safety protocols.
4. Employee truck struck by a tractor-trailer - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of tractor-trailer drivers.
5. Employee hospitalized due to pain - Lack of proper safety equipment, inadequate training of employees, failure to enforce safety protocols.
6. Employee crashes into road barrier wall - Lack of proper safety equipment, inadequate training of employees, failure to enforce safety protocols.
7. Employee struck by a falling light pole - Lack of proper safety equipment, inadequate training of employees, failure to enforce safety protocols.
8. Employee struck by a drunk driver - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
9. Employee's legs pinned between a public driver's car and the company's pickup truck - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
10. Employee struck by a truck-mounted attenuator - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.

Other causes include:

11. Employee struck by a cement truck - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
12. Employee falls from a temporary platform - Lack of proper safety equipment, inadequate training of employees, failure to enforce safety protocols.
13. Employee struck by a motorist - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
14. Crew truck struck by an automobile - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
15. Employee performing flagging duties struck by a privately owned vehicle - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
16. Employee crushed between two vehicles - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
17. Employee struck by a motorist while flagging - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
18. Employee jumps off a moving truck - Lack of proper safety equipment, inadequate training of employees, failure to enforce safety protocols.
19. Employee struck by a motor vehicle in a construction zone - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
20. Employee struck by a dump truck - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
21. Employee struck by a falling tree branch - Lack of proper safety equipment, inadequate training of employees, failure to enforce safety protocols.
22. Employee struck by a semi-truck - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
23. Employee struck by a truck while flagging - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
24. Two employees struck by a publicly owned vehicle - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.

25. Employee struck by a vehicle while installing raised pavement markers - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
26. Employee struck by a vehicle while working on the side of the road - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.
27. Employee struck by an automobile while setting up a work zone - Lack of proper traffic control measures and signage, failure to enforce safety protocols, inadequate training of employees.

Records in cluster 6:

115 out of 1031 (11.15%)

Cluster 7 Summary:

All of these road construction incidents involve hand injuries, ranging from fingertip amputations to more severe injuries such as fractures and soft tissue damage. Many of these incidents involve equipment or machinery, such as cranes, jackhammers, and forklifts, while others involve manual tasks such as lifting and moving equipment or materials. In many cases, the incidents could have been prevented with proper safety measures such as guarding equipment, wearing appropriate personal protective equipment, and following proper procedures for handling equipment and materials.

Cluster 7 top 10 major causes:

1. Contact with moving cables or pulleys
2. Caught body parts in vehicle latches or mechanisms
3. Accidents involving jackhammers
4. Amputations caused by spud bars or other tools
5. Crushing injuries to fingers caused by heavy equipment or machinery
6. Fractures or soft tissue damage caused by pinching or crushing injuries
7. Amputations caused by doors or other equipment malfunctioning
8. Pinning or crushing injuries caused by tipping machinery or equipment
9. Amputations caused by hitching or unhitching trailers
10. Injuries caused by high-pressure equipment or machinery.

Records in cluster 7:

212 out of 1031 (20.56%)

5. Eight Clusters

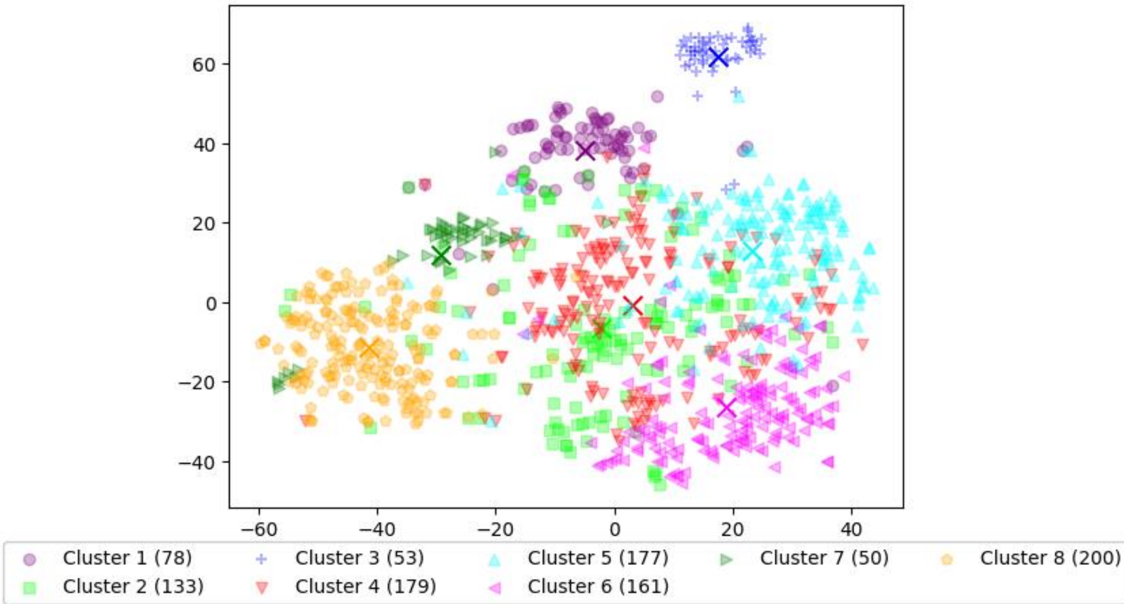

Figure 38: 8 clusters identified in road construction incidents (t-SNE)

Cluster 1 Summary:
All of these road construction incidents involve burns or injuries caused by heat, fire, or chemicals. Many of them also involve electrical hazards or equipment malfunctions. These incidents highlight the importance of proper training, safety protocols, and equipment maintenance in road construction work.

