Rapid Safety Assessment Tool for Non-Conventional Roadway Designs and Emerging Technologies: Innovative Artificial Intelligence Application

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1 Introduction

Motor vehicle crashes continue to be a leading cause of death in the US and worldwide. According to the US National Highway Traffic Safety Administration (NHTSA), motor vehicle crashes have been ranked 7th overall in terms of the years of life lost in 2014, and 2nd within unintentional injury deaths for all ages in 2015 (NHTSA, 2014 & 2018). In 2016, there were close to 37,500 fatalities; a 5.6 percent increase from 2015. In addition, there were more than 2.44 million injuries in the US alone in 2015. Of which, more than 94 percent are attributed at least in part to human errors. In recent years, new innovative roadway facility designs (i.e., road diet, continuous flow intersections, modern roundabouts, diverging diamond interchanges, etc.), advanced Traffic Control Devices (new Signal Phasing and Timing schemes, flashing yellow arrows, innovative intersection and roadway signs and markings, 6 inch marking, etc.), Intelligent Transportation Systems (Variable Speed Limit Systems, Advanced Traveler Information Systems, etc.), and improved roadside infrastructure (median cable barriers, rumble strips and stripes, safety edge, etc.) have proliferated in many countries including the US to improve mobility and mitigate adverse safety issues of conventional designs. Intersections safety is of a significant interest to transportation agencies due to their high frequency and severity of crashes. The complexity of traffic movements at signalized intersections leads to high amount of violations, conflicts and crashes. Moreover, other factors as geometric features, operational characteristics, and user familiarity may exacerbate this complexity. According to the Federal Highway Administration (FHWA), approximately 2.5 million intersection-related crashes occur in the US per year ("Federal Highway Administartion (FHWA),"). Intersection related crashes represent nearly 50 percent of total crashes in the US, of which 50 percent are severe and 20 percent are fatal.

In 2015, more than 50 percent of crashes in Wyoming were intersection-related with more than 4,000 urban intersection crashes. The Wyoming Department of Transportation (WYDOT) has been in the forefront of adopting a variety of these innovative intersection and roadway safety countermeasures with expectations of attaining operation and safety benefits. Nevertheless, there are a lot of speculations between transportation scientific communities and practitioners on whether traditional methodologies to assess the effectiveness of the safety and operation of these rapidly evolving countermeasures are appropriate.

While traditional safety assessment methods have been helpful to better understand crash trends, predict crashes, and evaluate the effectiveness of countermeasures, these techniques depend mainly on aggregate crash data. The primary explanatory variable in Safety Performance Functions is Average Daily Traffic, which is an aggregate exposure measured over a full year. When evaluating the safety performance of intersections Total Entering Volumes (TEV) is considered as the main exposure, which is considered as a main limitation to develop the SPFs for intersections. Intersections include 15 different crash patterns that could occur within the intersection area. TEV is not always the main indication for the 15 crash types, as some might depend only on the through traffic volumes and others might be affected with turning movements (i.e., left-turn movement is considered the most hazardous maneuver at intersections). However, due to the complexity to collect such refined turning movements data, researches utilizes the TEV. Other limitations could also be related to the crash reports; crash reports usually are not detailed. Data related to crash patterns, weather, road surface, and real-time traffic could be missing. Additionally, information on speeds, turning movement counts, and precise pre-crash conditions cannot be extracted from crash reports.

Traditional safety techniques are reactive in nature and they suffer a number of critical limitations; 1) crash police reports are subjective and inconsistent, 2) crash reporting system is evolving to keep up with new Intelligent Transportation Systems and advancements of automotive industry (i.e., Connected and Automated Vehicles), 3) underreporting issues of minor crashes, 4) lack of driver behavior in normal driving, pre-, during-, and post-crash events, 5) no information on violations and near crashes, 6) lack of a complete picture on the interaction between different road users, and 7) the need of crashes to happen (i.e., the Highway Safety Manual recommends 3-5 years of crash data to conduct a sound safety analysis).

On the other hand, proactive safety studies are gaining momentum because of their ability to rapidly assess new safety countermeasures. Proactive safety studies aim to investigate the dynamic factors that could affect crashes and near-crashes probability. These modeling techniques focus on individual Critical Safety Events (CSE) - known also as conflicts - and their precursors to predict the probability of crash risks in real time and to understand the underlying casual effects of their occurrences. Generally, real-time statistical techniques require a high-resolution speed, vehicle trajectory, conflict, traffic, and weather data. Traffic conflicts refer to incidents that could have been a crash if the road users continued their movement in the same direction and speed. Proactive safety analysis using traffic conflicts possess important advantages over crash-based ones; 1) compared to crash data, traffic conflicts are more frequent events (i.e., a comprehensive dataset could be obtained in a relatively shorter period of time than crash data), 2) detailed information could be extracted from traffic conflicts as it is mainly based on video recordings, 3) driver behavior is directly collected, 4) the associated social and economic cost of conflict analysis are relatively low compared to crash data, 5) with well-trained observers and machine learning algorithms, consistent data could be obtained, 6) faster recommendations could be provided to decision makers regarding non-conventional countermeasures and disruptive new technologies.

This study proposes to develop a new tool to efficiently assess the traffic safety at intersections as well as suggesting suitable countermeasures to be quickly implemented to enhance the performance of the investigated roadway facility. This tool could be applied on conventional and non-conventional intersections in addition to newly introduced intersection designs. Moreover, the safety and operational performance of new emerging technologies could be evaluated using this tool. Rapid and accurate assessment could be conducted, which are the main advantage of this approach. Hotspot analysis and ranking, WYDOT transportation experts' recommendations, and road users' preferences will be utilized to flag intersections that need an urgent intervention.

Conflict analysis using machine vision approaches will be applied to rapidly assess the operation and safety performance of the identified intersections. Video recording data will be collected from existing cameras equipped at intersection as well as using an already UW owned Data Acquisition System (DAS) trailer, shown in Figure 1A. The DAS system will be used when the existing cameras do not provide a full intersection coverage area or specific traffic and conflict patterns are needed for assessment. A comprehensive video recording data collection for two weeks per intersection will be conducted to form the conflict dataset. At least three cameras will be mounted on the DAS to collect continuous video recordings in addition of a LiDAR system. The system will include three cameras (two black & white cameras with IR for night vision and one wide view angle camera) to cover all the intersection area with a high resolution videos as shown in Figure 1B and Figure 1C. for data storage and collection, a self-powered system will be utilized including a mobile Network Video Recorder (NVR).

Figure 2 shows the power and data wiring diagrams of the DAS. The cameras will record video footages for different intersection approaches as well as the main intersection area. Additional video footages could be also collected from CCTV cameras when available at the study sites.

Figure 1: Equipment, components, and wiring diagram of the UW Data Acquisition System (DAS)

