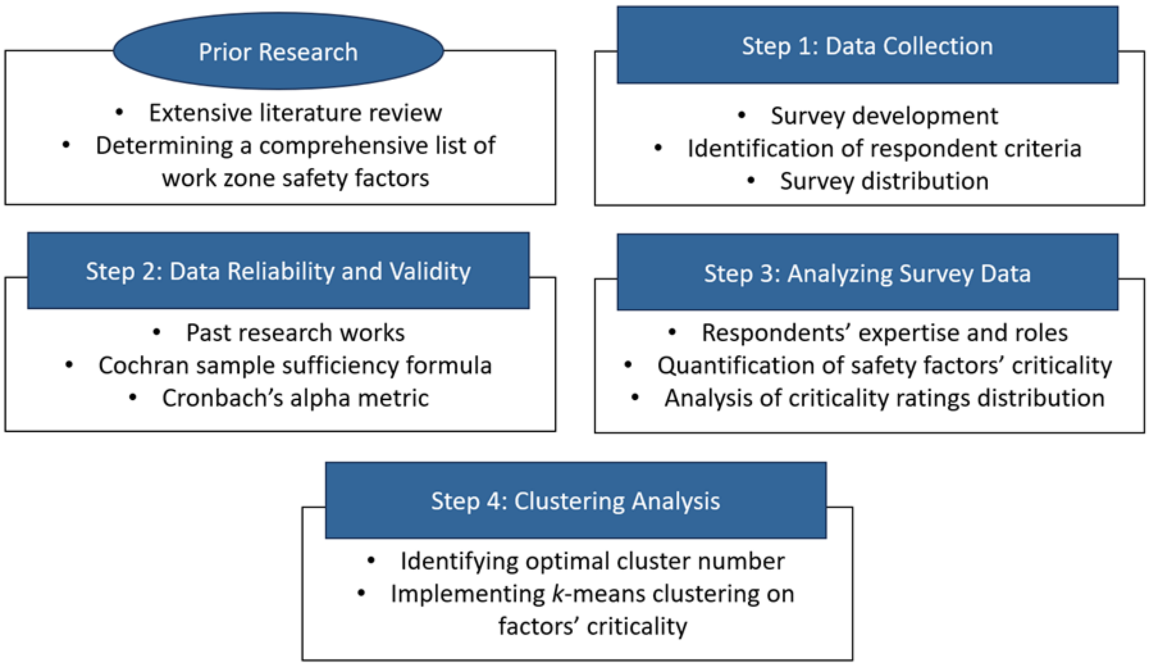
Mitigating and Preventing MoDOT Safety-Related Incidents through Root-Cause Elimination and Utilization of Leading Safety Indicators



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16. Abstract
This report thoroughly investigates and analyzes the diverse factors influencing incident occurrence in work zone environments, aiming to identify areas where proactive planning can enhance incident mitigation. Drawing from an extensive review of existing literature on work zone safety, 37 factors affecting both public and occupational safety were identified. Two surveys were then conducted among MoDOT employees and contractors to assess the relative criticality of these factors on worker safety within work zones. Survey results highlight driver-related factors, such as the driver's level of attention and unsafe driving, as the most critical to worker safety in work zones. Additionally, MoDOT employees and contractors evaluated MoDOT's performance on the studied factors. While MoDOT's performance received substantial ratings overall, contractors consistently rated it lower than MoDOT employees, indicating a divergence in perspectives between stakeholder groups. Notably, both groups identified the presence of law enforcement as a critical area requiring further improvement in Missouri work zones. Furthermore, MoDOT employees rated field compliance with safety policies and the overall safety culture in their workplaces. Variations in policy compliance were observed, with certain policies, such as those related to backing movements, requiring attention to improve adherence—a crucial aspect for occupational safety in work zone environments. Additionally, while MoDOT employees demonstrated strong knowledge of policies and safety procedures provided by MoDOT, they expressed lower satisfaction with the timely investigation of safety incidents and the effectiveness of subsequent improvements. This comprehensive analysis provides a benchmark for MoDOT and other stakeholders to address identified deficiencies and enhance work zone safety practices effectively.

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Final Report

Disclaimer

The opinions, findings, and conclusions expressed in this document are those of the investigators. They are not necessarily those of the Missouri Department of Transportation, U.S. Department of Transportation, or Federal Highway Administration. This information does not constitute a standard or specification.

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Executive Summary

This research project focused on evaluating the contributing factors to work zone incidents in Missouri. While work zones are crucial for infrastructure maintenance and improvement, ongoing projects within work zones can sometimes place workers and drivers in dangerous situations. Despite safety regulations, work zone accidents persist with notable severity and frequency, contributing to over 700 annual fatalities in the US. Previous research has explored work zone accident causation, but it has not provided a comprehensive understanding of the factors that impact work zone safety.

This project first conducted a systematic literature review (SLR) aimed at synthesizing the existing body of knowledge concerning work zone safety. The primary objective of the SLR was to identify the diverse elements and factors influencing accident causation within work zone environments. Additionally, social network analysis (SNA) was employed to scrutinize the interconnections among these identified factors, drawing upon theoretical frameworks and mathematical/computational methodologies documented in the literature. As a result of the SLR, a comprehensive list of 37 factors was delineated, encompassing design-related, roadway-related, work-related, driver-related, temporal-related, and state-related variables. The findings of the SNA indicate that design-related factors have received more extensive attention in the literature, whereas certain driver- and state-related factors have received comparatively less attention. This work contributes to the body of knowledge by consolidating the studies concerning work zone safety and using them to provide a robust roadmap for practitioners for enhancing the advancement of this field and ultimately leading to improved work zone safety practices.

Subsequently, this project administered surveys to both Missouri Department of Transportation (MoDOT) employees and contractors. The objective was to ascertain the relative importance of various factors affecting work zone safety, evaluate their perceptions of MoDOT's performance, and assess compliance with state and federal safety-related policies in the field. A total of 298 work zone professionals from diverse backgrounds participated in the survey, having an average of 17.75 years of construction experience and 13.78 years of work zone experience. To ensure the validity and reliability of the survey data, internal consistency and reliability were evaluated using Cronbach’s alpha metric. Furthermore, clustering analysis was utilized to partition the studied factors into distinct groups with varying levels of importance. This approach aimed to elucidate the factors considered most critical for ensuring work zone safety.

With regards to the relative importance of the safety factors, survey results indicate that driver-related factors, such as the driver's level of attention and unsafe driving, are perceived as most critical to worker safety in work zones. Conversely, factors associated with motorist vehicles, conditions of construction equipment, and technological sophistication are perceived as the least critical. Findings from the clustering analysis revealed three groups of factors with varying levels of criticality, where the most critical group comprised driver, work, and design-related factors, while other factors and their corresponding groups showed relatively lower criticality. The findings of this study contribute to guiding state departments of transportation and safety practitioners in enhancing their safety practices and culture with a focus on worker-centered perceptions. Additionally, this analysis offers valuable direction for future research to concentrate on underexplored areas deemed critical for worker safety in work zones, including driver impairments, level of attention, and clarity of signage and markings, among others.

Subsequently, respondents evaluated MoDOT's performance across factors influenced by the state. While MoDOT's performance received consistently above substantial ratings across all domains, contractors consistently rated MoDOT lower than employees did, suggesting a disparity between the viewpoints of MoDOT employees and those of on-site contractors. Notably, both stakeholder groups identified law enforcement as the aspect with the least satisfactory performance. Consequently, the presence of law enforcement agencies emerges as a challenging area requiring substantial improvement within MoDOT and at the state level. Moreover, both stakeholder groups assessed the impacts of enhancing safety performance on various project performance metrics, including schedule adherence, budget management, health and environmental considerations, productivity, and quality. Although certain areas showed alignment in priorities—such as the paramount importance of timely project completion and resource efficiency—discrepancies surfaced in the prioritization of quality and productivity metrics. These disparities underscore the necessity for MoDOT to engage stakeholders in collaborative decision-making processes and develop improvement initiatives to adequately address diverse perspectives and priorities.

To gain deeper insights into MoDOT's safety performance and overall safety culture, MoDOT employees were tasked with evaluating field compliance with various federally and state-imposed safety policies. The analysis of policy compliance ratings revealed that MoDOT employees generally perceive most policies to be strongly complied with or adopted on-site, with only three policies receiving moderately to largely complied ratings. Notably, among the policies with reduced compliance ratings is the "Backing" policy, which delineates the checklist drivers must complete before reversing, the presence and role of a spotter, and other pertinent work elements. Significantly, backing or reverse vehicle movements within work zones are recognized to be the primary cause of occupational injuries (i.e. excluding the public, such as intruding vehicles) in work zones. Therefore, this analysis of safety policy compliance serves as a benchmark for MoDOT to assess and enhance field compliance with policies exhibiting sub-optimal adherence, particularly those related to backing movements in work zones.

Additionally, MoDOT employees were asked to assess their agreement with several statements reflecting the overall safety culture within their workplaces. These statements encompassed aspects such as employees' familiarity with various policies, their confidence in the opportunities provided by MoDOT to enhance safety performance, among others. While employees expressed strong agreement regarding their knowledge of the various policies and their associated responsibilities, certain aspects pertaining to the prioritization of workers' physical and mental health, the prompt investigation of safety incidents, and the implementation of improvements following such incidents received comparatively lower ratings. This nuanced assessment highlights areas where MoDOT can further fortify its safety culture and enhance employee well-being.

Overall, this project conducted a comprehensive assessment of the diverse factors contributing to work zone injuries in Missouri, evaluated the differing perspectives of MoDOT employees and contractors, and pinpointed areas for improvement. By addressing the identified deficiencies, MoDOT can effectively mitigate risks and foster a safer work environment for its employees and all stakeholders engaged in transportation projects.

Chapter 1. Introduction

Roadway work zones refer to sections of roads or highways where construction, maintenance, or repair works are taking place. These zones are marked by specific signs, barriers, and other traffic control measures to guide and manage the flow of vehicles through the construction area (FHWA 2012). As the demand for infrastructure development continues to rise, the prevalence of work zone projects is consistently increasing, with motorists encountering a work zone per every 100 highway miles on average (Yang et al. 2015). However, within the space-restricted work zone areas, the variable interactions between workers, dynamic construction equipment, and passing motorists, give rise to risky circumstances (Jumari et al. 2022; Weng and Meng 2011). Additionally, collisions that transpire within work zones are more serious than those occurring elsewhere and affect both drivers and workers (Ha and Nemeth 1995; Ullman et al. 2006). Prior research reported a 21.5% increase in car crashes on the same freeways during work zone periods compared to non-work zone periods (Khattak et al. 2002). Motorists intruding into work zones account for 10% of nonfatal traffic accidents and 8% of traffic fatalities (Bryden et al. 2000). Moreover, these work zone intrusions are estimated to be responsible for 66% of injuries and fatalities among workers in such zones (Bryden and Andrew 1999).

With regards to accidents involving the public, rear-end collisions and head-on crashes are the predominant type of vehicular crashes in work zones, followed by collisions with small objects (FHWA 2017; INDOT 2017). It is estimated that 70% of these accidents only involve motorists out of the construction area, and 30% extend to involving construction workers (Mohan and Gautam 2002). These types of incidents have the potential to cause severe injuries and fatalities to both workers and drivers. According to national estimates, approximately 80% of work zone accident fatalities are attributed to motorist drivers and passengers (INDOT, 2017). In 2015, work zone intrusions led to 700 road fatalities and injuries in the US (NHTSA 2016). Within work zones, the most frequent cause of occupational injury not related to the public (i.e., intruder vehicles) is when workers are impacted by dump trucks in reverse motion, causing nearly half of the occupational work zone fatalities (FHWA 2022).

In addition to public motorists, other work-zone-related conditions give rise to heightened safety risks. Construction equipment and vehicles operating in confined spaces and blind spots elevate occupational safety risks for workers (Ferreira et al. 2017). Furthermore, the primary cause of occupational work zone fatalities is the movement of dump trucks in reverse within work zones, primarily attributed to the limited visibility and confined areas where work zone personnel are present (FHWA 2022; Leduc et al. 2019). Additionally, construction workers may frequently face distractions from the dynamic environment, including speeding roadway motorists, leading to reduced attention to the operations of construction equipment (Miller et al. 2009).

Previous research on work zone accidents and crashes has primarily concentrated on investigating their causes and implementing preventive safety technologies. Zhang et al. (2022) investigated the factors that affect work zone safety. They analyzed how different characteristics of roadways and work zones influence the likelihood of crashes. To achieve this, the authors utilized a supervised machine learning (ML) model, known as a random forest network, to analyze work zone crash data collected from the state of Pennsylvania. The developed model enabled the inference of crash probability and revealed that work zones with higher daily traffic volume and longer work zones are more susceptible to accident occurrences. Liang et al. (2014) developed a cellular automata model to simulate freeway work zone traffic flow and found that vehicles changing lanes in critical sections of work zones increased the likelihood of sideswiping and rear-end collisions. Moreover, several studies have been undertaken to improve work zone safety through the development and evaluation of safety technologies. For instance, Elghamrawy et al. (2012) examined the effectiveness of temporary work zone rumble strips in enhancing safety by studying their impact on audible warnings when vehicles pass through work zones, and ultimately concluding that temporary strips effectively increase audible warnings during work zone traversal. Hang et al. (2022) studied the significance of in-vehicle warnings, specifically emphasizing the importance of extended warnings beyond the drivers' line of sight, particularly for crash avoidance in foggy conditions.

Despite the existing body of research on work zone safety, the majority of studies have focused on specific combinations of work zone safety factors, resulting in a lack of comprehensive examination of these factors. For instance, Ermagun et al. (2021) investigated 14 factors related to driver response to work zone dynamic messages, but their analysis primarily considered driver-related factors while neglecting other work zone or environmental-related factors. Similarly, Mokhtarimousavi et al. (2021) examined temporal-related factors that impact work zone injury severity, along with specific driver and environmental factors such as alcohol involvement and rainy conditions, respectively, without extending their investigation to include worker-related factors. Furthermore, there is limited research that integrates stakeholders' perspectives, including those of DOT personnel and field workers, in assessing the critical factors influencing work zone safety and the adoption of traffic safety culture. This project aims to address this gap by initially identifying various factors that could impact work zone safety. Subsequently, surveys were conducted among Missouri Department of Transportation (MoDOT) personnel and contractors to gather their perceptions on the criticality of these factors. Additionally, respondents were asked to assess MoDOT's performance in areas within its control, such as safety budget and law enforcement. MoDOT employees were also tasked with evaluating the level of field adoption of safety policies and providing recommendations for further enhancing work zone safety in Missouri.

The initial section of this report outlines the identification of factors potentially impacting work zone safety. Following this, the second section presents survey findings regarding the perceived criticality of these safety factors among both MoDOT personnel and contractors. In the third section, the report delves into the perspectives of MoDOT employees and contractors regarding MoDOT's performance within its sphere of influence, along with anticipated impacts on project metrics. Additionally, the last section addresses MoDOT employees' perspectives on the implementation of safety-related policies in the field, including insights into potential additional policy requirements.

Chapter 2. Work Zone Safety Factors

Introduction

This chapter outlines the systematic literature review process (SLR) employed to analyze the existing body of knowledge concerning work zone safety, including factors influencing incident occurrence in such environments, and the extent of scientific exploration devoted to each factor. The comprehensive examination of these factors is documented in Chammout et al. (2024a) and Chammout et al. (2024b).

The structure of this chapter is as follows: Firstly, background information on research concerning safety, and specifically work zone safety, is provided. Next, the methodology utilized for the SLR is outlined in detail. Following this, a comparative analysis of the various factors is presented within the results section, followed by a discussion. Lastly, recommendations derived from the results are presented.

Background Information

Previous Research Works Related to Safety in General

Considerable research has been conducted to investigate safety aspects across various industries and domains, such as healthcare activities (Vincent and Amalberti 2015), agriculture (Murphy 1992), manufacturing (Silvestri et al. 2012), school sectors (Gairín and Castro 2011), and the construction industry (Törner and Pousette 2009; Choudhry 2014; Assaad and El-adaway 2021), among other industries. Similarly, the methodologies and modeling approaches vary across safety-related studies. In relation to that, Nabi et al. (2020) constructed a system dynamics model to simulate construction safety behavior, enabling the prediction of on-site injury occurrences and the identification of underlying causal factors. Zhao and Shi (2019) employed density-based clustering and recurrent neural networks to identify maritime anomalies, aiming to enhance the situational awareness of vessel traffic supervisors and reduce maritime accidents. Yuan et al. (2020) utilized case statistics and dynamic Bayesian networks to deduce scenarios related to fire accidents, with the aim of assisting decision-makers in formulating more precise emergency response measures. Chiang et al. (2018) studied fatal accidents in Hong Kong construction trades and revealed that a greater number of such accidents occurred in repair, maintenance, alteration, and addition works. Wilson-Donnelly et al. (2005) analyzed the macro-level perspective of safety in the manufacturing sector by conducting a review that examined the influence of organizational measures on worker safety and putting forth guidelines to promote occupational safety across multiple levels. Fang et al. (2020) conducted a literature review focused on computer vision studies related to construction safety, exploring the integration of deep learning with computer vision techniques to enhance safety practices in the field of construction. Eteifa and El-adaway (2018) investigated the fundamental causes of construction fatalities by employing a graph theory approach, a methodological step undertaken in this study, as later detailed upon in the "Methodology" section. Through their analysis, they identified the root causes, modeled their interrelationships, and concluded that the absence of job-specific training is the primary factor contributing to accidents involving struck by and caught in between incidents. Assaad and El-adaway (2021) expanded on the previous study by employing spectral clustering, Frequent Pattern

Mining, and the Apriori Algorithm to identify the significant combinations and associations of causes that predominantly contribute to fatal accidents on construction sites.

Previous Research Works Relevant to Work Zone Safety in Particular

Considerable focus has been dedicated in previous studies to unraveling the significant factors contributing to safety accidents within work zones. Primarily, a multitude of studies has centered on the theoretical examination and/or empirical testing of specific work zone safety parameters, namely employing driving simulations. Demenichini et al. (2017) conducted driving simulation experiments to examine the influence of work zone crossovers on driver speeding behaviors across various work zone configurations and found that the average speed significantly decreased only when there were alterations in the geometrical characteristics; based on these findings, they recommended increasing signage, enhancing work zone design, and implementing more effective speed enforcement measures. Similarly, Naujoks et al. (2017) utilized driving simulation experiments to evaluate the proficiency of drivers when transitioning from partially automated driving to manual driving in work zones where lane markings are absent or temporary lines are present. The study revealed that participants were able to safely handle the vehicles in such scenarios, indicating the harmlessness of these situations. Furthermore, in their study, Hou and Chen (2020) utilized simulator experiments to investigate the safety of traffic in work zones under inclement weather conditions. Their findings demonstrated that adverse conditions led to increased congestion and a higher frequency of lane changes, which in turn increased the likelihood of collisions occurring.

Alternatively, several studies have employed field or laboratory testing methods to assess specific work zone safety parameters, particularly those associated with work zone design and temporary traffic control measures. Patel et al. (2014) introduced a novel precast concrete barrier wall system designed specifically for bridge deck work zones, incorporating structural, freeze-thaw, and impact testing, and concluded that the system offers notable advantages compared to conventional cast-in-place concrete barriers, including simplified replacement of damaged sections to mitigate the impact of accidents or related concerns. Rayani and Wang (2018) conducted field data collection in work zones and found that the presence of law enforcement and changeable message signs had a statistically significant effect in reducing vehicular speeds. Kersavage et al. (2019) conducted field experiments to evaluate the effectiveness of different warning beacons and flash intensities employed on vehicles for accident prevention, aiming to enhance worker detection and driver reaction time. Park et al. (2017) conducted field testing to assess the effectiveness of a sensing system for enhancing work zone safety that utilizes Bluetooth low-energy devices to minimize the occurrence of occupational hazards between workers and construction equipment.

Additionally, numerous other studies have devised ML models to analyze work zone crash occurrence and severity, the majority of which are parametric in nature. For instance, Santos et al. (2021) investigated the risk factors influencing work zone crashes utilizing probit regression and binary logistic models, considering factors such as weather conditions, speed limits, pavement grip, and other relevant variables. Murthy et al. (2013) assessed the effects of intelligent transportation system operations on reducing traffic congestion and incidents, employing logistic regression models. Sze and Song (2018) developed a multinomial logistic regression approach to analyze the relationship between various factors and work zone crash severity, considering variables such as location, time, vehicle type, objects involved in the crash, lighting and weather conditions, and road surface conditions, among others. Weng et al. (2016a) employed a multinomial logistic regression model to investigate the relationship between factors such as environmental conditions, road characteristics, driver attributes, crash characteristics, and work zone crash severity. Debnath et al. (2014) introduced a Tobit regression model that analyzed the likelihood and extent of speed limit compliance in work zones, incorporating various vehicle and traffic factors. Their findings indicated that vehicles tend to exhibit higher speeds during periods of increased traffic volume and when a larger proportion of vehicles are speeding. It is important to acknowledge that parametric models, such as logistic regression, may encounter limited prediction accuracy due to the predetermined assumptions they rely on, in addition to the possible non-homogeneity of the input variables. For example, Weng et al. (2013) demonstrated that a tree-based logistic regression approach outperformed the standalone logistic regression model in assessing work zone casualties by effectively addressing the marginal effects of the risk factors. For this reason, several studies employed non-parametric models in assessing work zone safety. Rahim et al. (2021) utilized a deep learning approach to develop a crash severity model, incorporating a wide range of 98 variables including factors such as year, date, time, roadway features, and environmental features. Ghasemzadeh and Ahmed (2019a) introduced a probit-classification tree model, which combines nonparametric classification tree techniques with the parametric probit regression model, to investigate the influence of environmental factors and drivers' behavior on weather-related work zone crashes. Chang et al. (2020) proposed and evaluated four classification methods for crash event classification and prediction in work zones. Their findings highlighted the significance of factors such as speed, following distance, lane changes, driver distraction, work zone configuration, lane width, and signage in contributing to hazardous events.

Among the non-parametric ML models, association rule mining has been utilized in certain studies. Weng et al. (2016b) applied association rule mining to study factors affecting work zone crash casualties and uncover patterns in the crashes. Their findings revealed common occurrences of variables such as exceeding speed limit, involvement of alcohol, presence of four or more lanes, and proximity of the crash to the posted speed limit sign. Pande and Abdel-Aty (2009) adopted a unique approach by analyzing crashes as supermarket transactions, employing association rules aiming to identify interdependencies among crash characteristics. Geurts et al. (2003) employed the frequent item sets association algorithm to investigate patterns in areas with high crash occurrences, although not restricted to work zones.

Currently, the existing work zone safety studies have individually focused on several combinations of parameters, but there is a lack of comprehensive coverage of safety factors in line with the evolving nature of the literature. This chapter tackles this area of research need.

Research Methodology

This study employs an interdependent and multistep research methodology as summarized in Figure 1. The authors (1) conducted an extensive review and analysis of the literature on work zone safety, (2) identified the factors that impact public and occupational safety in work zones and mapped them with the reviewed articles, and (3) conducted a social network analysis (SNA) to measure the significance of the identified factors. Details pertaining to each step are presented in the subsequent subsections.