Cluster 1 top 10 major causes:
1. Burns from hot thermoplastic
2. Battery acid burns from jumpstarting a service vehicle
3. Concussion and lacerations from inflatable blow plug rupture
4. Burns from saw explosion and gasoline fire
5. Electric shock from dump truck contacting overhead electric line
6. Flash fire from battery wire contacting hydraulic hose
7. Burns from spilled hot asphalt sealer
8. Skin burns and abrasions from conveyor belt shock
9. Burns from power line contact with truck's light tower
10. Flash fire from residual solvent fumes during welding

Records in cluster 1:
78 out of 1031 (7.57%)

Cluster 2 Summary:
All of the road construction incidents involve employees being injured while performing their job duties. The incidents involve a variety of equipment, including trucks, cranes, excavators, and other heavy machinery. The injuries range from minor cuts and bruises to more serious injuries such as broken bones, head injuries, and amputations. Many of the incidents involve

employees being struck by equipment or objects, being caught in machinery, or being pinned between equipment and other objects. These incidents highlight the importance of proper training, equipment maintenance, and safety protocols in the road construction industry.

Cluster 2 top 10 major causes:

1. Tripping over equipment or machinery attachments
2. Being struck by falling objects or equipment
3. Contact with overhead power lines
4. Being pinned or run over by vehicles or equipment
5. Being caught between machinery or equipment
6. Being struck by moving machinery or equipment
7. Being struck by falling debris or materials
8. Being caught in machinery or equipment
9. Trench collapses or cave-ins
10. Hydraulic or mechanical failures of equipment or machinery

Records in cluster 2:

133 out of 1031 (12.90%)

Cluster 3 Summary:

All of these road construction incidents involve employees suffering from heat-related illnesses or injuries, such as heat exhaustion, dehydration, heat stroke, and cramping, while working in hot and humid conditions. These incidents highlight the importance of implementing effective heat stress prevention measures, such as providing adequate hydration, rest breaks, and shade, as well as training employees on the signs and symptoms of heat-related illnesses and how to prevent them.

Cluster 3 top 10 major causes:

1. Heat exhaustion and dehydration due to working in hot weather conditions
2. Heat stroke due to prolonged exposure to high temperatures
3. Heat stress while performing concrete work
4. Heat cramps and dehydration while stacking materials
5. Heat stroke while back-filling dirt
6. Dehydration due to working with concrete
7. Heat exhaustion while cutting 2x4's on a bridge
8. Heat exhaustion while rigging and walking around a construction site
9. Dizziness and loss of balance due to heat exposure while pouring concrete
10. Dehydration and possible kidney failure due to working in the heat.

Records in cluster 3:

53 out of 1031 (5.14%)

Cluster 4 Summary:

All of these road construction incidents involve employees suffering injuries to their feet, legs, or ankles. Many of the injuries are caused by heavy equipment or machinery, such as backhoes, trackhoes, and road graders. Other injuries are caused by falls, slips, or being struck by falling objects. These incidents highlight the importance of proper training, safety protocols, and equipment maintenance in road construction work.

Cluster 4 top 10 major causes:

1. Lack of proper training and supervision on the use of road graders.
2. Failure to establish and enforce proper safety protocols for approaching heavy equipment.
3. Inadequate safety measures for guiding and handling heavy objects such as concrete pipes and barriers.
4. Failure to properly secure and mark open manholes.
5. Lack of proper safety equipment and procedures for using power tools such as drills and jackhammers.
6. Inadequate safety measures for working around heavy equipment such as backhoes and paving machines.
7. Lack of proper safety equipment and procedures for working on elevated surfaces such as raised dump truck beds.
8. Inadequate safety measures for preventing slips, trips, and falls on the job site.
9. Failure to properly secure and store equipment and materials to prevent them from falling and causing injury.
10. Inadequate safety measures for working around moving equipment such as rubber-tired loaders and skid steers.

Records in cluster 4:

179 out of 1031 (17.36%)

Cluster 5 Summary:

All of the road construction incidents involve employees or workers who were injured or hospitalized while working in a road construction work zone. The incidents include being struck by a vehicle, falling, being hit by falling objects, being pinned between equipment, and being injured while performing various tasks such as painting, paving, or setting up cones. These incidents highlight the importance of safety measures and precautions in road construction work zones to prevent accidents and injuries.

Cluster 5 top 10 major causes:

1. Failure of drivers to obey traffic control devices and signs
2. Inadequate or improper use of personal protective equipment
3. Lack of proper training and supervision of employees
4. Failure to properly secure equipment and materials
5. Inadequate lighting and visibility in work zones
6. Distracted driving by motorists
7. Failure to establish and maintain proper work zone traffic control
8. Inadequate communication between workers and drivers
9. Unsafe work practices, such as working in areas not designated for workers
10. Failure to properly maintain equipment and vehicles used in the work zone.

Records in cluster 5:

177 out of 1031 (17.17%)

Cluster 6 Summary:

All of these road construction incidents involve employees suffering injuries or fractures due to falls, being struck by falling objects, or being caught in between objects. These incidents highlight the importance of proper safety measures and training for employees working in road construction to prevent such incidents from occurring.

Cluster 6 top 10 major causes:
1. Improper rigging and handling of heavy loads
2. Slips, trips, and falls on elevated surfaces
3. Falls from ladders and scaffolds
4. Contact with electrical power lines
5. Struck-by incidents involving falling objects
6. Falls on stairs and platforms
7. Equipment malfunctions and failures
8. Trips and falls on uneven surfaces
9. Failure to use fall protection
10. Caught-in/between incidents involving heavy equipment or materials.

Records in cluster 6:
161 out of 1031 (15.62%)

Cluster 7 Summary:
All of these road construction incidents involve the use of power tools or equipment, such as saws, grinders, and cut-off saws. In each case, the tool or equipment kicked back or malfunctioned, causing injury to the employee. These incidents highlight the importance of proper training, maintenance, and safety protocols when using power tools and equipment in road construction.

Cluster 7 top 10 major causes:
1. Improper use of chop saws
2. Improper use of construction saws
3. Improper use of telehandlers
4. Improper use of circular saws
5. Improper use of chainsaws
6. Lack of guarding on table saws
7. Improper use of angle grinders
8. Improper use of portable cut-off saws
9. Improper use of drift pins
10. Improper use of rivet busters

Records in cluster 7:
50 out of 1031 (4.85%)

Cluster 8 Summary:
All of these road construction incidents involve hand or finger injuries, and many of them involve amputations or partial amputations of fingers. These injuries are often caused by workers' hands being caught in machinery or equipment, or by being struck by objects. It is important for workers to receive proper training and use appropriate personal protective equipment to prevent these types of injuries. Employers should also ensure that machinery and equipment are properly maintained and guarded to prevent workers' hands from being caught or crushed.

