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Determining optimum speed limit reduction in freeway work zones

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Determining optimum speed limit reduction in freeway work zones

by

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ABSTRACT

This study aims to propose a set of procedures to establish the optimum speed limit reduction to be deployed at freeway work zones across Iowa. These work zones are classified as traffic critical work zones by the Iowa Department of Transportation due to their high average annual daily traffic, potential to cause major traffic hindrances and delays in the event of an incident, and presence of state border bridges. Due to the severe impacts these work zones pose on the operating traffic, it is imperative to quantify the safety risk associated with such construction operations both from the standpoint of crash frequency, as well as total damage incurred, in other words, crash severity.

As work zones on freeways are a dynamically progressing operation, it is often difficult to extract exact information regarding the specific construction activity in place at any specific point in time. A number of transient variables which are expected to be major influencers of crash counts and crash severities are often challenging to ascertain, rendering the work zone characteristic database relatively fuzzy. The primary goal of this study was to mine the highest resolution detail about the work zones possible through the available resources and by linking it to other typical traffic safety metrics, envisage the effect of various categories of speed limit drops on the frequency and severity of crashes.

CHAPTER 1

INTRODUCTION

1.1 Background

It is widely noted that road networks are integral quantifiers of social and economic development of a region. It can be therefore implied that their construction, maintenance, improvement, and by definition, work zones are a temporary, albeit, indispensable road block that every economy looking to expand, sustain or succeed, has to cater to. As work zones are essentially provisional blocks stationed on roads, they cause anomalies in the regular flow of traffic, causing discrepancies in various operational parameters of traffic flow, like average speed, thus increasing the variance in speeds. Increased variance in speed is found out to be one of the major factors of crashes – be it single vehicle crashes, intersection crashes, or head-on and rear-end collisions. Rendering work zones less prone to accidents is therefore one of the utmost priorities to ensure a sustainable environment for construction, maintenance and extension of road works. A majority of past literature unanimously agree to the fact that the most influential factor in achieving speed compliance in the work zone is the driver's perception of heightened risk. Work zone crash study is the need of the hour as studies show an enormous increase from 7% to 119% when pre-construction crash data is compared with work-zone crash data augmented by high speed variance of moving vehicles [6].

1.2 Research Objective

To identify and arrive at the best work zone speed limit, and speed zoning practices, it is imperative that the effect of such policies be examined on highway work zone crashes. Answers need to be sought to questions like under any given work zone condition, what is the optimum speed limit reduction. Such work zone conditions can be classified based on various metrics, for example, the number of lanes dropped, type of work taking place at dropped lanes, duration of the construction activity, direction of the road work, existing speed limit of the segment, etc. The aim of this study is to enlist, identify and analyze various speed limit policies in place at interstate work zones and arrive at the optimum work zone-specific speed reduction guidelines. This is achieved by exploring the existing differences in work zone and non-work zone crashes of various severity levels between 70 mph, 65 mph, and 55 mph speed limit zones. This study also seeks to quantify this variation, if found to be existing. For instance, in figure 1 shown below, the three blue lines represent the intuitive tendency of crash count in the respective speed limit reduction scenarios, wherein the y axis signifies the total number of crashes encountered. The purpose of this study is to propose a method to find out the actual inclination of crash count numbers in the given scenarios for the given set of work zones, provided.

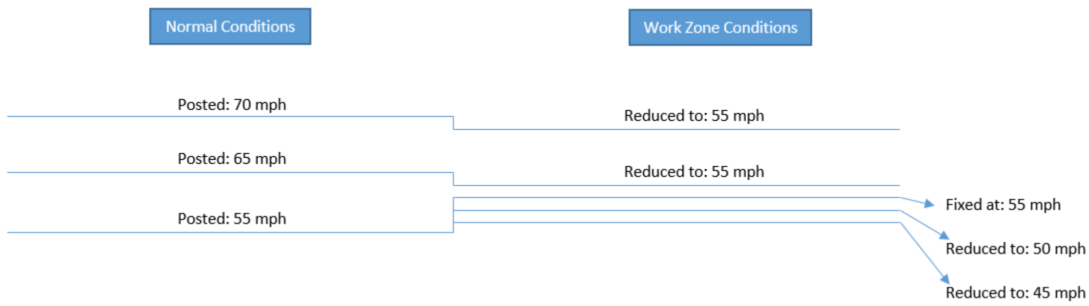


***Figure-1**: Pictorial Representation of Hypothesis Being Tested*

CHAPTER 2

LITERATURE REVIEW

2.1 Current speed control measures:

Past research studies on measures to reduce work zone incidents have examined the efficiency of ramp metering, variable speed limit signs and the combination of both. Different loading scenarios, i.e., traffic volumes were used to study the efficacy of each of the above in various congestion; conditions, also including a no congestion condition. In one approach [1], the safety effect and the efficiency effect of the countermeasures was studied separately in order to assess a non-overlapping safety result. Speed has been cited as the one of the major factors of crashes and its contribution as the major perpetrator for crashes has been observed to increase even as the total number of crashes have been reducing throughout the state [3]. A statistically significant decrease was observed in the aggressive driver behavior pattern when the speed limits were lowered more than 20 mph in the work zone areas [4].

2.2 Variable Speed Limits

2.2.1 Implementation and rules of operation:

Single-handed VSL implementation, meaning, using Variable Speed Limit Signs with no other speed controlling equipment, was seen to have brought about a two-fold change: crash risk reduction and driver lane change behavior. These changes were observed only where the traffic congestion was significantly lower than the saturation point [1]. In such conditions, a homogenous speed zone (a), i.e., the spatial range over which, the desired reduced speed limit with the least possible average speed difference, was successfully maintained; also, network travel time was reduced by almost 1%. These changes were observed to get enhanced with increase in the extent where Variable Speed Limits were implemented.

On the other hand, when VSL's were employed in combination with ramp metering, travel time was observed to have increased when a homogenous speed zone of 5 mph reduction was maintained in the work zone area. Travel time decreased only when a more than 2.5 mph speed reduction was implemented. This went on to prove that ramp metering acts as a speed-reducing reinforcement when VSL's or other methods of speed reduction were already in place. A greater reduction in speed therefore creates more variance causing the travel time to increase in the former case [2], not mentioning the increased crash risk. Employing variable speed limits also made use of dynamic factors like time of day and location to create a neural network stimulated response-specific VSL system instead of a fixed-time system. This system was employed in a simulated environment as opposed to earlier practices of on field deployment of the VSL's for study purposes [4]. Here, every point vehicle in the simulated space was capable of stimulating the speed-reduction mechanism. Various brackets of decreasing upstream and downstream speeds were tested in this system in order to find out the optimum speed for maximum driver compliance, minimum network travel time and crash risk.

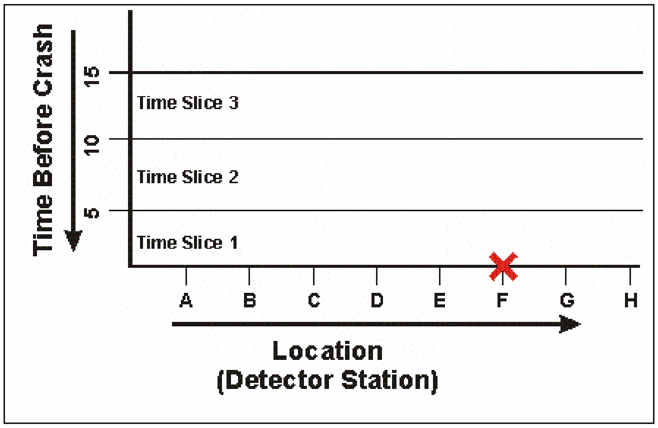


Figure-2: *Space time representation of detector position with respect to time before crash*

2.2.2 Variables affecting placement and effectiveness:

It was also observed that the distance between the freeway and the work zone area significantly affects the presence of speed limit enforcement [6], for example, only 28% of the instances where the distance was found to be greater than 10 feet deemed it necessary to enforce any kind of speed lowering operation. Similarly, speed reduction was found to be necessary in 65% of the cases where the distance was more than 2 feet but less than 10 feet, whereas 86% times when the distance was less than 2%. In such cases, driver compliance was found to be increasing even when the speed limit reduction was greater than 20 mph in staggered drops of 10 mph each over expanses of homogenous speed zones. Time intervals between speed-limit change was targeted and carried out for the 20mph block to analyze if a greater dependence of traffic response would result in a better operational result compared to the one actually deployed in the field [7]. During field deployment, staggering decrease blocks of 5 mph each worked towards a safer work zone but the effect of the same in heavily congested areas was only marginally significant. Variable speed limits resulted in a more credible compliance from the drivers as the dynamic speed limits take into account timely requirements of the traffic like road surface and weather conditions, traffic conditions and through harmonization on the part of drivers, bring down the variance in speed [6].

2.3 Speed Reduction in highway work zones

2.3.1 Factors triggering speed limit reduction in work zones:

Further, surrogate measures for calculating crashes and appending them to presence of work zones were speed, speed variance, time to collide, time of ollision and post encroachment time, which were analyzed through logistic regression analysis and real-time feedback loop data. Disparity in lane occupancy between adjacent lanes, average speed of upstream and downstream directions of the work zone stations are the major contributing factors to enhanced crash risk due to lane change in addition to lane geometry. Rear end crashes, requiring multiple neural networks were separately analyzed by carrying out the simulation 5 to 10 minutes prior to the real timestamp, which made this method extrapolable and predictive [1].

2.3.2 Speed Photo Radar Reinforcement:

Medina and Benekohal computed the effect of speed photo radar enforcement and traditional speed reduction treatments on work zones like speed feedback trailer, presence of police vehicles, etc. [6]. As established from earlier studies, all traditional speed feedback mechanisms prove ineffective in reducing speed in bottleneck conditions in the downstream direction of the work zone. Studies carried out in the interstate work zones displayed significant positive compliance by the use of speed photo radar enforcement for free flowing traffic 1.5 miles downstream of the work zone. This countermeasure to speeding reduced free flow traffic speed by a factor of approximately 4%-23.4% for light motor vehicles and 5%-48.3% for heavy motor vehicles. Speed characteristics of free flowing vehicles (headway greater than 4 seconds) was observed for finding out any reduction in speed 1.5 miles downstream of the work zone due to the impact of the presence of any speed control treatment among median and shoulder lanes, wherein it was concluded that cars display maximum compliance to speed reduction measures. It can therefore be considered implicit that any speed limit reduction most affects passenger cars. Any irregularities in traffic stream operating in free flow conditions within the presence of work zones: congestion, work zone crashes, high speed variance, etc. caused specifically by the respective category of vehicles can be altered through speed regulation methods.