Step 1: Systematic Literature Review

The first step was to conduct a SLR to review articles related to work zone safety. To this end, the authors followed the subsequent steps for the collection of scholarly articles, which are summarized in Figure 1:

- *Search*: The authors utilized the Scopus search engine to conduct an all-inclusive search with the article title, abstract, and keywords fields. Second, the search was restricted to papers classified as article type. The SLR for relevant publications utilized various keywords, such as "work zone", "work-zone" and "safety", among others, and focused on articles published within the previous 10 years (2012-2022). This time frame is considered appropriate for identifying the relevant literature body (Jin et al. 2018). Notably, this range of years has been used in previous research on various topics, including the construction field (Ma et al. 2019; Wang et al. 2020). This search led to the collection of 166 journal articles published.

It is imperative to note that even though the scope of this study is limited to the 10-year period, the essential aspects of research preceding the data collection period are incorporated into newer literature papers collected. Ultimately, the selected data collection period was deemed appropriate for the scope and objectives of this study. Furthermore, to avoid duplication of results or data, the search was restricted to journal articles, excluding theses or conference papers that may have been subsequently published in journals.

- *Screening*: The authors conducted a two-step screening to assess the relevancy of the collected articles. The screening process involved two steps to ascertain the relevance of each article to the research field. In the first step, the articles were screened based on their abstracts and titles. In the second step, the articles underwent a comprehensive content review. As a result, 10 articles were excluded in the initial screening step, and an additional 23 articles were excluded during the content review for one of the following reasons:
    1. Non-relevance to roadway work zones: These articles did not address safety within the context of roadway work zones.
    2. Irrelevant safety focus: The research in these articles did not specifically address safety within the work zone environment.
    3. Different work zone topics: These articles focused on work zone topics other than safety, such as construction materials used in work zones.
    4. Duplicate articles: These articles were duplicates of already included studies and were therefore excluded to avoid redundancy.

To illustrate an exclusion of an article, in

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- *Selection*: Following the adopted screening process, the dataset for the establishment of literature-studied work zone safety factors included the remaining 133 journal articles, as listed in Table 1, which were selected for review and analysis.

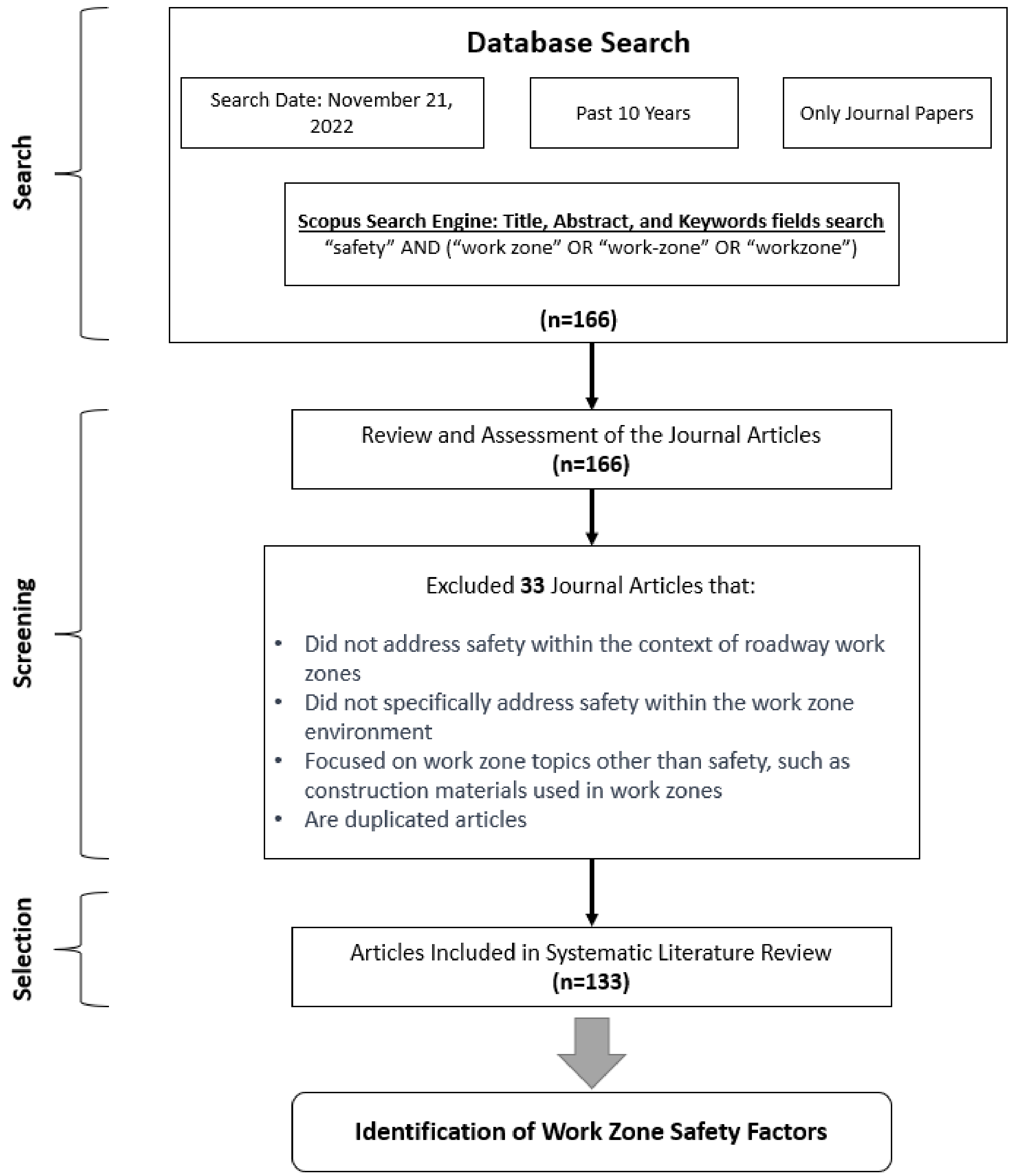


Figure 1. Steps followed for selection of articles

Table 1. Reviewed articles

Year	***Used Articles***	***Number of Articles***
2012	Elghamrawy et al. (2012) and Weng and Meng (2012)	2
2013	Meng and Weng (2013), Rayaprolu et al. (2013), and Yang et al. (2013)	3
2014	Bham et al. (2014), Choe et al. (2014), Debnath et al. (2014), Fan et al. (2014), Huang and Bai (2014), Liang et al. (2014), Shakouri et al. (2014), Weng and Meng (2014), and Yousif et al. (2014)	9

2015	Bai et al. (2015), Chen and Ahn (2015), Debnath et al. (2015), Jin and Jin (2015), Kaber et al. (2015), Ren and Wu (2015), Ščerba et al. (2015), Weng et al. (2015a), Weng et al. (2015b), and Yang et al. (2015)	10
2016	Ahmed et al. (2016), Cao et al. (2016), Genders et al. (2016), Martin et al. (2016), Melcher and Keller (2016), Nyende-Byakika (2016), Osman et al. (2016), Park et al. (2016), Weng et al. (2016a), Weng et al. (2016b), Wennström et al. (2016), Xu et al. (2016), and Zhu et al. (2016)	13
2017	Domenichini et al. (2017), Ferreira et al. (2017), Hamzeie et al. (2017), La Torree et al. (2017), Lyu et al. (2017), Park et al. (2017), Qiao et al. (2017), Rahman et al. (2017), Yang et al. (2017), and Zhang and Gambatese (2017)	10
2018	Abdelmohsen and El-Rayes (2018), Abdulsattar et al. (2018), Kachroo and Sharma (2018), Kang and Momtaz (2018), Kersavage et al. (2018), Nnaji et al. (2018), Osman et al. (2018), Park et al. (2018), Ravani and Wang (2018), Rea et al. (2018), Weng et al. (2018), and Zhan et al. (2018)	12
2019	Awolusi and Marks (2019), Banerjee et al. (2019), Du and Razavi (2019), Ge et al. (2019), Ghasemzadeh and Ahmed (2019a), Ghasemzadeh and Ahmed (2019b), Osman et al. (2019), Qing et al. (2019), Steinbakk et al. (2019a), Steinbakk et al. (2019b), Sze and Song (2019), Valdes et al. (2019), Vignali et al. (2019), Xu and Yang (2019), and Zhang and Hassan (2019)	15
2020	Al-Bdairi (2020), Ambros et al. (2020), Barlow et al. (2020), Chang et al. (2020), Cheng and Cheng (2020), Duan et al. (2020), Ge and Yang (2020), Ge et al. (2020), Hou and Chen (2020), Idewu et al. (2020), Koilada et al. (2020), Kummetha et al. (2020), Lee et al. (2020), Lopez-Flores et al. (2020), Nnaji et al. (2020a), Nnaji et al. (2020b), Raddaoui et al. (2020), Raju et al. (2020), Xu et al. (2020), and Zhang et al. (2020)	20
2021	Ahmed et al. (2021), Almallah et al. (2021), Bakhshi and Ahmed (2021), Cao et al. (2021), Dehman and Farooq (2021), Difei et al. (2021), Du and Razavi (2021), Ermagun et al. (2021), Hubbard and Hubbard (2021), Kim et al. (2021a), Kim et al. (2021b), Lv et al. (2021), Mahasirikul et al. (2021), Mokhtarimousavi et al. (2021), Nasrollahzadeh et al. (2021), Park et al. (2021), Rahim and Hassan (2021), Re et al. (2021), Saha (2021), Santos et al. (2021), Sayed et al. (2021), Shen et al. (2021), Son et al. (2021), Valdes-Diaz et al. (2021), Wang and Lee (2021), Wang et al. (2021), and Zhao et al. (2021)	27
2022	Dua et al. (2022), Galvis Arce and Zhang (2022), Hang et al. (2022), Islam (2022), Jumari et al. (2022), Kitali et al. (2022), Mathew et al. (2022), Niska et al. (2022), Sakhakarmi and Park (2022), Sakhare et al. (2022), Wang et al. (2022), and Zhang et al. (2022)	12

Upon selection of the articles, the authors conducted a manual content analysis of the selected 133 articles. The manual content analysis was carried out in a manner similar to that established by Neuendorf (2002) and Krippendorff (2004). According to Ahmed and El-adaway (2023), such manual review and analysis should increase the accuracy and specificity of the identification of factors impacting safety in work zones. First, the authors manually and independently read the articles, in detail, without using any content analysis software. Second, the authors independently recorded their identified work zones-related factors using Microsoft Excel. These factors were clearly stated throughout the articles. Moreover, the authors aggregated identical/similar factors during the process of reviewing and analyzing the selected 133 articles. Third, the authors compared the developed lists of factors. In the event of disagreement, another review cycle is carried out until an agreement is reached. Overall, a total of three review cycles were conducted. Ultimately, the authors identified a comprehensive list of 37 factors that are impacting safety in work zones. The identified list of 37 factors will be shown under the "Results and Analysis" section. Further, the collected factors were consolidated and classified into seven distinct categories: (1) Design-Related Factors; (2) Roadway-Related Factors; (3) Driver-Related Factors; (4) Vehicle-Related Factors; (5) Work-Related Factors; (6) Temporal-Related Factors; and (7) State-Related Factors. These categories will be further elaborated on and discussed in the "Results and Analysis" section of this chapter.

After performing content analysis of the articles, the journal articles were classified into two categories based on previous similar research (Assaad and El-adaway 2020; Khalef and El-adaway 2023a):

- Type 1: The articles included in this class cover theoretical discussions on topics related to work zone safety, which center on insights into the factors associated with work zone safety without conducting controlled experiments or testing. Additionally, articles focusing on statistical analyses of historical injury data are also encompassed within this category. The articles that contain theoretical discussions were incorporated into the reference matrix denoted as T in this study.
- Type 2: The articles in this class predominantly describe the results of controlled experiments investigating select safety factors, as well as the development of predictive ML models, tools, frameworks, and other computational methods related to work zone safety. These articles are included in reference matrix M. Notably, articles with substantial theoretical discussions, particularly within their literature review sections, have also been included in reference matrix T.

Step 2: Quantitative Analysis of the Literature

Following the SLR, the authors performed a quantitative analysis of the collected literature to develop two reference matrices T and M. The columns in these matrices correspond to the journal articles analyzed, while the rows represent the safety factors. Specifically, matrix T comprises factors that were addressed theoretically in the literature, while matrix M encompasses factors that were addressed mathematically or empirically. To construct these matrices, the authors assigned a binary value of 1 or 0 to each factor-article combination based on whether the factor was addressed in the article or not. This process is illustrated in Figure 2, where F_i represents an identified factor, and A_i represents an analyzed journal article. In this example, factor F_1 is recorded in article A_1, but not in Article A_2, as such, a value of 1 is added in the cell relating to [F_1; A_1], and a value of 0 is input in the cell corresponding to [F_1; A_2]. Consequently, binary reference T and M $i \times j$

matrices are constructed, where i is the number of factors identified, and j is the number of articles analyzed. Ultimately, analyzing each matrix independently, by implementing the subsequent methodological steps as detailed in the following subsections, enables the identification of research gaps and understudied safety factors in work zones. Furthermore, by comparing the two matrices, a clear distinction between theoretical and empirical studies on these factors emerges, offering valuable insights for guiding future research endeavors.

	A_1	A_2	…	A_j
F_1	1	0	…	0
F_2	0	0	…	1
…	…	…	…	…
F_i	0	1	…	1

Figure 2. Example of a reference matrix

Step 3: Social Network Analysis (SNA)

The utilization of the SNA approach in this study was driven by its inherent capability to capture and analyze the interconnections among the diverse factors investigated in this research, thereby enhancing the understanding of their interrelationships. SNA is a methodology rooted in graph theory that explores network behavior by taking into account the interconnections among its components (Otte and Rousseau 2002). SNA is a widely employed technique for creating, visualizing, and exploring network relationships between various topics, factors, and research themes. Furthermore, SNA has practical applicability in evaluating literature-based factors for their interconnectivity, relative importance, and for identifying understudied areas of research that require further investigation (Elbashbishy et al. 2022). To this end, this study utilizes SNA as a methodological approach to assess the interconnections among work zone safety factors as depicted in the literature, quantify the level of literature coverage concerning these factors, and identify work zone safety factors that have been inadequately investigated, both from theoretical and computational/mathematical perspectives.

The SNA method consists of multiple interconnected nodes (vertices) connected by links (edges). In this study, the nodes correspond to work zone safety factors, and edges are created between the nodes based on the number of articles connecting them. Figure 3 demonstrates an illustrative example of constructing an SNA model. The approach begins with constructing a reference matrix that cross-references the factors with the analyzed articles, as depicted in Figure 3. The quantitative analysis of the literature yielded two reference matrices: the theoretical matrix T and the mathematical matrix M. To obtain the adjacency matrix (AM) for each reference matrix, the reference matrix was multiplied by its transpose matrix, and the diagonal values were subsequently set to zero. Thus, the AM is a square matrix that portrays the relationships between the factors, enabling the calculation of the degree centrality for each of the identified factors. For literature-based work zone safety factors, the degree centrality signifies the factor's popularity from the standpoint of papers connecting it to other factors. The degree centrality for each node of the two networks is determined using Eq. (1), where DC_i denotes the weighted degree centrality of a factor i, and a_{ij} signifies the edge weight between factors i and j present in the AM.

$$DC_i = \sum_{j:j \neq i} a_{ij}$$

Equation 1. Degree centrality

As the number of articles used for matrices T and M is unequal, a normalized DC_i is computed by dividing the DC_i of each factor over the maximum DC_i obtained in the respective reference matrix, as shown in Eq. (2). The reason behind this is that the degree centrality is influenced by the network's size, resulting in the normalized DC_i for each work zone safety factor ranging from 0 to 1.

$$Normalized\ DC_i = \frac{DC_i}{Maximum\ DC_i\ in\ the\ network}$$

Equation 2. Normalized degree centrality

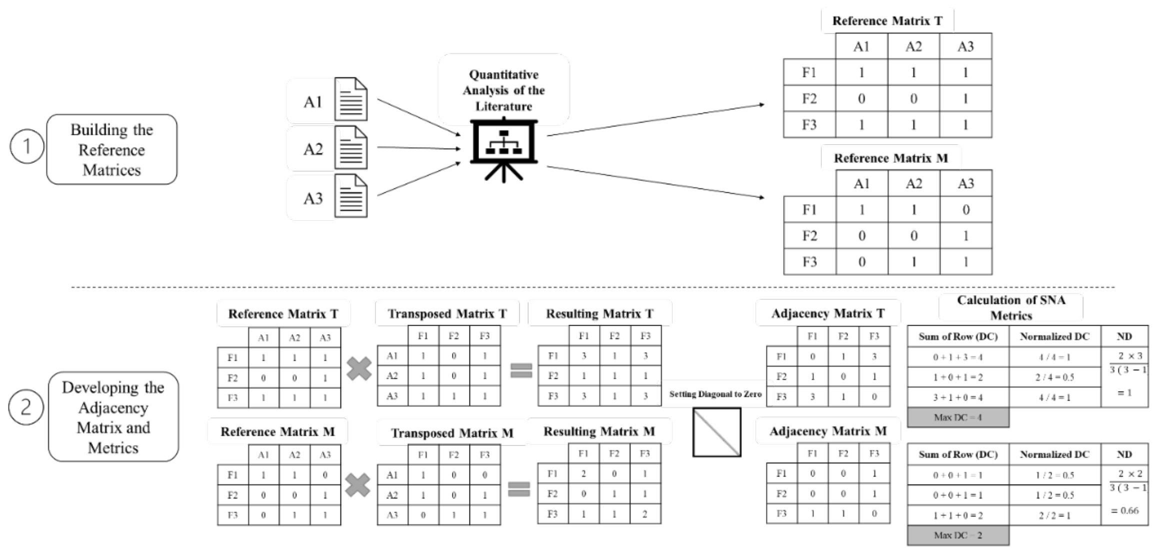


Figure 3. Overview of the SNA procedure

Furthermore, to quantify the connectivity among the work zone safety factors in each of the two networks, the authors utilized an additional SNA metric, known as network density (ND) (Eteifa and El-adaway 2018; Aljassmi et al. 2014). The ND is a measure of the proportion of links or edges that are established in the network out of all possible links (Giuffre, 2015). The ND was employed to evaluate the connectivity of the two networks individually (Park et al. 2011), as well as to serve as a point of comparison for the interconnectivity between matrices T and M. The calculation of ND is based on Eq. (3), where n denotes the number of vertices, i.e., work zone safety factors, present in the network.

$$ND = \frac{2 \times Actual\ Connections}{n \times (n-1)}$$

Equation 3. Network density

The Python programming language was employed in implementing the SNA model discussed in this chapter, which is an object-oriented programming environment that has considerable adoption in the domains of engineering and scientific computing research. The Python programming environment was instantiated via Project Jupyter, an open-source software tool that furnishes an array of packages and libraries that were employed in this study, including Pandas, Numpy, Matplotlib, and scikit. Data processing, computations, and clustering were performed within the Python programming language, and the resulting network was visualized and analyzed utilizing Gephi (Gephi 2017).

Results and Analysis

Work Zone Safety Factors

After conducting a SLR that resulted in the collection of 133 relevant articles (Table 1), the authors proceeded to perform a content analysis of the literature. This analysis aimed to extract the work zone safety factors investigated in each of the studies, which were subsequently utilized in the quantitative analysis of the literature to construct the reference matrices, as further described in a subsequent subsection of the "Results and Analysis" section. Consequently, a total of 37 factors that pertain to work zone safety considerations were identified and categorized into seven distinct groups based on their descriptions. The seven categories of work zone safety factors are presented in Table 2, while Table 3 provides a detailed list of the identified factors. Thus, Table 3 presents a comprehensive compilation of the work zone safety factors addressed throughout the literature. Additionally, Figure 4 highlights the identified factors (x-axis) and their citing sources (y-axis). This comprehensive list of factors incorporates all aspects of work zone safety addressed in the literature (both theoretically and mathematically). Accordingly, Figure 4 holistically maps the identified factors across the body of literature.

Table 2. Categories of work zone safety factors

Category	*Description*	*No. of Factors*
Design-Related Factors	Refers to the layout and elements of the work zone that are designed to ensure safe and efficient traffic flow, including roadway design, signage, pavement markings, and temporary traffic control devices.	5
Roadway-Related Factors	Refers to the characteristics of the roadway that may impact traffic flow and safety, including the road type, alignment, and slope, as well as factors such as pavement conditions, traffic volume, and speed limits.	7
Driver-Related Factors	Refers to the characteristics and behaviors of motor vehicle drivers that can impact safety in work zones, including distraction, impairment, fatigue, and aggressive driving.	9
Vehicle-Related Factors	Refers to the characteristics and conditions of the motor vehicles traveling through work zones that can affect safety, such as mechanical characteristics, vehicle size, weight, and speed.	4
Work-Related Factors	Refers to the occupational conditions and tasks that workers are exposed to while working in the zone, including the type of work being performed, duration of work, and proximity to moving traffic.	5

Temporal-Related Factors	Refers to the impact of time on safety conditions in the work zone. These factors may include the time of day, day of the week, and season of the year, as well as the duration of the project and the schedule of work activities.	4
State-Related Factors	Refers to the influence of state-level policies and regulations on work zone safety practices. These factors may include the state's work zone safety standards, policies for speed limit reductions, worker protection laws, and funding for safety programs.	3

Table 3. Identified factors related to work zone safety

Category	*Code*	*Factor*	*Description*
Design-Related Factors	F1	Design of Work Zone Layout	It refers to the configuration and design of a work zone, which can include a variety of elements such as reduced lane width, altered dimensions, entrance and exit bypasses, number of lanes, and median opening length. Additionally, protective systems may be implemented, such as concrete barriers, intrusion alarm systems, and the presence of spotters or flaggers.
	F2	Design of Safety Measures	It refers to mistakes or errors in the design of the work zone area, as well as issues with the implementation and location of safety measures. Such errors can include unclear temporary pavement markings and other factors that can contribute to confusion or hazards for drivers and workers within the work zone.
	F3	Additional Preventive Measures	It refers to the use of supplementary safety tools, equipment, and technologies intended to prevent accidents. These additional measures may include temporary rumble strips situated at the periphery of highway work zones, blue lights affixed to equipment, wearable light systems, animation-based message signs, sensing technologies, variable speed limits, and other similar measures.
	F4	Clarity of Signage or Pavement Markings	It refers to unclear safety signage or pavement markings that impede a driver's comprehension.
	F5	Speed Variance Regulations	It refers to the presence of abrupt changes in speed within a work zone that may not allow drivers enough time to react and avoid potentially dangerous accidents.
Roadway-Related Factors	F6	Type of Road	It refers to the type of roadway or highway, such as rural, suburban, or urban roads/motorways, arterial roads, local roads, and so on.
	F7	Roadway Lighting Conditions	It refers to the lighting conditions present on-site during nighttime hours.