Cluster 8 top 10 major causes:
1. Pinching injuries caused by heavy equipment or machinery
2. Fingertip amputations caused by doors or gates slamming shut
3. Finger amputations caused by steel plates or chains

4. Finger amputations caused by grooving machines or drill bits
5. Crush injuries caused by dump truck gates or loads shifting
6. Finger amputations caused by paver boxes or mechanical lifts
7. Hand injuries caused by concrete forms or spud bars
8. Finger amputations caused by aerial lifts or conveyor belts
9. Snake bites or infections resulting from finger wounds
10. Finger amputations caused by chain clamps or catwalks.

Records in cluster 8:

200 out of 1031 (19.40%)

6. Nine Clusters

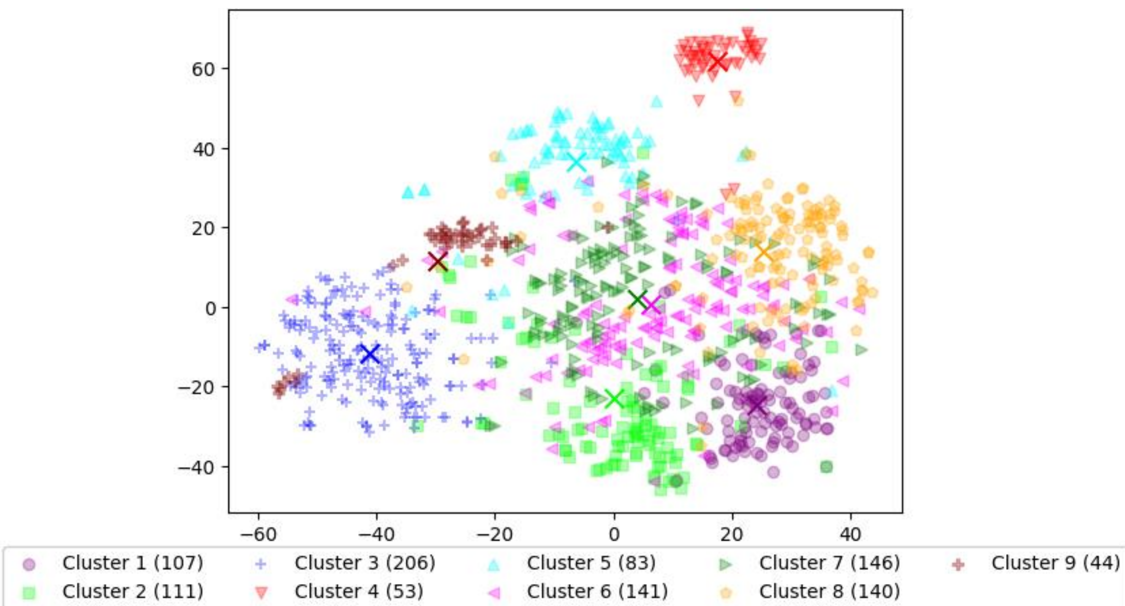

Figure 39: 9 clusters identified in road construction incidents (t-SNE)

Cluster 1 Summary:

All of the road construction incidents involve falls or falling objects, resulting in various injuries such as fractures, broken bones, and head injuries. Many of these incidents could have been prevented by implementing proper safety measures, such as wearing fall protection equipment, securing objects, and providing adequate training to employees.

Cluster 1 top 10 major causes:

1. Improper handling of materials and equipment
2. Climbing or working at heights without proper fall protection
3. Tripping or slipping on uneven surfaces or debris
4. Failure to secure or stabilize equipment or materials
5. Struck-by incidents involving heavy equipment or falling objects
6. Inadequate training or supervision
7. Failure to use proper personal protective equipment (PPE)
8. Working in confined spaces without proper precautions

9. Fatigue or physical limitations leading to loss of balance or falls
10. Failure to follow proper safety procedures and protocols.

Records in cluster 1:

107 out of 1031 (10.38%)

Cluster 2 Summary:

All of these road construction incidents involve employees being injured while performing various tasks related to road construction, such as lifting, welding, driving, assembling, and demolishing. The incidents also involve a variety of equipment, including cranes, forklifts, aerial lifts, and steel beams. In all cases, the employees suffered injuries ranging from fractures, lacerations, and electrical shocks to more severe injuries such as amputations and skull fractures. These incidents highlight the importance of proper safety training, equipment maintenance, and hazard identification and mitigation in road construction work.

Cluster 2 top 10 major causes:

1. Struck by crane or rigging equipment
2. Falling objects, such as MSE wall panels, rebar dowels, and angle iron
3. Forklift accidents, such as pallets falling on employees or fork attachments breaking and causing injuries
4. Slipping or tripping accidents, such as on dunnage or rebar
5. Falling I-beams or metal beams
6. Excavator accidents, such as buckets hitting employees or metal beams
7. Being pinned between objects, such as bridge beams or guillotine concrete breakers
8. Loose rigging equipment causing injuries, such as a steel I-beam striking and breaking an employee's leg
9. Struck by objects, such as pipe or a sheet piling hammer
10. Crane accidents, such as steel beams falling and striking employees or lifting straps breaking and causing outriggers to fall on employees.

Records in cluster 2:

111 out of 1031 (10.77%)

Cluster 3 Summary:

All of these road construction incidents involve hand or finger injuries, and many of them involve amputations or partial amputations of fingers. These incidents also involve a variety of equipment, including excavators, concrete pumps, circular saws, and trailers, among others. It is important for road construction workers to be trained on proper equipment use and safety procedures to prevent these types of incidents from occurring.

Cluster 3 top 10 major causes:

1. Spider bites or other insect bites
2. Metal slivers or other sharp objects causing infections or lacerations
3. Hands caught in rotating machinery or equipment
4. Pinching injuries from gates, levers, or other moving parts
5. Amputations or fractures from heavy objects falling or shifting
6. Pinching or amputations from aerial lifts or other elevated equipment
7. Fingers caught in grooving machines or other cutting equipment
8. Amputations or fractures from heavy objects or equipment falling or shifting

9. Fingers caught between steel plates or other heavy objects
10. Fingers caught in machinery or equipment, resulting in amputations or fractures.

