Leadership in Sustainable Infrastructure
Leadership en Infrastructures Durables

Vancouver, Canada
May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

LEVERAGING TELEMATICS AND REAL-TIME SENSOR DATA TO INCREASE SAFETY OF EQUIPMENT- INTENSIVE CONSTRUCTION OPERATIONS

Chan, Kelsey[1,3], Louis, Joseph[2,4]
[1] M.S. Student, School of Civil and Construction Engineering, Oregon State University, Owen Hall, Corvallis, OR 97331, USA
[2] Assistant Professor, School of Civil and Construction Engineering, Oregon State University, Owen Hall, Corvallis, OR 97331, USA
[3] chankel@oregonstate.edu
[4] Joseph.Louis@oregonstate.edu

Abstract: The number of safety incidents due to heavy equipment on construction sites has been increasing throughout the years, even though various safety techniques have been implemented into the equipment and worksites. The dynamically evolving nature of the typical construction worksite puts laborers in close proximity to heavy construction equipment for long periods of time that increases the potential struck-by accidents. Regulatory agencies such as OSHA have provided safety recommendations for a variety of construction activities including those involving heavy equipment. Despite these regulations, there is no way of ensuring that they are followed on the construction site. This paper describes a framework that enables the conversion of available literature on safe and best practices for heavy civil construction equipment to a rules-based system for checking against equipment sensor and telematics information collected from the worksite. This analysis informs the creation of safety systems that can be put in place to provide contractors and construction managers with the tools to automatically warn of imminent safety threats and also to assess safety measures that are currently employed in their worksite. A virtual experimental tool that enables the testing and validation of the developed research is also discussed in this paper. This research integrates existing safety standards with real-time sensor and telematics data, that can be obtained from equipment, to reduce fatality rates and accident occurrences on construction sites. Apart from its contributions to construction safety, this framework also provides for a novel use of telematics data, which is currently used only for equipment-centric analysis.

1.0 Introduction

The construction industry experiences a high injury and fatality rate due to interactions between the workers, materials, equipment, and the potentially hazardous nature of the tasks done on a typical construction site. The Occupational Safety and Health Administration (OSHA) has concluded that approximately 75% of struck-by fatalities involve heavy equipment such as large trucks and cranes (OSHA 2009). These injuries and fatalities involving heavy equipment can be the result of factors such as lack of warning systems attached to equipment or blind spots due to low visibility. There have been many studies conducted to improve worker safety through sensors and telematics data collection. Improvements such as laser scanning for safe equipment design to increase the operator visibility by measuring various blind spots (Marks et al., 2013) and real-time data collection and visualization of construction information related to both safety and to provide construction managers with an advantage in increased awareness to workers and equipment operators (Cheng and Teizer, 2012). Although telematics and safety technology has been widely used in construction, it has been focused primarily for equipment health monitoring and maintenance, limited research has been focused on its application towards the safety of construction operations.

Regarding the safety of construction operations, there are numerous standards and regulations available for construction management teams to use from regulatory agencies such as the Occupational Safety and Health Administration (OSHA) and Mine Safety and Health Administration (MSHA). Currently, there is no way of ensuring that these practices are actually followed on the construction site, unless resources are expended explicitly for this purpose. The research presented in this paper provides a framework that will use real-time data to generate safety warning through a rule-based system to deliver a warning to the construction manager when existing regulations are not followed.

The main objective of this research is the development of a safety model that is tailored to the operation being performed, that can detect potentially unsafe conditions on construction sites. The developed framework utilizes a rule-based safety model that uses equipment-state telematics data as an input to determine if unsafe situations are imminent on construction sites. A virtual construction site developed in a platform called Virtual Robot Experimentation Platform (V-REP) (Freese et al., 2011) is used to validate the proposed methodology. The developed system is expected to be amenable to a variety of construction operations and is anticipated to provide timely safety warnings to personnel on construction sites in the event of unsafe conditions on the worksite. The safety model will be developed by collecting and synthesizing best practice information from sources such as regulatory agencies (e.g.: OSHA, MSHA) and contractor best practices. The developed framework will be validated using case studies that are chosen to represent the wide variety of equipment-intensive operations such as earthmoving and crane operations.