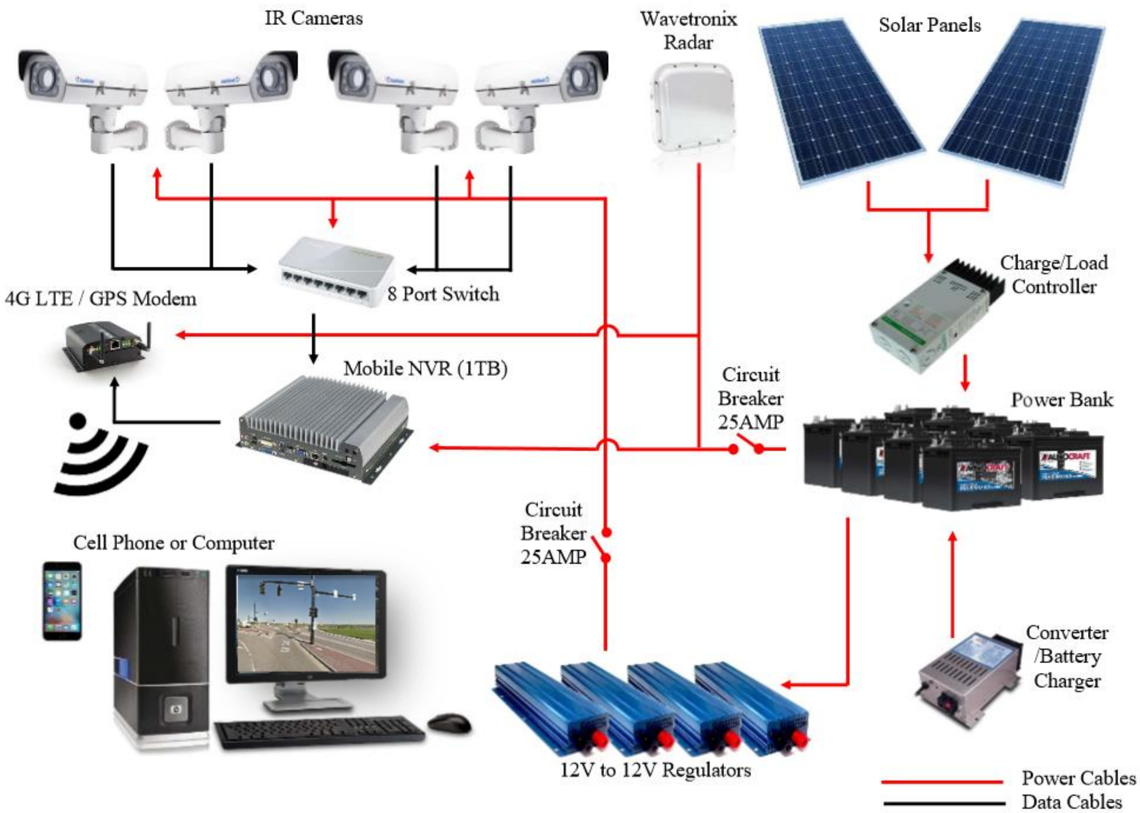


Figure 2: Wiring diagram of the UW Data Acquisition System (DAS)

Conflict analysis utilizing advanced computer vision and machine learning techniques will be adopted to analyze conflicts / near crashes. In this step, video recordings from existing cameras installed at intersections in Wyoming, as well as newly mounted cameras will be utilized to extract traffic conflicts. Figure 3 shows the general proposed framework to conduct the conflict analysis. The framework will mainly has three phases. The first step will focus on data collection, cleansing and preparation. Image processing algorithms will be used to reduce noise and adjust the collected video footage for the feature extraction. The second step focuses on identifying moving objects and classify the video entities into the different roadway users. The final phase will adopt motion estimation methodologies to extract motion trajectories and detect conflict identifiers. This will help transportation agencies to quickly pinpoint the roots of issues of newly implemented safety countermeasures and propose mitigation strategies. The following sections provide background on proactive safety assessment methodologies, the problem statement, objectives of the study, selected study areas, and tasks and timeline to achieve the proposed objectives.

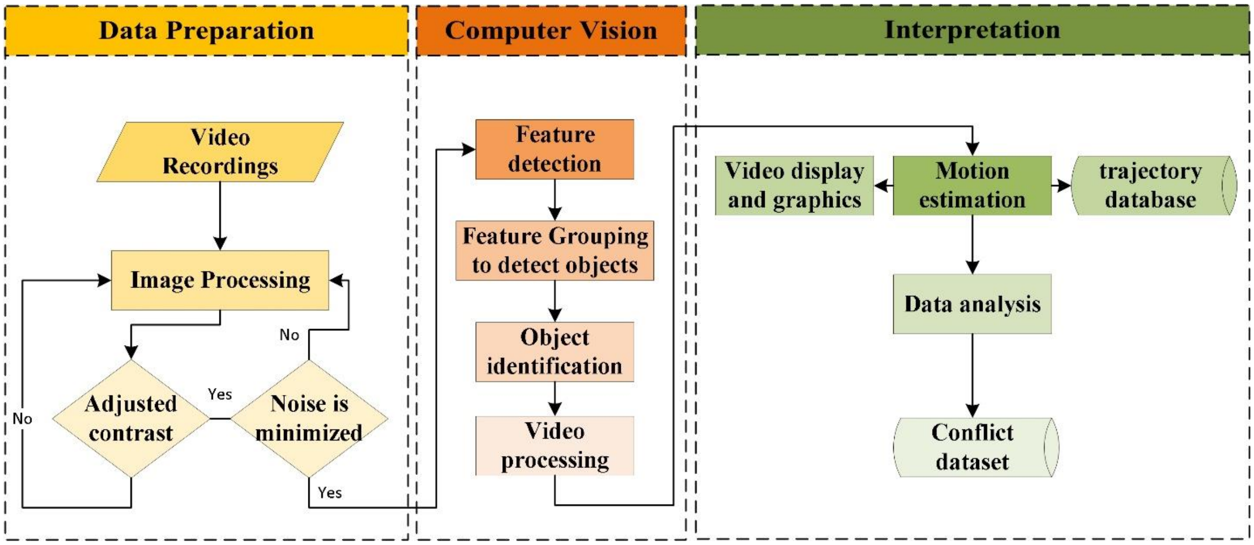


Figure 3: Framework of the Proposed Traffic Conflict Analysis

2 Background

In recent years with Vision Zero[1], new innovative safety evaluation procedures have been evolved to evaluate non-conventional roadway and intersection designs, as well as new safety and operation countermeasures. Nontraditional approaches has gained popularity to evaluate the traffic safety and operations of roadways and intersections; such as Conflict Analysis.

Transportation researchers had extensively used machine learning and computer vision techniques in recent years, especially with the presence of new emerging technologies such as Connected and Automated Vehicles. These techniques have been used in multiple aspects such as to enable vehicles to identify the surrounding features to safely and efficiently operate, to read license plates of vehicles for means of traffic surveillance (Arth et al., 2006; Du et al., 2013), trip routing estimation (Hu and Ni, 2018; Rao et al., 2018), and parking management systems (Rashid et al., 2012). Moreover, machine vision techniques were used to estimate Surrogate Measure of Safety (SMoS) by identifying vehicle trajectories were traffic conflicts could be extracted and furtherly analyzed. The rapid advancement in machine vision technologies, computer processing power, and high-speed connectivity has opened new outlooks of opportunities in the field of transportation engineering to improve traffic safety and operations. The potential of machine learning techniques in identifying unexpected events on the roadways, as well as real-time weather and surface conditions have been thoroughly explored in the literature.

[1] Vision Zero is a multi-national set of strategies to prevent fatalities and severe injuries related to road traffic.

The following sections provide a comprehensive background on the conflict analysis that has the capability of assessing not only new infrastructure changes, but also emerging technologies such as Connected and Automated Vehicles (CAV).

2.1 Conflict Analysis for Performance Assessment

Due to the stochastic nature of crashes and being rare events, traffic conflict analysis has gained momentum in recent years. The Federal Highway Administration (FHWA) published a guideline manual to conduct traffic conflict analysis (Parker and Zegeer, 1989). The traffic conflicts were manually collected by trained observers, in which diagrams and narrations were recorded for specific timeframes. Sayed and Zein (1999) conducted a study which provided standards of traffic conflict for intersections (Sayed and Zein, 1999). The research described the applications used to estimate traffic safety at intersections. An Intersection Conflict Index (ICI) was developed to measure conflict risk at intersections. The study utilized trained observers to manually collect traffic conflicts from 94 signalized and unsignalized intersections. With the rapid evolution pace of technology and artificial intelligence, computer vision techniques have been applied on video recordings to automate the data collection of traffic conflicts. A study introduced a feature-based algorithm to track vehicles at intersections (Saunier and Sayed, 2006). The feature tracking approach showed an improved ability to track vehicles in complex scenes with multiple entrance and exit regions. Another study investigated the processes that involve pedestrians in collisions (Ismail et al., 2009). The study developed an automated video analysis system that has the ability to detect and track road users in a traffic scene, classify road users into pedestrians or motorists, identify near crash events, and calculate conflict indicators in real time. The developed system was able to automatically capture 89.5 percent of the conflicts and 71.7 percent of the important events. Other researchers conducted a large-scale automated analysis of vehicle interactions and collisions (Saunier et al., 2010). The utilized dataset contained more than 300 severe interactions and collisions. The developed system identified traffic conflicts/collisions into 4 categories: head-on, rear-end, side, and parallel near crashes. The results showed the usefulness of the system to study driver behaviors that might lead to a collision. St-Aubin et al. presented a practical framework for implementing an automated, high-resolution, video-based traffic-analysis system (St-Aubin et al., 2015). The study utilized Closed-Circuit Television CCTV and regular video cameras to collect microscopic traffic flow data. Data were collected from roundabout weaving sections. The results showed that the developed system accuracy of detecting conflicts varies from 85 percent to 95 percent.