Records in cluster 3:

206 out of 1031 (19.98%)

Cluster 4 Summary:

All of these road construction incidents involve employees suffering from heat-related illnesses or injuries, such as heat exhaustion, dehydration, heat stroke, and cramping, while working in hot and humid conditions. These incidents highlight the importance of implementing effective heat stress prevention measures, such as providing adequate hydration, rest breaks, and shade, as well as training employees on the signs and symptoms of heat-related illnesses and how to prevent them.

Cluster 4 top 10 major causes:

1. Heat exhaustion and dehydration due to working in hot weather conditions
2. Heat stroke due to prolonged exposure to high temperatures
3. Heat stress while performing concrete work
4. Heat cramps and dehydration while stacking materials
5. Heat stroke while back-filling dirt
6. Dehydration due to working with concrete
7. Heat exhaustion while cutting 2x4's on a bridge
8. Heat exhaustion while rigging and walking around a construction site
9. Dizziness and loss of balance due to heat exposure while pouring concrete
10. Dehydration and possible kidney failure due to working in the heat.

Records in cluster 4:

53 out of 1031 (5.14%)

Cluster 5 Summary:

All of these road construction incidents involve burns or chemical reactions that caused harm to the employees. The incidents also occurred while the employees were performing various tasks related to road construction, such as asphalt paving, fueling equipment, cleaning machinery, and using tools like torches and saws. Many of the incidents also involved flammable materials, such as gasoline and hot tar, which can easily ignite and cause serious injuries. Overall, these incidents highlight the importance of proper safety training, equipment maintenance, and hazard identification and mitigation in road construction work.

Cluster 5 top 10 major causes:

1. Abrasive blasting material striking employee's leg
2. Battery acid burns from attempting to start an air compressor
3. Flash fire while attempting to open a gas cover/cap
4. Hot oil spraying onto employee's hand and arm while cleaning a clogged spray bar
5. Severe burns from hot asphalt tar kettle line failure
6. Electrical burn from truck's light tower striking overhead power lines
7. Minor burns from sparks in an auger hole
8. Electric shock from electricity traveling through the vehicle and down the wand while sealing cracks in the highway
9. Skin burns/abrasions from arm getting caught while spraying a tacky solution onto the

conveyor belt of a dump truck
10. Burns from a flame shooting out while heating up sealer on a seal coating sprayer

Other causes include:

11. Burns from a tack distributor catching fire on the burners while being fueled
12. Burns from residual hot material left in the hose after a cavitation splashing onto employee while disconnecting two adjoining 4" hoses from a slurry pump
13. Difficulty breathing due to fumes produced from the mixture of bleach and toilet bowl cleaner while cleaning toilets at a rest stop
14. Burns from molten thermoplastic splattering onto employee after a vehicle entered the work zone and struck the thermoplastic handliner
15. Fire caused by sparks from concrete sawing while mixing two-cycle fuel for a concrete saw
16. Burns from a butane torch bending, being punctured, and blowing up after being closed in the doors of a paver
17. Second-degree burns to the forearm and hand from tripping backwards over the mop cart while mopping hot tar
18. Fingers being caught in a V-belt pulley while performing maintenance on a drum at an asphalt plant
19. Burns from gasoline overflowing out of the fuel tanks and igniting while refueling a water pump
20. Burns on both ears, the front of the face, and neck from lighting a torch while cutting steel on an elevated expressway structure
21. Burns from the rear of the paving machine catching on fire while warming up
22. Second and third degree burns to the hands and face from hot asphalt flowing from a partially raised dump truck bed onto an employee while using a skid-steer to clean up debris
23. Second degree burns to the right and left forearms from a flash vapor fire occurring while investigating a clicking noise near the battery compartment while fueling a boat with gasoline
24. Third-degree burns to the arms, torso, and neck from hot asphalt splashing onto an employee while disconnecting an asphalt hose from a truck
25. Burns to the left hand from hot asphalt spilling on and burning an employee while sealing highway asphalt and tripping
26. Burns from hot tar splashing onto an employee after a machinery malfunction
27. Palm of the right hand being burned from hot liquid asphalt shooting out while trying to unclog an asphalt distribution (spreading) machine
28. Third degree burns on the back and lesser burns in the armpit area while torch cutting on a bolt
29. Flash burns from fumes/vapors being ignited by a spark from the battery post while assisting another employee with fueling a push boat
30. Bruises and internal bleeding to both upper legs from being pinned between a laydown asphalt paver controls and a subcontractor dump truck
31. Chemical burns to the left arm from oil remaining in the hose splashing back onto an employee while servicing a mill with a reported hydraulic leak
32. Burns to the upper body from a flash fire caused by a positive wire from a battery coming into contact with a hydraulic hose while mixing chemical products
33. Allergic reaction to yellow jacket stings while operating a weed eater cleaning around guard rails
34. Second and third degree burns to the body and arms from a fire/explosion while transferring

diesel fuel from the middle tank of a fuel truck to the forward tank using a barrel pump
35. Chemical burns to the face from a chemical reaction while mixing chemical products
36. Burns on the hand, face, and upper torso from a fire occurring while climbing the asphalt distributor tank to take measurements
37. Burns from hot tar kettle splashing onto employee's hands while slipping on a wet road
38. Third degree burns to the legs from gasoline catching fire after a saw exploded while cutting metal rebar on the Staten Island Expressway (Exit 13).

Records in cluster 5:

83 out of 1031 (8.05%)

Cluster 6 Summary:

All of these road construction incidents involve employees who were injured while performing their job duties. The incidents range from being struck by equipment or vehicles, being caught in between machinery, falling from heights, being electrocuted, and suffering from other types of injuries. These incidents highlight the importance of proper safety training, equipment maintenance, and following safety protocols to prevent accidents and injuries on road construction sites.