This research aims to create a means of implementing real-time and autonomous safety monitoring on construction sites. The research will also provide an analytical and automated means of assessing safety conditions on the construction site, which is typically difficult to implement due to the subjective nature of safety. A literature review is provided to give a brief overview of the general impacts of telematics and sensors data collection and how this data collection technology has impacted construction safety. An overview of the proposed methodology and a case study involving earth-moving equipment is then presented. A discussion of conclusions and plans for future work and proposed implementations follows the methodology section.

2.0 Literature Review

Various relationships between the equipment, materials, workers, and safety on a construction site have been studied in past research. These efforts have aided construction managers to improve the productivity, efficiency, and safety of the construction site. This literature review summarizes previous work on the use of technology, specifically sensors and telematics, that provide real-time information from a construction site. After that, research that focuses on the use of technology to improve safety on the worksite is presented to provide the context for this research.

2.1 Sensors and telematics research in construction

Telematics and sensors on the construction site provide real-time data that can be used to improve the productivity and efficiency onsite and to minimize equipment idle time. Due to the complexity and dynamic nature of the construction site, the use of real-time data and automated monitoring techniques have been difficult to implement in the past. Contractors and construction managers aim to use the data gathered from the construction site as a means to augment their project cost and schedule controls. The use of sensors on construction sites has been a subject of great interest in recent years and this section of the literature review provides a summary of research on telematics, sensors and real-time data collection on construction sites.

Vahdatikhaki and Hammad (2014) proposed a framework for a multi-step data process that would take into account equipment-specific geometric location and operational features to improve the quality of the location data and in result enhance the accuracy of the equipment state identification. With the data available from sensors, their work provides a technology-independent system that performs aims to identify equipment state through different steps of processing, analyzing, filtering, and visualizing the obtained data. to track the equipment states throughout the construction process. The developed rule set is capable of capturing details of truck and excavations motions through concurrent consideration of the entire fleet and when sensory data is accessible. The proposed framework in this study contributes to enhancing the quality of near real-time simulation and further capturing the details of truck and excavator motions through the concurrent consideration of the fleet as a whole (Vahdatikhaki and Hammad 2014).

Another study by Akhavian and Behzadan (2013) focuses on the efforts to design and test a methodology for multimodal-process data capturing, fusion, and mining that would provide a basis for automated generation and refinement of simulation models that realistically represent construction fleet operations. Different modes of operational data were collected through experiments and integrated to identify equipment states with the end goal of creating input to simulation models. This laid the foundation to systematically investigate the possibility of discovering computer-interpretable knowledge patterns from field data in order to create realistic simulation models from complex and unstructured operations such as heavy construction and infrastructure projects (Akhavian and Behzadan 2013). Furthermore, Said et al. (2014) presented their development of telematics-based computational methodologies to support fleet management tasks. This research provides novel methodologies to support heavy fleet managers to utilize and implement basic and CAN-bus telematics data into the tasks mentioned above. The framework created applies survival analysis techniques to the telematics health parameters that were collected to generate a dynamic hazard function for each type of equipment. These methodologies have been validated through the application of the telematics program to large equipment fleets from various companies and can be used for fleets of equipment to assist management teams to complete tasks on the construction site (Said et al. 2014).

Apart from the focus on preparing telematics data individually for equipment performance analysis, Louis and Dunston (2014) developed a methodology that facilitates real-time monitoring of construction operations by using sensor data to produce real-time input data to a context-rich operation model that codifies the construction process. In this research, Virtual Robot Experimentation Platform (V-REP) was used to virtualize a construction process to show the monitoring capabilities of the methodology. By using scripts within the V-REP program and the implementation of Finite-State Machines (FSM), they were able to obtain real-time data to contribute to their proposed methodology. In the application of equipment telematics, productivity and automation of the operation were distinguished to provide the construction manager with information that contributes to improving productivity of the construction site (Louis and Dunston 2014). This work presents a methodology that provides the construction manager with a dynamically updated operational overview that is automated and in real-time (Louis and Dunston 2014) to improve the productivity of the site. All of these efforts contribute to improving the relationship between heavy equipment and other entities on site and providing construction managers with systems that allow for the monitoring of operation productivity and safety.