Conflict detection algorithms were basically used to alleviate and expedite traffic safety analysis. This is due to the fact that traffic conflicts occur more frequently than crashes and can be clearly captured, which could provide insights about the deficiencies that could lead to a crash. Several studies developed safety performance functions for roadway facilities using traffic conflicts. The relationship between conflicts and crashes were investigated using a two-phase model (El-Basyouny and Sayed, 2013). The first phase employed a lognormal model to predict conflicts using traffic volume as a main exposure and other roadway geometric characteristics. The square root of the Product of Entering Volumes (PEV) was the surrogate measure used to predict conflicts. In the second phase, a negative binomial safety performance function was developed to predict crashes using traffic conflicts. The dataset was extracted from 51 intersections in Canada. The results showed that for each one percent increase in traffic conflicts, crashes increase by 0.738 percent, in which the p-value was less than 0.001. Zhang et al. 2014 developed a conflict prediction model using negative binomial and linear regression models for opposing left-turn conflicts (Zhang et al., 2014). Data was collected from 20 intersections in China. It was found that the linear model was not appropriate to model traffic conflicts as they do not follow a normal distribution. Additionally, the study showed that the effects of conflicting traffic had a different effect on predicting crashes.

Sacchi and Sayed, 2016 conducted a study that aims to establish the relationship between conflicts and crashes using a two-phased process (Sacchi and Sayed, 2016a). Poisson–gamma model was used in the two phases to develop the prediction models. In the first phase conflicts were predicted using traffic volumes as the main exposure, then predicted conflict were used to predict crashes in the second phase. Data was collected from 49 signalized intersections in Canada. Stratified analysis was adopted to consider different types of conflicts (i.e., left turn conflicts and collisions and rear end conflicts). The results indicated that the predicted average hourly conflicts increased with traffic volume, which showed a nonlinear relationship. The crash prediction model estimated a 0.8 percent increase in predicted crashes for each 1 percent increase in predicted conflicts. The prediction model for the left-turn conflicts showed a slow increase in conflicts compared to traffic volumes. On the other hand, the rear-end conflicts had a high increase compared to traffic volumes. Another study by Sacchi and Sayed, 2016 investigated the development of safety performance function for conflicts using Bayesian analysis (Sacchi and Sayed, 2016b). The focus of the study was on rear-end conflicts at signalized intersections utilizing Poisson –gamma and lognormal distributions. The results showed that Poisson-gamma distribution models outperformed the lognormal models. Additionally, it was found that traffic volumes had a coefficient slightly higher than 1.00, which means a slight rapid increase in conflicts compared to traffic volumes. Safety at the cycle level for signalized intersections were evaluated using traffic conflict models (Sacchi and Sayed, 2016b). The scope of this study is to investigate the effect of signal control and operational parameters on traffic conflicts. The variables considered in developing the conflict prediction models were the traffic volumes, maximum queue length, shock wave characteristics, and the platoon ratio. Time to Collision (TTC) was the measure to determine conflicts, in which TTC< 1.5 seconds is identified as a rear end conflict. The study developed multiple conflict prediction models using Generalized Linear Model with a negative binomial distribution. Three levels of models were investigated in which the first level included exposure only as the sole variable in the model. Then adding one variable at a time to develop additional 4 models. Finally, a combined model was introduced including all the collected variables. It was found that the combined model had the least AIC value indicating the best fit model. All the investigated parameters were found to be significant in the developed models at a confidence level of 95 percent.

Several studies applied Extreme Value Theory (EVT) to estimate crashes using traffic conflicts (Tarko, 2018; Wang et al., 2019; Zheng and Ismail, 2017; Zheng and Sayed, 2020, 2019). These studies have validated the effectiveness of predicting crashes using traffic conflicts as SMoS. Zheng and Ismail, 2017 developed a generalized link function to map the severity index of conflict indicators (Zheng and Ismail, 2017). A total of 21 segments from three freeways located in China were used in the study, where traffic conflicts and crashes were extracted. The results showed that the utilized empirical method along with the full Bayesian estimation method provided statistical support for using the generalized exponential link function. Tarko, 2018 compared between three aproaches to predict crashes from conflicts (Tarko, 2018). The threee approaches were Maximum Likelihood Estimate (MLE), Probability-Weighted Moments (PWM), and Single Parameter Estimation (SPE). The results showed that the SPE outperformed the other two methods in terms of reliability, accuracy, and efficiency. The obtained crash estimation bias using the SPE was found to be 0.142, which was lower compared to the crash estimation bias resulting from PWM and MLE methods, 0.214 and 0.249, respectively. Another study compared the estimated crashes from traffic conflicts with observed crashes (Zheng and Sayed, 2019). The selected crash estimation approach used in the study was the Peak Over Threshold (POT). Time to Collision (TTC), Modified Time to Collision (MTTC), Post Encroachment Time (PET), and Deceleration to Avoid a Crash (DRAC) were the four parametrs used to estimate crashes. The results showed that MTTC provided the most accurate crash estimates. DARC was found to provide crash estimates that are significantly different than the observed crashes. The other two parameters showed a reasnable estimation of crashes, however tendency of overestimation was observed with TTC and underestimation with PET. Wang et al, 2019 proposed a bivariate Extreme Value Theory (EVT) framework to predict crashes (Wang et al., 2019). Perception reaction failure and failure to proper evasive actions were considered to develop the crash prediction model. Unmanned Aerial Vehicle (UAV) was used to collect the video footage for the conflict analysis. Data was collected from 10 intersections in China, where 4 hour video clips were recorded per intersection. Univariate and bivariate EVT were applied to predict crashes using four conflict indicators (i.e. Time-to-Accident (TA), Post-Encroachment Time (PET), minimum Time-to-Collision (mTTC), and Maximum Deceleration rate (MaxD). The crash predictions were compared to observed annual crash frequencies. It was found that among the univariate models, univariate EVT model based on PET efficently predicted angle crash frequency, while those based on mTTC outperformed others in estimating rear-end crashes. However, bivariate EVT models had a better crash prediction compared to univariate models. Another study combined more than one conflict indicator to explain underlying level of safety comprehensively by applying extreme value theory (Zheng and Sayed, 2020). The study focused on rear end conflicts in intersections and applied a bivariate Bayesian hierarchical model for non-stationary conflict extremes to estimate crashes. Modified Time to Collision (MTTC) and

Post Encroachment Time (PET) were the two conflict measures investigated in the study. To account for non-stationary parameters, traffic volume per cycle, shock wave area, and platoon ratio were included in the analysis. The study showed that extreme value theory could help in extrapolating conflict to estimate crashes.

3 Problem Statement

Assessing the traffic safety performance of intersections is one of the important aspects that concerns transportation agencies. Intersections are locations where all the road users share the same geographical location, in which several complex conflicts occur. This complexity might even increase at non-conventional intersections, such as roundabouts. Road users' unfamiliarity with new traffic patterns of non-conventional intersections may lead to unexpected driving behaviors that could cause a near crash or even a crash. Traditional safety assessment approaches are mainly based on historical crashes and traffic volumes as the main exposures. Three to five years of traffic data and crashes are needed for traffic safety assessment. These procedures suffer from two main limitations, required data period and assessment strategy. Decent sample size of crash observations needs to be met before conducting the safety evaluation, which is considered a reactive approach. Additionally, assessment could be hindered due to low exposures. Although the reactive component of safety is a powerful tool for addressing existing safety problems, proactive safety has multiple advantages that should be utilized. With appropriate proactive safety analysis, the potential of crashes could be diminished before they occur by investigating traffic conflicts, which are crash indicators.