Cluster 6 top 10 major causes:

1. Loose equipment during transport
2. Tractor rollover
3. Struck by a vehicle
4. Impaled by broken equipment
5. Struck by falling debris
6. Struck by a vehicle from behind
7. Fall from height
8. Pinning between vehicles
9. Struck by equipment or debris
10. Caught in machinery

Records in cluster 6:

141 out of 1031 (13.68%)

Cluster 7 Summary:

All of the road construction incidents involve injuries to employees, ranging from minor injuries to severe injuries such as amputations and fractures. The incidents also involve various types of equipment, including cement trucks, milling machines, backhoes, and dump trucks. In many cases, the injuries were caused by the employee being struck by or caught in the equipment, or by the equipment running over their foot or leg. Additionally, some incidents involved employees slipping, tripping, or falling while working on or near the equipment. Overall, these incidents highlight the importance of proper training, safety protocols, and equipment maintenance in preventing injuries on road construction sites.

Cluster 7 top 10 major causes:

1. Struck by a cement truck
2. Spiral fracture while turning around
3. Struck by a piece of structural steel
4. Stumbled and fell due to a broken chain
5. Crushed ankle by a milling machine

6. Run over by an asphalt delivery truck
7. Caught and pulled into a deck finishing machine
8. Fractured leg/ankle due to uneven slope
9. Foot run over by a road grader
10. Fractured kneecap due to tripping over a concrete bumper

Other causes include:

11. Foot run over by a paver
12. Fractured fibula and tibia due to falling from a lowboy
13. Foot broken by a traffic cone laying vehicle
14. Foot broken by a mini-excavator
15. Struck and broken leg by falling soil in a trench excavation
16. Leg run over by a ready-mix truck
17. Amputated digits due to being struck by a concrete barrier
18. Broken leg and ankle due to being caught in an auger
19. Fractured leg due to a steel plate falling on it
20. Ankle run over by a truck
21. Dislocated hip due to losing footing on a string line
22. Open fracture due to being struck by an excavator
23. Laceration requiring surgery due to falling on rebar
24. Back injury and potential pelvic fracture due to being pinned by equipment
25. Foot punctured and fractured due to using a spud wrench
26. Broken tibia due to falling into an open manhole
27. Foot crushed between a trench box and sewer inlet
28. Leg broken by a skid steer
29. Foot injured and requiring surgery due to being run over by an aggregate spreader
30. Puncture to the knee from a bolt protruding on a paving machine
31. Leg run over by a Weber machine
32. Leg broken by a skid steer
33. Crushing injury to foot while unloading steel
34. Knee laceration, torn tendon, and punctured knee cap due to tripping and falling on broken concrete
35. Leg injuries due to a backhoe running over it
36. Severe lacerations on foot due to milling machine running over it
37. Leg broken due to being struck by a dump truck
38. Amputated toes due to milling machine catching foot
39. Severely lacerated leg due to being pinned between a roller and paver
40. Leg amputated at the knee due to being struck by an excavator.

Records in cluster 7:

146 out of 1031 (14.16%)

Cluster 8 Summary:

All of the road construction incidents involve employees or workers who were injured while performing their duties in a road construction work zone. The incidents **include** being struck by vehicles, falling, being hit by objects, and suffering from allergic reactions. These incidents highlight the importance of safety measures and precautions in road construction work zones to prevent accidents and injuries.

Cluster 8 top 10 major causes:

1. Failure to properly mark and delineate work zones
2. Inadequate traffic control measures
3. Distracted driving by motorists
4. Failure to wear high-visibility clothing by workers
5. Lack of proper training for workers
6. Poor lighting in work zones
7. Failure to properly secure equipment and materials
8. Slippery or uneven surfaces in work zones
9. Intoxicated driving by motorists
10. Inadequate supervision of workers.

Records in cluster 8:

140 out of 1031 (13.58%)

Cluster 9 Summary:

All of these road construction incidents involve employees using various types of saws or cutting tools, and in each case, the saw or tool kicked back or malfunctioned, causing injury to the employee. These incidents highlight the importance of proper training, safety equipment, and maintenance of tools and equipment to prevent accidents and injuries on construction sites.

Cluster 9 top 10 major causes:

1. Kickback of a cutoff saw
2. Kickback of a chainsaw
3. Falling object from a chop saw
4. Grinding wheel explosion
5. Kickback of a construction saw
6. Slip of a razor knife
7. Unguarded table saw
8. Kickback of a granite curb saw
9. Kickback of a PVC pipe saw
10. Loss of control of a concrete paving saw

Records in cluster 9:

44 out of 1031 (4.27%)

7. Ten Clusters

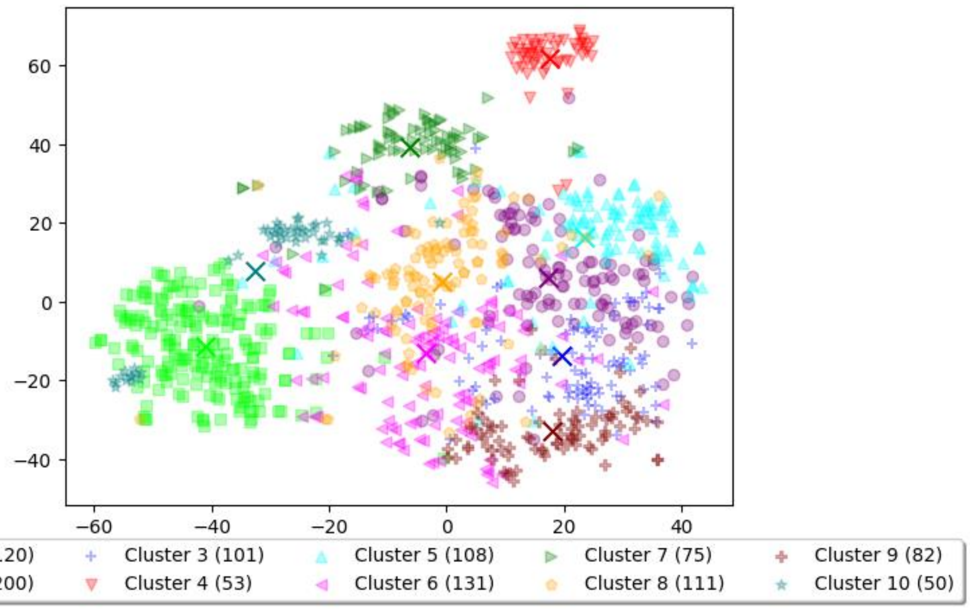

Figure 40: 10 clusters identified in road construction incidents (t-SNE)

Cluster 1 Summary:
All of the road construction incidents involve employees who were injured while performing their job duties. The incidents range from falls, being caught between equipment, being struck by equipment, and being involved in motor vehicle accidents. Many of the incidents involve heavy equipment such as rollers, dump trucks, and cranes. The incidents also highlight the importance of proper training, safety equipment, and following safety protocols to prevent accidents and injuries on road construction sites.