2.2 Technology implementations to improve construction safety

On-site interactions, coupled with the dynamic and uncertain nature of the construction site, serve to increase the amount of hazards present on site. This results in an additional increase for potential occurrences of safety incidents on the worksite. The emergence of technology to improve safety aspects on construction sites provides different alternatives and methods to creating a safer environment for workers and can potentially reduce fatality and injury rates due to heavy equipment in the future. This section provides literature reviews based on previously conducted research to provide insight on the use of technology to improve safety on various construction sites.

To improve the safety relationship between laborers and heavy equipment, Marks et al. (2013) developed a framework that incorporated laser scanning into the construction site to increase operator visibility through safe equipment designs. They noticed that the layout of construction sites caused the workers, materials and equipment to work in close proximity with each other, thereby increasing the chances of different entities entering the blind spots of heavy equipment. This research resulted in developing a framework for measuring and estimating blind spots based on laser scanning data collection in a manner that follows international safety standards and requires less effort to provide a higher accuracy of utilization than other developed methodologies. The equipment with minimized blind spots resulted in the best design to promote safety between the workers and equipment while also providing the operator with the highest amount of visibility when using the equipment on site (Marks et al. 2013). A study conducted by Cheng and Teizer (2012), provides methods for implementing real-time data collection and visualization for improving construction safety. Information gathered from the collection and visualization of real-time data was used to map the inter-relations between construction resources. From here, improvement to various safety aspects on site can be implemented through the new framework that implements real-time remote sensing and data visualization technology in two significant construction applications. The first application includes real time proactive construction safety assessment and training and the second application includes real-time construction productivity and performance monitoring. This research shows that safety of field operation activities could be monitored automatically and in real-time. It also provides advantages in areas including the increase of worker awareness and tracking equipment and materials in across the construction project (Cheng and Teizer 2012).

The framework presented in this paper enables the checking of real-time sensor data and equipment state to warn construction personnel of potentially unsafe conditions on the worksite. The literature review describes various utilizations of technology based solutions that improves on-site safety and is generated from sensor and telematics data. This analysis showed that there is limited literature on the application of technology to enforcing safety regulations on the jobsite. The authors posit that most previous efforts focused on identifying what factors needed, rather than how those regulations could be enforced on the site. The goal of this methodology is to enable the proper enforcement of safety standards and regulations on site through collecting real-time sensor data and creating a rule-based system to check for potentially hazardous situations.

3.0 Methodology

The objective of this study is to establish a rule-based system that uses real-time data from construction sites to generate real-time safety warnings. This will allow for the continuous and automated monitoring of the construction site for imminent safety hazards. This section describes the proposed methodology to enable real-time safety warnings and provides a description of the experimental setup and framework that will be used to validate the research/developed methodology.

3.1 Real-time safety warning methodology

Figure 1 provides an overview of the framework developed to deliver safety warnings from real-time sensor data to management and other affected personnel. With these safety warnings, operations involving both heavy equipment and workers can be improved to create a safer working environment and reduce fatalities.