Driver behavior is one of the most important factors that influence nearly all traffic crashes. Nevertheless, traditional safety studies depend primarily on aggregate crash data which is reactive in nature and cannot directly relay driver behavior prior to a crash nor provide detailed and accurate pre-crash information. As discussed earlier, crashes are fortunately quite rare events when compared to other traffic events, nevertheless, they are complex events caused by accumulation and interaction of multiple factors and failures. In addition, exposure information such as the frequency of behaviors in normal driving as well as the larger context of contributing factors to crashes and near crashes cannot be obtained from crash reports.

With the presence of newly emerging technologies such as CAV, traditional safety approaches will no longer be suitable to quickly assess their impacts on the safety and operations of our roadway facilities. Traditional safety approaches may not also be the appropriate methodology to assess a newly introduced non-conventional intersections due to lack of data and unfamiliar drivers population.

On the other hand, proactive innovative safety techniques have the ability to assess conventional, non-conventional intersections, driver behavior and performance interactions with roadway, environmental and vehicular factors as well as CAV and their impacts on collision risks. These evolving techniques could complement historical crash data and help proactively to identify hazardous locations with high probability of crashes and / or near-crash risks prior they occur and recommend effective mitigation strategies in relatively shorter time. This raises an ethical issue that transportation agencies must wait until a sufficient number of crashes, including fatalities and injuries, to happen before hazardous locations could be identified and mitigated. The proposed proactive safety approach will also provide insights about the human errors that led to a near crash. Hence, it will enable to observe the different human actions that caused an incident.

Innovative assessment techniques are critically required to evaluate the safety effectiveness of new emerging technologies, such as Connected and Automated Vehicles (CAV). CAV are equipped with multiple technologies that would affect the safety performance of the vehicles and the roadway facilities as well. Advanced Driver Assistant Systems (ADAS) such as forward collision warning, automatic emergency braking, lane keep assist systems, maintaining safe distance systems, and pedestrian detection systems are expected to significantly reduce crashes. Given the remote nature of Wyoming and the stochastic rare nature of crashes, utilizing traditional safety techniques would not be feasible. Utilizing video recordings, conflict, long-term safety countermeasures and instantaneous interventions could be developed and deployed.

4 Research Objectives

This research proposes a proactive road safety assessment for non-conventional designs and emerging technologies in Wyoming utilizing traffic conflict analysis. Furthermore, the innovative assessment methodologies will provide detailed observation and analysis of driving behavior, trajectory interpretation, and conflict measures. These methodologies will be based on computer vision applications utilizing recorded video data. It is suggested to apply the proposed methodologies on locations within Wyoming that received complaints from residents and/ or according to WYDOT recommendations. Below is a candidate list of the suggested intersection locations to conduct the study on:

1. 19th/Pershing/Converse roundabout at the city of Cheyenne.
2. The two DDI intersections at the city of Cheyenne.
3. Gros Ventre Junction roundabout near the city of Jackson.
4. Jackson Hole down town intersection at the city of Jackson.
5. Centennial Hills Blvd and Waterford St. roundabout intersection at the city of Casper

Final selection will be based on recommendations from WYDOT Safety Office. The objectives of this research include the following:

- Conduct a hotspot analysis to determine the crash prone intersections
- Provide a quick nonintrusive traffic and turning movement counts at intersections as a temporary traffic count methodology.
- Perform a conflict analysis to provide insights about the causes that lead to Critical Safety Events (CSE) (i.e., crashes and near crashes).

- Develop an automated conflict analysis system to evaluate the performance of roadway facilities with a focus on intersections/ interchanges.
- Investigate driving behaviors that mostly influence CSE.
- Assess the traffic safety performance of intersections and roadway facilities using conflict and crash prediction models using predicted conflicts.
- Evaluate the effectiveness of applied countermeasures at intersections.
- Conduct a sensitivity analysis to assess the safety performance of proposed countermeasures under different traffic demand levels and various weather conditions. The demand levels will be determined based on average annual growth rate multiplied by the number of years to the current year demand.
- Determine the applicability of the conflict analysis to assess CAV applications.
- Provide WYDOT with a new framework of safety assessment techniques which is more appropriate for evaluating emerging technologies.

5 Study Benefits

Due to several limitations of traditional safety assessment techniques discussed above, they might not be suitable to quantify the safety effectiveness of non-conventional roadway and intersection designs as well as emerging safety countermeasures. This study proposes developing a new tool to assess the safety performance of intersections in Wyoming and suggesting potential countermeasures to improve their safety and operations. The framework begins with a comprehensive hotspot analysis using spatial analysis on Arc-GIS to identify crash prone locations. Conflict analysis will be conducted to rapidly detect conflict identifiers, which are known as Surrogate Measures of Safety (SMoS). These SMoS will be used to identify potential crash patterns that are likely to occur at the flagged intersections. Based on the detected conflicts, countermeasures will be identified. After implementation, conflict analysis will be conducted to evaluate the effectiveness of the applied treatments. Additionally, microsimulation could also be utilized as an evaluation approach.

This technique will utilize the power of machine vision to rapidly quantify the safety benefits of roadway infrastructure, traffic control devices, ITS, and emerging transportation technologies. It is worth mentioning that most of the Wyoming interstate roads, highways, and main intersections are continuously monitored using CCTV. The main task of the conflict analysis is to develop an automated system that could be utilized on any roadway facility (i.e., intersections or roadway segments) to identify the different driving behaviors that might lead to a collision. Additionally, the collected video recordings will be used to identify traffic real-time counts and turning movements. The outcomes from this study will provide WYDOT and researchers with an effective tool to evaluate the safety effectiveness in a more proactive fashion and hence long-term safety countermeasures and instantaneous interventions could be developed and deployed. This is expected to reduce the frequency and severity of crashes and mitigate adverse implications of non-conventional roadway designs and emerging countermeasures.

Easymile®, which is one of the leading companies that provides driverless vehicle solutions, has several autonomous shuttle deployments in the mountain plains region. In Utah, EZ10 driverless shuttle has been deployed in 10 locations around Salt Lake City. Moreover, in Colorado they have deployed EZ10 shuttle which operates on a dedicated road section near the Technology and Operations Center of Panasonic Enterprise Solutions Company as well as in the National Renewable Energy Laboratory (NREL) campus in Denver. With the widespread of such emerging technologies, this research will help in facilitating and accelerating the deployment of CAV on Wyoming roadways by providing a quick procedure to assess their safety and operations performance.

6 Statement of Work

6.1 Overview of Research Tasks

The primary goal of this research is to utilize site-based observations of Surrogate Measures of Safety (SMoS) to fill in the gaps in methodical knowledge to effectively assess the safety performance of innovative roadway designs and new emerging transportation technologies and countermeasures. This goal will be achieved by developing a safety assessment framework using computer vision and machine learning to study conflicts and Surrogate Measures of Safety (SMoS) and road users' behavior obtained from conflict analysis. Multiple tasks will be conducted to achieve the main objectives of this study. These tasks are summarized as follows:

1) Literature Review

Conduct a comprehensive literature review about innovative approaches used to evaluate safety performance of unconventional roadway and intersections;

2) Data Collection and Processing

a. Conduct a comprehensive data collection for the variables that mostly influence the facility performance (real-world traffic volume, crash data, signal timing information, posted speed limits, actual vehicle speeds and acceleration rates, and geometric characteristics;
b. Collect video recordings for the study locations to capture traffic volumes, turning movements, weather, and traffic conflicts. Video recordings will be collected using existing equipped cameras at intersections as well as newly added cameras, if needed to cover the required intersection area for the analysis. The additional cameras will only be needed if the investigated intersection does not have any monitoring cameras or if the existing ones do not provide a full coverage for the intersection;

3) Network Screening Analysis

Conduct a hotspot analysis using historical data to determine crash prone intersections using rate quality control method. Selection of sites to be furtherly investigated will be based on recommendations from WYDOT Safety Office.