Cluster 1 top 10 major causes:
1. Heart attack while driving a concrete mixer
2. Caught between two asphalt rollers
3. Foot injury from a falling spring lock handle
4. Caught between a buggy and a delivery truck
5. Roller tipping over and injuring the employee's face
6. Operator going over an embankment with a dual-drummed roller
7. Falling out of a flatbed truck and suffering injuries
8. Slipping off the steps of a cone trailer and hitting head on pavement
9. Struck by a box truck while working
10. Pinning of an employee against the control panel by a twisted seat of a paver

Other causes include:
11. Roller falling off a flatbed trailer and breaking the employee's femur
12. Compactor truck tipping over and causing an amputation injury
13. Leg injury from getting stuck between the ground and the vehicle while working as a coner
14. Falling from the tire of a front-end loader while performing maintenance
15. Falling approximately 4.5 feet from a flatbed truck while unloading

16. Broken pelvis from being impacted by another truck while parked in the safety zone
17. Falling from a striper truck and suffering head trauma
18. Falling from the top of a hot oil tanker trailer while attempting to remove the lid
19. Rolling over the edge of the highway embankment while moving a shoulder widener paving machine
20. Caught between crane mats and an excavator while loading a trailer
21. Fractured ankle from jumping down from the exit area of a crane
22. Back and pelvis injury from roller rolling down the hill
23. Hand injury from being pinched between the tailgate and the vehicle frame
24. Fractured arm from falling from the flatbed of a truck
25. Head laceration and broken collarbone from tripping over the edge of a box scraper attachment
26. Thigh injury from getting pinched between a trailer and a pickup truck
27. Multiple injuries including lacerations to liver and lungs, crushed ribcage, and vertebrae from being struck by a tri-axle asphalt truck
28. Shock and burns from being shocked while touching a dump truck that contacted overhead electrical lines
29. Broken leg and pelvis from losing control of a water truck and being partially run over
30. Fractured ribs and burned leg from roller machine rolling down a hillside
31. Fractured T-12 vertebrae from a dump truck tipping over
32. Head laceration, injured elbow, and three broken ribs from falling off a road milling machine
33. Head trauma from falling while tightening a loose tarp over the load of a dump truck
34. Back injury from a tractor rolling onto its side
35. Rib fractures and punctured lung from being struck by a loose headache rack on a forklift
36. Injuries to the head, face, mouth, and body trauma from being struck by an 18-wheeler while sitting in a TMA truck
37. Back vertebrae injury from an asphalt plant component falling and hitting the lift platform
38. Four broken ribs and a hematoma from slipping and falling while getting out of a delivery truck
39. Fractured pelvis from being pinned between a truck's bumper and a concrete batch plant
40. Leg injuries from being backed into by a company pickup truck.

Records in cluster 1:

120 out of 1031 (11.64%)

Cluster 2 Summary:

All of these road construction incidents involve hand injuries, with many resulting in finger amputations. The injuries occurred while employees were performing various tasks such as repairing equipment, lifting heavy objects, operating machinery, drilling, pouring concrete, and removing barriers. Many of the incidents involved the employee's hand being caught or crushed between objects, while others involved puncture wounds or lacerations. These incidents highlight the importance of proper training, personal protective equipment, and safe work practices to prevent hand injuries in road construction.

Cluster 2 top 10 major causes:

1. Improper handling of equipment and machinery
2. Lack of proper grip or control of equipment
3. Puncture wounds from hydraulic couplers or other sharp objects

4. Lacerations from machinery or equipment
5. Fingers caught between loader bucket and attachments
6. Being struck by dump trucks or other vehicles
7. Amputation from unkinking chains or using sledgehammers
8. Fingers caught in grooving machines or other machinery
9. Fingers caught in guardrails or other mechanical lifts
10. Fingers caught between cable and timber pile or other objects

Records in cluster 2:

200 out of 1031 (19.40%)

Cluster 3 Summary:

All of these road construction incidents involve falls or slips, resulting in various types of injuries such as broken bones, torn ligaments, and lacerations. Many of these incidents also involve employees working at heights, such as on ladders or scaffolds, or in excavated pits. These incidents highlight the importance of proper safety measures and training for employees working in road construction to prevent falls and other accidents.

Cluster 3 top 10 major causes:

1. Lack of fall protection or safety measures on conveyors
2. Uneven or unstable terrain causing slips and falls
3. Lack of fall protection or safety measures on formwork walls
4. Inadequate or unstable temporary platforms
5. Poorly marked or elevated manholes
6. Improper ladder use or lack of fall protection
7. Inadequate or unstable finishing platforms
8. Lack of fall protection or safety measures on concrete catcher baskets
9. Poorly maintained or marked ditches
10. Lack of fall protection or safety measures on retaining walls

Records in cluster 3:

101 out of 1031 (9.80%)

Cluster 4 Summary:

All of these road construction incidents involve employees suffering from heat-related illnesses or injuries, such as heat exhaustion, dehydration, heat stroke, and cramping, while working in hot and humid conditions. These incidents highlight the importance of implementing effective heat stress prevention measures, such as providing adequate hydration, rest breaks, and shade, as well as training employees on the signs and symptoms of heat-related illnesses and how to prevent them.