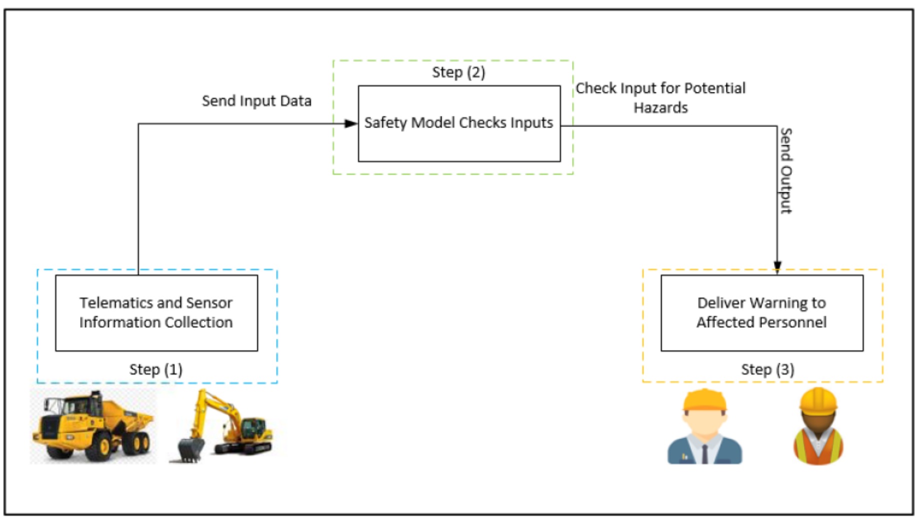

Figure 1: Overview of Framework

As seen in Figure 1, the overall methodology consists of three steps: (1) Collecting data from telematics and sensors in regards to heavy equipment; (2) Checking this data against a rules-based safety model developed from regulations and best practices; and (3) Delivering a warning to affected parties in case of an imminent hazardous situation.

Step (1) of the proposed methodology consists of the communication of real-time sensor data from entities on the worksite to the safety model as input. Step (2) includes a safety model that incorporates a rule-based system that checks for unsafe conditions. The data collected from Step (1) will be analyzed and used as input for the rule-based system realized in the safety model. If there is a potentially hazardous situation, the safety model will send an output to deliver a warning to the affected personnel to notify them to make the appropriate safety adjustments to the current equipment state on the construction site. Step (1) could be implemented using telematics, sensors and monitoring on heavy equipment to obtain field data to provide information on how the equipment is being utilized and provide a general understanding of the safety issues present. From here, the data collected will be input into a rule-based system that will later be developed. Step (3) could be implemented on the site through a variety of extant technologies and tools such as sirens, flashing strobe lights, alarms or buzzers to warn affected workers of an imminent hazard. The warning systems will be delivered after the real-time data generated from the sensors and telematics are compared to the safety model consisting of a rule-based system created from recommended safety standards. This will promptly alert the laborers of the unsafe conditions and evaluate the current safety measure state of the site. Due to the existence of technologies that can perform the tasks necessary to implement Steps (1) and (3) as described above, this paper will focus on providing a framework to develop the safety model of the operation that is concerned with detecting potentially unsafe conditions on construction sites.

Step (2) relates to the development of a framework that will synthesize existing and established safety regulations to create a safety model for contractors and construction management to properly implement real-time and autonomous safety monitoring on the site. The framework proposed in this paper to develop safety models for a broad variety of equipment-intensive operations is provided in Figure 2.