	F8	Road Surface Condition	It refers to the surface conditions (roughness, smoothness, etc.) of the road on which traffic is passing through the work zone area.
	F9	Road Alignment	It refers to the characteristics of the road alignment, such as whether it is straight or curved, and whether there are slopes that are either upgrading or downgrading.
	F10	Median Type	It refers to the different types of medians, such as rigid post barriers, grass, flexible post barriers, and semi-rigid post barriers.
	F11	Sight Distance	It refers to the line of sight and the buffer segment of the work zone, located between the upstream transition area and the working area.
	F12	Volume of Traffic at the Area of Work Zone	It refers to factors such as the traffic volume, whether the work zone is located in a high or low-traffic area, and the percentage of trucks or commercial vehicles present.
Driver-Related Factors	F13	Driver's Compliance with Work Zone Speed Limited	It refers to vehicles moving at high speeds through work zones and disregarding the required speed reductions.
	F14	Driver's Level of Attention	It refers to drivers who are inattentive while passing through work zones and may become distracted by various factors such as using their smartphones, focusing on GPS, or having their attention diverted elsewhere. This also applies to drivers who may only realize they are entering a work zone area at a late stage.
	F15	Driver's Unsafe Behavior	It refers to drivers engaging in unsafe behaviors while passing through work zones. Such behaviors include driving under the influence of drugs or alcohol, engaging in aggressive driving maneuvers like queue jumping, straddling lanes, forcing merges, or riding motorcycles without helmets.
	F16	Driver Impairments	It refers to potential reasons for obstructed driver behavior, decision-making, or driving skills, which may include factors associated with advanced age.
	F17	Driver Gender	It refers to the gender of the vehicle driver.
	F18	Driver's Age	It refers to the age of the vehicle driver.
	F19	Driver's Income	It refers to the income of the vehicle driver.
	F20	Driver's Ethnicity	It refers to the ethnicity of the vehicle driver.
	F21	Driver's Educational Level	It refers to the educational level of the vehicle driver.

Vehicle-Related Factors	F22	Characteristics of Driving Vehicle	It refers to the characteristics of the vehicle being driven, such as its type, features, workability, age, weight, etc.
	F23	Level of Technology within Driving Vehicle	It refers to automated and connected vehicular systems.
	F24	Characteristics of Construction Equipment	It refers to characteristics of heavy-construction equipment, such as type, maneuverability, and weight.
	F25	Level of Technology within Construction Equipment	It refers to the use of technology controls, such as radars or backup cameras, within construction equipment or vehicles that can help prevent accidents involving pedestrians or workers when backing up.
Work-Related Factors	F26	Work Zone Type	It refers to the type of work zone, which may include construction, maintenance, utilities, and others (such as traffic management operations, among others).
	F27	Job Training	It refers to the job training provided to workers, drivers, and operators working in work zone areas, such as training on how to deal with associated risks and hazards, and how to avoid becoming accustomed to workplace hazards.
	F28	Worker's Behavior	It refers to the behavior exhibited by workers due to their habituation of the risks associated with work zone areas and their judgment of hazardous situations.
	F29	Traffic Control inside Work Zone	It refers to the traffic control plan within the work zone area to regulate the movement of construction equipment and vehicles.
	F30	Level of Congestion in the Work Zone	It refers to the limitations of the work zone area in terms of congestion with workers and equipment.
Temporal-Related Factors	F31	Weather Condition	It refers to the adverse weather conditions that can result in accidents and incidents within work zones due to reduced visibility. Such factors also increase the risk of safety incidents to workers who are working in unfavorable weather conditions.
	F32	Time of the Year	It refers to the month/season of the year.
	F33	Day of the Week	It refers to the specific day of the week and involves a comparison between weekdays and weekends.
	F34	Time of day	It refers to the time of day, such as morning time, evening, and night-time.
	F35	Adequacy of the Safety	It refers to deficiencies or insufficiencies in the safety policies of the state.

State-Related Factors		Guidelines and Procedures	
	F36	Law Enforcement	It refers to the presence of law enforcement in work zones, which can be either active (ready to pull over drivers) or passive (for warning purposes). It also includes the enforcement of driving laws and the work zone restrictions.
	F37	Limited Safety Budget	It refers to the budget allocated for the safety countermeasures such as the widening of highway shoulders, augmenting police presence, etc.

Figure 4. (a and b) Mapping of the work zone safety factors and the analyzed articles

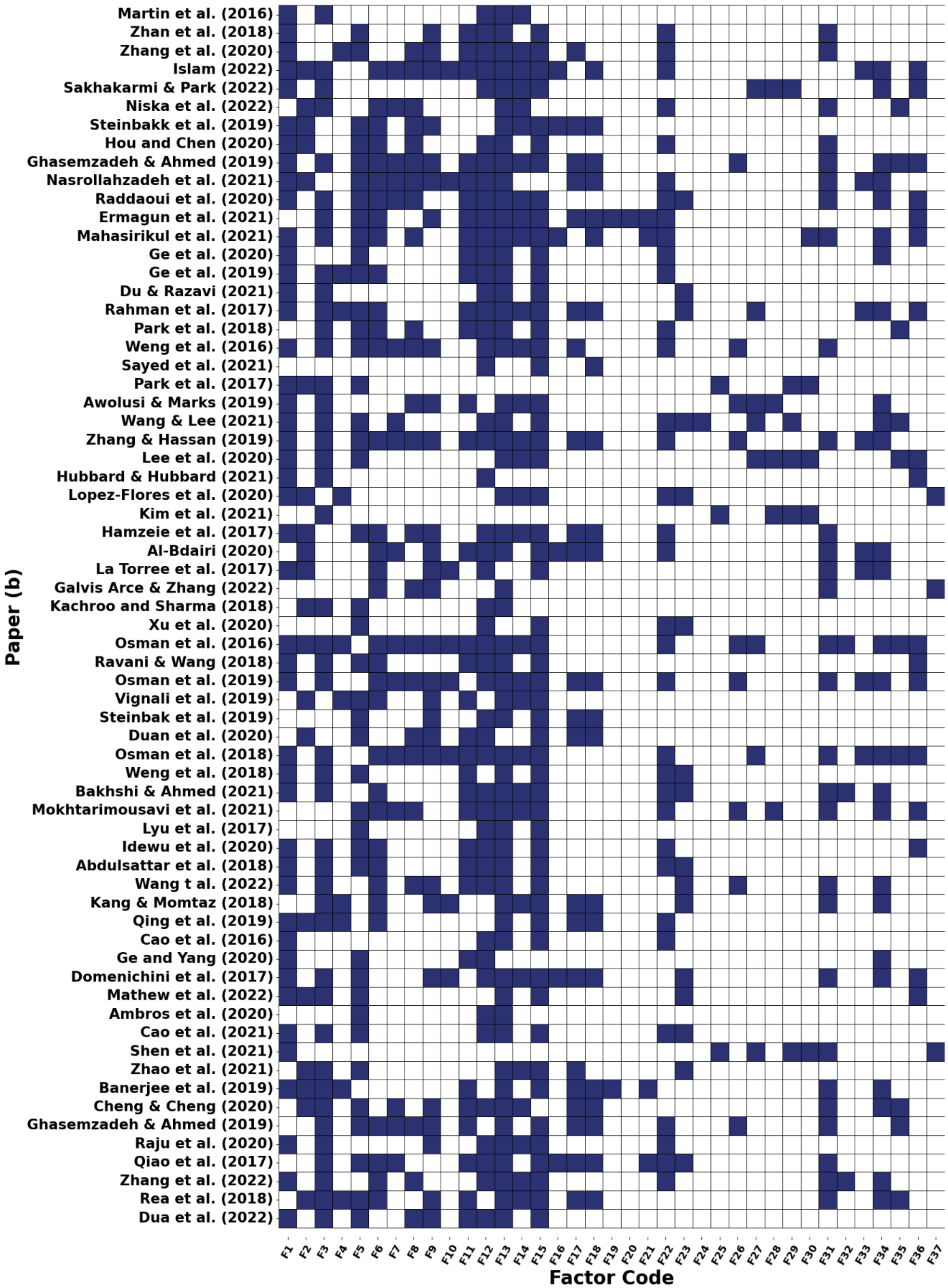


Figure 4. ***(Continued.)***

Articles Classification and Constructing the Reference Matrices

After conducting a quantitative analysis of the literature and identifying 37 work zone safety factors, the authors created reference matrices T and M using the classification criteria previously outlined in the "Research Methodology" section, as presented in Table 4. According to the table, 38 articles focused solely on theoretical discussions about work zone safety, falling into Type 1 and being included in Matrix T. Conversely, 95 articles involved experimentation or mathematical modeling of work zone safety, belonging to Type 2 and contributing to Matrix M. Among these 95 articles, 70 also incorporated extensive theoretical discussions, thereby contributing to both Matrix T and Matrix M. With the identification of 37 work zone safety factors in this study (Table 3), the dimensions of Matrix T are 37 by 108, while Matrix M has dimensions of 37 by 95.

Table 4. Classification of reviewed articles and their corresponding matrices

Article Citation	Type	Corresponding Reference Matrix		Article Citation	Type	Corresponding Reference Matrix	
		Matrix T	Matrix M			Matrix T	Matrix M
Kitali et al. (2022)	1	X	-	Park et al. (2021)	2	X	X
Santos et al. (2021)	1	X	-	Valdes-Diaz et al. (2021)	2	X	X
Son et al. (2021)	1	X	-	Du and Razavi (2019)	2	X	X
Dehman and Farooq (2021)	1	X	-	Nnaji et al. (2018)	2	X	X
Weng and Meng (2012)	1	X	-	Nnaji et al. (2020)	2	X	X
Meng and Weng (2013)	1	X	-	Xu et al. (2016)	2	X	X
Yang et al. (2013)	1	X	-	Kummetha et al. (2020)	2	X	X
Rayaprolu et al. (2013)	1	X	-	Rahim and Hassan (2021)	2	X	X
Yousif et al. (2014)	1	X	-	Almallah et al. (2021)	2	X	X
Weng and Meng (2014)	1	X	-	Difei et al. (2021)	2	X	X
Debnath et al. (2014)	1	X	-	Choe et al. (2014)	2	X	X
Liang et al. (2014)	1	X	-	Bham et al. (2014)	2	X	X
Fan et al. (2014)	1	X	-	Shakouri et al. (2014)	2	X	X
Weng et al. (2015)	1	X	-	Huang and Bai (2014)	2	X	X
Debnath et al. (2015)	1	X	-	Kaber et al. (2015)	2	X	X

Chen and Ahn (2015)	1	X	-	Sakhare et al. (2022)	2	X	X
Jin and Jin (2015)	1	X	-	Park et al. (2016)	2	X	X
Nyende-Byakika (2016)	1	X	-	Ren & Wu (2015)	2	X	X
Melcher and Keller (2016)	1	X	-	Ferreira et al. (2017)	2	X	X
Wennström et al. (2016)	1	X	-	Nnaji et al. (2020)	2	X	X
Jumari et al. (2022)	1	X	-	Barlow et al. (2020)	2	X	X
Xu & Yang (2019)	1	X	-	Yang et al. (2015)	2	X	X
Koilada et al. (2020)	1	X	-	Zhu et al. (2016)	2	X	X
Chang et al. (2020)	1	X	-	Ščerba et al. (2015)	2	X	X
Mahasirikul et al. (2021)	1	X	--	Kersavage et al. (2018)	2	X	X
Sayed et al. (2021)	1	X	-	Wang et al. (2021)	2	X	X
Lee et al. (2020)	1	X	-	Sze & Song (2019)	2	X	X
Hubbard & Hubbard (2021)	1	X	-	Saha (2021)	2	X	X
Lopez-Flores et al. (2020)	1	X	-	Zhan et al. (2018)	2	X	X
Hamzeie et al. (2017)	1	X	-	Zhang et al. (2020)	2	X	X
Al-Bdairi (2020)	1	X	-	Islam (2022)	2	X	X
La Torree et al. (2017)	1	X	-	Sakhakarmi & Park (2022)	2	X	X
Kachroo and Sharma (2018)	1	X	-	Niska et al. (2022)	2	X	X
Osman et al. (2016)	1	X	-	Ghasemzadeh & Ahmed (2019)	2	X	X
Osman et al. (2019)	1	X	-	Nasrollahzadeh et al. (2021)	2	X	X
Steinbak et al. (2019)	1	X	-	Raddaoui et al. (2020)	2	X	X
Osman et al. (2018)	1	X	-	Ermagun et al. (2021)	2	X	X
Cao et al. (2016)	1	X	-	Rahman et al. (2017)	2	X	X
Genders et al. (2016)	2	-	X	Park et al. (2018)	2	X	X
Valdes et al. (2019)	2	-	X	Weng et al. (2016)	2	X	X

Abdelmohsen and El-Rayes (2018)	2	-	X	Park et al. (2017)	2	X	X
Zhang and Gambatese (2017)	2	-	X	Awolusi & Marks (2019)	2	X	X
Hang et al. (2022)	2	-	X	Wang & Lee (2021)	2	X	X
Yang et al. (2017)	2	-	X	Kim et al. (2021)	2	X	X
Bai et al. (2015)	2	-	X	Galvis Arce & Zhang (2022)	2	X	X
Ahmed et al. (2016)	2	-	X	Xu et al. (2020)	2	X	X
Weng et al. (2015)	2	-	X	Ravani & Wang (2018)	2	X	X
Weng et al. (2016)	2	-	X	Vignali et al. (2019)	2	X	X
Re et al. (2021)	2	-	X	Duan et al. (2020)	2	X	X
Martin et al. (2016)	2	-	X	Weng et al. (2018)	2	X	X
Steinbakk et al. (2019)	2	-	X	Bakhshi & Ahmed (2021)	2	X	X
Hou and Chen (2020)	2	-	X	Mokhtarimousavi et al. (2021)	2	X	X
Ge et al. (2020)	2	-	X	Lyu et al. (2017)	2	X	X
Ge et al. (2019)	2	-	X	Idewu et al. (2020)	2	X	X
Du & Razavi (2021)	2	-	X	Abdulsattar et al. (2018)	2	X	X
Zhang & Hassan (2019)	2	-	X	Wang t al. (2022)	2	X	X
Kang & Momtaz (2018)	2	-	X	Qing et al. (2019)	2	X	X
Domenichini et al. (2017)	2	-	X	Ge and Yang (2020)	2	X	X
Ambros et al. (2020)	2	-	X	Mathew et al. (2022)	2	X	X
Cao et al. (2021)	2	-	X	Shen et al. (2021)	2	X	X
Banerjee et al. (2019)	2	-	X	Zhao et al. (2021)	2	X	X
Ghasemzadeh & Ahmed (2019)	2	-	X	Cheng & Cheng (2020)	2	X	X
Rea et al. (2018)	2	-	X	Raju et al. (2020)	2	X	X
Elghamrawy et al. (2012)	2	X	X	Qiao et al. (2017)	2	X	X
Ahmed et al. (2021)	2	X	X	Zhang et al. (2022)	2	X	X
Kim et al. (2021)	2	X	X	Dua et al. (2022)	2	X	X

Lv et al. (2021)	2	X	X

Results of SNA

Overview

Using the identified factors and the developed matrices T and M, the authors constructed the AMs for each dataset, as previously described in the "Research Methodology" section. Subsequently, the authors conducted SNA on each AMs respectively, to highlight the literature addressment of work zone safety factors, and to provide a basis to recommend research undertaking of the under-addressed factors. The normalized DC values of AMs T and M are depicted in Figure 5, which indicate the importance of a work zone safety factor in terms of articles addressing it. Factors having a normalized DC value greater than 0.8 are generally considered to be significant in a network (Abotaleb and El-adaway 2018). As shown in Figure 5, F1 "Design of Work Zone Layout", F13 "Driver's Compliance with Work Zone Speed Limit", and F15 "Driver's Unsafe Behavior" emerge as highly addressed factors in both theoretical and mathematical/computational literature. Conversely, certain driver-related factors such as F19 "Driver's Income", F20 "Driver's Ethnicity", and F21 "Driver's Educational Level" received relatively little attention. Notably, driver-related factors such as F17 "Driver Gender" and F18 "Driver's Age" are relatively more extensively discussed in the literature, particularly in computational models (Koilada et al., 2020; Chang et al., 2020; Steinbakk et al., 2019b).

Furthermore, factor F37 "Safety Budget", which belongs to the category of state-related factors, has been inadequately addressed in both theoretical and computational models. This work zone safety factor has a significant impact on several other factors, especially the design-related factors, as the cost of work zone safety systems can hinder their implementation (Nnaji and Gambatese, 2018). To address this issue, Saha (2021) developed an optimization model using linear integer programming to determine the optimal budget allocation for implementing work zone safety countermeasures. Similarly, Galvis Arce and Zhang (2022) proposed a framework to estimate the benefit-to-cost ratio of improving pavement friction to reduce crashes. However, the factor of safety budget has not been further comprehensively addressed in the literature with relation to work zone safety.

Additionally, notable disparities exist in the normalized DC values between the theoretical and computational treatment of work-related factors, specifically F28 "Worker's Behavior", F29 "Traffic Control inside Work Zone", and F30 "Level of Congestion in the Work Zone", as well as state-related factors, namely F35 "Adequacy of the Safety Guidelines and Procedures" and F36 "Law Enforcement". These factors are more extensively discussed in theoretical literature compared to computational models. It is anticipated that such discrepancies may arise due to various reasons, such as the challenge of modeling theoretical factors (Iyer and Sagheer, 2010) and the unavailability of data owing to confidentiality concerns (Krizek et al., 2009). Nonetheless, these gaps highlight potential avenues for future research on factors that do not fall under the aforementioned constraints. Moreover, as depicted in Figure 5, all of these factors have been addressed to some extent in computational models, indicating that they are not entirely excluded from mathematical/computational approaches.

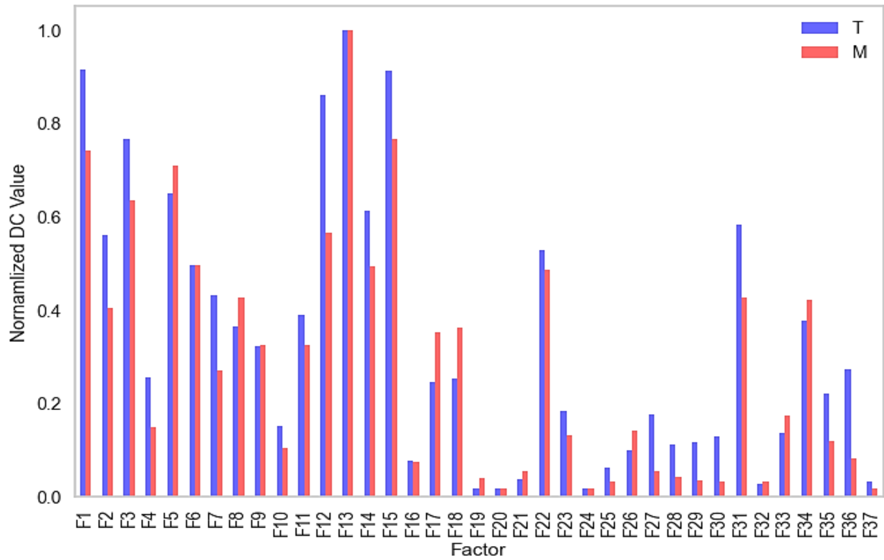


Figure 5. Normalized degree centrality (DC) values for adjacency matrices (AMs) T and M

Network Analysis

Using the developed AMs and the computed DC weights, the network graphical illustrations were generated using Gephi software (Figure 6). Additionally, a heatmap was produced for each AM, as presented in Figure 6. The thickness and darkness of the web-shaped network edges, as well as the darkness of the network nodes and heatmap color coding, correspond to the DC values indicated on the scale.

Figure 6 demonstrates that the networks exhibit variations in their node and edge counts, as well as their connectivity weights. Network T displays a density of 77.6%, indicating that 77.6% of the connections within the network were realized. In contrast, Network M exhibited a density of 58.3%, signifying that only 58.3% of its connections were realized. Similarly, Network T exhibits more pronounced and robust links, indicative of a densely interconnected system with a greater proportion of realized connections among the work zone safety factors. Conversely, Network M displays more subtle and slender links, reflecting a sparser interconnected system with fewer realized connections among the work zone safety factors.

Furthermore, the heatmap of the networks, presented in Figure 6, highlights the disparities in the theoretical and mathematical approaches utilized to tackle the work zone safety factors. Although both networks' heatmaps suggest that certain factors have received relatively inadequate attention from the literature, Network M's heatmap displays darker hues (greater DC values) for most of the factors compared to Network T. Moreover, the correlation gap between the mathematically addressed factors is wider than that under theoretical treatment. For instance, Network T's heatmap reveals some literature-based correlation between the work-related factors (F26, F27, F28, F29, and F30) and F2 "Design of Safety Measures," whereas such correlation is largely absent in Network M. Similarly, the correlation between the work-related factors and F1 "Design of Work Zone Layout" is more pronounced in Network T than in Network M, as indicated by the darker color (higher DC value).

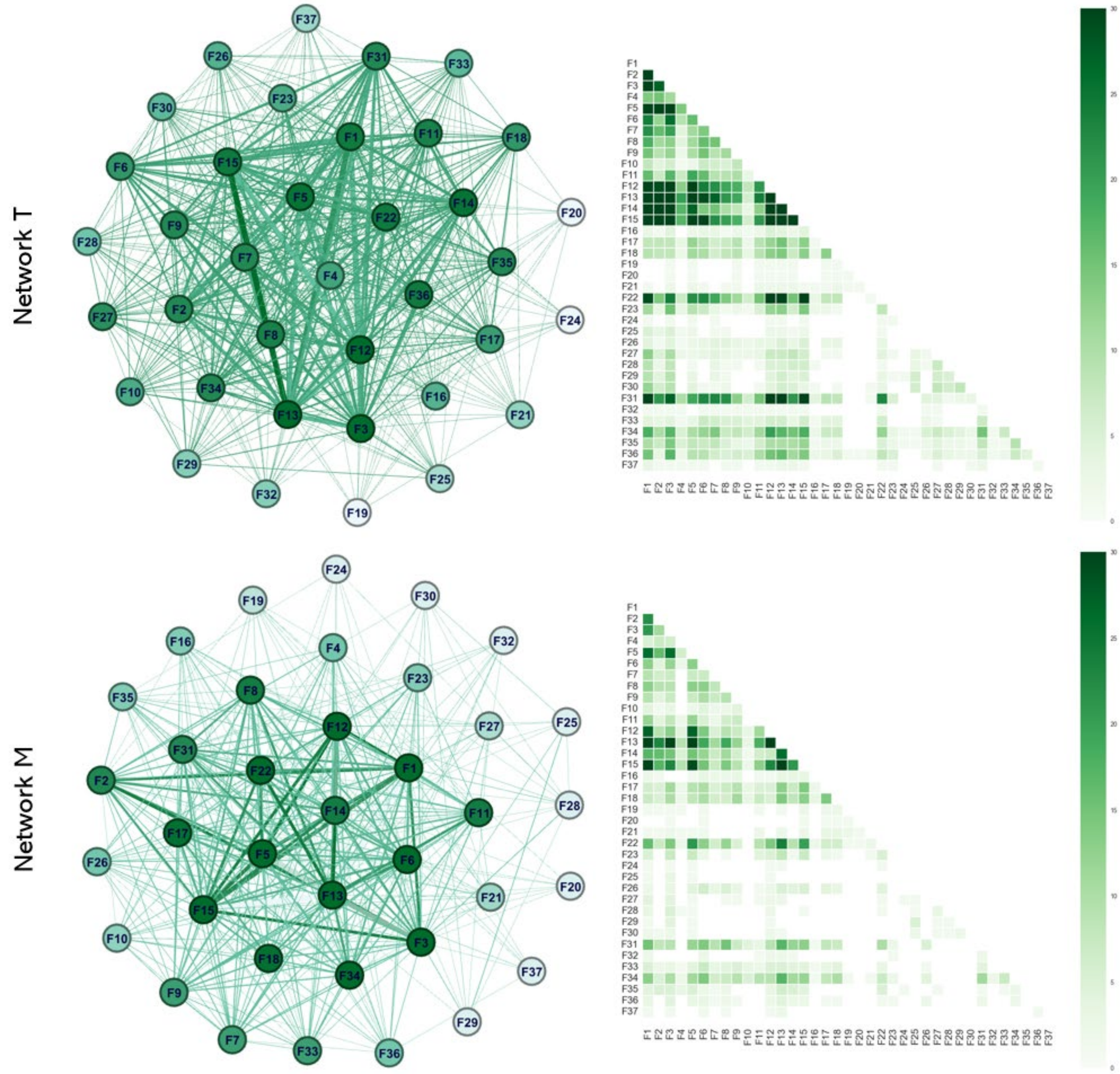


Figure 6. Visualization of networks T and M

Conclusion and Recommendation

This chapter presented a comprehensive review of the existing literature pertaining to work zone safety.