Cluster 4 top 10 major causes:

1. Heat exhaustion and dehydration due to working in hot weather conditions
2. Heat stroke due to prolonged exposure to high temperatures
3. Heat stress while performing concrete work
4. Heat cramps and dehydration while stacking materials
5. Heat stroke while back-filling dirt
6. Dehydration due to working with concrete
7. Heat exhaustion while cutting 2x4's on a bridge
8. Heat exhaustion while rigging and walking around a construction site

9. Dizziness and loss of balance due to heat exposure while pouring concrete
10. Dehydration and possible kidney failure due to working in the heat.

Records in cluster 4:

53 out of 1031 (5.14%)

Cluster 5 Summary:

All of the road construction incidents involve employees being struck by motor vehicles or equipment while working in a construction zone. The incidents also resulted in various injuries, ranging from broken bones to head injuries and hospitalizations. These incidents highlight the importance of implementing proper safety measures and training for employees working in road construction zones to prevent accidents and injuries.

Cluster 5 top 10 major causes:

1. Motor vehicles entering the work zone and striking employees
2. Semi-trucks making right turns and striking employees performing milling work
3. Vehicles striking employees performing paving operations
4. Employees being struck by vehicles while flagging traffic
5. Employees tripping and falling while crossing the road to retrieve flagger signs
6. Vehicles striking employees who are flagging traffic in a highway work zone
7. Dump trucks striking employees
8. Employees crashing into road barriers while operating vehicles to move traffic control drums
9. Private vehicles striking employees while setting up flagging stations
10. Employees experiencing pain or being hospitalized due to incidents on the job site.

Other causes include:

11. Food trucks striking employees
12. Employees being struck by hatch doors of vehicles while conducting equipment and vehicle maintenance
13. Vehicles involved in high-speed police pursuits entering work zones and striking employees
14. Vehicles swerving around stopped cars and striking employees who are flagging traffic
15. Light poles falling and striking employees
16. Passengers vehicles entering work zones and striking employees
17. Employees making contact with overhead powerlines
18. SUVs driving onto the shoulder and striking employees
19. Road sweeping vehicles striking employees
20. Employees being struck by company trucks.

Records in cluster 5:

108 out of 1031 (10.48%)

Cluster 6 Summary:

All of these road construction incidents involve employees being injured while performing their job duties. The incidents involve a variety of equipment, including cranes, bulldozers, conveyor belts, excavators, and backhoes. The injuries range from fractures and lacerations to amputations and head injuries. Many of the incidents involve employees being struck by equipment or caught in machinery. These incidents highlight the importance of proper training, safety protocols, and equipment maintenance in preventing workplace injuries in road construction.

Cluster 6 top 10 major causes:

1. Improper rigging and crane operation
2. Equipment failure and operator error
3. Caught in machinery
4. Pinch point accidents
5. Struck by falling objects
6. Electrical hazards
7. Contact with heavy equipment
8. Trench collapse
9. Struck by vehicle
10. Slip, trip, and fall accidents

Records in cluster 6:

131 out of 1031 (12.71%)

Cluster 7 Summary:

All of these road construction incidents involve burns or injuries caused by fire, hot materials, or chemicals. They also involve a variety of tasks and equipment, including fueling vehicles, mixing fuel, heating materials, welding, and using machinery. These incidents highlight the importance of proper training, safety protocols, and personal protective equipment to prevent accidents and injuries in road construction work.

Cluster 7 top 10 major causes:

1. Flash vapor fire caused by investigating clicking noise near battery compartment while fueling a boat with gasoline.
2. Fire caused by sparks from concrete sawing igniting gasoline vapors while mixing two-cycle fuel for a concrete saw.
3. Flame shot out while heating up sealer on a seal coating sprayer, burning the employee's left hand and forearm.
4. Battery acid burns to the face while attempting to start an air compressor on the back of a service vehicle by boosting the battery with jumper cables.
5. Third degree burns on the back and lesser burns in the armpit area while torch cutting on a bolt.
6. Chemical reaction while mixing chemical products causing chemical burns to the face.
7. Slip and fall on hot tar while operating a tar truck on the highway.
8. Sparks from grinding a weld causing shirt to catch on fire and resulting in second and third degree burns from the mid torso to the upper chest area.
9. Hot asphalt cement sprayed out of the connection and struck the employee while unloading liquid asphalt cement from a semi-tanker, causing second-degree burns to the left and right forearm, left thigh, lower stomach, and right shin toward the ankle.

Other causes include:

10. Residual solvent fumes igniting while using welding equipment, resulting in hospitalization for burns.
11. Rupture of an inflatable blow plug into a 30-inch ADS pipe causing a concussion and lacerations to the upper lip and left ear, requiring hospitalization.
12. Hot asphalt splashing onto the employee's arms, torso, and neck, causing third-degree burns while disconnecting an asphalt hose from a truck.
13. Allergic reaction to yellow jacket stings while using a weed eater to clean around guard rails.
14. Falling into hot asphalt while paving a road, resulting in burns to the hands and elbows.