2.3.3 Speed activated limit reduction measures and economic feasibility:

Effect of speed-activated speed reduction measures was calculated by Mattox, Sarasua, and et al. [7] in work zones of South Carolina highways. They found that cutting-edge speed regulating technologies are currently too nascent and consequently, expensive to be implemented on a large scale. On the other hand, it can be reasonably assumed that the older a speed rise countermeasure is, the more likely it is to be ignored by speeding vehicles, especially heavy motor vehicles. This study and its results, thus, were applicable only to short-lived work zones requiring reduction in speed on highways surrounding work zones. Targeting individual speeding vehicles through speed-activated feedbacks resulted in a significantly increased compliance ratio on the part of drivers.

The cost of manufacturing radar assemblies was calculated to be able to being brought down to match an advantageous cost-benefit ratio if mass-produced.

A quantitative assessment of the traffic impact of speed limit reduction signs through measures of effectiveness (MOE's) like change in mean speed, 85^{th} percentile speed and percentage of vehicles exceeding posted speed limits revealed that compliance increases and speed variance reduces significantly with changeable message signs (with and without radar) directed towards reducing speed on highway construction zones. At 95% confidence level, sites were speed variance was presumed to be majorly governed by speed limit reduction signage/measures were selected by selecting work zones which were uncompromising of level of service (that is, where the probability of speed reduction due to nature of work/degradation in level of service was minimal) were selected so that the isolated effect of speed reduction measures can be gauged. The conclusions which could be drawn from the observations enlisting the differences between switched on changeable message signs. Lane spillovers contributing to traffic congestion upstream of the work zone can be addressed by avoiding using two sign configuration, which, incidentally, was also seen to have been decreasing compliance with passage of time. All the three measuring criteria for speed reduction on freeways displayed enhanced operational benefits when switched for speed triggered activation during peak hours.

2.3.4 Procedure for ascertaining speed limit reduction in work zones:

A procedure for determining work zone speed limits for the purpose of temporary traffic control was studied by Migletz, Graham, et al. [9]. Restrictions imposed by work zone activities in the road geometry as well as operational traffic characteristics were taken into account in this study. For example, change in travelled way due to lane closure and/or lane reduction having impact on bottleneck speeds 1.5 miles to 2 miles from within to downstream of the work zone needs to be taken into account in order to propose speed limit reduction in construction zones. Economic feasibility of mandating speed reduction in long stretches of work zones also play a major role in deciding policies for the same. As the number of stakeholders in a road affected by a construction project increase, it becomes as much more difficult to validate speed reduction on major highways. This is a reason in addition to the ever present risk of increasing speed variance. As has been iterated through various studies before, as crashes increase with deviation from average speed, it is unadvisable to post speed signs indicating a return to normal speed limits as soon as the work zone approaches the end of its expanse. As a result, the time period an average vehicle spends traversing a mandated low speed zone increases.

This is exactly the form of calculative conundrum that traffic policy makers seek to address. A blanket reduction in speed in work zones is therefore unwarranted in states wherein the number of transportation stakeholders are high (4/51). It was observed that regulatory speed reduction signs were successful in decreasing speeds by up to twice the reduction generated by drivers basing their speeds on judgement alone in work zones. The current NCHRP work zone speed limit setting procedure bases the decision of reducing speed limits in work zones by categorizing the work zones into several functional categories like construction work zones, maintenance work zones, etc. and identifying the potential hazards associated with each of these respective categories of work zones. Prevailing speeds are accounted for but speed limit reductions are placed in accordance to the actual conditions in the work zone. Differences were detected between upstream of the work zone and within work zone expanses in speed reduction as well as speed variance. Although heavy vehicles showed more or less similar, albeit slightly increased speed variances, passenger cars posted a marked reduction in speed variances when speed limit reduction signs were posted (new temporary speed limit signs posted 16 mph speed limit reductions, as is the norm for work zone speed limit reduction in states with low grade roads, like Iowa, that is, 15 mph). Also, reduction in bottleneck conditions within and downstream of the work zone triggered by speed trends upstream and within the work zone was observed for reduced signage sites.

2.4 Importance of maintaining operational level of service with traffic safety:

Another study by Kang, Chang, et al [10] impressed upon the necessity of enhancing traffic operations in addition to diminishing crashes in highway work zones. This study focused on construction sites across United States and Europe. They developed an online algorithm for variable speed limit reduction measures. The VSL strategy they developed is based on fragmentation of the roadway segment in question and analyzing the level of service and traffic operational characteristics, like queue formation, hourly traffic volume, average rate of deceleration for heavy vehicles and passenger cars, position of variable message and/or speed limit signs (trailers), speed variance, etc. on each of the segments individually. Impact of both traffic actuated variable message signs and variable speed limit signs were considered and studied. Time varying optimal speeds were calculated at separate time stamps in a day and posted.

Although this method was experimentally sound, the economic feasibility of such a system on a large scale freeway construction/remodeling zone was not calculated. The boundaries of the subsections designed to minimize congestion within and downstream of the work zone were dynamically based on empirical representation of queue length. Flow of traffic in neighboring subsections affected the sectional boundaries and it was found that the solution to these nonlinear formulations was not sufficiently fast to be deployed on highway work zones.

Thus in adding to the tally of safety criteria in work zones apart from crash count and/or crash rate, level of service and other surrogate traffic operational characteristics also were observed to be maintained. Average delay was seen to have significantly dropped for moderate traffic volumes (3000-4000 vehicles per hour) when variable speed limit signs were pitted against no speed limit reduction conditions, as well as fixed posted speed limit reduction signs. Such decrease in delays stopped getting observed at high (>4250 vehicles per hour) and low (<2500 vehicles per hour) traffic volumes. It can therefore be concluded that decisions regarding speed limit reduction, whether variable or fixed, in highway work zone conditions should also be governed by traffic volumes and pre-existing speed limits.

2.5 Speed Monitoring Display signs: Effects and effectiveness:

Pesti and McCoy, as a part of the research done for the Midwest States Smart Work Zone Development Initiative, carried a study on the effectiveness of Speed Monitoring Display signs (SMD's) in rural interstate highway work zones [11]. These signage in conjunction with several traffic control maneuvers like speed limit reduction, strategic sign posts for advance warning of work zone areas were hypothesized to increase acquiescence to reduced sign measures. This study found out that these signs significantly increase reduced speed compliance in passenger cars more than other vehicles for an initial stretch of 3-6 miles (or two consecutive SMD signs). Further it was seen to have no statistically significant influence on compliance increment beyond the mentioned region. A spatial analysis of the measure of effectiveness of similar inventories across the Midwest region was interpreted to be generally positive.

A temporal analysis of the same across a two week time period found that the increment in compliance to mandated reduction in speed was still in place, albeit slightly moderated. The candidate sites for testing these signs were selected by keeping in mind maximum deviation from normal operating conditions. The site selected had a 2-lane lane drop with majorly commuting traffic. Due to severe lane dispersion, high variances in speed were being observed due to a tendency of slowing down of vehicles right before entering the work zone and subsequently speeding through the work zone. Percentage of vehicles complying with the speed limit, 85^{th} percentile speed, standard deviation of speed (for measuring variance) was measured to determine the effectiveness of SMD signs. The differences between the two conditions were calculated through F-tests. Possible speed reduction residuals were quantified by measuring their statistical significance against the improvements shown in lowering of speeds by passenger cars. The temporal analysis of speed reduction in work zone conditions before installing the SMD’s was found to be expressively different from the data extracted within the first and second week of SMD installation. The compliance was seen to be either deteriorating or statistically insignificant from the onset of the third week, continuing well into the fifth week before catching up again with the compliance levels shown in the first and second weeks.

2.6 Tendency of crash change within highway work zones:

A study on crash patterns displayed in highway work zones carried out by Khattak, Asad and Khattak, Aemal, et al [12] looked into the difference in contribution to injury and non-injury crashes between roadway characteristics and work zone specifications on limited access highways in California (2000). They found that the duration of work zone alone was subject to scrutiny based on stakes of safety as well as operational traffic disruption. Policies governing speed limits based on type of work and work zones were also found substantially indicative of the safety measures within California work zones. They conclusively determined the statistical increase in injury crashes and non-injury incidents on highways due to presence of work zones normalizing for all other contributing variables. The non-work zone period used for the purpose of this study was the pre-work zone period instead of attempting to find an average susceptibility to crashes by including both preceding and post work zone conditions. This might prove to be a necessary distinction as the singularity of a construction zone is ascertained by the nature of work being carried out. This is assuming that no distinction was made based on the temporal changes in the nature of the work zone during the analysis period. They found that after controlling for other pointers contributing exclusively to work zone crashes, longer work zone durations correlated with increased crash frequencies. A detailed breaking down of these crashes revealed that the number of non-injury crashes experienced a sharper increase in frequency than injury-crashes.

2.7 Importance of speed regulation at and near highway work zones:

Wang and Dixon, et al evaluated the impact of speed control and/or speed reduction strategies for highway work zones (2014) [13]. The study focused on immediate effect of various speed control methods like orange sheeting, innovative message signs, changeable message signs with and without radar technology, etc. The immediate effect methodology was warranted keeping in mind the short term duration of highway work zones as delegated by various stakeholders associated with such types of construction projects. Also a differential study was done in order to separate these impacts from long-term effects which can be extrapolated to other incidents or conditions demanding speed control procedures. The control groups for this study were non-interrupted traffic flow in highway sections adjacent to the work zones being studied. They concluded that any measures or strategy found adequate in achieving the desired traffic speed within a 95% confidence interval was more effective in daylight conditions than night time. Fluorescent orange sheeting was found to be an effective solution to high speed crashes on highway work zones with the measure of efficacy reducing over time. This novelty effect was not displayed by changeable message signs, although a trade-off was observed as this was not found as suitable in reducing speeds over a longer stretch of the highway.

2.8 Change in speed profile at highway work zone approaches:

Benekohal, Wang et al (1992) performed a speed-reduction based profiling study for vehicles traversing through different speed zones in the vicinity of highway work zones [14, 15]. The speed profiles revealed different categories of speed reduction tendencies on part of drivers inside a work zone. Passenger cars and heavy vehicles were observed to be displaying similar speed reduction patterns in this study. More than half of the followed vehicles reduced speeds post encountering the first reduced speed limit signs and a tenth of the total observed vehicles dropped speed based on their own judgment when nearing the actual construction area. Another speed reduction pattern observed for a fraction of the vehicles consisted of an increase in speed between two regulatory speed limit signs, based again on driver judgment. A considerable fraction of vehicles exceeded the reduced regulatory speed limit even within the construction zone. The speed profiles showed a Pearson Type III distribution instead of a typically expected bell shaped curve due to the inconsistency in reducing and regaining existing speed during the expanse of upstream, within and downstream expanses of the work zone area.