The SNA DC metric, shown in Figure 5, displays the normalized DC values for Networks T and M, with significant factors exhibiting comparatively high normalized DC values, while under-addressed factors generally have lower normalized DC values. Furthermore, the DC values are provided for each of the theoretical and mathematical approaches employed in examining the factors. Notably, certain factors such as F27 "Job Training", F28 "Worker's Behavior", F30 "Level of Congestion in the Work Zone", and F36 "Law Enforcement" emerge as particularly understudied mathematically.

The network visualization presented in Figure 6 effectively highlights the contrasting approaches employed in the examination of work zone safety factors, with a particular emphasis on the theoretical and mathematical perspectives. The visualization demonstrates the varying densities of Networks T (77.6%) and M (58.3%), providing insight into the level of interconnectivity among the factors under investigation. Notably, Network T exhibits a higher density than Network M, indicating a greater degree of interconnections among the theoretically discussed factors in the existing literature compared to their mathematical or computational counterparts. Consequently, it can be inferred that the current work zone safety models do not necessarily encompass the comprehensive range of relevant factors, which underscores the significance of focusing on theoretical approaches. Therefore, a thorough analysis encompassing all pertinent work zone safety factors is lacking, highlighting the critical need for such a comprehensive investigation.

Based on the analysis presented in this chapter, several recommendations can be inferred to advance the existing knowledge on work zone safety. Scholars are advised to integrate the relatively under-addressed work zone safety factors, specifically those pertaining to drivers and state-related factors, into their future research endeavors. Specifically, researchers can utilize the SNA results presented in Figures 5 and 6 as a reference to assess the under-addressed factors, considering the adopted theoretical and mathematical approaches, and subsequently incorporate them into future studies. By doing so, the knowledge base pertaining to the impact of these factors on work zone safety will be expanded, thus contributing to a more comprehensive understanding of the subject matter.

The research conducted in this chapter has significant theoretical contributions to the body of knowledge pertaining to work zone safety, including: (1) identification of an unprecedented comprehensive list work zone safety factors affecting both occupational and driver safety within work zones; (2) investigation of the interconnectivity among the identified work zone safety factors and identification of understudied factors in previous literature related to safety in work zones; and (3) identification of ill-studied work zone safety factors in the theoretical discussions versus mathematical/computational-based studies. The aforementioned provide a solid foundation to provide recommendations and directions for researchers so as to avoid redundancies and enhance the benefits of relevant future research efforts. Additionally, this study provides practical contributions to safety practitioners by promoting a comprehensive understanding of potential factors that impact safety in work zones. More specifically, this research identifies various factors as potential determinants of safety in work zone projects including specific state-related factors, such as F35 "Adequacy of Safety Guidelines and Procedures", F36 "Law Enforcement", and F37 "Safety Budget", along with other factors influenced by the state, such as work zone-related factors. These factors can serve as benchmarks for relevant state safety personnel to evaluate their state's performance and strive towards improving work zone safety measures accordingly.

Chapter 3. Safety Factors Criticality

Introduction

This chapter delineates the outcomes of surveying MoDOT employees and contractors regarding their perceptions of the criticality of the work zone safety factors identified in Chapter 2. The chapter is structured as follows: Firstly, background information on previous survey-based related safety research is discussed. Secondly, the research methodology, encompassing survey development and quantitative analysis of the survey results is outlined. Thirdly, a comprehensive discussion of the survey findings and their perceived criticality is presented. Lastly, recommendations derived from the results are presented.

Background Information

Despite the expanding literature on work zone safety, work zone injuries and fatalities in the US continue at alarming rates. As such, work zone safety remains a critical concern for practitioners. The Associated General Contractors (AGC) conducts annual surveys of highway contractors on work zone safety, with 58% and 57% of work zone contractors reporting increased safety risks in 2022 and 2023 compared to the previous year, respectively (AGC 2022; AGC 2023). Hence, there persists a research imperative to deepen the understanding of the factors influencing work zone safety.

To gain insights from work zone stakeholders, several studies conducted surveys or interviews with work zone experts to delve into various aspects of work zones. Mostafavi et al. (2012) interviewed work zone workers in Indiana to assess the factors impacting nighttime paving activities. Debnath et al. (2015) conducted interviews with work zone workers in the Australian context to explore their perceptions of hazards in work zone environments. Their findings revealed common hazards, including non-compliance with posted speed limits, distracted driving, aggression toward workers, and low worker visibility. Nyende-Byakika (2016) conducted interviews with work zone workers in Uganda, revealing poor working conditions, inadequate training, lack of personal protective equipment, and insufficient training as primary causes of occupational accidents and injuries. Nnaji et al. (2020) surveyed Department of Transportation (DOT) professionals and work zone contractors to evaluate the industry's application of various work zone safety technologies related to alerting workers to errant vehicles. Nnaji et al. (2018) surveyed members of the American Association of State Highway and Transportation Officials (AASHTO) and the AGC to assess awareness levels regarding work zone intrusion alert technologies. Long et al. (2014) surveyed MoDOT professionals and public personnel, revealing differences in perceptions regarding the sufficiency of warning signs and other work zone safety measures.

Accordingly, while several research studies have involved work zone practitioners to gather their perspectives on various factors impacting work zone safety, there is a lack of studies comprehensively assessing these factors collectively. Chammout et al. (2024a,b) identified a list of 37 factors influencing work zone safety; however, their analysis did not extend to an examination of the criticality of the impacts of these factors on work zone safety. Building on the approach of involving the practical perspectives of work zone practitioners, this study aims to quantitatively assess the critical importance of various factors on worker safety in work zone environments. This empowers the practical implementation of targeted mitigation measures rooted in a workforce-centered safety perception. The contributions of this study are contrasted with those of relevant research in Table 5.

Table 5. Literature contribution of this research

Reference	Addressing several factors impacting work zone safety	Involvement of work zone practitioners' perspective	Analyzing a comprehensive list of factors impacting work zone safety	Examine the relative importance and criticality of the factors impacting work zone safety
Mostafavi et al. (2012)	-	√	-	-
Debnath et al. (2015)	√	√	-	√
Nyende-Byakika (2016)	√	√	-	-
Nnaji et al. (2018)	√	√	-	-
Nnaji et al. (2020)	√	√	-	-
Long et al. (2014)	√	√	-	√
Chammout et al. (2024a,b)	√	-	√	-
This research	√	√	√	√

Research Methodology

This study adopts a multistep methodology to achieve the goal and objectives of this research, as summarized in Figure 7. To this end, the authors (1) developed a survey instrument to collect data on the criticality of work zone safety factors identified in a previous study; (2) validated the sample sufficiency and internal reliability of the survey data; (3) analyzed survey data, considering respondents' expertise, positions, and their ratings of safety factor criticality; and (4) applied clustering analysis to the obtained ratings to identify groups of factors with varying levels of criticality. The subsequent subsections offer comprehensive insights into each step of the methodology.

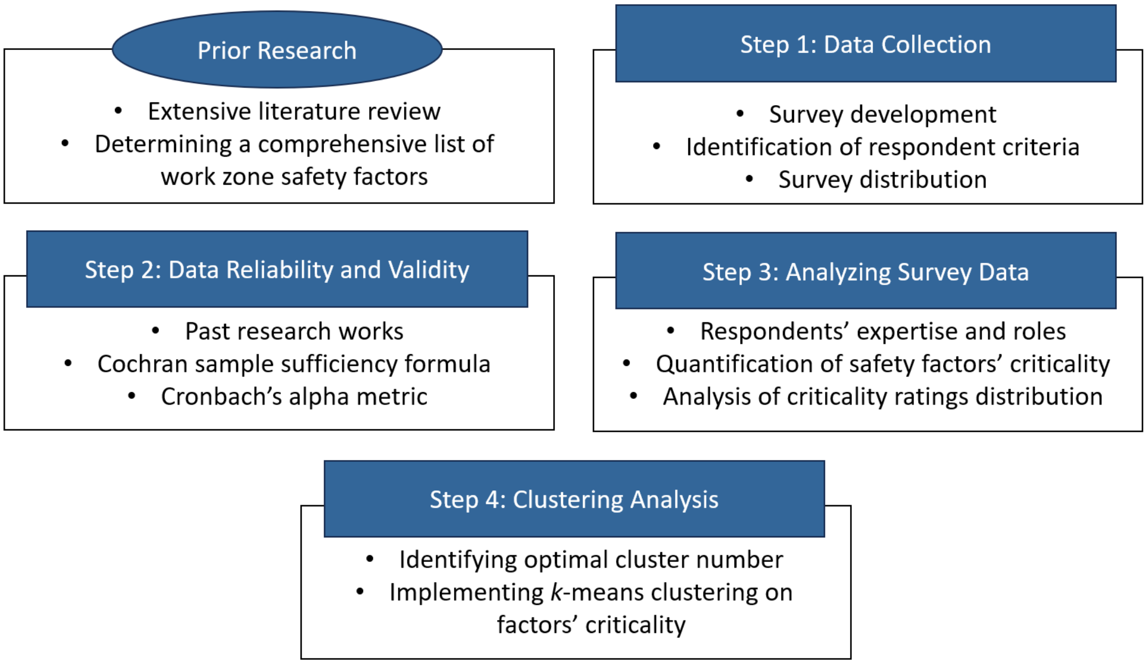


Figure 7. Research methodology

Identification of Work Zone Safety Factors

To achieve the objectives of this research, the authors initially incorporated a comprehensive set of 32 work zone safety factors, drawn from a list of 37 factors identified in Chapter 2 through an extensive literature review on work zone safety. The literature review involved examining peer-reviewed journal articles addressing various aspects of work- and public-related work zone safety, published in scholarly journals from 2012 to 2022. The selection of factors for this chapter excluded socioeconomic considerations (such as driver's ethnicity, education, and income), commonly regarded as pre-incident factors, as their criticality assessment would not offer practical guidance for mitigation measures, rendering their inclusion redundant. Table 6 presents the work zone safety factors along with their respective groups, and additional details can be found in Chammout et al. (2024a).

Table 6. Factors impacting work zone safety

Category	*Code*	*Factor*
Design-Related Factors	F1	Design of Work Zone Layout
	F2	Design of Safety Measures
	F3	Additional Preventive Measures
	F4	Clarity of Signage or Pavement Markings
	F5	Speed Variance Regulations
Roadway-Related Factors	F6	Type of Road
	F7	Roadway Lighting Conditions
	F8	Road Surface Condition
	F9	Road Alignment
	F10	Median Type
	F11	Sight Distance
	F12	Volume of Traffic in the Area of Work Zone

Driver-Related Factors	F13	Driver's Compliance with Work Zone Speed Limit
	F14	Driver's Level of Attention
	F15	Driver's Unsafe Behavior
	F16	Driver Impairments
Vehicle-Related Factors	F17	Characteristics of Driving Vehicle
	F18	Level of Technology within Driving Vehicle
	F19	Characteristics of Construction Equipment
	F20	Level of Technology within Construction Equipment
Work-Related Factors	F21	Work Zone Type
	F22	Job Training
	F23	Worker's Behavior
	F24	Traffic Control inside the Work Zone
	F25	Level of Congestion in the Work Zone
Temporal-Related Factors	F26	Weather Condition
	F27	Time of the Year
	F28	Day of the Week
	F29	Time of Day
State-Related Factors	F30	Adequacy of the Safety Guidelines and Procedures
	F31	Law Enforcement
	F32	Limited Safety Budget

Step 1: Data Collection

Survey Development

Upon identification of the factors influencing work zone safety, an online survey was created to evaluate the criticality and significance of each factor on worker safety. Qualtrics, an online survey distribution platform, was employed to gather the necessary data on the criticality of these factors. The survey comprised three sections, each providing clear instructions on the questions, definitions, and how to proceed with completing the survey. The first section included an introduction to the research project, the survey's objectives, and the anticipated time commitment for respondents. The second section of the survey consisted of questions in relation to the respondent data in terms of profile and years of experience. The third section comprised questions aimed at evaluating the criticality of the factors on worker safety in work zones, drawing on respondents' professional experience. Clear definitions of the categories and their respective factors were provided for each category to ensure clarity regarding the factors' scope.

Moreover, the survey encompassed an evaluation section aimed at ranking MoDOT's performance on factors falling within their sphere of influence, including job training and safety budget, among others, detailed in Chapter 4. Additionally, the MoDOT employee survey featured a section dedicated to assessing the field adoption of various safety policies and measures, elaborated upon in Chapter 5. For the purposes of this chapter, analysis is restricted to the first three sections. Survey participants were tasked with rating the criticality of each safety factor based on their construction experience, particularly within work zone projects, utilizing a five-point Likert scale outlined in Table 7.

Table 7. Adapted scale for work zone criticality rating

Likert Scale	Description
1	Very low criticality: minimal to negligible impact on worker safety in work zones.
2	Low criticality: may have a minor impact on worker safety in isolated instances.
3	Moderate criticality: likely to impact worker safety under typical conditions.
4	High criticality: poses a significant and substantial impact on worker safety under various conditions.
5	Very high criticality: represents an exceptionally severe and substantial impact on work zone worker safety

Survey Distribution

Following the development of the survey, the authors distributed it to targeted professionals with expertise in work zone projects and safety. Acknowledging that work zone projects are typically under local/state jurisdictions in terms of ownership, the specific survey respondents targeted were individuals associated with the Missouri DOT (MoDOT) and personnel affiliated with general contractors and subcontractors engaged in previous work zone projects. Accordingly, the targeted respondents were professionals who (1) are involved in the US construction industry, (2) possess at least 1 year of experience in work zone projects, and (3) are affiliated with one of the aforementioned stakeholders. Based on this criterion, the survey was distributed to a total of 826 professionals, with 298 respondents successfully completing the survey, resulting in a response rate of 36.08%. Further details regarding the sufficiency of the sample size and the profiles of the respondents are expounded upon in the "Results and Analysis" section of this chapter.

Step 2: Data Reliability and Validity

Ensuring the reliability of collected data is essential for the validity of subsequent analyses. In the context of a survey, internal reliability signifies the degree to which the utilized scale consistently measures an underlying construct of interest (Singh 2017). To assess this, the internal consistency of the survey data was evaluated through the computation of Cronbach's alpha (Cronbach 1951). Cronbach's alpha facilitates the assessment of the reliability of factors derived from dichotomous or multipoint scales (Santos 1999). High Cronbach's alpha values suggest that survey respondents generally have a consistent understanding of the survey questions, ensuring the reliability of their inputs. The threshold for Cronbach's alpha used as a measure for the internal reliability of survey data is 0.75, a cutoff recommended by Christmann and Van Aelst (2006) and previously utilized in relevant research studies (Khalef and El-adaway 2023b; Al-Mhdawi et al. 2022; Jiang et al. 2023). For this study, the Cronbach's alpha metric was employed to assess the internal reliability of the scale employed for evaluating the criticality of the factors for the safety of the work zone workforce.

Step 3: Analyzing Survey Data

Following the distribution and validation of the survey sample size and internal reliability, the authors proceeded to calculate the average criticality of factors influencing work zone workforce safety. Notably, the methodology employed for risk or criticality rating finds extensive application in related research. Okpala et al. (2023) utilized expert interviews to propose risk ratings for safety hazards associated with the use of robotics and automation in construction. Mohamad and Tran (2021) introduced a risk-based inspection approach to optimize the construction inspection process based on factor criticality. Diab et al. (2017) conducted a survey among construction professionals to explore industry perceptions of risk drivers and their impact on cost contingency, particularly in the context of transportation projects. Castro-Nova et al. (2018) introduced a risk rating system for geotechnical-related factors, drawing on industry perspectives obtained through an industry survey. Russell et al. (2013) analyzed the criticality of factors influencing scheduling buffers, based on insights from surveying construction experts. To this end, given the substantial utilization of expert surveys in prior research to explore factor criticality, this research conducts an analysis of respondents' perspectives on the criticality of factors influencing worker safety in work zone environments.

Step 4: Clustering Analysis

For increased insight, this study utilizes clustering analysis to categorize work zone safety factors according to their criticality ratings by the respondents. This analysis facilitates the identification of groups of factors that are perceived collectively at varying levels of criticality. That said, clustering analysis, an unsupervised ML algorithm, is employed to partition safety factors of variant criticalities into separate groups. Clustering techniques have found widespread applications across diverse CEM domains. For instance, Al Qady and Kandil (2014) employed clustering as an unsupervised approach for categorizing construction documents based on textual similarities, avoiding the complexities related to training in supervised approaches. Kärnä et al. (2009) utilized clustering to categorize construction projects according to customer satisfaction, revealing influential factors such as effective cooperation and the management's professional skills. Ahmed et al. (2024) employed clustering analysis to quantitively group factors impacting competitive construction bidding based on their level of investigation in previous literature. Considering its relevance in CEM research, clustering is employed in this study to facilitate the identification of groups of factors with varying criticality levels. This approach guides the formulation of targeted safety mitigation recommendations.

In the context of this study, the authors employed the k-means clustering technique, a well-established methodology extensively utilized in pertinent academic research (Yen et al. 2007). This approach was selected to systematically categorize a set of x data points into k clusters, discerning the nuances in their criticality ratings. The k-means clustering, a centroid-based algorithm, accomplishes this objective by minimizing the distances between each data point and the centroid of its corresponding cluster. In this research, clustering was applied based on the criticality ratings of the safety factors and the proportion of respondents selecting the criticality rating. The implementation of k-means clustering necessitates the initialization of the number of clusters k. To obtain the optimal number of clusters, the authors employed the elbow plot, a method widely recognized for its precision, simplicity, and computational efficiency in obtaining the k-value (Kodinariya and Makwana 2013). This technique involves plotting distortion values corresponding to varying cluster numbers and pinpointing the juncture (elbow) where the addition of further clusters yields diminishing contributions to the data modeling (Shi et al. 2021; Syakur et al. 2018).

Upon computation of the number of clusters, k-means clustering is implemented to group the various safety factors into groups of varying criticalities. The utilization of the k-means clustering technique was executed in the Python programming language, employing the Scikit-Learn package (Pedregosa et al. 2011). The clustering procedure consists of sequential steps, including: (1) the initialization of cluster centroids; (2) the allocation of each data point to its closest centroid; and (3) the recalibration of centroids and reclassification of data points, considering dissimilarity between the updated and previous centroids. As aforementioned, the primary goal is to minimize inertia and the cluster sum of squares. Subsequently, steps 2 and 3 are repeated until the cluster centroids converge.

Results and Analysis

Sample Sufficiency

Ensuring the sufficiency of the survey's response rate is crucial to classify respondents as representative of the populations, thereby ensuring the validity of the analysis and the generalizability of the findings. Accordingly, the authors assessed the sample sufficiency of the 298-sample size through empirical examination based on previous related studies and employed statistical analysis.

Regarding empirical-based sample sufficiency, Assaad et al. (2020) found that a typical response rate in survey-based research often falls within the range of 20-30%. This aligns with analogous ranges found in other studies, such as Fellows and Liu (2015) (25-35%) and Tan et al. (2014) (10-20%), among others. Accordingly, the achieved response rate in this study, 36.08%, is in line with comparable research. Moreover, the number of respondents in this study (298) surpasses the sample size reported in many previous related research studies. Assaad et al. (2022) conducted a survey-based analysis to examine the state of practice of offsite construction with a sample size of 100 respondents. Hao et al. (2022) explored organizational and personal factors influencing workers' pro-environmental behavior within Chinese organizations, with a sample size of 152. Goh et al. (2023) utilized a survey to investigate professionals' views on the economic considerations of sustainable construction, drawing responses from 36 participants. Elbashbishy and El-adaway (2024) surveyed industry professionals to analyze labor shortages across various construction trades, obtaining a sample size of 106. Consequently, both the response rate and the sample size achieved in this study are considered empirically viable.

In addition to empirical-based sufficiency, the authors utilized statistical analysis to further ensure the validity of the attained sample size. To this end, the Cochran formula (Cochran 1977), as shown in Eq. (4), was applied to calculate the minimum sample size n needed for statistical validity.

$$n = \frac{t^2 s^2}{e^2}$$

Equation 4. Cochran formula

Where t is the Z-statistic for a significance value α, s represents the estimated standard deviation for the adopted Likert scale, and e is the acceptable error multiplied by the adapted scale points.

A 95% confidence interval is commonly adopted in pertinent research (Kamali and Hewage 2017; Khalef and El-adaway 2023b), and thus similarly applied in this study. This confidence interval corresponds to an $\alpha = 0.05$ which, in turn, corresponds to a $t = 1.96$. Regarding the estimated standard deviation, it would entail the fraction of the range of the adapted scale to the number of standard deviations including all possible values in the range. Consequently, s is typically calculated as 5/6 for a 5-point Likert scale (Randiwela and Wijayaratne 2017). Moreover, the margin of error is commonly set at 5%, based on its application in previous research (Pereira et al. 2018; Abdul Nabi and El-adaway 2021). Accordingly, the required sample size is computed as

$$n = \frac{t^2 s^2}{e^2} = \frac{(1.96)^2 (\frac{5}{6})^2}{(5 \times 0.05)^2} = 42.68 \approx 43$$

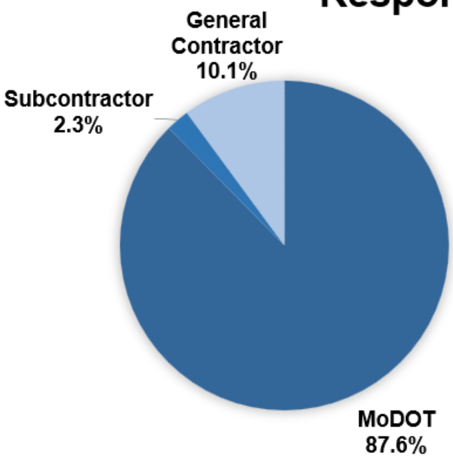
As the statistical sufficiency requires a sample size of 43 responses, it can be concluded that the number of respondents attained in this study (298) is both statistically and empirically sufficient.