4) **Traffic Conflict Analysis**

a. Reduce the collected videos using manual video observation by trained observers then manually extract the conflict events and data;
b. Develop an automated system using feature tracking algorithms to identify vehicles paths and traffic conflicts;
c. Validate the conflict analysis to estimate the accuracy of the automated system in capturing traffic conflicts;
d. Estimate thresholds to identify traffic conflicts based on occurred near crash events.
e. Extract all the traffic conflicts from the video recordings using the estimated near crash thresholds.

5) **Countermeasures Identification**

a. Develop conflict prediction models for different types of conflict using indicator measures.
b. Develop crash prediction models using predicted crashes to assess the overall safety of the investigated road facilities.
c. Propose safety countermeasures to WYODT for implementation.
d. Assess the effectiveness of suggested/ selected countermeasures after implementation using conflict analysis.

6) **Conclusions and Recommendations**

Provide WYDOT recommendations regarding accuracy and efficiency of the developed 2-step safety assessment tool as well as the applicability on other roadway facilities and emerging technologies. Figure 4 illustrates an overview of the proposed research tasks and expected products from each group of tasks.

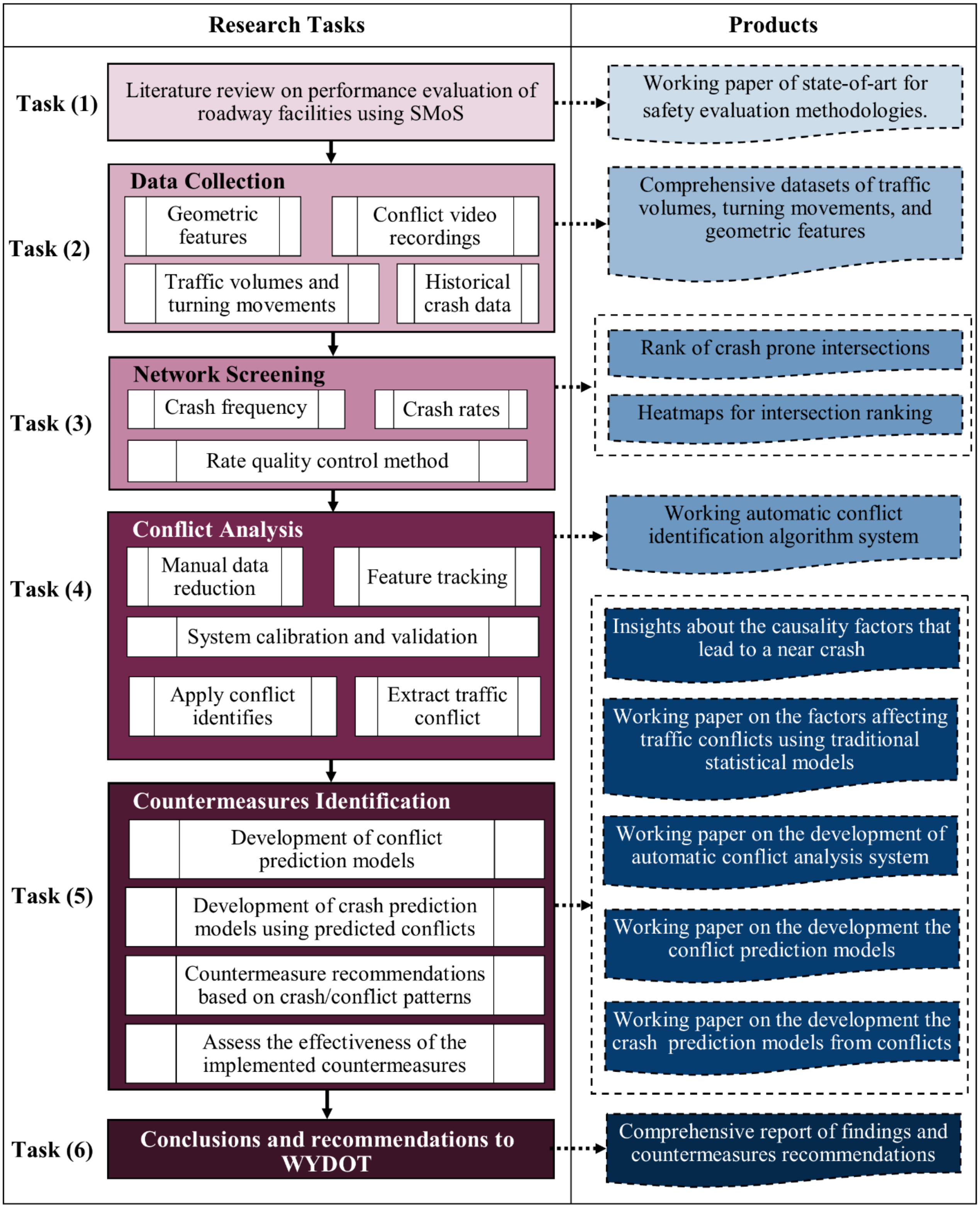


Figure 4: Overview of the Proposed Research Tasks and Expected Products

6.2 Elaboration of Tasks

6.2.1 Task 1: Literature Review

A thorough review of the literature regarding the state-of-the-art of the methodologies utilized to evaluate safety performance using the Highway Safety manual and conflict analysis will be detailed and concluded. The literature review will include the multiple approaches used to detect and trace vehicles in complex environments using machine learning.

6.2.2 Task 2: Data Collection and Processing

With consideration of the unique traffic and weather conditions in Wyoming, a high-resolution traffic data for the selected roadway facilities will be collected, which includes:

- ✓ High resolution turning traffic volume (5-minute traffic volume data) as well as traffic composition.
- ✓ Traffic characteristics including traffic volumes, speeds and speed variances of trucks and cars under various weather conditions.
- ✓ Existing geometric features, such as number of lanes, lane width, locations of merging and diverging areas, entrance and exit turning radii, etc.
- ✓ Existing traffic control strategies, such as locations of traffic signals and yield/stop signs, signal timing information, posted speed limits, etc.
- ✓ Detailed crash information including frequency, location, type of crash, manner of collision, etc. Data should include at least three years in the before construction periods and the crash data for the after-construction period.

6.2.3 Task 3: Network Screening

Collected data will be used to develop a comprehensive network screening to identify intersection with high crash probabilities. Different methodologies provided in the Highway Safety Manual (HSM) will be utilized in this analysis. Crash frequencies, crash rates and rate quality control method will be the core adopted methodologies. The ranking of the intersection based on their crash likelihood severity will be identified. Based on the analysis and WYDOT recommendations, certain intersections will be identified for further investigation.

6.2.4 Task 4: Conflict Analysis

6.2.4.1 Manual Data Reduction

Data reduction and processing will be initially performed manually to identify and classify traffic conflicts according to the Federal Highway Administration guidelines and recent state-of-the-art literature. Observers will be trained to accurately identify traffic conflicts according to their types and severity. The severity of the identified traffic conflicts will be determined by several independent measures. Table 1 shows a summery list of the proposed conflict indicators that could be utilized to conduct conflict analysis.