Fig-3*: Issues in a typical work zone (Savolainen, Apr-2016)*

2.9 Background: Requirement Analysis for Current Study:

As literature showed, speed variance and deficiencies are major cause contributors to crashes arising in most roadway environments. A preliminary study regarding the occurrence of speed deficits in work zones was therefore necessary to analyze the importance, as well as, the validity of regulated speed reduction measures in work zones to attain the goal of lower crash risk. If natural reduction in speed is observed at work zones, it is assumed to entail greater speed variance in the absence of uniform speed reduction measures. Random decrease in average vehicle speed at work zones would heighten variance in speed in such circumstances as the only factor responsible for natural selection of speed in work zones would be based on driver judgment.

For the purpose of carrying out the said requirement analysis, speed data corresponding to the work zones studies was downloaded from the INRIX website. INRIX is a software and data service company providing real time traffic and driving data in addition to processing and converting this data into other metrics such as driver delay predictions, road congestion information, special events, etc. It also keeps track of traffic forecasts and road construction activities using data sourced from anonymous mobile phones, vehicles and other bodies through embedded GPS tracking devices [Wikipedia, INRIX website]. INRIX uses a different set of road mapping identifiers than that of other sources of data collection used in this study. These unique identifiers are called “TMC segments”. All road segments are divided into TMC segments and different traffic metrics like occupancy, vehicle count, and speed can be queried for these TMC’s (and their subsets) from the INRIX website. The least count of speed data derived from the INRIX website is 5 minutes. Graphs were plotted to find the difference in speed deficiency in work zone conditions and non-work-zone conditions. The following results were obtained for a subset of work zones.

In the prototypical diagrams shown in figure 4 and figure 5, the X-axis (horizontal axis) represents the time of day, the Y-axis (depth-axis) denotes the distance of the point from the starting point of the speed analysis area, whereas the Z-axis (vertical axis) shows the difference between the measures speed and 55 mph. The data for plotting had been filtered for speed values below 55 mph to plot only the variable of interest: speed deficiency and to eliminate any attenuation contributed by regular values of speed (>55 mph). An average weekday was defined as a culmination of Tuesday, Wednesday, and Thursday within a week.

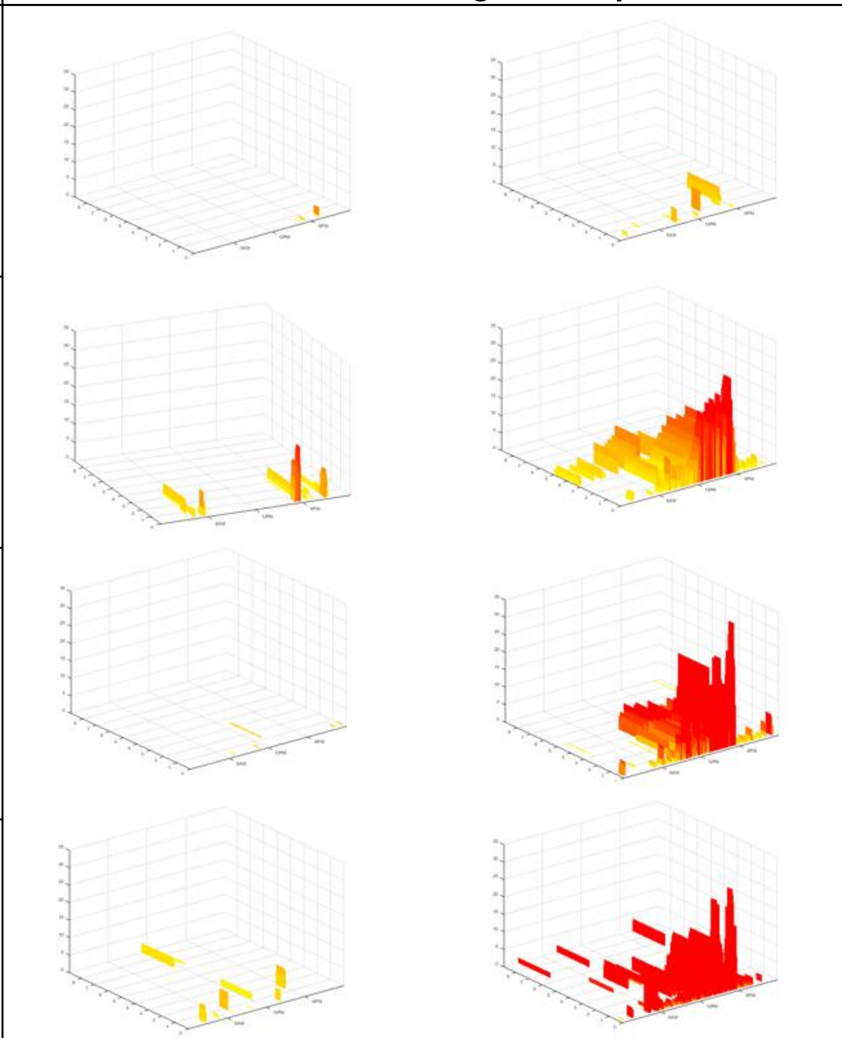
Sioux City	**An Average Monday**	
Jan-14		**May-14**
Feb-14		**Jun-14**
Mar-14		**Jul-14**
Apr-14		**Aug-14**

Fig 4: *Example of monthly variations in speed deficiency plots on an average Monday in the Sioux City area work zone during the construction season of year 2014*

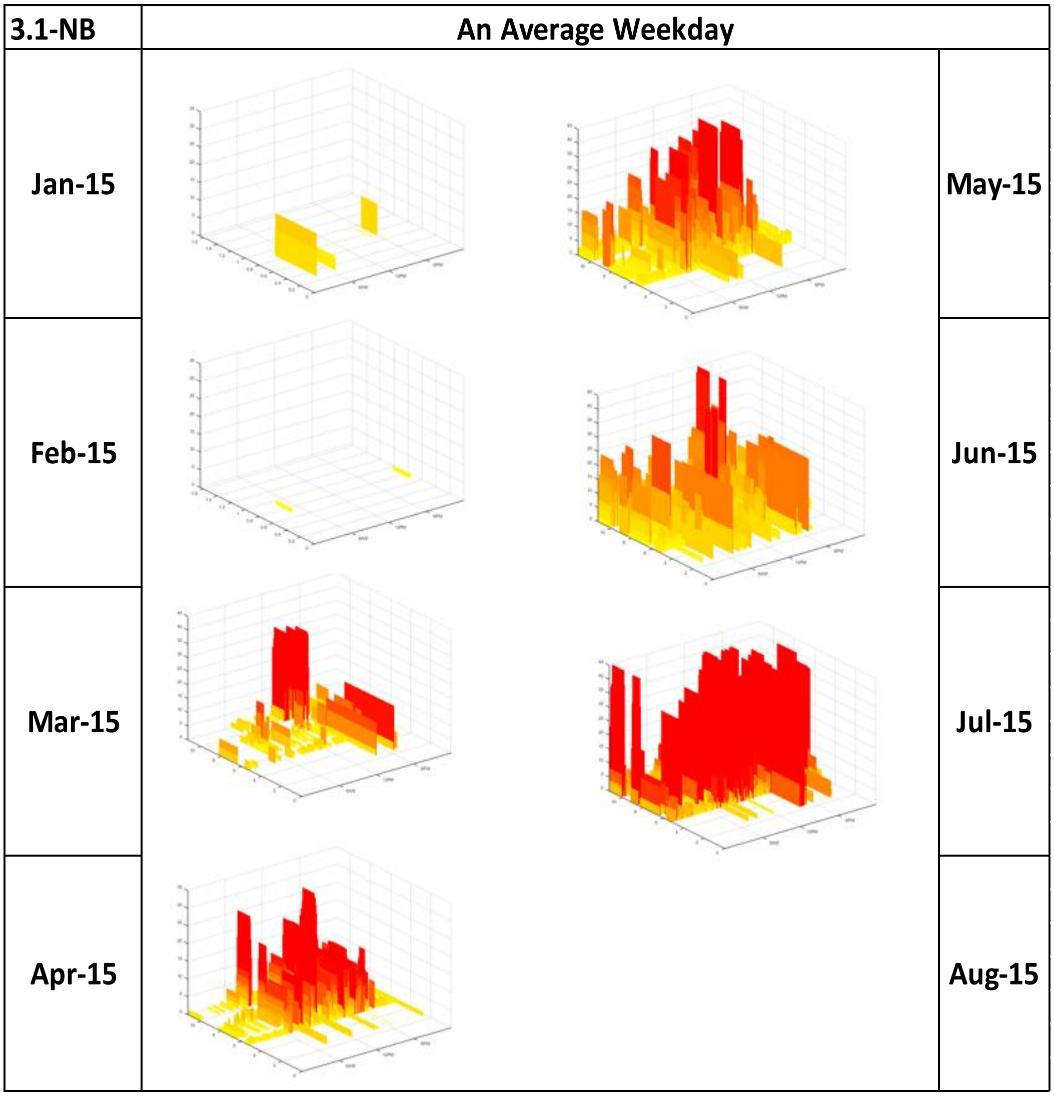


***Fig 5**: Example of monthly variations in speed deficiency plots on an average weekday in the Sioux City area work zone during the construction season of year 2014*

Figures 4 and 5 are examples that show the marked difference in speed deficiency during and without work zones in adjacent work zones in the Sioux City area. Speed reduction would thus be necessitated in these construction areas to minimize speed variance and attain a regulated average speed targeted at a lower value than that in non-work-zone conditions.

CHAPTER 3

SURVEY FINDINGS

A survey was designed for the purpose of identifying current practices regarding setting speed limit at work zones followed by states participating in the compendium of the "Safe Work Zone Deployment Initiative" project. An understanding was sought related to policies affecting work zone speed limits in interstate/highways and rural freeways. Impact and threshold of various factors like traffic density, historic crash data, speed limit research studies, locations with respect to work zones (definitions and demarcations regarding upstream and downstream areas could potentially differ by state), work zones located in school zones, holiday and seasonal speed limits, transition zone speed limits, type of work affecting construction zone speed limits, day time and night time working conditions were to be isolated. Kansas, Missouri, Nebraska responded to the survey, whereas a study was carried out to find out the analogous policies for the state of Iowa. The following questions were forwarded to the states:

1. Does your agency reduce speed limits in work zones?
2. Under what conditions are speed limits reduced in work zones?
    a. Workers are located near an open travel lane without positive protection
    b. Temporary traffic barrier or pavement edge drop off near an open travel lane
    c. Narrow lanes
    d. Lane closures
    e. Temporary crossovers
    f. Unexpected conditions (e.g., access points, traffic congestion, etc.)

3. Please provide a description of your agency's policies for where, when, and by how much speeds are reduced in specific work zone environments as compared to normal road operations.
4. If your agency's work zone speed limit policy is available online, please provide a link here.
5. What speed management technologies does your agency use to reduce speeds in work zones?
6. Does your agency utilize dynamic speed limits in work zones?
7. Has your agency conducted any research with respect to speed management in work zones?