Characteristics of Surveyed Professionals

As outlined in the "Methodology" section, the survey was disseminated via Qualtrics to work zone professionals, resulting in 298 comprehensive responses. Figure 8 illustrates the distribution of responses across the identified stakeholder groups. Notably, 87.6% of respondents were linked with MoDOT, 10.1% were aligned with contractors engaged in work zone projects, and 2.3% were associated with subcontractors involved in work zone projects. With regard to the professional experience of the survey respondents, the professionals have an average of 17.75 years of experience in construction and 13.78 years in work zones, respectively. The average construction experience for the surveyed stakeholders ranges from 13.14 to 20.38 years, while the average work zone experience varies between 7.61 and 10.43 years. Furthermore, considering the positions of the surveyed professionals, the average construction experience ranges from 12.72 years for field workers to 22.51 for site management positions. Similarly, the work zone experience varies from 9.96 years for field workers to 18.81 years for site management positions. Additionally, a significant proportion of the respondents demonstrated substantial professional experience, with over 74.16% possessing more than 10 years of experience in construction. Similarly, 59.4% of the surveyed individuals reported a work zone experience exceeding 10 years.

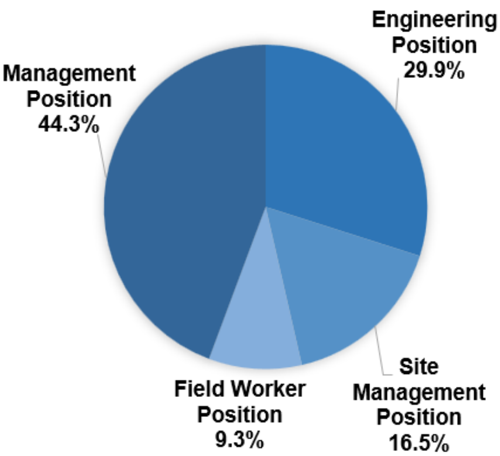
In terms of the professional roles assumed by each group of respondents, Figure 9 illustrates the distribution of professional positions within the identified stakeholder groups. As depicted in Figure 9, individuals from subcontractors and general contractors were predominantly in company/corporate management roles. In contrast, respondents associated with MoDOT occupied diverse positions, with engineering roles being the most prevalent among MoDOT participants. This diversity in respondent groups and their respective positions enhances the comprehensiveness of professional and expert insights gathered in this study.

Respondent Groups



Group	Years of Experience in Construction		Years of Experience in Work Zone Projects:	
	Average	SD	Average	SD
General Contractor	20.38	11.04	16.28	9.20
MoDOT	19.73	11.12	15.34	10.43
Subcontractor	13.14	10.15	9.71	7.61
All respondents	**17.75**	**10.77**	**13.78**	**9.08**

Respondent Positions



Position	Years of Experience in Construction		Years of Experience in Work Zone Projects:	
	Average	SD	Average	SD
Management	19.87	11.03	14.31	9.52
Engineering	15.91	11.09	12.31	10.90
Site Management	22.51	8.77	18.81	6.63
Filed Worker	12.72	12.19	9.96	9.26

Figure 8. Distribution of the respondents

To ascertain the acceptability of the surveyed respondents' experience in line with industry thresholds, the authors compared the characteristics of the obtained respondents with those reported in analogous survey-based studies. Jin and Gambatese (2020) conducted a survey to evaluate professionals' perspectives on the use of technological innovation in temporary construction, obtaining 46 responses, 76% of which reported having over 10 years of construction experience. Correia et al. (2021) employed a survey involving 6 experts with experience ranging from 3 to 9 years to investigate the adoption of reverse logistics. Votano and Sunindijo (2014) explored the influence of clients on construction safety by surveying 45 professionals, 20% of which had over 11 years of construction experience. Jiang et al. (2023) surveyed 67 experts, with 35% having experience greater than 10 years, focusing on public–private partnership project risk management. Accordingly, based on the sufficiency of data and the experience of respondents in this study’s survey, it can be inferred that the obtained data reflect the insights of highly experienced professionals.

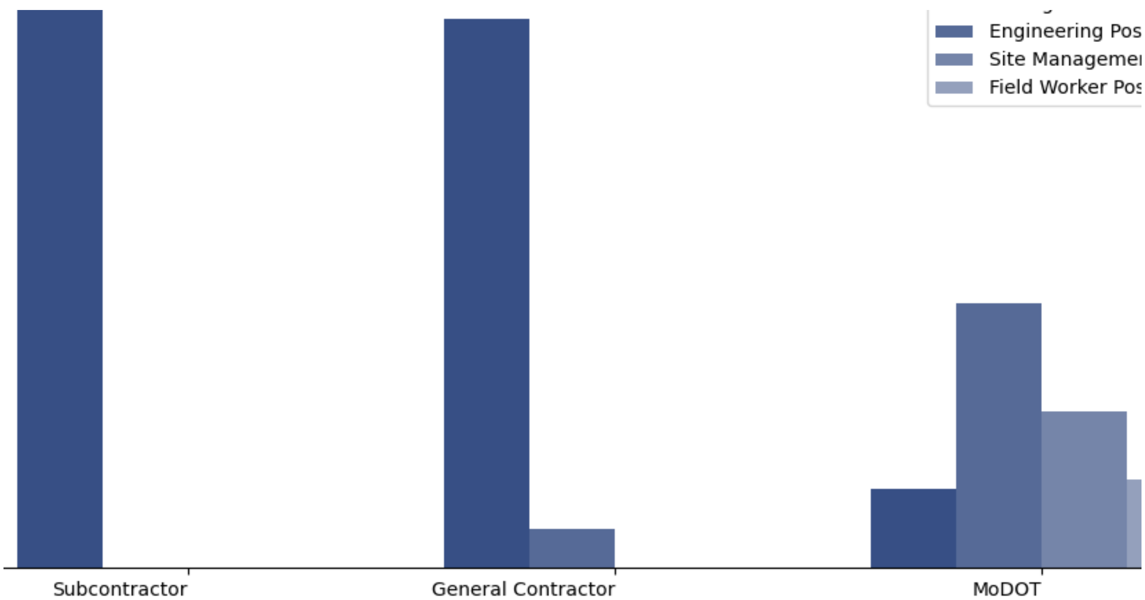


Figure 9. Distribution of respondents' positions across stakeholder groups

Data Reliability

As previously mentioned in the "Methodology" section, the Cronbach's alpha metric is employed to assess the internal consistency and reliability of survey results. Generally, high Cronbach's alpha values are indicative of a sufficient understanding of survey questions by respondents. In this study, the computed Cronbach's alpha for data pertaining to the criticality of factors was 0.942, with a 95% confidence interval of [0.932; 0.951]. Given that Cronbach's alpha metric significantly surpasses the 0.75 threshold, as corroborated by the confidence interval, it can be inferred that the survey data's internal reliability is robust.

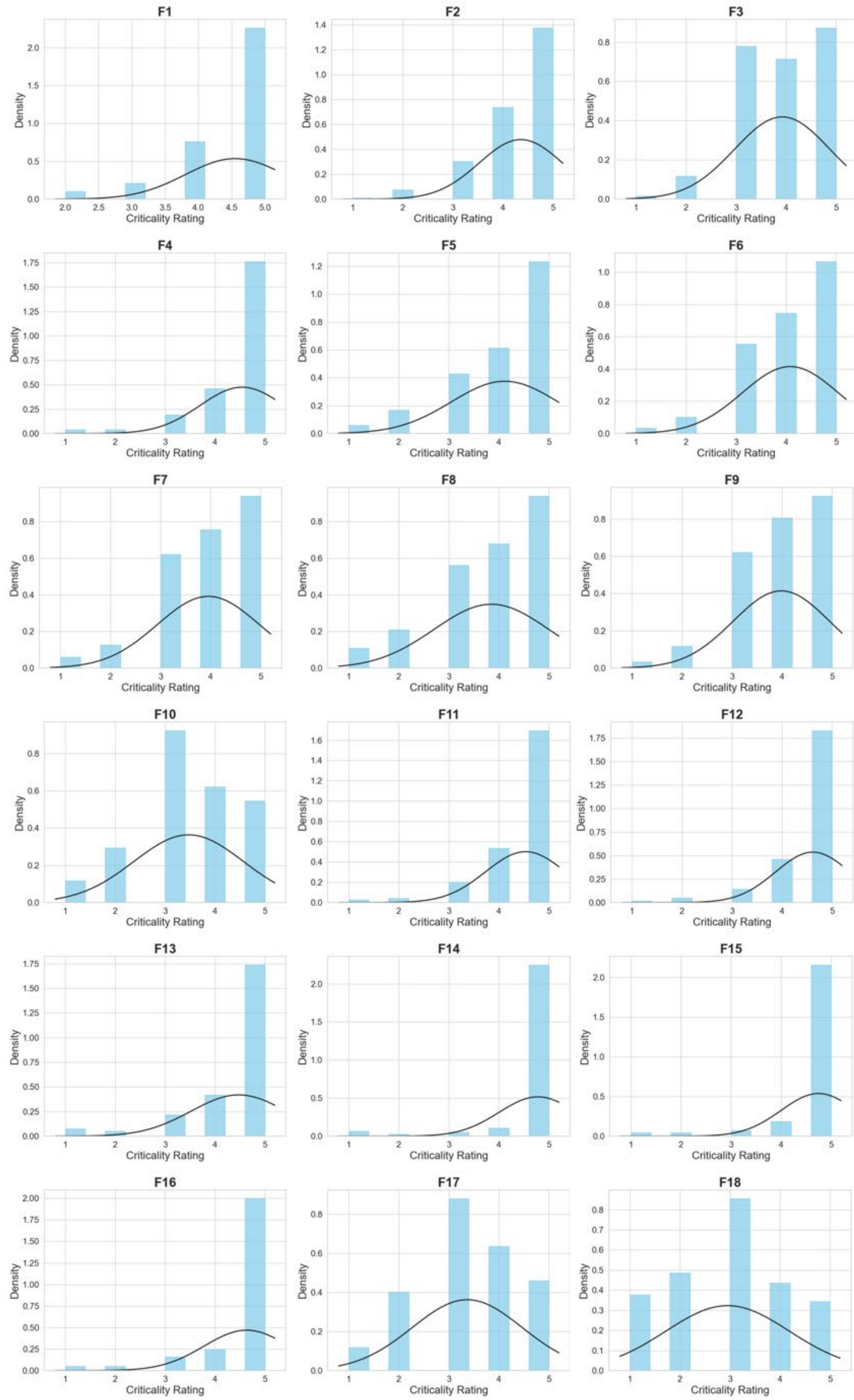
Work Zone Factors Criticality

Following the validation of the data's internal consistency, the authors proceeded to calculate the criticality of work zone safety factors based on respondents' input. Table 8 presents an overview of the survey results concerning the criticality of identified factors on worker safety. As indicated in Table 8, the mean criticality rating for the factors ranges from 2.95 for F18 ('Level of Technology within Driving Vehicle') to 4.78 for F14 ('Driver's Level of Attention'). Importantly, all factors demonstrate a mean rating surpassing 2.5 (moderate criticality). Consequently, all identified factors demonstrate moderate to significant effects on work zone worker safety, with F14 ('Driver's Level of Attention') identified as the most critical factor by survey respondents. In terms of variability in respondents' input, the standard deviation for the criticality ratings of factors ranges from 0.74 for F14 ('Driver's Level of Attention') to 1.25 for F20 ('Level of Technology within Construction Equipment'). Notably, F14 ('Driver's Level of Attention') achieved both the highest criticality rating and the lowest standard deviation. This suggests a consistently robust assessment by the respondents regarding the factor's criticality, positioning it as the most crucial among all. Additionally, F15 ('Driver's Unsafe Behavior') had the second-highest criticality rating, underscoring the respondents' collective viewpoint on the impact of driver-related factors on worker safety.

In addition to the average criticality ratings, Figure 10 illustrates the distribution of ratings for each factor among the survey respondents. As depicted in Figure 10, F14 ('Driver's Level of Attention') exhibits the highest density of respondents assigning a criticality rating of 5 (very high criticality). Conversely, all vehicle-related factors (F17, F18, F19, and F20) exhibit higher densities for a rating of 3 (indicating moderate criticality), along with limited-to-null skewness. This suggests that the characteristics of driving vehicles and construction equipment in work zones do not pose significant safety risks other than under typical conditions.

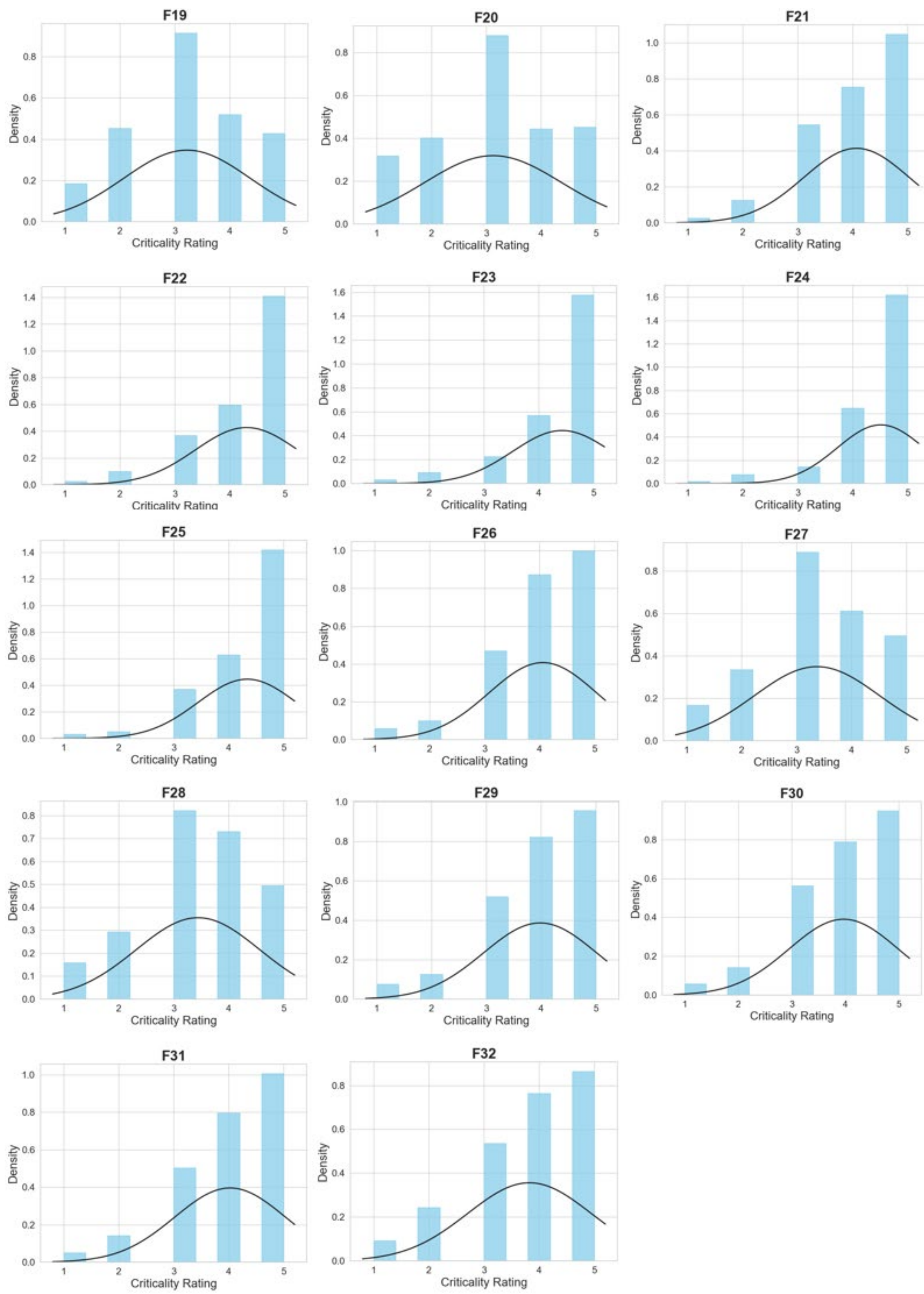
Table 8. Safety factors criticality rating

Factor	Mean	Standard Deviation	Rank by Mean	Distribution Characteristic	
				Skewness	Kurtosis
F1	4.55	0.75	5	-1.74	2.52
F2	4.36	0.83	11	-1.21	0.90
F3	3.92	0.95	23	-0.36	-0.76
F4	4.54	0.84	6	-2.15	4.72
F5	4.12	1.07	14	-1.04	0.23
F6	4.08	0.96	15	-0.80	0.03
F7	3.96	1.02	22	-0.73	-0.03
F8	3.85	1.15	24	-0.75	-0.28
F9	3.99	0.96	19	-0.65	-0.17
F10	3.47	1.10	26	-0.24	-0.56
F11	4.53	0.80	7	-1.94	3.91
F12	4.61	0.74	4	-2.23	5.24
F13	4.48	0.95	9	-2.05	3.86
F14	4.78	0.77	1	-3.89	14.76
F15	4.75	0.74	2	-3.45	12.09
F16	4.63	0.85	3	-2.61	6.53
F17	3.37	1.10	29	-0.14	-0.66
F18	2.95	1.24	32	0.05	-0.85
F19	3.22	1.15	30	-0.05	-0.71
F20	3.12	1.25	31	-0.07	-0.86
F21	4.07	0.96	16	-0.75	-0.17
F22	4.31	0.93	13	-1.24	0.83
F23	4.43	0.90	10	-1.69	2.48
F24	4.51	0.79	8	-1.86	3.56
F25	4.34	0.90	12	-1.34	1.45
F26	4.06	0.98	17	-0.98	0.65
F27	3.37	1.14	28	-0.23	-0.61
F28	3.44	1.12	27	-0.36	-0.49
F29	3.98	1.03	20	-0.90	0.34
F30	3.97	1.02	21	-0.79	0.05
F31	4.03	1.01	18	-0.86	0.16
F32	3.83	1.12	25	-0.70	-0.32



(a)

Figure 10. (a and b) Distributions of factors' criticality ratings



(b)

Figure 10. ***(Continued.)***

In addition to the driver-related factors, other elements were also considered significantly critical for work zone safety. F12 ('Volume of Traffic in the Area of Work Zone') was ranked as the fourth most critical factor. Similarly, F11 (Sight Distance)' was identified among the roadway-related factors viewed as safety-critical by the respondents, along with certain design-related factors (F1 and F4). Conversely, other design-related factors (F2 and F3), as well as roadway-related factors (F6, F7, F8, F9, F10), received lower criticality ratings. Work-related factors (F21, F22, F23, F24, and F25) attained varying criticality ratings, with generally more density for higher criticality ratings. Among this category, F24 ('Traffic Control inside Work Zone') was deemed a critical factor. Additionally, concerning temporal-related factors, F26 ('Weather Condition') was viewed as the most critical, followed by F29 ('Time of Day'), while F27 ('Time of the Year') and F28 ('Day of the Week') had greater densities for moderate criticality ratings. Within the state-related factors, F31 ('Law Enforcement') was viewed as the most critical, followed by F30 ('Adequacy of the Safety Guidelines and Procedures') and F32 ('Limited Safety Budget'), which had more moderate criticality ratings.

Results of k-Means Clustering

As detailed in the 'Research Methodology' section, clustering analysis has been employed to systematically categorize the factors into groups of varying criticalities, based on the ratings provided by survey respondents. To determine the optimal number of clusters (k) necessary for the clustering algorithm, the elbow plot (Figure 11) was generated. The elbow plot visually illustrates the relationship between the number of clusters and the distortion in the data. In this context, the distortion represents the sum of squared distances between data points and their assigned cluster centroids. The optimal number of clusters, as indicated by the 'elbow' point where the distortion starts to level off, is found to be three (Figure 11).

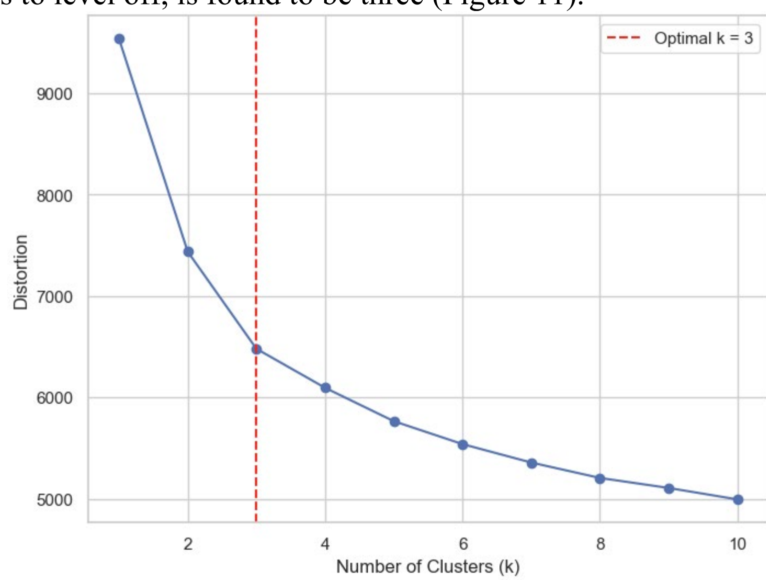


Figure 11. Elbow plot

Following the determination of the optimal number of clusters, the k-means algorithm is implemented on the criticality ratings of the work zone safety factors. Table 9 presents the clusters of work zone safety factors along with their respective categories. The clustering algorithm resulted in three clusters, each characterized by varying degrees of criticality and a distinct number of factors. As previously mentioned, all factors had criticality ratings exceeding 2.5, signifying their moderate to severe impact on work zone safety. The clustering algorithm plays a crucial role in further stratifying the criticality of these factors, facilitating the identification of groups with differing degrees of criticality. This, in turn, guides the development of targeted mitigation measures and recommendations.

As indicated in Table 9, Cluster 1, housing the factors deemed relatively most critical, encompasses a total of 13 factors. Cluster 2, characterized by a relatively moderate level of criticality, consists of 12 factors, while Cluster 3, identified as relatively less critical, comprises 7 factors. The distribution of factors across the clusters initially suggests that the identified safety factors yield either strong or moderate influence on work zone safety, while a minority of factors exhibit relatively low criticality. Figure 12 further illustrates the distribution of factors among the clusters. Notably, all driver-related factors are categorized within cluster 1, suggesting a high level of criticality for these factors in relation to worker safety. In contrast, all vehicle-related factors are assigned to cluster 3, signifying a relatively lower level of criticality for factors associated with motor vehicles or working equipment at the work zone site. The distribution of the design-related factors, as well as the majority of roadway-related factors, within clusters 1 and 2, reveal a high to moderate criticality of these groups on work zone safety. Moreover, the majority of work-related factors are assigned to Cluster 1, with the exception of F21 ('Work Zone Type'), which falls into Cluster 2. This highlights the criticality of factors related to work training and work zone layout in influencing safety performance. In terms of temporal-related factors, F26 ('Weather Condition') and F29 ('Time of Day') are part of Cluster 2, suggesting a higher impact on safety compared to F27 ('Time of the Year') and F28 ('Day of the Week'). All state-related factors are allocated to Cluster 2, indicating a moderate influence on work zone worker safety.