6.2.4.2 Develop the Automatic Conflict Detection

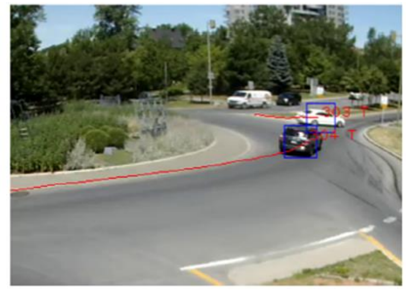
Feature-based tracking is the proposed methodology of tracking vehicles on the roadways. Feature-based algorithm are mainly used to identify any moving object in the recorded videos and track their motion path. A sample of feature tracking algorithms applied on a signalized intersection and roundabout is shown in Figure 5A and Figure 5B, respectively. Matlab®, "a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks" (Mathworks, 2000), will be utilized to develop the conflict analysis framework. Additionally, the open-source Traffic Intelligence will be used in feature tracking as it is based on the Open CV, which includes a useful library of feature tracking. This library includes the basic feature tracking, trajectory management and clustering, coordinate projection functionality, and motion prediction functions (Brahmbhatt, 2013). The provided open CV libraries will be utilized to extract the vehicle trajectories and plot their traces on the recorded videos, as shown in Figure 5C. Heat maps could be generated to clarify locations within the intersection with increased conflict probabilities and/or severities.

Figure 6 shows a flowchart explaining the planned methodology to detect and identify traffic conflicts. Using the video recordings for the selected sites, vehicles will be identified and tracked using feature tracking algorithms. Road users' trajectories will be determined by identifying their spatial location in Cartesian space over time. Measure of Tracking Precision, MOTP will be utilized as a tracking optimization tool to ensure optimal accuracy of tracking parameters. Correlating the developed vehicles trajectories with the roadway geometric features will be conducted using trajectory clustering. Unsupervised approaches (i.e. K-means and hidden Markov models) as well as adaptive Multi-Kernal-based estimations will be used in the trajectory clustering. Finally, propagation of projected interactions between vehicles will be used to identify traffic conflicts

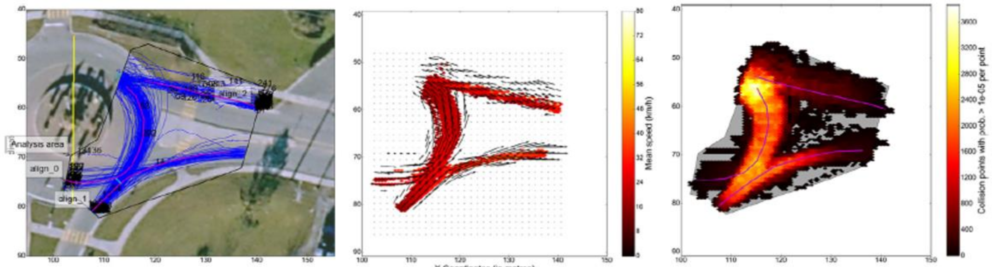
Table 1: Summary of Proposed Traffic Conflict Measures

Indicator	Definition	Description	Type
TTC	Time to Collision	The time required for two vehicles to collide if they continue at their present speeds and on the same path (Hayward, 1972).	Temporal
MTTC	Modified Time to Collision	Include the effect of acceleration in the TTC (Zheng and Sayed, 2019).	Temporal
PET	Post-encroachment time	The time difference between the moment an 'offending' vehicle passes out of the area of potential collision and the moment of arrival at the potential collision point by the 'conflicted' vehicle possessing the right-of-way (Cooper, 1984).	Temporal
TIT	Time Integrated Time-to-Collision	The level of safety, or relative probability of conflict, using the integral of the time-to-collision profile of drivers (Minderhoud and Bovy, 2001).	Temporal
TET	Time Exposed Time-to-Collision	The total time spent in safety-critical situations (Mahmud et al., 2017).	Temporal
TA	Time to Accident	The time that remains to an accident from the moment that one of the road users starts an evasive action, If they had continued with unchanged speed and directions (Svensson, 1998).	Temporal
CI	Crash Index	The influence of speed on kinetic energy involved in collisions. It also considers the elapsed time before the conflict, to interpret the severity and the likelihood of a probable conflict (Ozbay et al., 2008).	Temporal
H	Headway	Time that passes between two vehicles' reaching the same location.	Temporal
PSD	Proportion of Stopping Distance	The ratio between the remaining distance to the potential point of collision and the minimum acceptable stopping distance (Guido et al., 2011).	Spatial
PICUD	Potential Index for Collision with Urgent Deceleration	The possibility that two consecutive vehicles might collide, assuming that the leading vehicle applies its emergency brake, particularly during lane changing (Uno et al., 2003).	Spatial
MTC	Margin to Collision	The possibility of collision in a case where the preceding vehicle and the following vehicle decelerate abruptly at the same time (Mahmud et al., 2017).	Spatial
DSS	Difference of Space and Stopping Distance	The difference between the space and stopping distances (Okamura et al., 2011).	Spatial
TIDSS	Time Integrated DSS	This indicator evaluates the safety of traffic flow by the total value of the time integrated value gap between DSS and the dangerous threshold value (Okamura et al., 2011).	Spatial
DARC	Max. Deceleration Rate to Avoid a Crash	The rate at which a following vehicle must decelerate to avoid the collision with the leading vehicle (Okamura et al., 2011).	Deceleration Based
CPI	Crash Potential Index	The probability that a given vehicle DRAC exceeds its maximum available deceleration rate(MADR) during a given time interval (Mahmud et al., 2017).	Deceleration Based
CIF	Criticality Index Function	It assess the safety level involved in traffic conditions in terms of evaluating probability and severity of collision (Chan, 2006).	Deceleration Based
Jerks	Jerk	Is a composite of g-force and speed or a derivative of acceleration (Af Wåhlberg, 2000; Zaki et al., 2014).	Other
J-value	J-Value	Is an accumulative safety indicator related to the accumulation of risk of vehicles inside a platoon (Mahmud et al., 2017).	Other

(A) Feature tracking on a signalized intersection *



(B) Feature tracking on a roundabout **



(C) Motion paths and heatmap for conflict analysis **

Figure 5: A Sample of Feature Tracking Algorithms

** Source (St-Aubin et al., 2015)* *** Source (Saunier et al., 2010)*

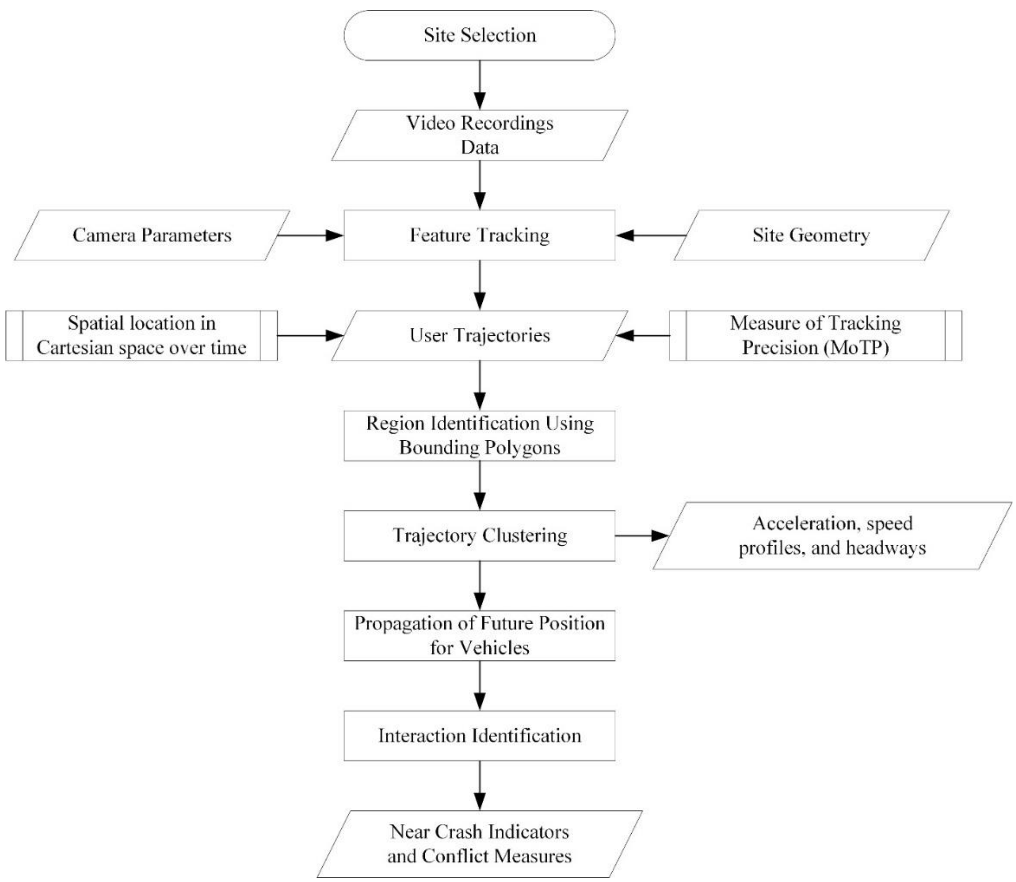


Figure 6: Flowchart for the Machine Vision and Feature Tracking Applications

6.2.4.3 System Validation and Calibration

In this task, validation of the data obtained from the automated system will be compared with the manually annotated data extracted from the video recordings. This step is crucial to check the accuracy of the automatic system, in which measures of true positive, true negative, false positive, and false negative will be utilized.