Results were deduced from the results of the above survey. The links provided as an answer to question 4 were studied and the following database as regard to the speed limit reduction and work zone control measures was created. It was observed that dynamic speed limit systems are not currently very prevalent in these states but could be deployed in near future. Also, 55 mph was found to be the standard speed limit in work zones in the states without any extenuating circumstances.

Another similar survey carried out by Maze, Kamyab and Schrock (2000) [ref] reported the then existing work zone speed reduction measures across all states in the United States. Kansas was reported to be reducing work zone speed limits as little as necessary and aimed to develop all traffic control activities at the pre-existing speed limits, but routinely used a 10 mph reduction due to physical constraints, basing largely on the decision of the field engineer. These measures were established using a bottom-up approach deliberated by the traffic engineering team and the roadway geometry design team. Missouri also employed a bottom-up approach and made use of the Missouri DOT work zone standards “Quality Circle”. Missouri usually saw a 10 mph reduction in speed limit on highway work zones, based on roadway geometrics. In cases where a higher speed limit reduction was necessitated, staggered reductions were made use of with a minimum speed limit of 35 mph during major scale construction projects. Similarly, Nebraska followed legislature-inspired guidelines for establishing work zone speed management and control strategies. They used a top-down approach jointly established by their Traffic Engineering Division, Maintenance Division and the Director’s Office. Nebraska was reported to reduce speed limits to 55 mph on freeways and to 35 mph on state highways if the pre-existing speed limits were greater than the respectively mentioned values. These limits were subjected to increments by 5 mph based on the type of construction activity, and the judgement of the field engineer. Also, higher (X2) fines for speeding in work zones were established by Nebraska. Iowa was not reported to have any written policies regarding setting work zone speed limits. The engineering decision was to use a 55 mph speed limit for 2-4 lane roads and a 65 mph speed limit for highways exceeding 4 lanes. Figure 6 tabulates the data obtained through the DOT survey. Table 1 summarizes the construction work and traffic configuration information reduced about the work zones in study.

Treatments	Iowa	Kansas	Missouri	Nebraska
Workers located near open travel lane without positive protection	No	Yes	No	Yes
Speed Limit Reduction	Engineering Judgement	Yes	Yes	Yes
Temporary traffic barrier or pavement edge drop off near open travel lane	Yes	Yes	No	Yes
Temporary crossovers	Yes	Yes	No	Yes
Dynamic speed limit usage	No	VSL owned but not used	No	No
Speed Reduction based only on engineering judgement	Yes	10 mph or further study	Yes	Yes
Study on speed limit reduction	Yes	Yes	Yes	No
Photo Radar speed reinforcement	No	No	No	No
PCMS with radar	Yes	Yes	No	No
Speed display trailers	Yes	Yes	Yes	No
Transverse Rumble Strips	Yes	Yes	Yes	No
Sign Placement	0.5 mile-1 mile	Half Mile	No	No
Lane Reduction	Yes	Yes	Yes	Yes
Citizen band (CB) radio information systems	No	Yes	No	No

Yes	(green)
No	(red)

***Fig 6**: Summary of survey response of work zone speed control treatments applied by state DOT's*

Table 1: Traffic Configuration in Work Zones**:**

Work Zones	Traffic Configuration
Project 1.3 I80 from Des Moines to Newton	Lanes shifted to the median. Lane closures at night only
Waterloo US218 southbound	Night work lane closures only
Sioux City I29	Project specific traffic control
US30 Cedar Rapids	Two lane, Two way Operation
Project 3.1 I29 in Sioux City	Project specific traffic control
Project 1.4 I80 US65	Project specific traffic control
Project 4.1 I80/I29 Council Bluffs	Project specific traffic control
Project 2.1 I380 in Waterloo	Single lane closures with temporary barrier rail and glare screen
Project 1.2 Polk-DSM Route 235 SW Mix_31St	Night work lane closures only
Project 1.5 Polk Des Moines I-80	Night work lane closures only

Table 1 continued

Project 3.2 Woodbury-Sioux City-Bacon River Bridge-Floyd River Bridge	Project specific traffic control
Project 3.3 Woodbury-Sioux City-Wesley Way & Hamilton Blvd.	Project specific traffic control
Project 4.2 Dallas DSM Rt169-6 Bridge North I80	Single lane closures with temporary barrier rail and glare screen
Project 4.3 Pottawattamie Council Bluffs Interstate	Project specific traffic control
Project 5.1 DecaturLamoniI-35MissouriUS69	Two lane, Two way Operation
Project 6.1 Linn-Cedar Rapids Over CIC Road & City Street (NBL or SBL)	Single lane closures with temporary barrier rail and glare screen
Project 6.2 Scott-Davenport Rt74 Mississippi River Bettendorf	Single lane closures with temporary barrier rail and glare screen
Project 6.3 Scott Davenport Rt-280	Two lane, Two way Operation
Project 6.4 Linn Cedar Rapids Rt-30 Hwy (Edgewood Stoney Point Road)	Two lane, Two way Operation

The work zones selected as a part of this study where work zones classified as traffic critical intelligent work zones ascertained by the Iowa DOT based on the following criteria:

1. Traffic Critical Network – Expressways over 17000 vehicles per day.
2. Projects that can repeatedly or quickly lead to significant travel delays.

3. Projects where an incident could have severe traffic impacts as predicted by construction contractors affiliated to the Iowa Department of Transportation.

4. Projects located at state border bridges: Sioux City, Council Bluffs, Davenport and Lamoni.

CHAPTER 4

DATA DESCRIPTION

4.1 Crash Data Reduction

Geometric road information data from the Geographic Information Management System maintained by the Iowa DOT was used to join the respective information to the crash data for the work zones. The crash data was selected by creating these 16 different geographical subsets of the entire crash database maintained by the Iowa DOT. These were locations for the active work zones in the year 2015. This was done in order to establish a comparative study about the changes in crashes and crash characteristics based on a spatial variable between when the work zone was present and when absent. This distinction in crash characteristics and frequency is implicit to being contributed by changing traffic condition, work zone and other roadway dimensions and characteristics. The temporal variables selected to do an active work zone versus a non-active work zone crash study were periods of time during which no work zones were present in the past ten years. An example for classifying these periods of time in the years 2006 to 2014 is shown in figure 7. For the year 2015, a more detailed analysis was carried out to recognize periods of lane closures, shoulder closures and/or other identifiers of active work zone conditions. These steps are proposed assuming that there exists an inherent relationship between the construction dates obtained from the field contractors and those identified by the road closure message signs corresponding to roadwork category. As we can see, this was not always found to be true. The figure 7 shows an example of how the two construction periods were not found to be consistent. Such inconsistencies in construction periods were found at a lot of sites. These anomalies might affect the results of the crash count and crash severity model. Utmost care should thus be taken to ensure the data quality, and subsequently the classification of crashes as being work zone related or otherwise are dependable with the field data. Thus, through the Active Traffic Monitoring System data, lane closure information was used to find intersecting periods of time with the construction dates and verifying the crash tags which mentioned any crash as being work zone related. The procedure to attain and use the same are described in the latter sections. Due to the inconsistencies present across the multiple databases mentioned it is recommended that additional efforts be taken to replicate the results of this study with a better quality dataset. The geometric characteristics were found to be consistent within the two stated periods, which is, in the year 2015, and the years preceding 2015.

Figure 7 details the space time distribution of crashes in the work zone 1.5 at Polk-Des Moines on I-80 in the north-south direction. The time periods where work zone related crashes were classified so in the crash data base obtained from the DOT were omitted from the non-active work zone crash counts. For instance, in this case, four week durations associated with the following time periods were omitted:

1.) September, 2006

2.) December, 2009

3.) April, 2010

4.) September, 2011 to November, 2011

5.) January, 2012

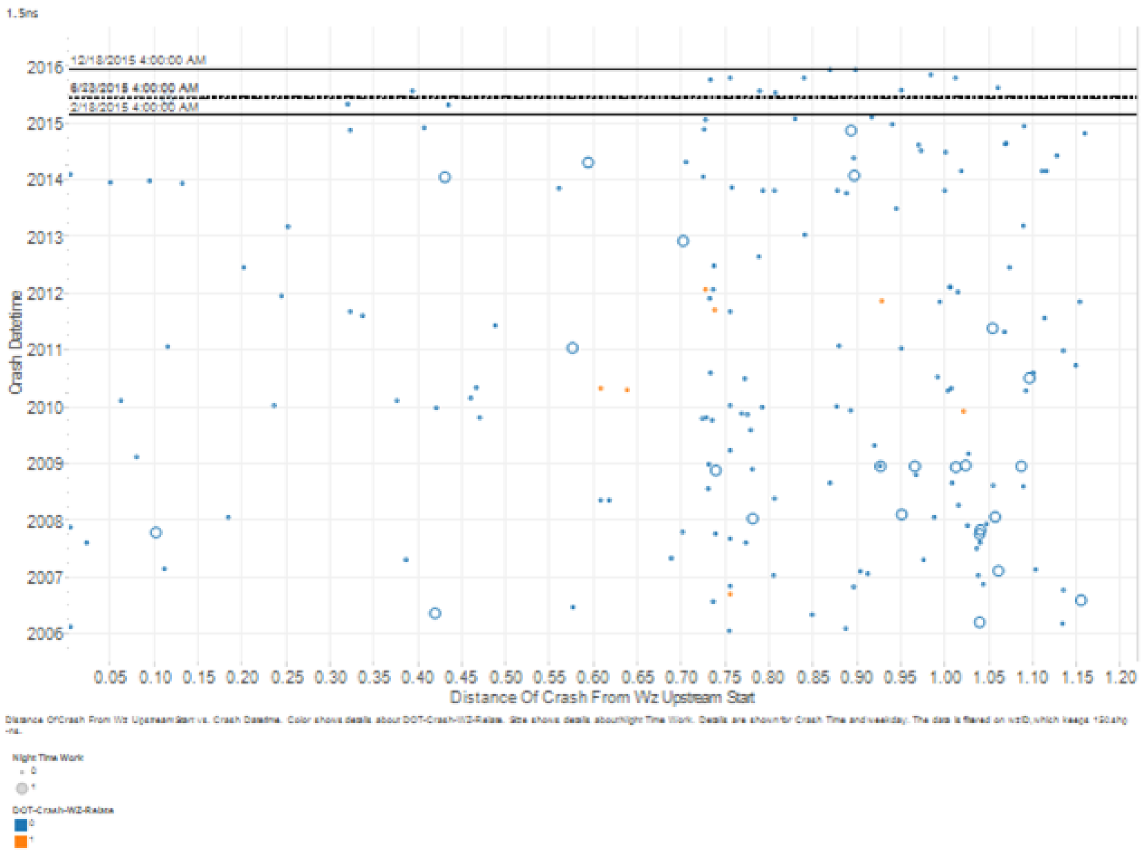


Fig 7: *Space time distribution of day time, night time, work zone and non-work zone crashes from year 2006 to2015*

Similarly, a non-work zone period was devised in order to track the crashes occurring in the said period.