Table 9. Clustered factors

Category	***Cluster 1***	***Cluster 2***	***Cluster 3***
Design-Related Factors	F1, F2, and F4	F3 and F5	-
Roadway-Related Factors	F11 and F12	F6, F7, F8, and F9	F10
Driver-Related Factors	F13, F14, F15, and F16	-	-
Vehicle-Related Factors	-	-	F17, F18, F19, and F20
Work-Related Factors	F22, F23, F24, and F25	F21	-
Temporal-Related Factors	-	F26 and F29	F27 and F28
State-Related Factors	-	F30, F31, and F32	-
No. of Factors	13	12	7

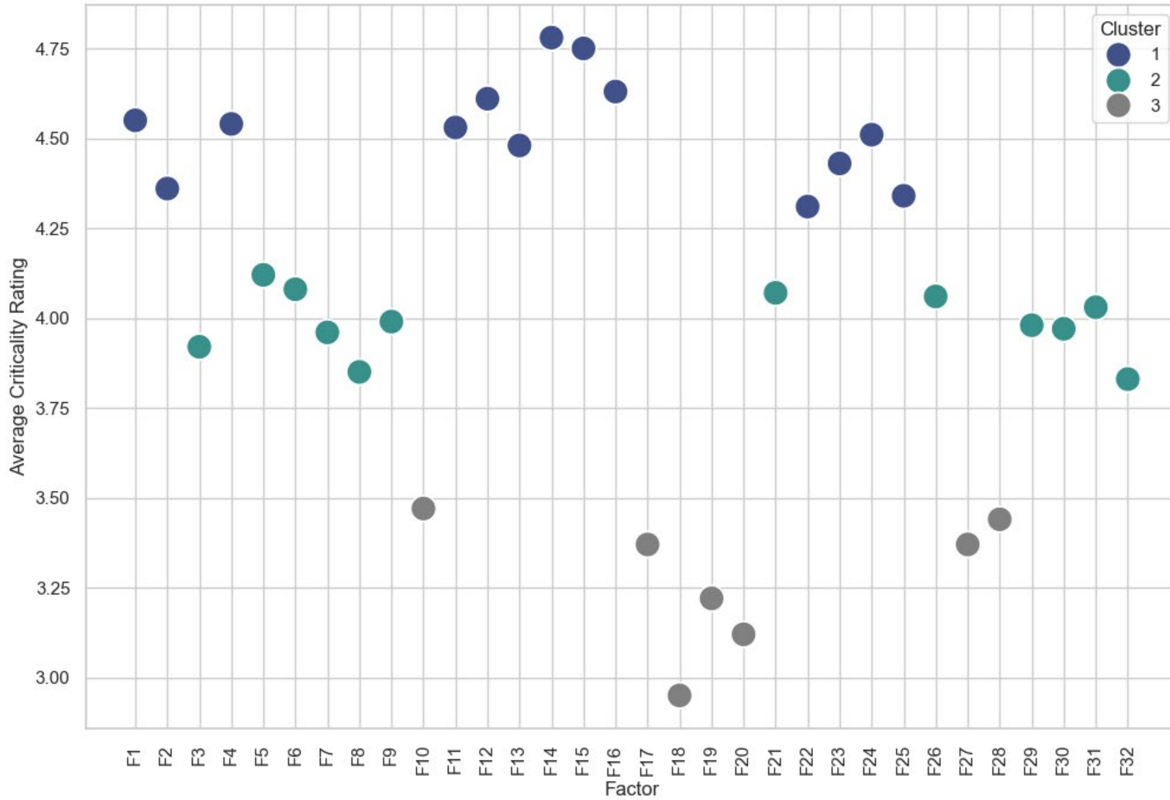


Figure 12. Clustered factors and their criticality ratings

Discussion

This section analyzes the acquired results concerning factor criticality, the identified clusters with varying criticality levels, and their implications for work zone safety.

Driver-Related Factors

As indicated by the survey and clustering outcomes, factors related to drivers (F13, F14, F15, and F16) are among the most pivotal elements influencing work zone worker safety, as perceived by expert respondents. Namely, F14 ('Driver's Level of Attention') stands as the most critical factor among all identified factors. Driver inattention and distracted driving were recognized by numerous state DOTs as one of the leading factors for work zone accidents (MoDOT 2022; KDOT 2009; VDOT 2021; TxDOT 2023). Additionally, numerous studies that investigated crash occurrences data identified driver distraction as a leading cause (Chang et al. 2020; Mokhtarimousavi et al. 2021; Tahmidul et al. 2021; Lym and Chen 2021). Several studies employing surveys or driving simulation methodologies emphasize the critical importance of driver attention in work zones, attributing accidents, in part, to inadequate levels of driver attention in the dynamic and stimulating environments presented by work zones. For instance, Valdés-Díaz et al. (2021) found that the use of GPS in work zones on two-lane rural highways might cause significant driver distraction compared to other conditions and environments. Valdes et al. (2019) surveyed drivers and identified that the most distracting activity while driving was talking to other passengers in the car. Similarly, based on surveying drivers, Ermagun et al. (2021) highlighted crucial aspects related to technology use distraction and the cognitive distraction of drivers affecting work zone safety.

Conversely, among the driver-related factors, F13 ('Driver's Compliance with Work Zone Speed Limit') is ranked as the least critical in this category and the 9th overall among all factors. Chammout et al. (2024a) observed that this factor is the most extensively studied, both theoretically and empirically, among work zone safety factors in existing literature, while F14 (‘Driver's Level of Attention’), was significantly less studied under both methodologies. Additionally, F16 (‘Driver Impairments’) was ranked as the third most critical safety factor (Table 8) yet is the least researched factor among this category of driver-related factors, and amongst the least addressed factors overall (Chammout et al. 2024a). This underscores the necessity to realign research endeavors according to factors' criticality, addressing over-researched areas and redirecting research efforts toward understudied yet perceived critical areas.

Work-Related Factors

Work-related factors mostly belonged to Cluster 1 (most critical factors relatively), with the exception of F21 ('Work Zone Type'), which belonged to Cluster 2 (moderately critical factor relatively). Among this category, F24 ('Traffic Control inside Work Zone') is recognized as the most critical. Numerous studies have highlighted the importance of proper traffic control inside work zone areas, both in relation to public drivers and construction equipment. Zhang and Gambatese (2017) evaluated various traffic control measures and found that combining portable changeable message signs and speed radar displays was the most effective. Sakhare et al. (2022) proposed a methodology for traffic control employing connected vehicle data to develop mitigation frameworks for congestion and hard braking in work zones. Ahmed et al. (2021) found that placing flashing blue lights, emulating the presence of law enforcement, led to a significant reduction in speed by motorists, hence recommending it for nighttime operations to increase overall safety. Additionally, F22 ('Job Training') and F23 ('Worker's Behavior') were perceived as critical factors by the respondents. This aligns with the findings of Osman et al. (2016) regarding the criticality of work zone worker training and education in dealing with crash-developing situations. Kim et al. (2021) employed a VR environment and found that work zone workers' risk alertness decreased with repeated exposure to hazards, such as trucks backing up, proposing VR as an approach to assess behavioral-based interventions. Similarly, Venthuruthiyil et al. (2023) proposed technology-based work zone worker training, such as VR-aided training, to prepare workers and enhance safety performances.

Design-Related Factors

Design-related factors were distributed across Clusters 1 and 2, highlighting the significant criticality of factors within this category for worker safety in work zones. Notably, three factors (F1, F2, and F4) of the design-related factors were grouped in Cluster 1, while F3 and F5 were categorized under Cluster 2. Within this category, F1 ('Design of Work Zone Layout') emerged as the most critical factor, ranking fifth among all factors. Conversely, F3 ('Additional Preventive Measures') was rated as the least critical, which is expected given its complementary or secondary nature to the primary design measures addressed by F1. Previous research has recognized the significance of effective design in enhancing work zone safety. Banerjee et al. (2019) assessed the effectiveness of various work zone signage in reducing speeds, recommending the use of photo-enforced signs in high-speed and prolonged work zones. Patel et al. (2014) proposed the implementation of a novel precast concrete wall barrier to streamline operations and enhance safety in bridge deck work zones. Domenichini et al. (2017) examined nine distinct work zone crossovers, observing that driver speeds surpassed designated limits in all configurations except those with altered geometrical characteristics. La Torre et al. (2017) explored the impact of stationary work zones, analyzing different layout configurations and identifying factors such as narrower lane widths, alterations in traffic flow patterns, and reduced distances between signs as contributors to heightened crash risk.

Roadway-Related Factors

Regarding roadway-related factors, F12 ('Volume of Traffic in the Area of Work Zone') and F11 ('Sight Distance') emerge as the most critical, while the remaining factors (F6, F7, F8, and F9) are grouped in Cluster 2, and F10 ('Median Type') is assigned to Cluster 3. The impact of traffic congestion within work zones, alongside considerations such as sight distance and work zone length, has been underscored as a key factor of accident occurrence. Zhang et al. (2022) highlighted that elevated traffic volumes in medium to longer work zones (exceeding 5000 meters) increase the likelihood of accident incidence. Cao and Liu (2016) emphasized the influence of traffic volume on work zone traffic dynamics, affecting merging behaviors and overall traffic flow. Additionally, Yang et al. (2013), through an analysis of 60 work zone projects, observed correlations between work zone length, traffic volume, and crash frequencies. Similarly, Zhang et al. (2020) formulated a traffic risk assessment tool, with testing in a work zone context revealing positive correlations between driving risk and traffic volume, alongside negative correlations with transition section length.

Other studies have addressed F19 ('Road Alignment'), which belonged to Cluster 2, indicating a relatively moderate criticality. For instance, Osman et al. (2016), analyzing a large dataset of work zone crashes, found significant impacts of road alignment, among other factors, on injury severity in crashes involving large trucks. Similarly, Lym and Chen (2021) investigated crash severity based on various factors, including roadway design elements such as the number of lanes, median type, and roadway curvature, observing lower crash severity in urban areas or at roundabouts, while higher severity crashes were more frequent in work zones and on curved roadways.

State-Related Factors

Factors falling under the purview of the state's control were all grouped within Cluster 2, indicating a relatively moderate criticality for work zone safety. Particularly, F31 ('Law Enforcement') emerges as the most critical factor within this category. The impact of law enforcement agencies on work zone safety has been underscored by numerous studies and DOTs, particularly regarding their influence on driver behavior and speed reductions. In response to crashes in rural work zones in California, the US DOT initiated the Augmented Automated Enforcement Systems to address aggressive and speeding driving behaviors (Smith et al. 2010). Ravani and Wang (2018) examined speeding in California work zones and the impact of police presence on speed reduction. Their analysis of various law enforcement levels revealed that any police presence decreased speed in both urban and rural settings. Similarly, Saha (2021), through an analysis of Indiana work zone data, determined that live police presence and portable rumble strips with queue warning systems were the most effective measures in crash reduction.

Additionally, F30 ('Adequacy of the Safety Guidelines and Procedures'), which ranks second in criticality within state-related factors, has been the focus of several studies. Zhu et al. (2016) assessed the performance of an alternative merging sign compared to standard ones in Missouri, resulting in a 6% increase in occupancy in the open lane with the new sign. Rea et al. (2018) conducted a field study to evaluate and recommend intensities for flashing yellow warning lights in work zones, an aspect not covered by existing standards. Sze and Song (2019) investigated work zone crash data in New Zealand, identifying the stipulated speed limit as a contributing factor to crash occurrences and recommending a reduction in speed limits in work zones.

Temporal-Related Factors

Temporal-related factors are distributed across Clusters 2 and 3, reflecting moderate to low criticality on work zone safety. Within these clusters, F26 ('Weather Condition') and F29 ('Time of Day') are categorized under Cluster 2, indicating moderate criticality. The significance of these factors for work zone safety has been highlighted in previous research. For instance, Hou and Chen (2020) utilized simulated driving environments to evaluate traffic safety in work zones under adverse conditions, revealing that lane change frequency increased during adverse weather conditions, thereby heightening the risk of collisions. Nnaji et al. (2020) emphasized the challenge of reduced visibility in nighttime work zones and proposed the use of wearable light systems, which, as per an employee-based survey, were found to improve their sense of safety. Al-Bdairi (2020) investigated the impact of the time of day on the severity of driver injuries in work zone crashes, and found that nighttime crashes resulted in higher injury severity and were more likely to involve fixed objects, whereas daytime crashes were predominantly rear-end collisions. Furthermore, the significance of these factors aligns with the findings of several prior studies examining crash occurrence and severity data (La Torre et al. 2017; Weng and Meng 2012; Kitali et al. 2022; Weng and Ma 2016; Mokhtarimousavi et al. 2021; Ghasemzadeh and Ahmed 2019).

Vehicle-Related Factors

Construction equipment and motorist vehicle-related factors were all clustered within Cluster 3, indicating lower criticality on work zone safety compared to other categories, as perceived by the expert survey respondents. Technological advancements related to motorist vehicles have been investigated with the aim of improving work zone safety. Genders and Razavi (2016) suggested utilizing connected vehicle technologies to notify drivers about road conditions ahead in work zone areas. Similarly, Raddaoui et al. (2020) assessed the efficacy of connected vehicle technologies in alerting truck drivers about adverse work zones and weather conditions. Khattak et al. (2022) proposed employing connected and automated vehicles for lane management and merging in work zones, with testing indicating a significant reduction in crash risk. Furthermore, studies have analyzed characteristics related to motorist vehicles to understand their impact on crash occurrence and severity, particularly focusing on factors such as vehicle age and size. For example, Ghasemzadeh and Ahmed (2019) utilized ML modeling to classify the severity of work zone crashes, taking into account factors such as vehicle type and vehicle age. Zhang et al. (2020), through simulation modeling, found that the driving risk increases with a higher proportion of large vehicles in traffic. Elghamrawy et al. (2012) emphasized the importance of considering rumble strip designs in highway work zones, especially where cargo trucks frequently pass, as these larger vehicles produced the lowest rumble strip decibel readings.

Characteristics related to construction equipment and their technological sophistication also received comparatively lower criticality ratings, akin to those associated with motorist vehicles. Numerous studies have proposed technological advancements in construction equipment, particularly for dump trucks, which are a major contributor to occupational injuries in work zones, aiming to improve overall work safety performance. For instance, Park et al. (2016) proposed a Bluetooth-based sensing device to alert workers of their proximity to hazardous equipment in work zones. Ferreira et al. (2017) proposed the use of backup cameras on dump trucks to prevent occupational injuries in work zones. Choe et al. (2014) evaluated the effectiveness of ultrasonic and radar-based sensing devices mounted on dump trucks and pickup trucks to prevent back-over injuries in work zones.

Conclusion and Recommendation

This chapter systematically examined the diverse factors influencing work zone safety, with the aim of quantifying their criticality to establish a robust foundation for targeted safety interventions. This was done following an identification of a comprehensive list of factors impacting work zone safety. To collect the data, a survey was disseminated to work zone professionals and answered by 298 professionals, with an average of 17.75 years of construction experience and 13.78 years of work zone experience, to examine the effects of 32 factors on work zone safety. Second, Cronbach's alpha metric was employed to ensure the internal reliability of the data. Third, the survey responses underwent analysis to assess the criticality rating and distribution of each factor. Lastly, employing *k*-means clustering analysis, the identified factors were categorized into three distinct groups based on their varying impacts on work zone safety.

The findings reveal that driver-related factors, specifically driver's level of attention, unsafe behavior, and impairments, are perceived as paramount for work zone workforce safety. Subsequently, roadway and design-related factors such as traffic volume, layout design, and signage clarity are deemed critical. Furthermore, traffic control measures within the work zone, categorized as work-related factors, were also rated as critical. The clustering results further supported these findings, revealing three groups of factors with varying levels of criticality. Cluster 1, characterized by the highest criticality, primarily comprised of driver and work-related factors. Design and roadway-related factors were distributed between Cluster 1 and Cluster 2, the latter showing relatively moderate criticality and also including state-related factors. Temporal-related factors were divided between Cluster 2 and Cluster 3, with the latter exhibiting relatively lower criticality and mainly encompassing characteristics and technological levels of motorist vehicles and construction equipment.

The results of this work provide valuable insights into potential targeted safety measures, particularly highlighting factors influenced by DOTs and other stakeholders. Specifically, DOTs can (1) influence design- and roadway-related factors to enhance safety for both the public and workers, (2) guide the development of work zone awareness campaigns to address driver-related factors and improve work zone safety, and (3) enforce state-related factors, such as law enforcement presence, to impact driver-related factors and ensure worker safety.

Additionally, future research can expand upon the findings of this study by delving into factors perceived as highly critical, such as driver's level of attention, driver's impairment, and the clarity of signage or pavement markings, which are relatively understudied. Investigating these factors further would complement existing scholarly works and enhance understanding of underexplored areas. Ultimately, such efforts will contribute to the advancement of safety practices for both the public and work zone workers.

Chapter 4. MoDOT Performance Perspectives

This chapter presents the findings derived from surveying both MoDOT employees and contractors concerning their perspectives on MoDOT's performance regarding a subset of factors identified in Chapter 2, falling under MoDOT's influence. The chapter is structured as follows: Firstly, the included factors and the addressed project performance metrics are presented and discussed. Secondly, the chapter examines the ranking of MoDOT's performance by its employees, offering analysis. Thirdly, the chapter explores and analyzes the ranking of MoDOT's performance from the viewpoint of contractors and subcontractors. Fourthly, a comparative analysis of the differing perspectives between MoDOT employees and contractors is presented. Lastly, recommendations derived from the comparative analysis are presented.

Analyzed Factors and Project Performance Metrics

To achieve the objectives of this research, only the factors that could be influenced by MoDOT are examined, as assessing MoDOT's performance on factors beyond their control (e.g., weather, driver age) would yield redundant and limited insights. Therefore, driver-related, vehicle-related, and temporal factors were excluded from this survey section. The authors selected a subset of 19 factors from the initial list of 37 identified in Chapters 1 and 2. Table 10 displays the analyzed work zone safety factors and their corresponding categories. The performance rating was conducted using a 5-likert scale detailed in Table 11.

Table 10. Factors used to assess MoDOT's performance

Category	*Code*	*Factor*
Design-Related Factors	F1	Design of Work Zone Layout
	F2	Design of Safety Measures
	F3	Additional Preventive Measures
	F4	Clarity of Signage or Pavement Markings
	F5	Speed Variance Regulations
Roadway-Related Factors	F6	Roadway Lighting Conditions
	F7	Road Surface Condition
	F8	Road Alignment
	F9	Median Type
	F10	Sight Distance
	F11	Volume of Traffic in the Area of Work Zone
Work-Related Factors	F12	Work Zone Type
	F13	Job Training
	F14	Worker's Behavior
	F15	Traffic Control inside the Work Zone
	F16	Level of Congestion in the Work Zone
State-Related Factors	F17	Adequacy of the Safety Guidelines and Procedures
	F18	Law Enforcement
	F19	Limited Safety Budget

Furthermore, respondents were requested to assess the effect of enhancing MoDOT's performance on each category concerning various project-related metrics, such as the project budget and schedule. Table 12 outlines the project metrics examined in this chapter.

Table 11. Adapted scale for MoDOT performance rating

Likert Scale	Description
1	Very poor performance: extremely inadequate performance characterized by significant deficiencies and shortcomings.
2	Poor performance: substandard performance characterized by notable shortcomings and inadequacies.
3	Moderate performance: fair to middling performance characterized by moderate effectiveness and satisfactory but not exceptional outcomes.
4	Good performance: adequate performance marked by effective outcomes and satisfactory results.
5	Very good performance: highly commendable performance characterized by exceptional effectiveness and outstanding results.

Table 12. Project metrics used

Project Performance Metric	Definition
Project Schedule	It refers to the timeline that outlines the planned start and end dates for the work zone project.
Project Budget	It refers to the financial plan that outlines the estimated costs required to complete the work zone project.
Productivity	It refers to the measure of efficiency with which a person, group, or organization uses resources to achieve their goals or objectives.
Quality	It refers to the work's compliance with design requirements, codes, and quality assurance/control measures.
Health and Environmental Considerations	It refers to the adherence to applicable regulations and standards related to health and environmental considerations, including those related to worker safety, air and water quality, and waste management.

Given that this section of the survey follows the examination of factor criticality in Chapter 3, it utilizes the same pool of respondents. Therefore, for details regarding sample sufficiency, survey reliability, and respondents' profiles, please refer to Chapter 3.

Employees' Performance Perspective

The authors proceeded to compute the average performance rating provided by MoDOT employees for the selected 19 factors, as detailed in Table 10. Table 13 displays the outcomes of the performance rating provided by the employee survey respondents. As depicted in Table 13, the performance rating by MoDOT employees ranges from 3.23 for F18 ('Law Enforcement') to 4.17 for F10 ('Sight Distance'). Notably, the first quartile, third quartile, and mean rating for all factors, except F18, surpass a rate of 3 (considered moderate), suggesting an overall satisfactory performance across various factors, as reported by the employee survey respondents. However, the rating for F18 ('Law Enforcement') emerges as the lowest, indicating an overall poor perspective regarding the adequacy of the presence of police and other law enforcement agencies on MoDOT work zone projects.

Furthermore, F10 ('Sight Distance'), F1 ('Design of Work Zone Layout'), F11 ('Volume of Traffic in the Area of Work Zone'), and F12 ('Work Zone Type') are highlighted with above-moderate performance rankings, suggesting an overall positive perspective regarding roadway-related and certain design-related factors. Additionally, F17 ('Adequacy of the Safety Guidelines and Procedures') had a mean rating of 3.99, indicating MoDOT employees' perspective in the adequacy of the safety guidelines implemented by MoDOT. This aspect will be further discussed in conjunction with the contractor rating in subsequent sections of this chapter.

Table 13. MoDOT's performance rating by MoDOT employees

Factor	Mean	Standard Deviation	Q1	Q3	Rank by Mean
F1	4.07	0.863563	4	5	2
F2	3.98	0.911336	4	5	6
F3	3.83	0.979092	3	5	10.5
F4	3.98	0.948404	4	5	7.5
F5	3.64	1.106181	3	4	16
F6	3.80	0.926188	3	5	12
F7	3.61	1.070434	3	4	17
F8	3.46	1.042976	3	4	18
F9	3.74	0.890729	3	4	14
F10	4.17	0.921083	4	5	1
F11	4.05	1.010423	3	5	3
F12	4.04	0.826524	4	5	4
F13	3.98	0.948404	3	5	7.5
F14	3.83	0.926618	3	5	10.5
F15	3.97	0.833926	4	5	9
F16	3.67	0.979919	3	4	15
F17	3.99	0.934315	3	5	5
F18	3.23	1.214754	2	4	19
F19	3.75	0.967372	3	4	13

Subsequently, employees were tasked with evaluating the potential impact of enhancing MoDOT's performance across various factor categories outlined in Table 12 on project metrics. As depicted in Figure 13, it is evident that augmenting MoDOT's performance would notably elevate the quality aspect across all factor categories. This suggests that improvements in MoDOT's operations could yield substantial benefits in ensuring project quality, reflecting positively on project outcomes.

Moreover, upon analyzing the metric impact across different categories, it becomes apparent that the anticipated improvements in MoDOT's performance are expected to have a consistent effect on all project metrics. There is a uniformity in the projected impact, with no significant deviation observed between categories. This indicates that enhancing MoDOT's performance in any particular area is likely to have a balanced influence on various project metrics, revolving around an average impact of 50%. Such uniformity underscores the interconnectedness of different factor categories and their collective influence on project outcomes.