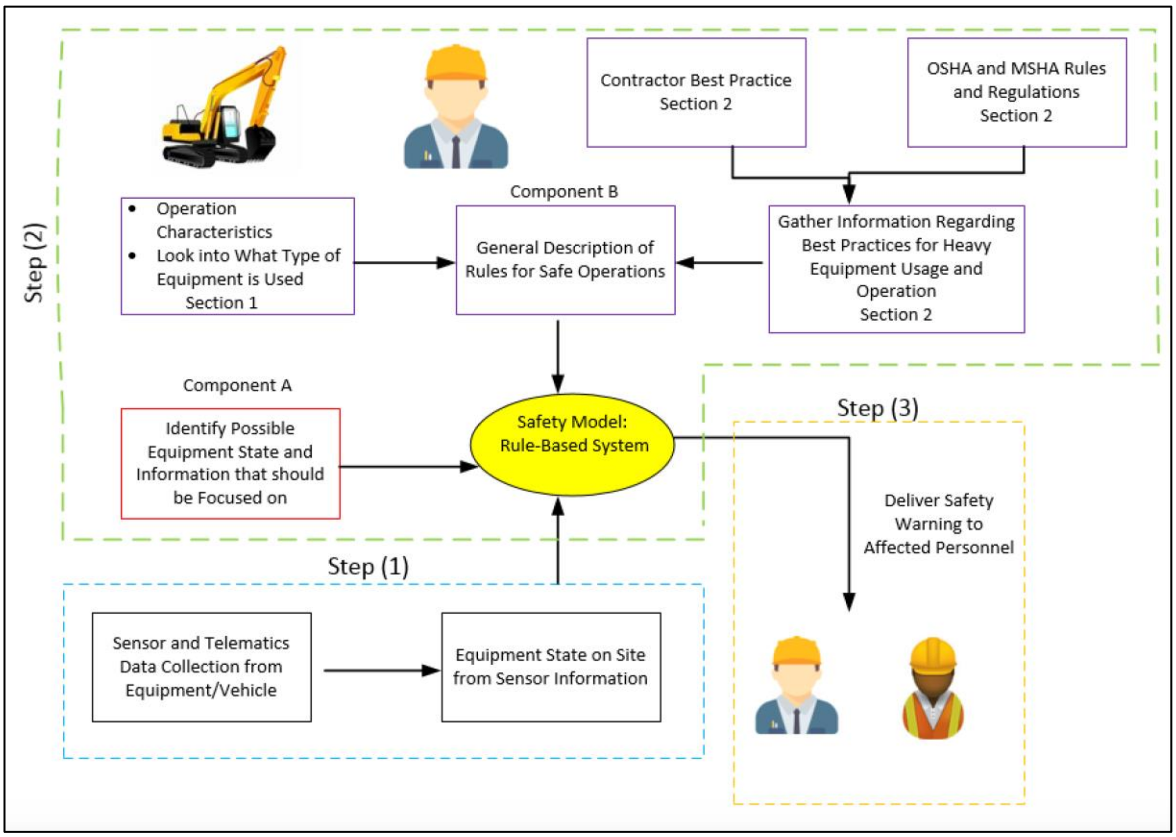

Figure 2: Framework to Develop Safety Model

As shown in Figure 2, the framework is made up of three contributing steps that include collecting real-time data that is received from sensors and telematics, creating a rule-based system based on various components, and delivering warning signals to affected personnel. Step (1), as previously mentioned, will obtain and gather data through monitoring sensors and telematics on various heavy equipment to observe current equipment states. The data collected will be used as an input to the rule-based system and will be compared to the existing regulations developed in the rule-based system. If there are areas in the data that do not meet the regulations in the system, a warning will be delivered through Step (3), back to the construction site from the rule-based system to allow management teams to make the appropriate adjustments. The main focus of this work will be on Step (2), creating the safety model through a rule-based system. This step includes multiple components such as identifying possible equipment states and determining what type of data needs to be obtained (A) and a general description of the rules for a safe operation (B).

Component (A) will use information about heavy equipment on a construction site, which will be obtained through interviewing manufacturers, site observations, and analyzing various databases on any equipment characteristics and states. This research will determine the type of information that needs to be focused on when observing equipment characteristics on site through future studies. Component (B) requires two sections. The first section focuses on obtaining data on the operational characteristics heavy equipment undergo. This information will be obtained by interviewing manufacturers and construction managers, collecting site observations, and analyzing multiple databases on equipment operations to determine what operations the equipment is used for on site. The second section will focus on gathering information regarding best practices for heavy equipment usage to input into the rule-based system. In order to obtain the data for this section, contractor best practices will be investigated and standards created by regulatory agencies such as the OSHA and MSHA will be analyzed. This information will then be filtered to pick out the regulations and rules of thumb that apply to the equipment that will be present on the construction site. From the components and sections shown in Figure 2, the rule-based system can be developed to provide construction management with a safety model to implement into construction sites to reduce fatality and injury rates as well as create a safe working environment.

4.0 Experimental Framework to Validate Research Methodology

The methodology will be validated using case studies to identify areas in the operations of commonly performed equipment intensive construction operations that could create unsafe conditions. This approach will focus on the operation of the system to improve the safety during the various stages of a general construction zone. There are two types of experiments that will be conducted through the case studies. The first is a survey that will be developed to identify current implementations of safety practices by interviewing contractors for rules of thumb and other guidelines they incorporate into the sites they oversee to obtain information on contractor best practices. In addition to the survey, regulations from other entities such the Occupational Safety and Health Association (OSHA) will be investigated to identify aspects of these best practices that focus on the utilization of equipment operations to provide safety improvements to reduce fatality rates. Identification of the type of data that should be obtained from the equipment involved in the operation will also be conducted to provide the potential rues based system with valid comparison points between the various construction sites. From the surveys and regulation information gathered, a rule-based system will be generated to analyze and observe a site in hopes to evaluate it on the proper enforcement of the existing regulations to produce safe working environments. The next section will discuss the utilization of V-REP. This program will be used to accommodate liability issues that are present during unsafe conditions on site, which limit real-world data collection.