In order to put together a database consisting of normalized records for crashes, the duration of the work zone activity was derived from the Iowa-DOT bid records, and was tested against the dates of the activity from the field deployment of the work zones. Only the intersection of the durations obtained from the ATMS log and the DOT records were treated as construction durations, and by extension, the crashes occurred in the respective period were classified as construction period crashes.

4.2 Average Annual Daily Traffic:

AADT was available for the year 2014 for all the chosen locations. To enable us to study and compare the factors affecting crashes in work zone conditions versus non work zone conditions, traffic volumes changing through the entire study period is needed. Presence of work zone on a segment of the road affects the traffic conditions both upstream and downstream (for the purpose of this study, east/north and west/south) of the work zone. For instance, it can influence speed limit compliance, thus necessitating different policies for speed limit reduction in these locations, regulate queue build ups, increase rear-end collision risk, etc. AADT is thus required for all the crash data throughout the years of analysis. The GIMS database at Iowa DOT had AADT data for the years 2009 to 2014. The AADT for all segments of interest for these six years were isolated and extrapolated backwards to predict the corresponding AADT's for the preceding years as shown in the sample data below. It should also be noted that the AADT recorded in the crash count data table and that in the crash severity database are different. This is because the crash count data base takes into account the average of the AADT of all roadway segments comprised in the work zone. These segments are represented in the GIMS database by a unique ID, that is, MSLINK. On the other hand, the crash severity data table reports the exact AADT of each specific MSLINK where the crash took place.

The normal probability plots for the regression equations used to extrapolate annual average daily traffic backwards and forward are given as parts of figure 8. These plots provide a measure of the reliability of the normal regression method used to obtain the extrapolation equations for predicting the AADT's for the years 2006-2009 and the year 2015:

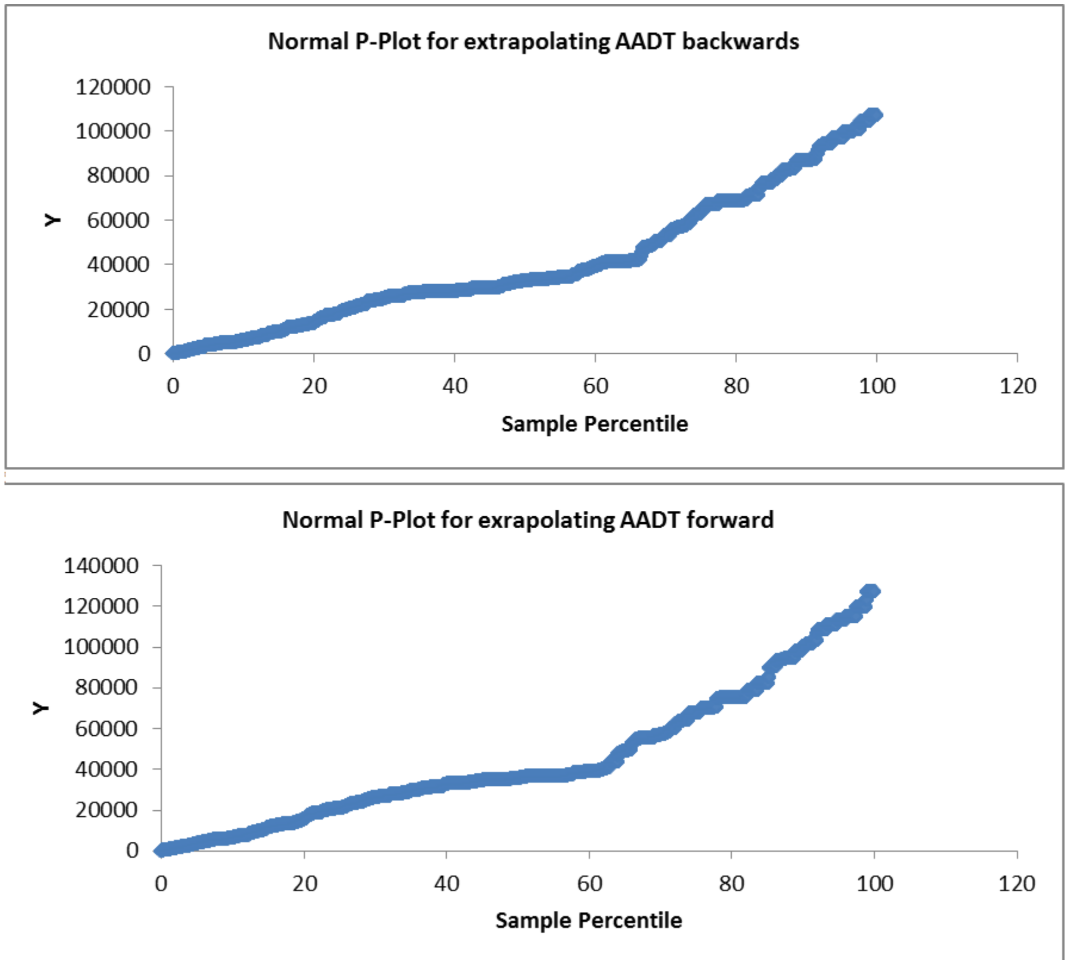


***Fig 8**: Normal probability plot for AADT calculation*

Backward Extrapolation for AADT_2008:
587.5-0.045*(AADT_2014)-0.0037*(AADT_2013)+0.0585*(AADT_2012)+0.8204*(AADT_2011)+0.1223*(AADT_2010)+0.133*(AADT_2009)

Forward Extrapolation for AADT_2015:
-
762.926+0.0139*(AADT_2014)+0.01245*(AADT_2013)+0.0298*(AADT_2012)+1.121*(AADT_2011)-0.0146*(AADT_2010)-0.0662*(AADT_2009)

4.3 Typical traffic control plans employed in the work zones:

The following graphics summarize the work zone type and traffic controls employed by each of the analyzed work zones. These traffic control plans are standard geometric regulations recommended by the Iowa Department of Transportation for work zone activities warranting specific changes made to the roadway passages.

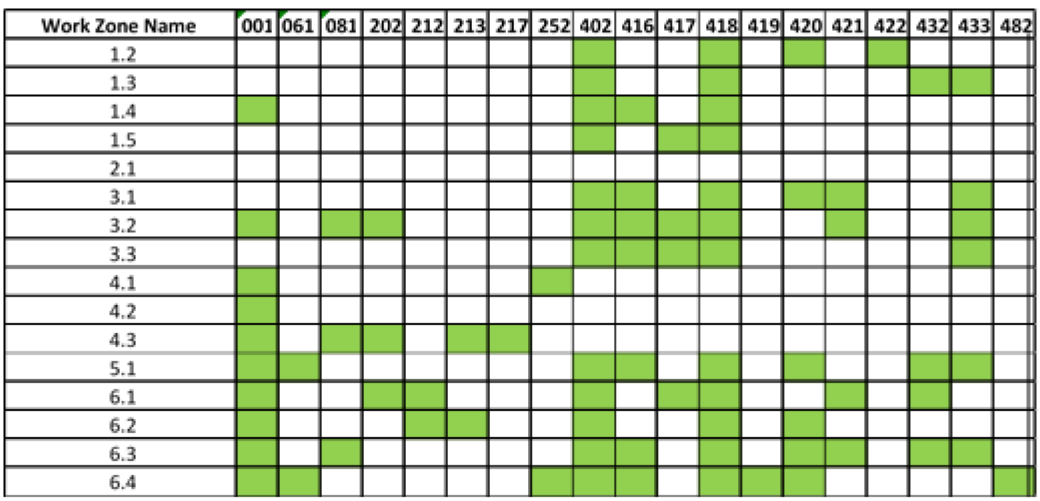


Fig 9*: Frequency Distribution of traffic control plans used for work zones in study*

4.4 List of Traffic Control Plans

A list of all traffic control plans mentioned in figure 9 has been included in the appendix B.

4.5 Location Overview

A brief description of the work zone locations for the year 2015 are given in table 2 along with the duration of the work zone, speed limit reduction values, length of the work zone in miles, starting date, ending date and type of work undertaken at each of these work zones.

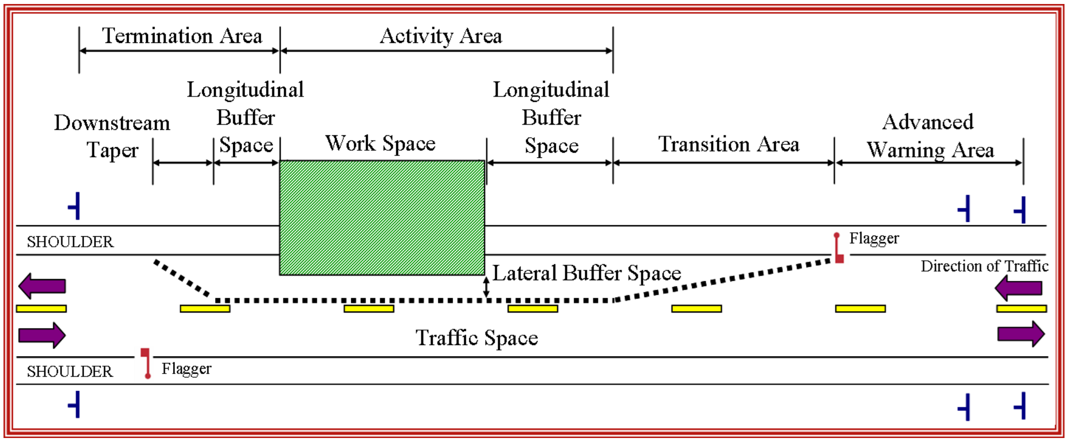


***Fig 10**: Typical work zone layout (Savolainen, Apr-2016)*

It should be noted that the durations for the spilt over work zones are mentioned for the year 2015 only and have therefore been treated as a singular work zone entity. This led to a smaller database of work zone related crashes but doing so addressed the bias towards non construction period crashes at other locations. Figure 11 shows the work zone locations marked on the state map of Iowa. Also, the lengths of such work zones have changed between the two years, a concern which is addressed by merging the work zone length for the two years into one for every road segment where the construction activity took place in both the years.