Overall, these findings underscore the importance of a comprehensive approach to enhancing MoDOT's performance across diverse factor categories. By addressing areas identified for improvement, MoDOT can not only enhance project quality but also ensure a balanced and holistic impact across all project metrics, leading to more effective project management and successful project outcomes.

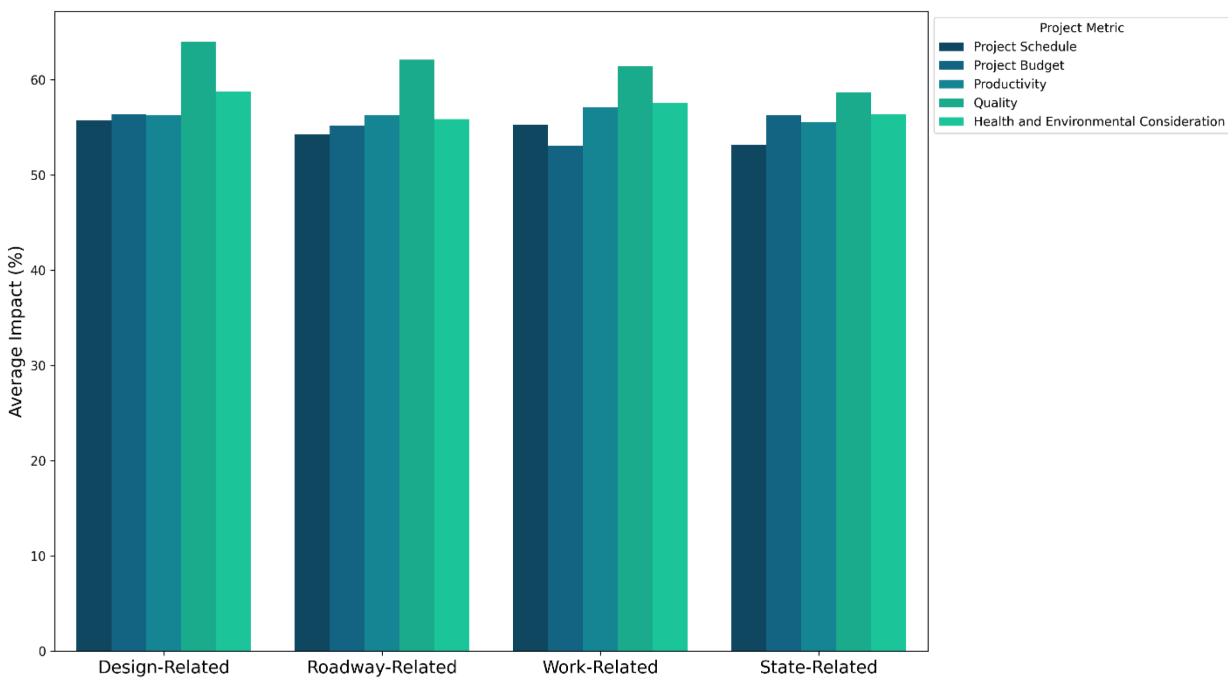


Figure 13. Project metric impact rating by MoDOT employees

Contractors' Performance Perspective

Subsequent to the analysis of the employee survey, the authors similarly computed the performance ratings provided by MoDOT contactors for the 19 factors, as presented in Table 14. As depicted in Table 14, the performance rating by the contractors varies between 2.57 for F18 ('Law Enforcement') to 3.71 for F10 ('Sight Distance'). Notably, F18 consistently receives the lowest rating from both contractors and MoDOT employees, highlighting a shared concern regarding law enforcement aspects. Conversely, F10 ('Sight Distance') has the highest rating from both stakeholder groups, indicating its perceived significance in work zone management. Additionally, most of the contractors' ratings fall in the range of 2.5-3.7, indicating a moderate to good performance on the overall areas.

The results of the performance ratings provided by MoDOT contractors across the selected factors reveal interesting insights into their perspectives on various aspects of work zone safety and management. Notably, factors such as F10 ('Sight Distance'), F11 ('Volume of Traffic in the Area of Work Zone'), and F12 ('Work Zone Type') emerge as top-ranking factors with mean ratings above 3.5, indicating a generally positive perception of MoDOT's performance in addressing roadway-related and design-related considerations. These findings suggest that MoDOT's efforts in ensuring adequate sight distance, managing traffic volume, and adapting work zone types are perceived favorably by work zone contractors.

Conversely, factors such as F18 ('Law Enforcement') and F17 ('Adequacy of the Safety Guidelines and Procedures') received lower mean ratings, indicating areas where MoDOT's performance might be perceived as lacking or needing improvement. Specifically, the low rating for 'Law Enforcement' suggests concerns among employees regarding the presence and effectiveness of police and other law enforcement agencies in MoDOT work zone projects. Similarly, while 'Adequacy of the Safety Guidelines and Procedures' had a mean rating close to 3.5, indicating overall satisfaction, the standard deviation suggests some variability in perceptions among respondents, warranting further investigation into specific concerns or areas for enhancement.

Table 14. MoDOT's performance rating by MoDOT contractors

Factor	Mean	Standard Deviation	Q1	Q3	Rank by Mean
F1	3.25	1.040833	3	4	11.5
F2	3.36	1.061595	3	4	9
F3	2.86	1.078898	2	4	17.5
F4	3.50	0.922958	3	4	3.5
F5	2.86	1.297127	2	4	17.5
F6	3.39	0.875142	3	4	7.5
F7	3.11	0.99403	3	4	14.5
F8	3.11	0.956045	3	4	14.5
F9	3.25	1.004619	3	4	11.5
F10	3.71	1.049061	3	4.25	1
F11	3.57	1.288944	3	5	2
F12	3.43	0.878912	3	4	6
F13	3.39	0.956045	3	4	7.5
F14	3.50	0.881917	3	4	3.5
F15	3.29	0.9759	3	4	10
F16	3.14	1.208436	2.75	4	13
F17	3.46	1.070899	3	4	5
F18	2.57	1.230133	1	3.25	19
F19	3.07	1.214986	2	4	16

Following the performance ratings, contractors were tasked with evaluating the impact of enhancing performance on the project performance metrics, as depicted in Figure 14. The analysis reveals that contractors prioritize specific project metrics differently based on the category. For instance, within the Design-Related category, contractors assign the highest impact rating to project budget, closely followed by productivity. This observation suggests that contractors emphasize financial aspects and operational efficiency during the design phase of the project. Likewise, in the Roadway-Related and Work-Related categories, project schedule and project budget receive relatively higher impact ratings for performance changes compared to other metrics. This trend implies that contractors consider timely project completion and efficient resource allocation as critical factors influencing project success in these categories should MoDOT's performance change.

Furthermore, quality emerges as a recurring concern across all categories, consistently receiving lower impact ratings from contractors. This indicates that contractors perceive quality-related issues as areas in need of improvement and attention within the project framework. Additionally, health and environmental considerations also receive relatively lower impact ratings across all categories. This suggests that contractors may view these aspects as less critical compared to other project metrics and would subsequently be less influenced by performance changes in these areas.

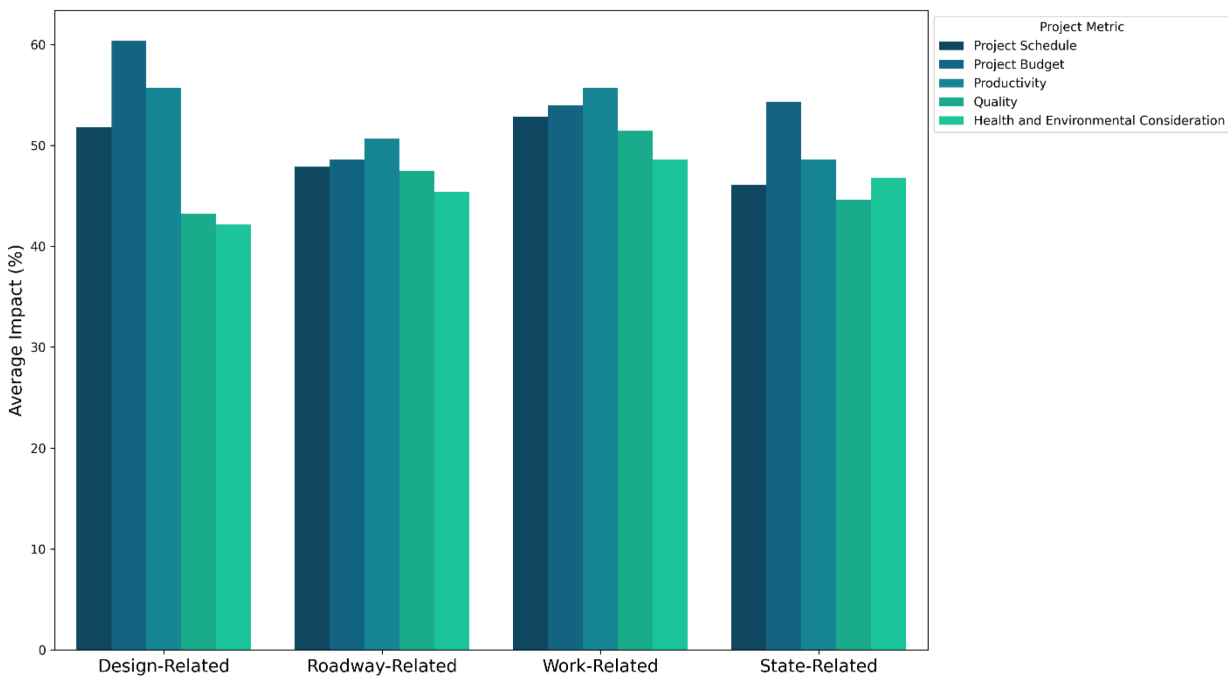


Figure 14. Project metric impact rating by MoDOT contractors

Comparative Analysis

To further understand the performance rating and identify areas for improvement, a comparison of the ratings provided by MoDOT employees and contractors is presented in Figure 15. In reviewing the ratings across the 19 factors, it becomes evident that contractors consistently assigned lower ratings compared to MoDOT employees across several key areas. This discrepancy underscores the differing perceptions of the two groups regarding project performance and highlights potential areas for improvement and alignment. For instance, factors related to safety measures and preventive measures received notably lower ratings from contractors compared to MoDOT

employees, suggesting a potential gap in understanding or implementation of safety protocols between the two groups. This discrepancy may indicate a misalignment in performance perceptions between the two stakeholder groups, potentially stemming from on-site challenges directly experienced by contractors and subcontractors. Therefore, enhancing communication channels among stakeholder groups, including MoDOT, contractors, subcontractors, and suppliers, could help bridge the gap in performance perceptions among stakeholders.
Furthermore, the analysis reveals consistent trends in both high and low-rated factors across MoDOT employees and contractors. For example, both groups rated F10 ('Sight Distance') highest, indicating a shared perception that the visibility in transition areas for work zones meets current standards on MoDOT projects. Conversely, both stakeholders rated F18 ('Law Enforcement') lowest, signifying a consensus that the presence of law enforcement agencies, or efforts to mimic their presence (e.g., by incorporating flashing lights to influence driver behavior), is notably inadequate and requires further enhancement.

Moreover, the analysis underscores specific areas of divergence between MoDOT employees and contractors, highlighting potential areas for further examination and improvement. For instance, while MoDOT employees rated F3 ('Additional Preventive Measures') relatively high, contractors provided notably lower ratings, signaling a discrepancy in the perceived effectiveness or necessity of additional preventive measures. Similarly, F19 ('Limited Safety Budget') received relatively lower ratings, particularly from contractors, suggesting that they perceive the safety budget allocated by MoDOT to be somewhat insufficient. This viewpoint contrasts with that of MoDOT employees, highlighting another area of discrepancy between the two groups that necessitates closer examination and improvement efforts.

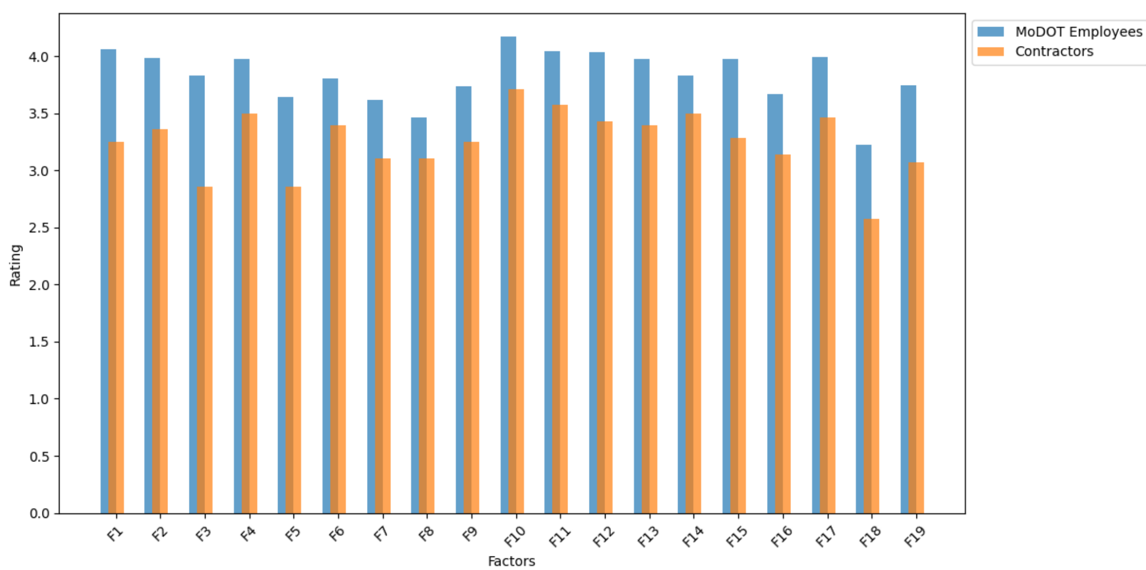


Figure 15. MoDOT performance ratings

Additionally, the impact of improving MoDOT performance on project metrics, with respect to the factors categories, is contrasted in Figure 16. The comparative analysis between the project metric impact ratings provided by MoDOT employees and contractors reveals insights into their perceptions of potential improvements resulting from enhanced performance across distinct categories.

Upon scrutinizing the ratings across different project metrics, it becomes evident that MoDOT employees and contractors exhibit varying perspectives on the potential impacts of performance enhancements across different categories. Notably, there are instances where both groups demonstrate alignment in their ratings, suggesting a consensus on certain critical aspects of project performance. For instance, in the Design-Related category, both MoDOT employees and contractors accord relatively high ratings to 'Project Schedule' and 'Project Budget', indicating a shared recognition of the importance of timely project completion and efficient resource allocation within the design phase should MoDOT’s performance change in this area.

However, the comparative analysis also highlights areas of discrepancy and divergence between MoDOT employees and contractors in their perceptions of the potential impacts of enhanced performance. For instance, while MoDOT employees prioritize 'Quality' as a crucial metric across all categories, assigning consistently high ratings to this factor, contractors rate 'Quality' relatively lower compared to other metrics, especially within the Design-Related category. This incongruence suggests differing interpretations of quality standards and project deliverables between the two stakeholder groups, warranting further exploration and potential alignment initiatives.

Moreover, the analysis reveals nuanced differences in the prioritization of project metrics within each category. For instance, in the Roadway-Related category, MoDOT employees and contractors exhibit similar preferences for 'Project Schedule' and 'Project Budget' as key performance indicators. However, contractors assign relatively higher ratings to 'Productivity' compared to MoDOT employees, indicating a stronger emphasis on operational efficiency and resource optimization from the contractor's perspective.

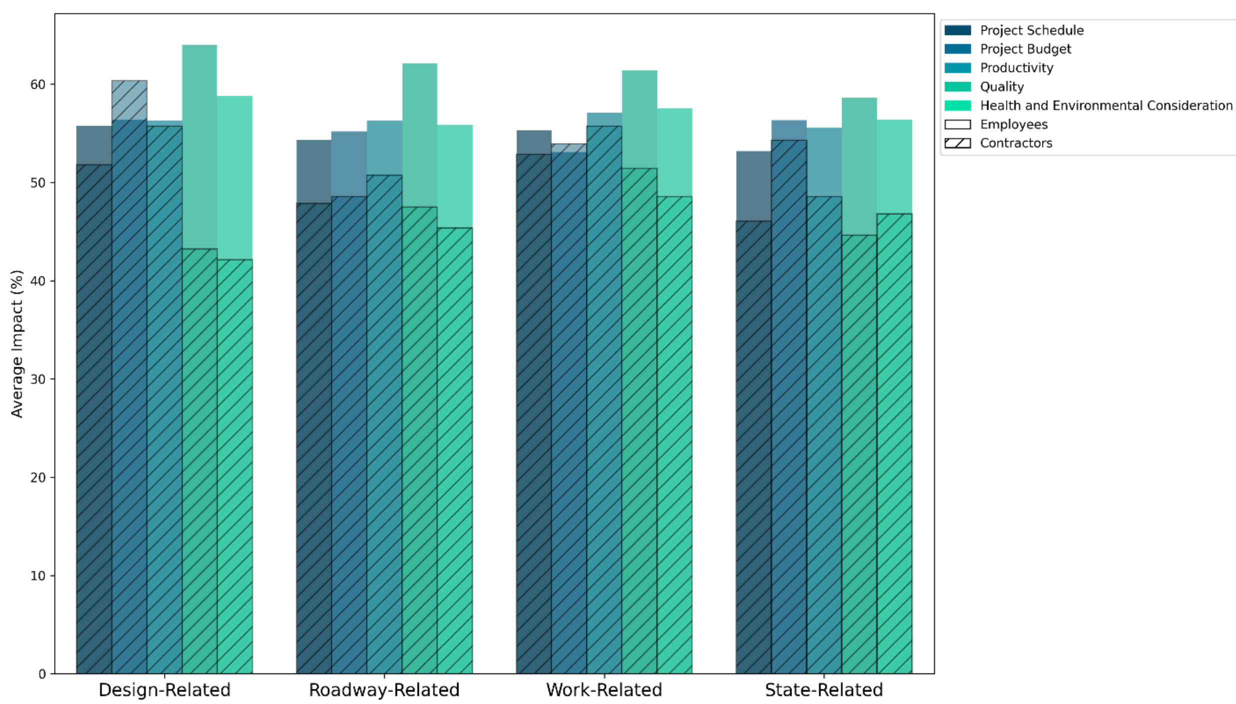


Figure 16. Impacts on project metrics

In addition to evaluating various aspects of work zone safety, survey respondents were tasked with assessing the current safety conditions of work zones compared to the previous year (Figure 17). The analysis of these responses reveals a notable trend: only a minority of respondents reported a reduction in safety risks. Instead, the majority of respondents, both MoDOT employees and contractors, indicated that the safety risks in work zones are the same or greater now. Notably, a significant proportion of contractors and MoDOT employees expressed a belief that the safety risks have increased compared to the previous year. This observation is consistent with findings from the AGC survey (AGC 2022; AGC 2023), which also highlighted concerns regarding escalating safety risks in work zones, although the results presented herein specifically reflect respondent views for Missouri work zones.

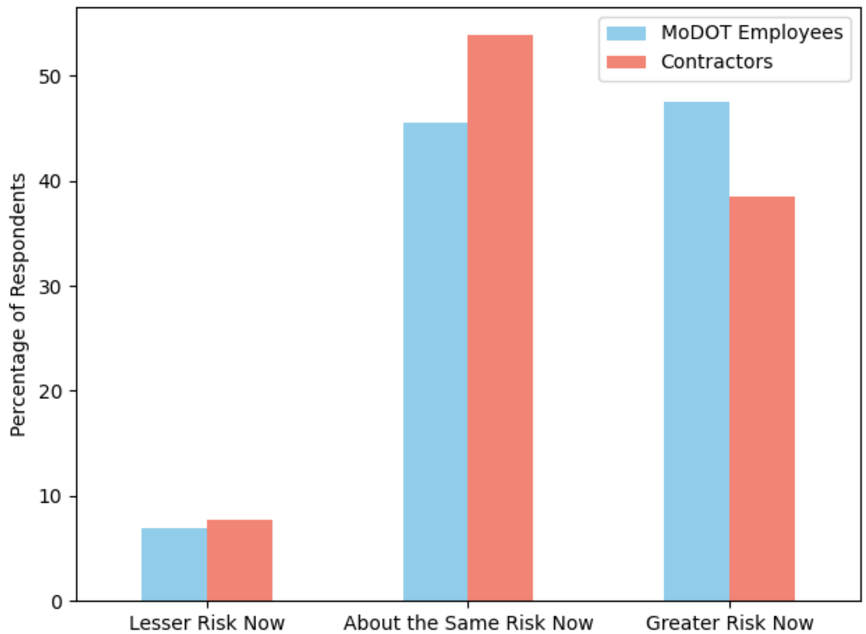


Figure 17. Trajectory of work zone safety risks

Conclusion and Recommendation

The extensive analysis conducted in this chapter offers valuable insights into the performance perspectives of MoDOT as perceived by both its employees and contractors. By delving into performance ratings and project metric impact assessments, a comprehensive understanding of the intricacies surrounding MoDOT's operational performance and the varying viewpoints of stakeholders has been presented. The comparative analysis offers valuable insights into the diverse perspectives and priorities within the project environment. By identifying areas of agreement, discrepancy, and divergence, stakeholders can gain a deeper understanding of the underlying factors influencing project performance and collaborate effectively to address potential areas for improvement and alignment in future projects.

The comparative analysis of performance ratings highlighted significant areas of agreement and divergence between MoDOT employees and contractors. While some consensus was observed regarding MoDOT's performance, contractors consistently assigned lower ratings across all evaluated factors, indicating a disconnect between the perspectives of MoDOT employees and the opinions of site-based contractors. Crucially, both stakeholder groups pinpointed law enforcement as the aspect with the least satisfactory performance. Consequently, the presence of law enforcement agencies emerges as a challenging area necessitating substantial improvement within MoDOT and at the state level.

Moreover, the analysis of project metric impact ratings serves as a benchmarking framework for MoDOT, providing insights into the anticipated changes in project schedule, budget, productivity, quality, and health and environmental considerations. These insights delineate the expected outcomes of performance changes within the identified categories, including design-related, roadway-related, work-related, and state-related factors. Furthermore, the comparative analysis of project metric impacts provided by both employees and contractors revealed nuanced disparities in stakeholders' perceptions of performance enhancement effects across different categories. While certain areas demonstrated alignment in priorities, such as the paramount importance of timely project completion and resource efficiency, divergences were evident in the prioritization of quality and productivity metrics. These discrepancies underscore the imperative for MoDOT to engage stakeholders in collaborative decision-making processes and develop improvement initiatives to address diverse perspectives and priorities adequately.

Fundamentally, the findings extracted from this chapter underscore the pivotal importance of fostering transparent communication, collaborative endeavors, and mutual comprehension between MoDOT and its stakeholders. By acknowledging and rectifying divergent viewpoints, MoDOT can cultivate a more harmonized and efficacious operational environments, culminating in augmented stakeholder engagement, refined project management methodologies, and, ultimately, the delivery of more successful and safer roadway work zone projects for the benefit of all stakeholders and the broader community.