4.1 V-REP Virtualization

This research will develop a virtual construction site through a program called Virtual Reality Experimentation Platform (V-REP) in order to simulate construction operations that can be used to validate the proposed methodology instead of collecting data in the real-word under unsafe conditions. V-REP is a platform that provides a 3D robot simulator that concurrently simulates actions such as control, actuation, sensing, and monitoring (Freese et al. 2010). This program is ideal for complex scenarios where diversity of sensors and actuators operate asynchronously with various rates and characteristics (Freese et al. 2010). Due to factors such as liability issues, the methodology for this research will be difficult to validate. Potentially hazardous situations in real-life cannot be investigated on a real construction site due to lives being put at risk. Another factor that contributes to this difficulty is if there is new equipment being utilized on site then it is hard to know exactly how the equipment operates without putting lives at risk as well. V-REP will be able to build the equipment into the program with similar dimensions and model characteristics to accurately represent the equipment to provide the best results and most effective observations. V-REP will also provide the virtualization of the construction site as well to create a site layout that is similar to the site under investigation. From here, V-REP can act out unsafe conditions and scenarios that potentially could occur on site during the construction phase without any worker getting injured during the experiment. This will alert the construction management teams to be aware of these potentially hazardous situations and an action plan to reduce the risk of the heavy equipment causing injuries or fatalities.

Studies using V-REP have been conducted by Louis and Dunston (2014). Their research focused on providing a methodology that enables real-time monitoring of construction operations by integrating sensor data through the consideration of resources as finite-state machines that can provide real-time inputs into an operation model that codifies the construction process. They used an earth moving project as their case study to demonstrate real-time monitoring and virtualization capabilities. Through V-REP they were able to build a construction site and the desired equipment using primitive shapes and models in the V-REP repository to show the actions of the equipment under examination (Louis and Dunston 2014). Due to V-REP allowing the user to recreate typical construction sites, they were able to achieve their goals by saving time from manually taking data and providing the construction industry with a way to monitor the construction operations efficiently. V-REP will be synthesized into the research of interest to create a construction site for the case studies to perform unsafe conditions that are not acceptable to perform on real-world sites due to the liability.

This program will be able to use the real-time sensor and telematics findings to create or recreate unsafe environments based on worst case scenario situations or observations from collected field data to compare to the generated rule-based system to improve the safety on site when in close proximity with heavy equipment. This program will create a safe alternative to test the methodology and hypotheses by taking into consideration the limitations when attempting to conduct experiments in unsafe conditions and putting workers' lives in danger. For this program to be most effective, the data that is obtained from real-time sensor and telematics findings will need to be related back to safety regulations so that the incorporation of the site conditions being inputted into the program are accurate. This research will use V-REP to create unsafe conditions and situations to compare to the generated rule-based system, which will provide information on improvements and alternatives that should occur to produce a safe working environment and reduce fatality rates. Throughout this research, V-REP will be used as an experimental virtual test to relate to construction sites in order to test and validate the methodology. Figure 3 shows the interactions between heavy equipment and workers on site through a construction site virtualization in V-REP. The various interactions will be evaluated through V-REP by modeling and simulating unsafe conditions to validate the proposed methodology.