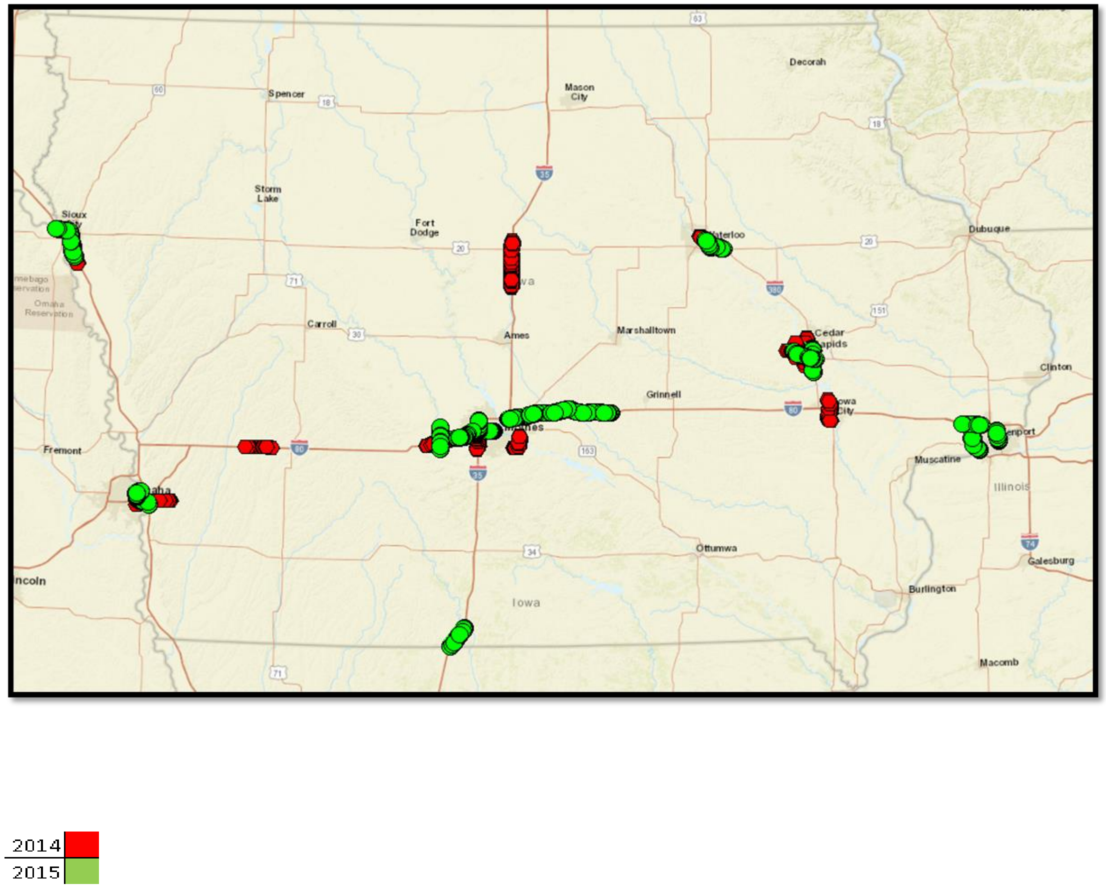


Fig 11: *Work zones studied in year 2015*

Table 2: Description of work zones studied

2015	Start Date	End Date	Duration (month)	Length (mi)	Number of Lanes	Original Speed Limit(mph)	Work Zone Speed Limit Reduction (mph)	Type of Work
Project 1.2 Polk-DSM Rt 235 SW Mix_31St	7/20/2015	9/8/2015	1.67	1.76	3	55	5	HMA resurfacing and patching
Project 1.3 I80 from Des Moines to Newton	4/7/2014	7/26/2015	16	24.72	3	70	15	New paved shoulder construction
Project 1.4 I80 US65	3/1/2015	11/30/2015	9	3.54	3	65	10	Interstate reconstruction in urban area. High traffic volume with congested work areas
Project 1.5 Polk DesMoines I-80	10/5/2015	10/20/2015	0.5	1.88	2	55	10	Pavement Marking placement
Project 2.1 I380 in Waterloo	5/1/2015	11/27/2015	7	0.67	2	65	10	Bridge deck overlay
Project 3.1 I29 in Sioux City	3/1/2015	11/30/2015	9	5.33	3	70	15	Interstate reconstruction in urban area. High traffic volume with congested work areas
Project 3.2 WoodburySiouxCity BaconRiverBridge FloydRiverBridge	3/11/2015	11/1/2015	8	1.06	2	55	10	Interstate reconstruction in urban area. High traffic volume with congested work areas
Project 3.3 WoodburySiouxCity WesleyWay & HamiltonBlvd	4/15/2015	11/1/2015	6.5	1.78	2	55	10	Interstate reconstruction in urban area. High traffic volume with congested work areas
Project 4.1 I80/I29 Council Bluffs	3/1/2015	11/30/2015	9	5.7	3	55	0	Interstate reconstruction in urban area. High traffic volume with congested work areas
Project 4.2 DallasDSMRt169-6BridgeNorthI80	3/16/2015	11/20/2015	8.33	0.6	2	55	0	Bridge deck overlay
Project 4.3 PottawattamieCouncilBluffsInterstate	4/6/2015	5/6/2015	1	0.7	2	55	0	Interstate reconstruction in urban area. High traffic volume with congested work areas
Project 5.1 DecaturLamonI-35MissouriUS69	6/22/2015	10/20/2015	4	4.9	1	55	0	Interstate reconstruction on opposite side of median
Project 6.1 LinnCedarRapidsOverCICRoad&CityStreet(NBL orSBL)	7/20/2015	9/18/2015	2	1.14	3	55	0	Bridge deck overlay
Project 6.2 ScottDavenportRt74MississippiRiverBettendorf	4/13/2015	11/1/2015	6.33	1.34	2	55	0	Bridge deck overlay
Project 6.3 ScottDavenportRt280	3/30/2015	9/2/2015	5.2	9.61	2	55	0	Interstate reconstruction on opposite side of median
Project 6.4 LinnCedarRapidsRt30Hwy(Edgewood_StoneyPtRd)	6/23/2014	9/26/2014	3.2	2.77	2	55	0	Multilane highway reconstruction on opposite side of median. Are these the same project?

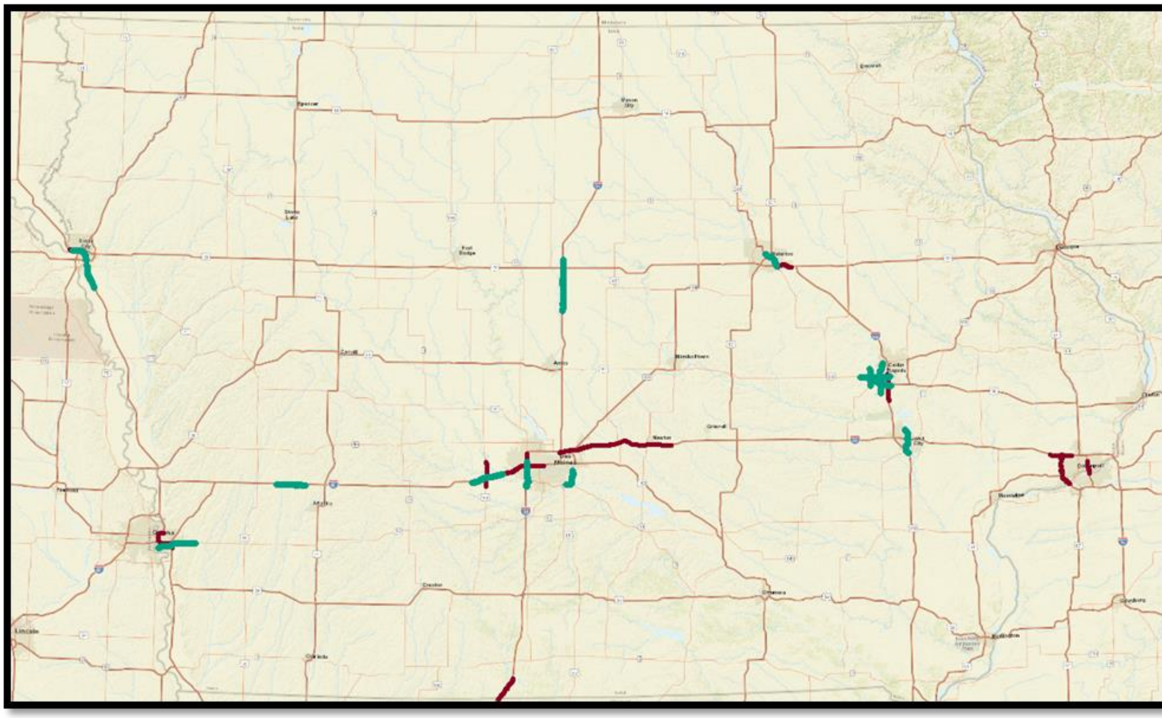


***Fig 12**: Overlapping road segments between work zones in 2014 and 2015*

A certain number of road segments were found to be overlapping for the two years in these locations. There were some segments within and upstream of the work zone which in spite of being included within the same work zone, corresponded uniquely to only one of the work areas among the two years. A typical example of this is shown in Figure 13.

Fig 13*: Accounting for overlapping work zone segments between years 2014 and 2015*

In such cases, the crash keys obtained from the joint database of work zone specific crashes for each of the two years were compared exclusively for the overlapping segments and all repetitive values were eliminated to avoid double counting of such crashes.

The crash data corresponding to both the years were therefore coded as active work zone data for these locations. The severity levels of these crashes derived from the crash database was stored as an important dependent variable to be used for the crash severity analysis study.

4.5.1 Data reduction procedures

A GIS module was used to retain the identity of all the work zones while joining the geometric characteristics to the crash data. This module prevented the loss of identity for the crashes catalogued to their respective work zones while in the process of database merging. The module structure is shown in figure 14.

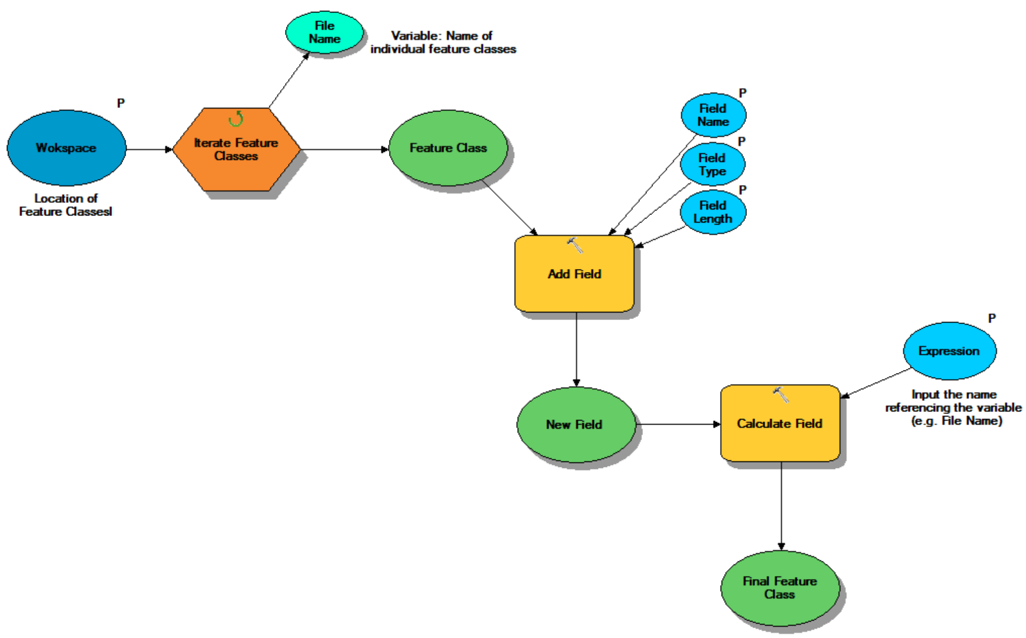


Fig 14: *GIS Module for preserving work zone identity and merging spilt-over and overlapping work zones characteristics*

Other important variables in this crash database were alcohol-test, weather information (which was validated against the weather data obtained from the 511 archive), sight distance, drug test, driver characteristics, pavement condition at the time of crash, crash date, number of vehicles involved in crash, presence of heavy vehicles, distance of crash from the mainline road segment (a factor introduced due to the join operation between crash data and roadway geometry data from the Geographical Information Management System, used to filter for crashes occurring very close to the mainline work zone road segment), etc.