15. Electric shock from an overhead electric line while standing adjacent to an asphalt dump truck, resulting in burns and blistering on the legs and damage to the big toe on the right foot.
16. Fire occurring while climbing the asphalt distributor tank to take measurements, resulting in burns on the hand, face, and upper torso.
17. Safety gate releasing and hitting the employee in the head while attempting to fix an air/oiler on an air tank under an asphalt silo.
18. Hot thermoplastic coming through the joints and burning the employee while heating thermoplastic to open a pipe, requiring hospitalization.
19. Hot asphalt flowing from a partially raised dump truck bed onto the employee resulting in second and third degree burns to the hands and face, requiring hospitalization.
20. Burns to the left hand and arms while troubleshooting the preheater of a repaver.
21. Hot rubber contacting the skin and causing a third-degree burn to the right forearm between the wrist and elbow while using a wheelbarrow to pour hot stone and rubber into a bridge plug joint.
22. Slipping on a wet road and falling into hot tar, resulting in burns to 40 percent of the surface of the hands.
23. Fire/explosion occurring while transferring diesel fuel from the middle tank of a fuel truck to the forward tank using a barrel pump, causing second and third degree burns to the body and arms.
24. Tack distributor catching fire on the burners while fueling with gas, resulting in burns on the right hand.
25. Heated asphalt bubbling out of the pipe and onto the employee as he walked by, burning his arms and legs.
26. Hot asphalt spilling on and burning the left hand while sealing highway asphalt and requiring hospitalization.
27. Rear of the paving machine catching on fire and burning the employee sitting in the seat while preparing to pave a road.
28. Falling into hot asphalt after tripping on the arm of a machine, resulting in burns and hospitalization.
29. Explosion occurring while opening the door to an asphalt truck, causing burns to both arms and the chest, neck, and face.
30. Molten thermoplastic splattering onto the injured employee after a vehicle struck the thermoplastic handliner, causing burns to the neck, right side of the face, and right ear.
31. Flash fire occurring while walking down a catwalk as an automated system cleaned and removed aggregate from the drag conveyor of asphalt equipment by spraying diesel fuel onto the conveyor, resulting in burns on the face, neck, and arms and requiring hospitalization.
32. Splashed with hot tar after a machinery malfunction.
33. Flash fire occurring while attempting to open a gas cover/cap, burning the employee's face.
34. Trouble breathing due to fumes produced from the mixture of bleach and toilet bowl cleaner while cleaning toilets at a rest stop.
35. Electrical burn to the right hand after wind blew a section of sheet metal into a powerline while installing sheet metal at a business.
36. Flash fire occurring after a positive wire from a battery came into contact with a hydraulic hose while servicing a mill with a reported hydraulic leak, resulting in burns to the upper body.
37. Hot liquid asphalt shooting out and burning the palm of the right hand while trying to unclog an asphalt distribution (spreading) machine.

38. Assault from a coworker causing loss of consciousness and falling into hot asphalt that had been freshly poured nearby, resulting in burns to the left side of the face, the left shoulder, and left forearm.
39. Skin burns/abrasions on the left forearm and left hand after the arm got caught while spraying a tacky solution onto the conveyor belt of a dump truck, requiring hospitalization and an incision to relieve the swelling.
40. Thermal burns to the lower left and right arms and face after a hot bolt or part of the frame pin punctured an adjacent aerosol can of brake cleaner and the contents ignited into a ball of flame while heating up a track frame pin with a torch.

Records in cluster 7:

75 out of 1031 (7.27%)

Cluster 8 Summary:

All of these road construction incidents involve injuries to employees' feet or legs. Many of the incidents involve heavy machinery or equipment, such as forklifts, excavators, and backhoes, running over or crushing employees' feet or legs. Other incidents involve employees being struck by falling objects or caught in machinery, resulting in fractures or amputations. These incidents highlight the importance of proper safety training, equipment maintenance, and hazard identification and mitigation in road construction work.

Cluster 8 top 10 major causes:

1. Forklift accidents
2. Struck-by accidents involving heavy equipment
3. Failure to use proper tools and equipment
4. Struck-by accidents involving falling objects
5. Backhoe accidents
6. Slip, trip, and fall accidents
7. Struck-by accidents involving concrete barriers
8. Pinching accidents
9. Burns
10. Caught-in/between accidents

Records in cluster 8:

111 out of 1031 (10.77%)

Cluster 9 Summary:

All of these road construction incidents involve some form of fall, being struck by falling objects, or being caught in between objects. They also all resulted in injuries that required hospitalization or surgery. These incidents highlight the importance of proper safety measures and training for workers in the road construction industry.

Cluster 9 top 10 major causes:

1. Falls from heights
2. Struck by falling objects
3. Struck by moving equipment or vehicles
4. Dismantling or removing scaffolding or forms
5. Failure of rigging or lifting equipment
6. Slips, trips, and falls on uneven surfaces
7. Collapsing structures or forms

8. Overheating or dehydration leading to dizziness or loss of balance
9. Improper use or failure of personal protective equipment (PPE)
10. Impalement by rebar or other sharp objects.

Records in cluster 9:

82 out of 1031 (7.95%)

Cluster 10 Summary:

All of these road construction incidents involve the use of cutting tools, such as chainsaws, saws, and cut-off saws. In each case, the tool either kicked back or slipped, causing the employee to be injured. These incidents highlight the importance of proper training, personal protective equipment, and safe work practices when using cutting tools in road construction.

Cluster 10 top 10 major causes:

1. Improper use of chainsaw
2. Kickback from construction saw
3. Pinching of blade while cutting concrete curb
4. Kickback from chop saw
5. Laceration from gas powered saw
6. Kickback from circular saw
7. Kickback from chop saw
8. Slip of chainsaw while cutting tree
9. Amputation from radial arm saw
10. Kickback from pipe saw

Other causes include:

11. Laceration from saw blade while cutting pipe
12. Amputation from unguarded table saw
13. Kickback from cut-off saw while cutting PVC pipe
14. Amputation from table saw
15. Cut from concrete paving saw
16. Cut from partner saw while cutting wood
17. Explosion of grinding wheel while using angle grinder
18. Cut from razor knife while cutting plastic battery box
19. Laceration from cut-off saw while cutting vertical board
20. Laceration from circular saw while operating
21. Cut from cut-off saw wheel explosion
22. Laceration from angle grinder while cutting temporary support
23. Laceration from cut-off saw while cutting concrete
24. Kickback from multi-purpose saw while cutting plank lagging board
25. Kickback from chop saw while cutting 6-foot pipe
26. Amputation from portable handsaw while cutting lumber
27. Laceration from chainsaw while cutting down tree
28. Laceration from saw while cutting stakes for concrete forms
29. Amputation from circular saw while cutting wood plank
30. Injury from falling pipe while using chop saw
31. Cut from circular saw while cutting wood board
32. Laceration from cut-off saw while cutting lumber
33. Kickback from skill saw while cutting 4X4s

34. Kickback from saw while cutting clay sewer pipe
35. Cut from circular saw while cutting 2-by-4 board
36. Partial amputation from circular saw while cutting 2x4
37. Injury from kickback of cut-off saw while cutting concrete pipe
38. Injury from kickback of portable saw while cutting metal pipe
39. Injury from falling tree branches while cutting down tree.

Records in cluster 10:

50 out of 1031 (4.85%)

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