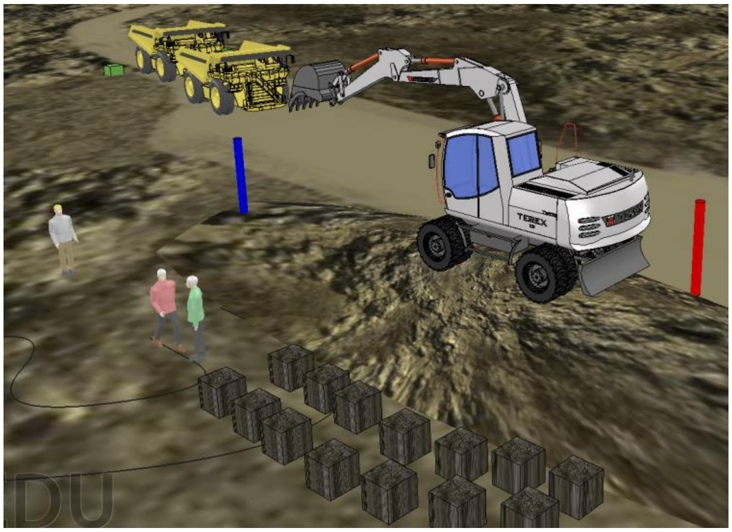

Figure 3: V-REP Simulation of Construction Site

5.0 Conclusions

This research proposes the creation of a rule-based model to check sensor data for unsafe conditions that might arise on construction sites. To determine the safety regulations that apply to this research, databases will be analyzed to select the safety regulations that pertain to the specific studies that will take place. Studying regulations for construction operations and surveying contractors and construction management will propose guidelines and a foundation for the rule-based system that will be developed.

The main contribution of this research is to propose a framework that integrates existing safety regulations with real-time sensor and telematics data that can be obtained from equipment in order to reduce the occurrence of unsafe conditions on the construction site. This research provides an analytical approach to objectively examine safety conditions, which is antithetical to prevailing conceptions of safety being of a subjective nature and therefore difficult to quantify. The conditions of the resources on construction sites can be tracked using sensors and checked with the proposed safety model to monitor the status of the worksite and also document the relationship between workers and heavy equipment. This data can be used to implement the proper safety regulations and enhance the safety of the construction site. This research and development of a rule-based system will provide safety personnel with a real-time system to continuously monitor and improve the safety conditions on site. By incorporating real-time data to the construction site, the research introduces a new use for real-time sensor and telematics data to continue to make changes to the safety on site. This research will also introduce a state-of-the-art methodology that could record near-misses that may not be apparent, which will reduce injury rates.

Limitations of this research exist due to the rule-based system having to be developed manually, which could possibly delay the time spent on this particular section of the research. The research focuses on equipment intensive operations, which could make it unsuitable for labor intensive operations, wherein it is more difficult to automatically identify what human laborers are doing. Other limitations will be discovered when the research and rule-based system are applied to the case studies and seen through the virtualization of the construction phase. Even though this research is proposed for generic operations, the case studies will cover only a few typical construction cases. To further this research, possibly evaluating a wider variety and larger amount of case studies could be beneficial and help to validate this rule-based system for different types of construction projects.

Acknowledgements

This work has been by the US Department of Transportation's University Transportation Center program, through the Pacific Northwest Regional University Transportation Center (PacTrans).The authors would like to thank PacTrans for their support.

References

Akhavian, R., & Behzadan, A. H. (2013). Knowledge-based simulation modeling of construction fleet operations using multimodal-process data mining. *Journal of Construction Engineering and Management*, *139*(11), 04013021.

Cheng, T., & Teizer, J. (2013). Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications. *Automation in Construction*, *34*, 3-15.

Freese, M., Singh, S., Ozaki, F., & Matsuhira, N. (2010, November). Virtual robot experimentation platform v-rep: A versatile 3d robot simulator. In *International Conference on Simulation, Modeling, and Programming for Autonomous Robots* (pp. 51-62). Springer Berlin Heidelberg.

Gambatese, J., Behm, M., & Hinze, J. (2003). Engineering mandates stipulated in OSHA regulations. In *Construction Research Congress: Wind of Change: Integration and Innovation* (pp. 1-8).

Louis, J., & Dunston, P. S. (2016). Methodology for Real-Time Monitoring of Construction Operations Using Finite State Machines and Discrete-Event Operation Models. *Journal of Construction Engineering and Management*, 04016106.

Louis, J., Dunston, P., & Martinez, J. (2014). Simulating and Visualizing Construction Operations using Robot Simulators and Discrete Event Simulation. In *Computing in Civil and Building Engineering (2014)* (pp. 355-363).

Marks, E. D., Cheng, T., & Teizer, J. (2013). Laser scanning for safe equipment design that increases operator visibility by measuring blind spots. *Journal of Construction Engineering and Management*, *139*(8), 1006-1014.

Occupational Safety and Health Administration (OSHA). (2009). "Inspections within industry." ⟨http://www.osha.gov/SLTC/etools/construction/struckby/mainpage.html⟩ (February 10, 2017).

Vahdatikhaki, F., & Hammad, A. (2014). Framework for near real-time simulation of earthmoving projects using location tracking technologies. *Automation in Construction*, *42*, 50-67.