A variable very crucial in establishing the crash count was the “INITDIR” field. The north, east, south and west bound directions were represented as different numbers from 1 to 4 respectively, while the crashes not falling into any of these categories, as well as those the traveling direction of which were unknown, were classified into a different numeral class. The analogous variables in the 511 data log and the ATMS archive were the “Direction” field, wherein the north and east bound directions for the messages pertaining to several traffic control procedures were coded as positive direction, south and west bound directions were coded as negative direction and the operations involving both the directions were coded as “rest” manually. The segregation of crashes based on direction is important for a variety of reasons. The joining of crash data to the ATMS data archive was carried out based on the three categories of direction as mentioned in the next section due to the varied nature, duration and time period of work being undertaken in the two directions of the roadway. These traffic control operations may affect crashes in different nature and magnitude, depending upon the difference in traffic volume, roadway geometry and other heuristic factors like the presence of distracting roadway components, access controls, etc. It is therefore important to categorize work zones in different directions as separate entities, as well as their corresponding work zone crashes.

Roadway geometry was then appended to the crash data by leveraging multiple files sourced from the GIMS database maintained by the Iowa DOT, last updated in the year 2014. These files were “TRAFFIC 2014”, “ROAD INFO 2014” and “DIRECT LANE 2014”, contributing major independent variables to the crash data like AADT, Shoulder Width, Median Width, Median Type, Shoulder Type, Segment Length, Presence of Truck Route, Surface Characteristics, etc. respectively. Information from these datasets were joined using the embedded roadway segment unique identifier "MSLINK" common to all the three datasets. Directional geometry data, stipulated for the directional crash analysis requirement, was retained from the "DIRECT LANE 2014" database, which was treated as the base map for overlaying the crash data. A spatial join was subsequently carried out to join the remaining data to this layer.

4.5.2 Exploring work zone characteristics

The following discussion details the inferences drawn out of a preliminary exploratory analysis of the exposure variables for the work zones included in the analysis.

1. It can be observed from the following graph, figure 15 that the *average annual crashes* in 2015 work zone locations increased by 24.4% as compared to when the work zones were not in place.

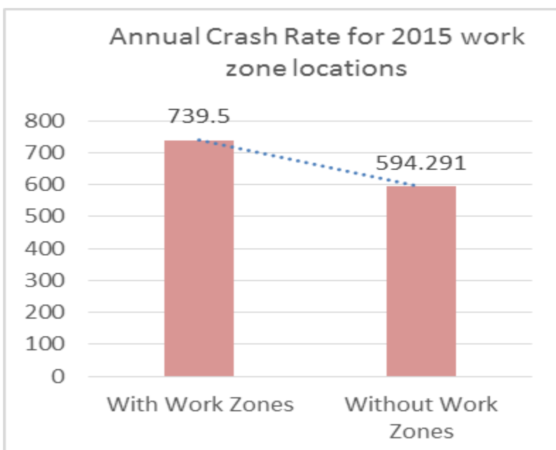


Fig 15: *Annual crash frequency in construction conditions for active work zones in 2015*

Breaking this information down further by resolving work zone name and position with respect to work zone into the data, we obtain the information in figure 16:

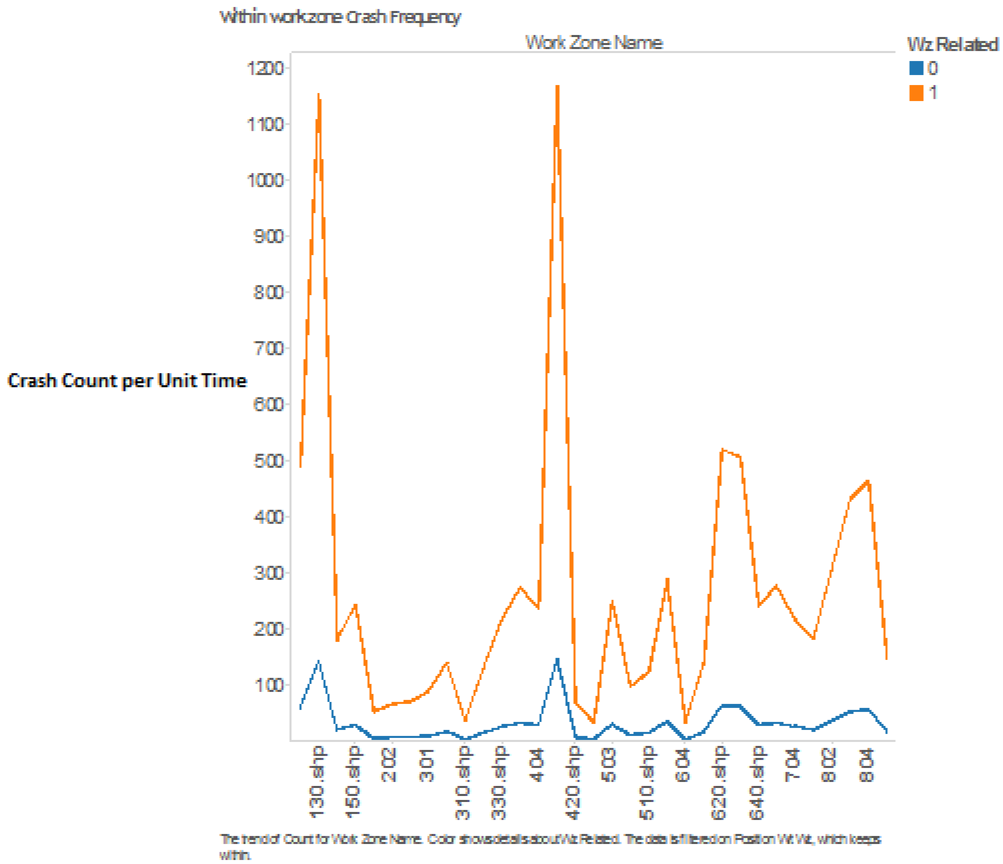


Fig 16: *Comparison of Crash Count per Day within Active & Absent Work Zone Conditions*

It was observed that the average annual crash frequency increased considerably in work zone conditions when compared to annual crashes occurring in no work zone conditions. Some of these increments were slightly less pronounced as in the case of Project 4.2 situated at Route 169-6 on I-80 near Dallas, East Des Moines, and Project 3.3 in Northern Sioux City. Nevertheless, marked increase in crashes were observed in this dataset inclusive of work zone related crashes coded so by the Iowa DOT crash database. Within work zones, these increments were even more pronounced, firmly establishing ground for crash study directed solely at work zone conditions.

2. Work zone length distribution:

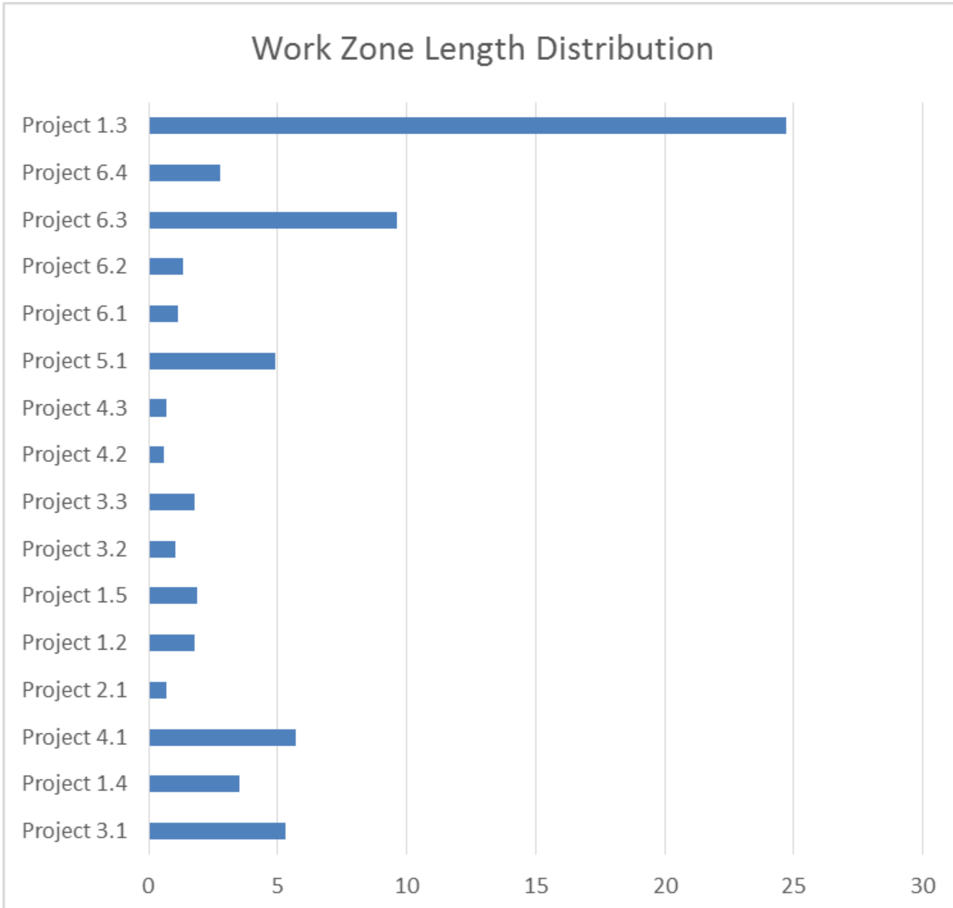


Fig 17: *Frequency of Active Work Zone Lengths*

The above graph details the frequency of work zone lengths in the analysis dataset. It can be interpreted that most of the work zones have lengths in the interval of 0.5-3.5 miles, while the work zone "Project 1.3" on I-80 from Des Moines to Newton is longer than the rest of them, having a total length of 24.72 miles. The average work zone length was calculated to be 4.21 miles, with a standard deviation of 5.99 miles.