6.2.4.4 Extraction of traffic conflicts

This subtask includes two main steps: 1) estimating conflicts identifiers thresholds and 2) extraction of conflicts for the recordings. Thresholds for different identifiers (i.e. TTC, MTTC, DARC, etc.) should be initially identified. This will enable the developed algorithm to classify the recorded events into distinct conflict severities. Afterward, the identified threshold will be applied to extract the occurred traffic conflicts.

6.2.5 Task 5: Countermeasures Identification

The main goal of conducting traffic conflict analysis is to identify the appropriate roadway treatments that will enhance the operation and safety of the investigated facility. By identifying the occurred conflict types and severity, probable crashes could be estimated. By identifying probable crash types, suitable countermeasures could be identified that will help in eliminating crashes before they occur. This task is divided into four subtasks that are discussed below.

6.2.5.1 Development of Conflict Prediction Models

Conflict prediction models are essential to rapidly assess the safety and operation performance on the investigated locations. By identifying the conflict indicators, conflict prediction models could be developed. These models will be able to estimate future conflicts and the causal factors that might affect the severity and frequency of conflicts.

6.2.5.2 Development of Crash Prediction Models Using Predicted Conflicts

As a result of the previous subtask, crashes could be estimated using predicted conflicts. The crash prediction models could be useful to evaluate the effectiveness of deployed countermeasures.

6.2.5.3 Identification of Possible Countermeasures

Conflict analysis will result in identifying probable conflict cause, which can indicate certain crash types. By recognizing the probable crash types that could occur at the intersection, potential countermeasure will be identified. Figure 7 shows the different types of common traffic conflicts that could be observed on an intersection. These common traffic conflicts are indicators of certain crash types that are clarified in Table 2. In addition, Table 2 shows the probable cause of the crash and the potential countermeasures code number, which are listed in Table 3.

6.2.5.4 Assessment of the Implemented Countermeasures

A quick video recording could be conducted after implementing the suggested countermeasure to ensure its effectiveness. The video recordings will be utilized in developing an addition conflict analysis to investigate the improvement in performance and safety at the investigated site. This can be considered as a before-after analysis using traffic conflicts.

6.2.6 Task 5: Recommendations to WYDOT

This study will provide recommendations and insights to WYDOT regarding the crash causal factors that are related to the driving behavior. Surrogate measures of safety and traffic conflict analyses are the proposed innovative approaches to evaluate the performance of non-conventional intersections and emerging safety countermeasures. Advanced computer vision and machine learning techniques will be utilized to develop an effective framework for a rapid safety assessment. The outcomes from this study will provide WYDOT and researchers with an effective tool to evaluate the safety effectiveness of countermeasures in a more proactive fashion and hence long-term mitigation strategies and instantaneous interventions could be developed and deployed.