Chapter 5. Safety Policies and Culture

This chapter presents the results obtained from surveying MoDOT employees regarding their viewpoints on the field adoption of safety-related federal and state policies and procedures, as well as their overall perception of the safety culture within their workplaces. The chapter is structured as follows: Firstly, the relevant policies included in the survey are identified and defined. Secondly, the chapter examines the ratings given by the employees to the field adoption of the various policies. Thirdly, the chapter examines the ratings assigned to general statements reflecting employees' perspectives on the safety culture prevailing in their work environment. Lastly, recommendations are formulated and discussed.

Analyzed Safety Policies

To achieve the objectives of this chapter, a comprehensive review of the various state- and federal-level policies that are followed by MoDOT was conducted by the research team. To this end, the examined policies in this research are summarized in Table 15. The performance rating was conducted using a 5-likert scale detailed in Table 16. In addition to the safety policies, survey respondents were asked to assess their agreement with several general statements, which are presented subsequently in this chapter, to reflect on the safety-related environment that is embraced in MoDOT's work environment.

Table 15. Safety policies examined in this research

Category	Policy	Description
Personal Worker Related Policies	CPR & First Aid Training	A minimum of 2 members/unit or crew trained. Aimed to train at least 50% of the department's workforce.
	PPE General Guidelines	Appropriate attire should be worn at all times to cover sunburns. Workers who are exposed to the risk of flying or falling objects (such as those involved in cutting, grinding, mining, etc.) are required to wear protective eyewear. For workers involved in field operations or engaged in fabrication and warehousing activities, it is necessary to wear work gloves.
	Cell phone-hand-communications	Can be used only for official business/emergencies and away from traffic. Flaggers, spotters, and equipment operators shall not be using phones.
	Driving Procedures	All traffic rules apply, otherwise considered a safety violation.
	Fit for Duty Program	Needed for employees that have condition/illness/injury that may impact their performance/cause safety risk. Temporary or permanent restrictions may be required.
Working Area Related Safety Policies	Lockout Tagout	To avoid injuries from working with proximity to energy sources, such as the power utility lines, boilers, heaters, etc., Energy control procedures, such as energy tagout or isolating system, must be used.

	Overhead Lines	Until energy lines are cut off, work shall be kept at least 10 feet away from the power lines.
	Poisonous Plants	Allergic employees should be careful of their surroundings for poisonous ivy plants.
General Work Activities Related Safety Policies	3 Points of Contact	Workers entering a truck should keep both feet and 1 hand in contact with the truck to avoid falling backward.
	Backing	To eliminate backing incidents, a spotter shall be utilized when a worker is available and if there is a significant blind spot/in a confined area.
	Working on or adjacent to the Highway	Employees should work facing the traffic, wear visibility safety apparel, not wear headsets or earphones, and look in all directions before crossing the highway.
	Confined Space Entry Procedure	Workers are trained on entering confined spaces, including 1 CPR/first aid trained member, with warning signs/permits required at the entrance.
	Fall Protection Policy	All workers operating at heights of 6 feet or above ground level must undergo comprehensive training, encompassing proper techniques for harnessing, anchoring, and fall rescue procedures. Guardrail systems should also be employed to protect workers from falling.
	Incident Reporting	All incidents must be reported, regardless of how minor is the damage.
	Safety Violation Disciplinary Guide	Starts with a written warning, to probation without pay, to termination, for violating safety policies.
	Employee Safety Empowerment Policy	MODOT employees have the right to take immediate actions to stop an unsafe practice.
Work Zone Related Safety Policies	612 Impact Attenuators	Impact attenuators are effectively employed to absorb energy of an impacting vehicle and reduce the force on a passenger to an acceptable level. Could be truck mounted, stationary (like sand barrels), or trailer mounted.
	616 Temporary Traffic Control	Regulatory signs and Type III Movable Barricades and other work zone items such as Changeable Message Signs, flashing arrow panels, channelizing devices, lighting devices, pavement edge treatment, and signals are employed to minimize risk to workers and travelers.
	616.19 Quality Standards for Temporary Traffic Control Devices (TTCDs)	The legibility, visibility and other safety and mobility requirements for TTCDs (e.g., impact attenuators, signs, flashing arrows...) are kept to standard levels.

	616.20 Flagger Training	Workers engaged in flagging operations on the state highway system shall have successfully completed a recognized flagger training course (with re-certification every 4 years).
	616.21 Work Zone Technician Training	Each person whose actions affect temporary traffic control work zone safety, from the upper-level management through field workers, should receive training appropriate to the job decisions each individual is required to make.
	616.22 Advanced Work Zone Training	MoDOT staff and contractors engaged in work zones undertake a "Work Zone Specialist WZS" certification (renewed every 4 years).
	616.23 Traffic Control for Field Operations	Should deviations from standard procedures be needed due to conditions and requirements of a particular site or jurisdiction such as work location, duration, work type, time of day, weather conditions, road type, geometrics... The respective engineering staff is contacted for deviation assistance.
	616.6.60 Portable Changeable Message Signs	TTC devices are installed for temporary use with the flexibility to display a variety of messages.
	910.3 Dynamic Message Signs (DMS)	Stationary traffic control devices are employed to display messages of real-time traffic-related variable messages.

Table 16. Adapted scale for safety policies compliance rating

Likert Scale	Description
1	Not in compliance: failure to meet established standards or regulations, marked by deviations from prescribed protocols or guidelines.
2	Rarely in compliance: infrequent adherence to established standards or regulations, characterized by occasional deviations from prescribed protocols or guidelines.
3	Moderately in compliance: demonstrating adherence to established standards or regulations to a fair extent, characterized by occasional deviations or shortcomings in meeting prescribed protocols or guidelines.
4	Largely in compliance: exhibiting substantial adherence to established standards or regulations, characterized by occasional minor deviations or shortcomings that do not significantly impede overall compliance with prescribed protocols or guidelines.
5	Totally in compliance: demonstrating complete adherence to prescribed standards or regulations, characterized by consistent and thorough compliance without any deviations or deficiencies.

It is important to note that this section of the survey was exclusively administered to MoDOT employees, as outlined in Chapter 3, due to their direct involvement in field compliance with safety policies. For further information regarding sample sufficiency, survey reliability, and respondents' profiles, please refer to Chapter 3.

Policies' Compliance Survey Results

The authors proceeded to calculate the average compliance rating provided by MoDOT employees for the 25 pertinent policies, as outlined in Figure 18. As illustrated in Figure 18, the compliance rating ranges from 3.79 for the poisonous ivy policy to 4.4 for the PPE guidelines. Given that the compliance range exceeds 3.5 for all policies, it can be initially inferred that the various policies are adhered to in the field to a significant extent.

Firstly, policies pertaining to employee safety empowerment, fit for duty programs, and procedures related to hazardous situations exhibit commendable average compliance ratings. This indicates a conscientious approach by MoDOT employees towards personal safety and workplace preparedness.

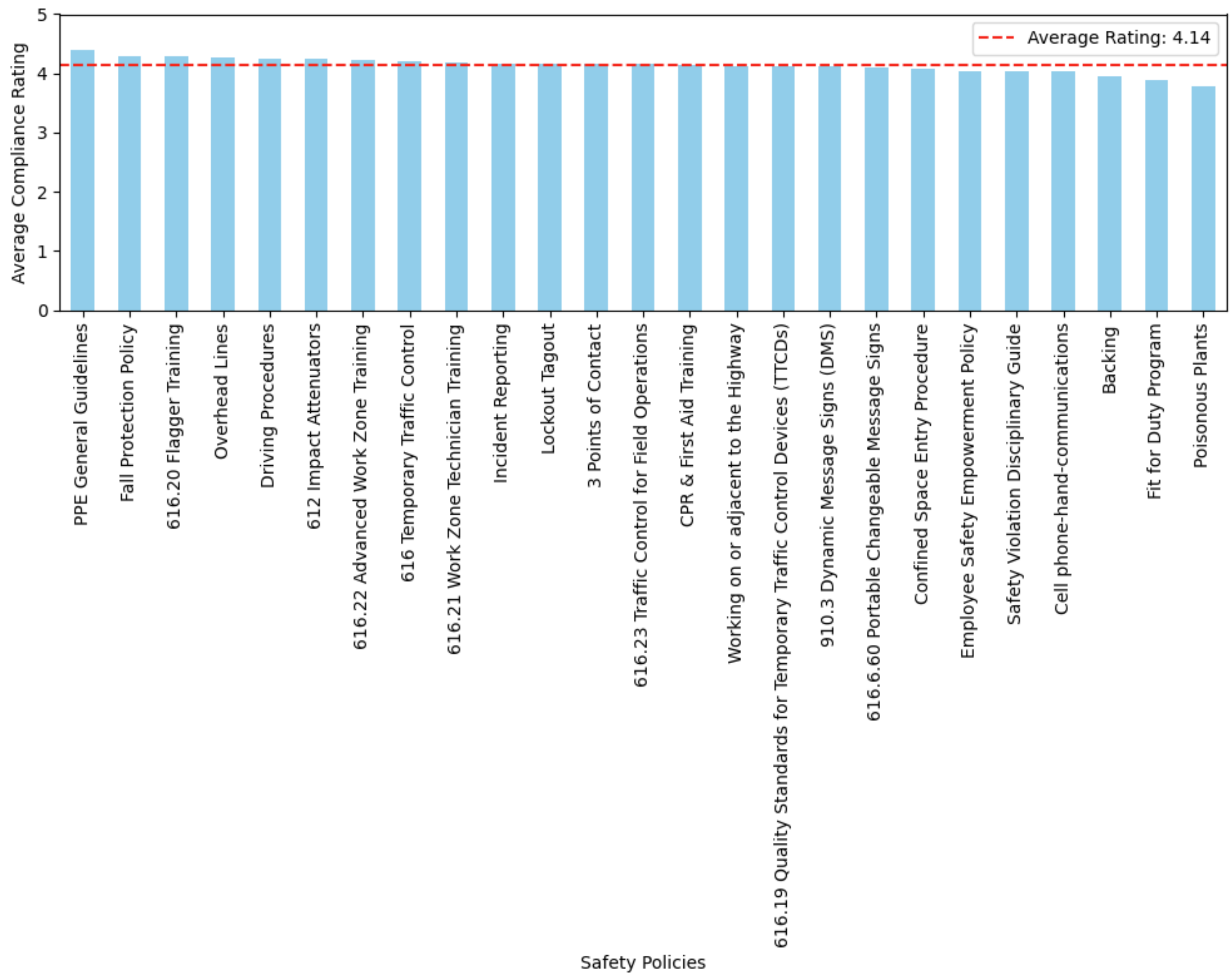


Figure 18. Safety policies field compliance

However, the rankings also bring to light notable discrepancies in compliance levels across various policies. Notably, policies concerning fall protection, personal protective equipment (PPE) guidelines, and general driving procedures received comparatively higher average compliance ratings. While this signifies a positive inclination towards adherence to fundamental safety measures, it also prompts a critical examination of potential factors influencing compliance disparities. One plausible explanation for variations in compliance levels could stem from differences in policy visibility, clarity, and accessibility. Policies that are more prominently communicated, easily comprehensible, and readily accessible are likely to attain higher compliance rates. Thus, the observed disparities may warrant a reevaluation of communication strategies and the accessibility of safety protocols within MoDOT's operational framework.

Moreover, the rankings underscore the multifaceted nature of workplace safety, encompassing diverse domains ranging from traffic control procedures to specialized training programs. Policies such as CPR and first aid training, dynamic message signs (DMS), and traffic control for field operations emerge as pivotal components of MoDOT's safety infrastructure, as reflected by their high compliance rankings. This highlights the organization's holistic approach towards ensuring employee preparedness and competency across a spectrum of safety-related domains.

Nevertheless, the rankings also draw attention to potential areas for enhancement within MoDOT's safety framework. Policies related to portable changeable message signs, work zone technician training, and flagger training exhibit relatively lower average compliance ratings. Such findings warrant a thorough investigation into the underlying factors contributing to suboptimal compliance levels, including potential resource constraints, training deficiencies, or procedural complexities.

Moreover, of particular significance within work zone environments is the adherence to the Backing Policy, which delineates the checklist vehicle operators must follow before executing reverse maneuvers, along with the responsibilities assigned to spotters. Remarkably, this policy ranks among the lowest in terms of compliance. Notably, backing maneuvers stand out as the primary cause of occupational injuries in work zone environments, attributed to the presence of numerous blind spots and the challenges of maneuvering in confined and frequently congested work areas (FHWA 2022). Consequently, the relatively deficient compliance with backing procedures necessitates immediate attention to ensure robust adherence across MoDOT's work zones.

Lastly, the observed rankings underscore the dynamic nature of safety priorities within MoDOT, necessitating continual reassessment and adaptation of safety protocols to align with evolving industry standards and regulatory requirements.

Work Environment and Safety Culture

Subsequent to the analysis of the field compliance with safety policies, the authors proceeded to analyze the input for the safety culture statement as rated by MoDOT employees and presented in Figure 19. The ratings provided insights into the collective sentiment and perceptions of MoDOT employees regarding workplace safety practices and organizational commitment to health and well-being. In other word, these ratings serve to gauge the efficacy of existing safety protocols, communication strategies, and training initiatives while also identifying potential areas for improvement.

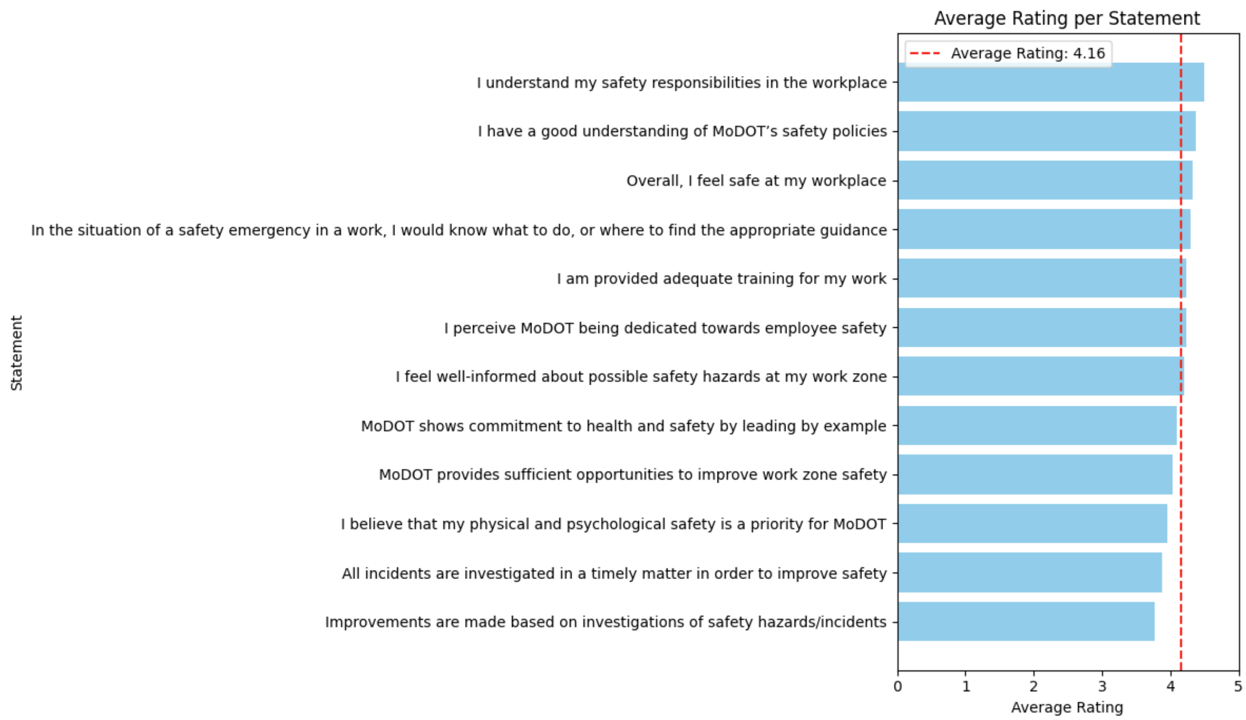


Figure 19. MoDOT safety culture rating

At the forefront of the ratings are statements reflecting employees' sense of security and confidence in workplace safety measures. Notably, statements such as "I understand my safety responsibilities in the workplace" and "Overall, I feel safe at my workplace" resonate with high average ratings, indicating a prevailing culture of responsibility and clarity regarding safety protocols among MoDOT employees. These ratings reflect positively on MoDOT's efforts to foster a safety-conscious work environment, suggesting effective training programs and robust communication channels that empower employees to actively contribute to their own safety and that of their colleagues.

Similarly, statements affirming MoDOT's organizational commitment to health and safety, such as "MoDOT shows commitment to health and safety by leading by example" and "I perceive MoDOT being dedicated towards employee safety," have favorable ratings. These ratings underscore the perceived alignment between organizational values and employee expectations, signaling a strong stance towards prioritizing safety as a fundamental organizational value. By setting a precedent for safety-conscious behavior and fostering a culture of trust and collaboration, MoDOT plays a pivotal role in reinforcing employee confidence in the organization's commitment to their well-being.

However, amidst the commendable ratings, certain disparities, and areas for improvement within MoDOT's safety framework also come to light. Statements pertaining to incident investigation and improvement initiatives, such as "All incidents are investigated in a timely manner in order to improve safety" and "Improvements are made based on investigations of safety hazards/incidents," receive comparatively lower ratings. These findings underscore potential gaps in incident reporting mechanisms, investigation protocols, and follow-up procedures, suggesting room for enhancement in transparency and organizational learning. By streamlining incident reporting processes, strengthening investigation protocols, and implementing proactive improvement measures, MoDOT can foster a culture of continuous improvement and organizational resilience in the face of safety challenges.

Moreover, statements concerning the provision of adequate training and opportunities to improve work zone safety exhibit moderate average ratings. These findings suggest areas where MoDOT could further invest resources and initiatives to bolster employee preparedness and competency in safety-related domains. By prioritizing ongoing training and development programs tailored to address evolving safety challenges and regulatory requirements, MoDOT can ensure that employees are equipped with the necessary knowledge and skills to effectively mitigate risks and adapt to changing work environments. Additionally, by providing ample opportunities for employees to participate in safety improvement initiatives and contribute their insights and expertise, MoDOT can leverage the collective skillset of its employees to drive meaningful change and innovation in safety practices.

Furthermore, the ratings underscore the pivotal role of communication and information dissemination in fostering a safety-conscious culture within MoDOT. Statements such as "I have a good understanding of MoDOT's safety policies" and "I feel well-informed about possible safety hazards at my work zone" highlight the significance of clear, accessible, and transparent communication channels in empowering employees to make informed decisions and take proactive measures to safeguard their well-being. By fostering open dialogue, soliciting employee feedback, and providing regular updates on safety policies, procedures, and hazard assessments, MoDOT can foster a culture of shared responsibility and collective ownership of safety, driving continuous improvement and organizational excellence.

Conclusion and Recommendation

This chapter examined the compliance of safety policies and assessed the overall safety-related culture within MoDOT. Through the analysis of field compliance with safety policies and employee perceptions of safety culture, this chapter has offered a comprehensive overview of the strengths and areas for improvement within MoDOT's safety framework.

The findings from the analysis of field compliance reveal commendable levels of adherence to safety policies across various domains, indicative of MoDOT's proactive stance towards ensuring employee safety and operational excellence. However, disparities in compliance levels and areas of suboptimal performance, namely with regards to backing movements in work zone environments, underscore the need for more interventions and continuous improvement initiatives.

Moreover, the insights gained from employees' perceptions of safety culture highlight the pivotal role of leadership, communication, and training in shaping organizational norms and behaviors. The high ratings for statements reflecting employee confidence in safety protocols and organizational commitment to health and well-being underscore MoDOT's efforts in instilling a culture of safety consciousness among its workforce. To build upon these strengths and further enhance safety culture, MoDOT should prioritize leadership development programs, promote open dialogue, and invest in ongoing training initiatives tailored to address emerging safety challenges and promote a culture of continuous improvement.

The findings presented in this chapter underscore the multifaceted nature of safety management within MoDOT, encompassing compliance with safety policies, employee perceptions of safety culture, and organizational commitment to health and well-being. The presented ratings serve as a valuable tool for assessing the prevailing safety culture within MoDOT and identifying opportunities for enhancement. This critical analysis advocates for a holistic approach towards safety management, encompassing robust communication strategies, targeted training initiatives, and continuous evaluation to foster a workplace environment characterized by unwavering commitment to employee well-being and operational excellence. By addressing identified gaps, leveraging employee feedback, and fostering a culture of continuous improvement, MoDOT can further strengthen its safety culture and reinforce its position in promoting health and safety within its workforce and the general public interacting with MoDOT’s work zones.

Chapter 6. Conclusions

This research project addressed the multifaceted factors influencing work zone incidents in Missouri, recognizing the critical need for proactive measures to enhance incident mitigation in these environments. Work zones, integral to infrastructure maintenance and development, often pose significant risks to both workers and drivers due to the dynamic and potentially hazardous nature of ongoing projects. Despite the presence of safety regulations, work zone accidents persist with alarming frequency and severity, underscoring the critical need for a deeper understanding of the underlying factors driving these incidents.

The initial phase of the project involved a comprehensive SLR, which served for synthesizing existing knowledge on work zone safety. Through the SLR, a comprehensive list of 37 factors affecting work zone safety was delineated, spanning various domains including design, roadway conditions, work-related practices, driver behavior, temporal factors, and state-level regulations. Leveraging SNA, the interplay and interconnectedness of these factors were scrutinized, shedding light on previously underexplored areas such as driver-related and state-level influences.

Subsequently, surveys were administered to MoDOT employees and contractors to assess their perceptions of safety factors, MoDOT's performance, and compliance with safety policies. The participation of 298 work zone professionals from diverse backgrounds provided valuable insights into the relative importance of safety factors, with driver-related aspects emerging as particularly critical for ensuring worker safety in work zones. Moreover, the discrepancy observed between MoDOT employees and contractors in their assessment of MoDOT's performance highlighted the need for alignment and improvement initiatives, especially in law enforcement aspects, which were identified as areas of concern.

Furthermore, the analysis of MoDOT's safety policies and overall safety culture revealed areas of strength, such as strong compliance with most policies, but also highlighted deficiencies, notably in adherence to the "Backing" policy. Given the significant association between backing maneuvers and occupational injuries in work zones, addressing compliance gaps in this area emerges as a priority for enhancing work zone safety. Additionally, while employees demonstrated a robust understanding of safety policies, certain aspects of safety incident investigation and improvement processes received lower ratings, signaling opportunities for strengthening MoDOT's safety culture and incident response mechanisms.

This study represents a significant step towards enhancing work zone safety in Missouri by providing a comprehensive assessment of contributing factors, MoDOT's performance, and safety culture. By addressing identified deficiencies and embracing a culture of continual improvement, MoDOT can effectively mitigate risks and ensure the safety and well-being of workers and drivers in work zones. Additionally, it is important to acknowledge the limitations inherent in this study, including potential response bias in survey data and the subjective nature of self-reported perceptions. Furthermore, work zone safety is a complex and evolving domain, influenced by numerous dynamic factors, necessitating continual assessment and adaptation of strategies to effectively mitigate risks and foster a safer environment for all stakeholders involved in transportation projects.

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