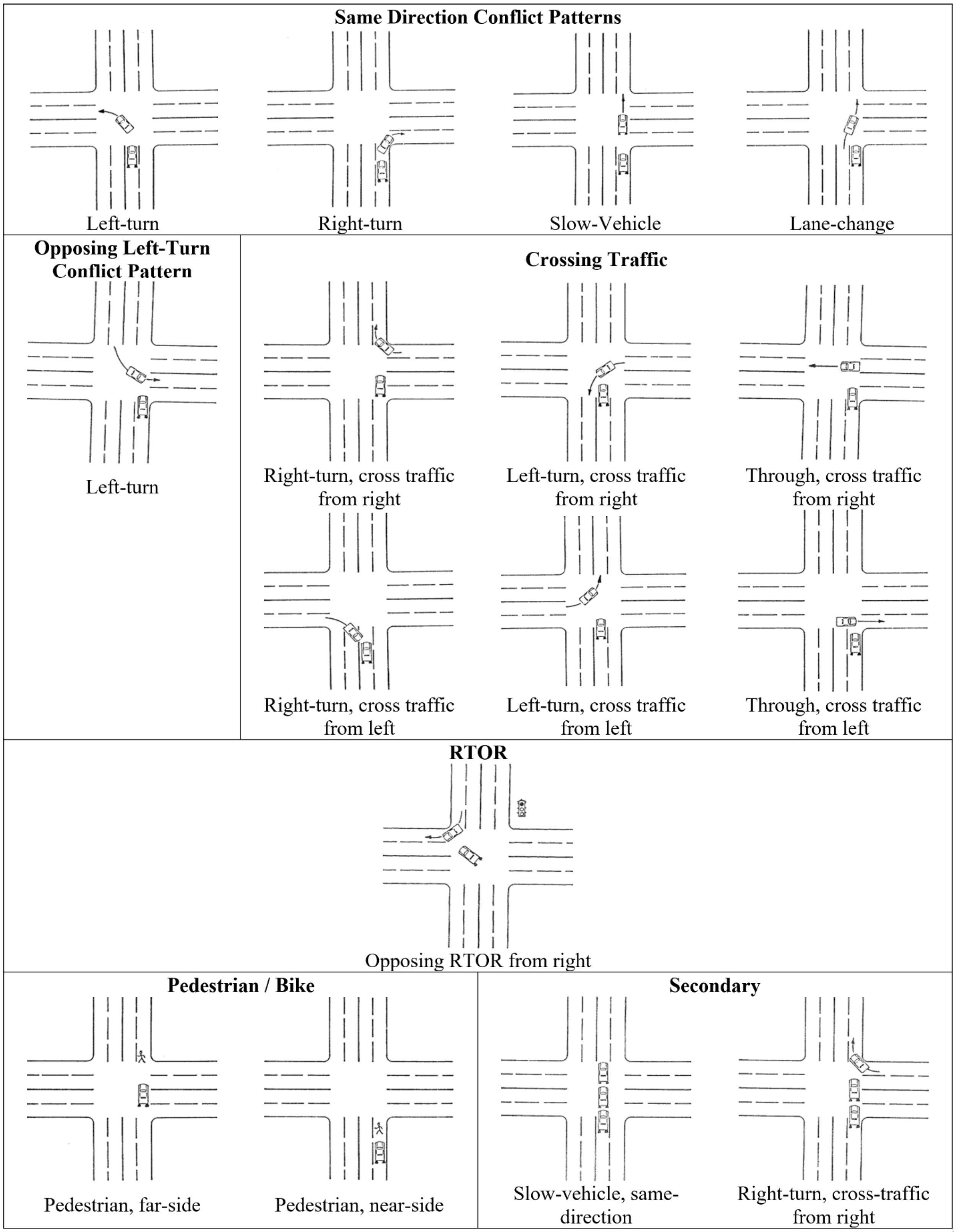


Figure 7: Different Traffic Conflict Patterns

Table 2: General Conflict and Crash Countermeasures

Conflict type	Description	Pattern	Crash type	Probable Cause	Countermeasure
Same-direction	Occurs when the first vehicle slows and/or changes direction, placing the following vehicle at crash risk.	• Left-turn • Right-turn • Slow-vehicle • Lane-change	• Rear-end • Side-swipe	Large turning volumes	3, 4, 13, 18
				Slippery surface	15, 19-22
				Poor lighting	23
				Crossing pedestrian	25, 26
				Poor visibility of TCD	12, 14, 15, 27-32
				Inadequate signal timing	16, 17, 33
				Unwarranted signal	34
Opposing left-turn	Occurs when an oncoming vehicle makes a left-turn having a vehicle going in the other direction	• Left-turn	• Head-on • Broadside collision	Large turning volumes	1-11
				Insufficient sight distance	3, 6, 12-15
				Short signal phase	16, 17
				Lack of protect phase	3
				Speeding	15
Crossing traffic	Occurs when a vehicle on the crossing street turns or crosses into the path of a second vehicle which has the right of way	• Right-turn, cross traffic from right • Left-turn, cross traffic from right • Through, cross traffic from right • Right-turn, cross traffic from left • Left-turn, cross traffic from left • Through, cross traffic from left	• Rear-end • Sideswipe • Broadside collision	Insufficient sight distance	6, 12, 14, 15, 35, 36
				Speeding	15, 16, 37
				Poor lighting	23
				Poor visibility of TCD	14, 27-32, 38
				Inadequate signal timing	11, 16, 17, 33, 39, 40
				Inadequate advance intersection warning	14
				Large total intersection volume	2, 11
RTOR	Occur when a RTOR vehicle makes a turn and crosses into the lane of a second vehicle which has the right-of-way	• Opposing RTOR from right	Same as “crossing traffic” conflict		
Pedestrian / Bike	occur when a pedestrian crosses in front of a vehicle that has the right–of–way	• Pedestrian-Vehicle, far-side • Pedestrian-Vehicle, near-side	Pedestrian-Vehicle	Insufficient sight distance	12, 25, 35, 46
				Speeding	14, 15, 45, 47
				Poor lighting	23
				Lack of adequate gaps	10, 25, 26
				Poor signal timing	11
				Inadequate TCD	26
				Lack of pedestrian protection	47, 48
				School crossing area	49
				Lack of crossing warning signs	14, 15, 47, 50
				Poor pavement marking	51-53
Secondary	In all of the conflict situations, when the second vehicle makes an evasive maneuver, it may place another road user (a third vehicle) in danger of a crash	• Slow-vehicle, same-direction • Right-turn, cross-traffic from right	Same as “same-direction” conflict		

Table 3: List of the Potential Countermeasures

#	Countermeasure	#	Countermeasure
1	Create one-way street	28	Install 12-inch signal lenses
2	Add lane	29	Install signal visors
3	Provide left turn signal phase	30	Install signal back plate
4	prohibit turn	31	Relocate signal
5	Reroute left turn traffic	32	Add signal heads
6	Provide adequate channelization	33	Provide progression for a set of intersections
7	Install stop sign	34	Remove signal
8	Revise signal phase sequence	35	Restrict parking near corner
9	Provide multiple left turn lanes	36	Provide markings to supplement signs
10	Provide traffic signal	37	Install rumble strips
11	Retime signal	38	Install illuminated street name sign
12	Remove sign obstruction	39	Install multi-dial signal controller
13	Prohibit turn lane	40	Install signal actuator
14	Increase curb radii	41	Install yield sign
15	Reduce speed limit	42	Install limit lines
16	Adjust amber phase	43	Reroute through traffic
17	Provide all-red phase	44	Upgrade TCDs
18	Increase curb radii	45	Increase enforcement
19	overlay pavement	46	Reroute pedestrian path
20	Provide adequate drainage	47	Install pedestrian barrier
21	Groove pavement	48	Install pedestrian refuge island
22	Provide "slippery when wet" Sign	49	Use crossing guard at school crossing area
23	Improve roadway lighting	50	Prohibit parking
24	Provide stop sign	51	Install thermoplastic markings
25	Install or improve pedestrian crosswalk TCDs	52	Provide signs to supplement markings
26	Provide pedestrian signal	53	Improve or install pavement markings
27	Install overhead signal		

7 Work Plan and Implementation Process

7.1 Project Kickoff Meeting

A kick-off meeting shall be scheduled to occur within the first 30 days of execution by the University of Wyoming. The preferred method for the kick-off meeting is via teleconference or video conference. At minimum, the project manager and the principal investigators will attend. The WYDOT Research Center staff must be advised of the meeting and given the option to attend. Other parties may be invited, as appropriate. The subject of the meeting will be to review and discuss the project’s tasks, schedule, milestones, deliverables, reporting requirements, and deployment plan. A summary of the kick-off meeting shall be included in the first progress report.

7.2 Deliverables

Quarterly progress report will be submitted. In addition, any major achievement, i.e., the completion of tasks will be reported to the project managers. Draft final report and a final report incorporating the project managers’ comments and corrections will be submitted at the end of the project.

7.2.1 *Progress Reports*

The University of Wyoming research team will submit quarterly progress reports to the WYDOT Research Center. The first report will cover the activity that occurred in the 60 days following the issuance of the task work order.

7.2.2 *Draft Final Report*

The Draft Final Report is due 60 days prior to the end date of the task work order. The draft final report will be submitted to the WYDOT Research Center. It should be edited for technical accuracy, grammar, clarity, organization, and format prior to submission to the WYDOT Research Center for technical approval.

7.2.3 *Final Report*

Once the draft final report has been approved, the University of Wyoming research team shall prepare the final report. The UW research team will email the final report in PDF as well as MS Word format.

7.2.4 *Project Closeout Presentations*

The findings of this study will be presented to the WYDOT Research Center at the conclusion of the project.

8 Timeline and Budget

The study will be performed in 24 months after the Notice to Proceed (NTP). The project will be led and supervised by Drs. Gaweesh, and Ahmed. One PhD graduate student will be assigned to different tasks throughout the project. As shown in Table 4, the total cost of the project is $175,115. The total cost will cover all tasks listed above and illustrated in Table 5 including the literature review, travel, as well as technology transfer. In addition, the total cost will cover the salaries of one full-time PhD student for 24 months, 6 months’ salary for one postdoc, and two month salary for one faculty member. The PIs will be submitting a proposal to MPC for additional funds for this study.

Table 4: Project Budget

2 Year Budget : 2020-2022		
Innovative Safety Assessment Methods for Non-Conventional Roadway Designs and Emerging Technologies		
CATEGORY	Budgeted Amount from WYDOT	Total
Faculty Salaries	$20,208	2-month salary for 1 Co-PI
Administrative Staff Salaries	$0	
Other Staff Salaries (Engineers/ Postdocs)	$30,000	6-month PI/Postdoc salary
Student Salaries	$45,720	1 PhD student - 2 Years
Staff Benefits	$27,321.22	
Total Salaries and Benefits	**$123,249**	
Student Support Other Than Salaries	$18,816	Tuition/No indirect
Permanent Equipment	$3,000	LiDAR & Storage Media/No indirect
Expendable Property, Supplies, and Services	$500	
Domestic Travel	$4,000	
Foreign Travel	$0	
Other Direct Costs (specify)	$0	
Total Other Direct Costs	**$26,316**	
F&A (Indirect) Costs	$25,550	20% WYDOT
TOTAL COSTS	**$175,115**	

Table 5: Tentative Schedule for the Proposed Research

Research Task	Month																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Task 1																								
Literature Review																								
Task 2																								
Data Acquisition and Processing																								
Task 3																								
Network Screening																								
Task 4																								
Conflict Analysis																								
Task 5																								
Countermeasures Identification																								
Task 6																								
Recommendations to WYDOT																								
Documents and Deliverables Schedule																								

Quarter Reports

Draft Final Report

Final Report

9 Technology Transfer

The research results will be disseminated through technical paper publications and presentations in academic venues and press releases using media outlets. The technology transfer activities in this project will benefit both the scientific community and authorities responsible for decision-making.

10 Data Management Plan

A Data Management Plan (DMP) is attached to this proposal. The plan provides a description of the nature, scope, and scale of data that will be collected during the course of the project. The plan provides information on how the data will be collected, shared, where the data will be housed, who will have access to the data, and any backup strategies that will be implemented.

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