3. Duration of work zones (in days):

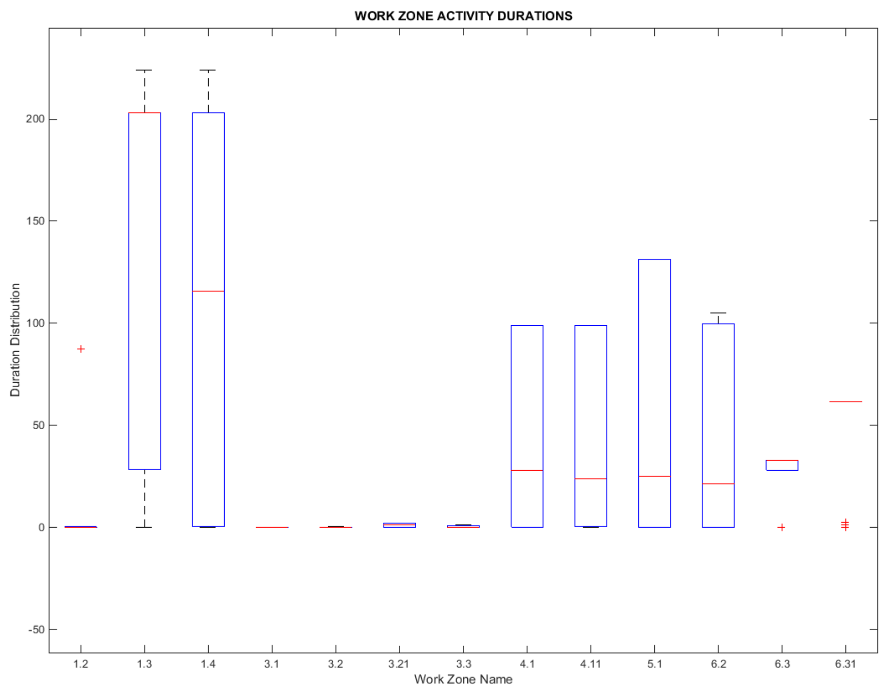


Fig 18: *Frequency of Active Work Zone Construction Periods*

Figure 18 separates the three 2-year long work zones mentioned previously into separate work zones in order to accurately calculate the number of days each of all the work zones were active. The number of days each construction zone could be classified as an active work zone was obtained from the ATMS data log maintained by the Iowa DOT for work zone operations. The continuous number of days each work zone was subjected to one or more specific type of traffic restriction was determined using Gantt charts shown in the next chapter and locating every individual crash within these chunks of durations. The above figure shows the distribution of duration of continual bouts of each specific category of lane closure corresponding to each work zone.

4. Speed Limit Reduction:

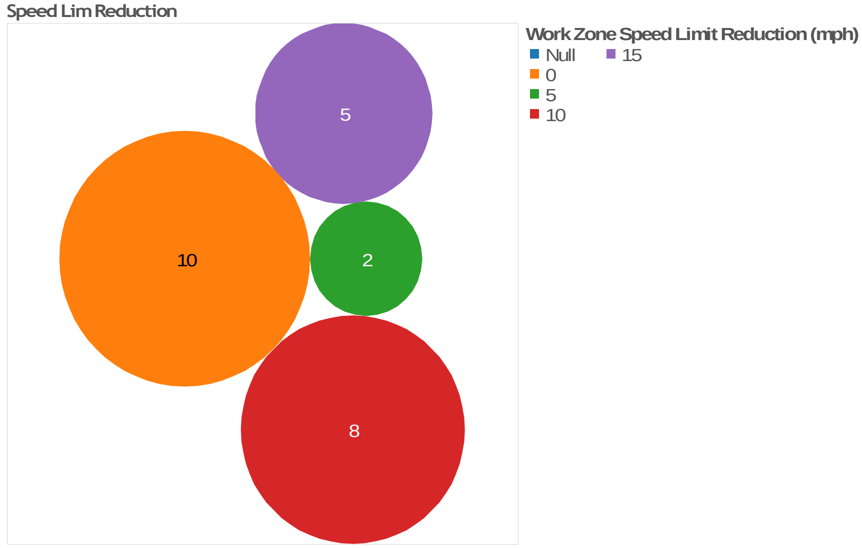


Fig 19: *Distribution of work zone speed limit reductions*

Speed limit reduction was observed to be in three brackets of 5, 10, 15 mph wherever employed. Sample size distribution for all the four cases are shown in the figure 19. Most work zones reduced speed limits by 10 mph if at all. This is in accordance with the results of the survey as well as maximum compliance insurance values recovered from the literature review of past studies.

5. Distribution of crashes with respect to work zone location:

The following diagram compares data sourced from the Iowa DOT crash database with the crashes located through spatial analysis done using ArcGIS by defining upstream (south and west bound directions), downstream (north and east bound directions) and within the work zone. The unclassified category represents crashes for which no location information was found in the database.

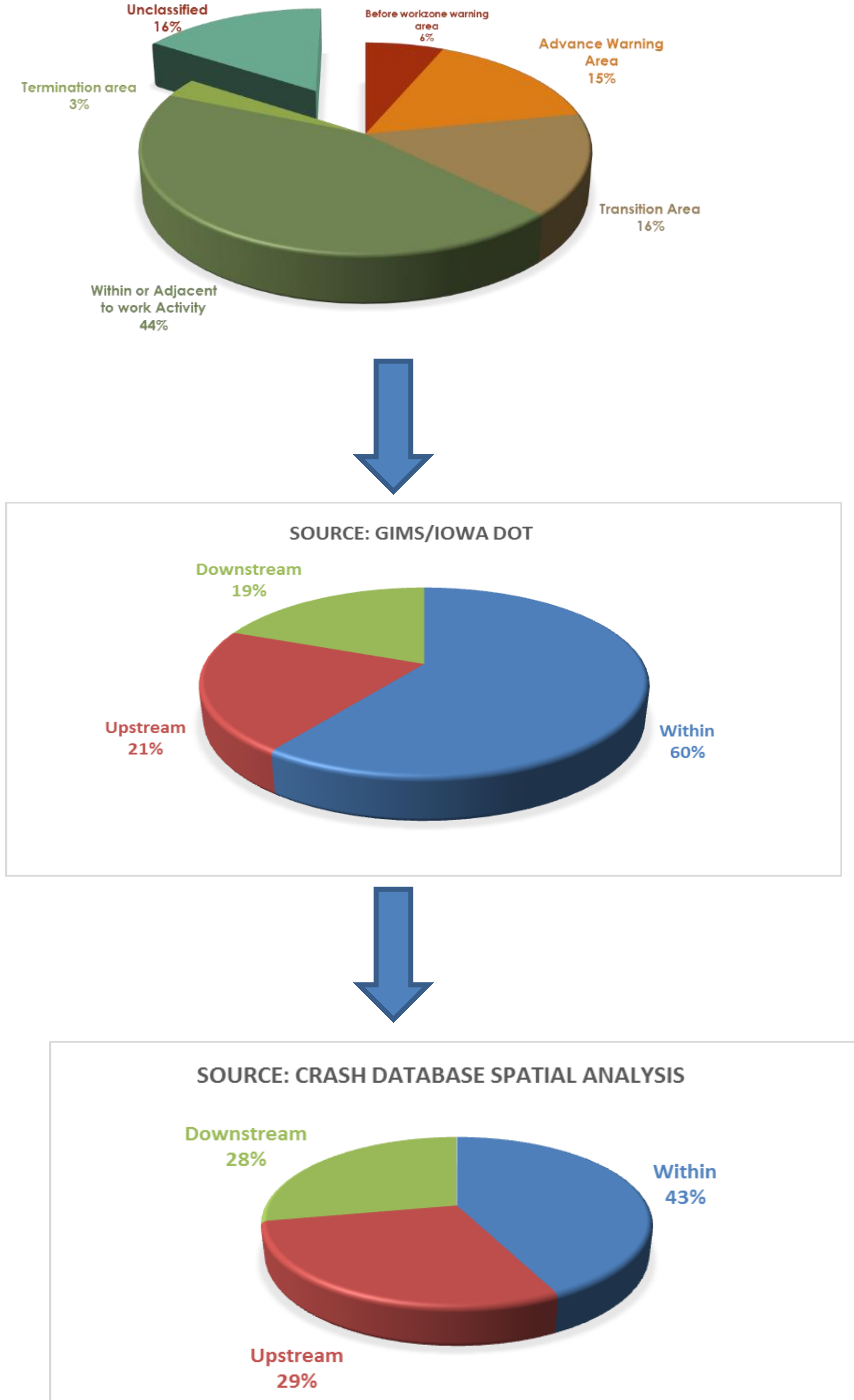


Fig 20: Comparison of databases defining spatial location of crashes

Spatially locating the crashes and classifying them into the three mentioned categories revealed a different picture about the ratio of crashes falling within the three positions with respect to the work zones. A reasonably equitable distribution of crashes was observed between the three locations with the highest number of crashes occurring within the work zone. A data set including work zone related crashes occurring before the analysis construction period of the year 2015 was used for exploring this trend. For the purpose of this study, crashes occurring only within the work zone boundaries were analyzed across the given 10 years. The upstream and downstream crash data was used solely to identify the presence and/or absence of work zones in the said locations and the duration of each such construction activity.

Other summary statistics gathered for the crash-roadway-geometry database are attached in table 3:

Table 3 Descriptive Statistics of Crash Count

Variable	Mean	Std.Dev.	Minimum	Maximum
Reduced Number of Lanes	3.05	1.91	2	5
Crash Count	9.24	12.77	1	94
Crash Frequency Rate	5.29	19.47	0.211951	200
Work Zone Relation (from Crash Database)	0.08	0.27	0	1
Number of Traffic Control Operations (ATMC)	0.69	1.47	0	9
Work Zone Relation (Deduced)	0.27	0.45	0	1
Work Zone Length	6.32	8.72	0.6	28.26
Interstate	0.96	0.19	0	1
Rumble Strips Present	0.96	0.19	0	1
No speed limit reduction	0.88	0.33	0	1
Speed Limit Reduction=5 mph	0.02	0.14	0	1
Speed Limit Reduction=10 mph	0.05	0.21	0	1

Table 3 continued

Speed Limit Reduction=15 mph	0.05	0.23	0	15
Speed Limit	54.77	11.55	45	70
Work Duration	226.93	140.66	0.003168	365
Unidirectional Work	0.80	0.40	0.037718	1
Right Shoulder Closed	0.14	0.35	0.070834	1
Middle Lane Closed	0.17	0.37	0	1
Left Shoulder Closed	0.09	0.28	0	1
Two Middle Lanes Closed	0.05	0.21	0	1
Surface Width	31.44	9.97	24	41.28
Concrete Surface	0.64	0.50	0	1
Composite (Combination) Surface	0.36	0.49	0	1
No shoulder Present	0.07	0.35	0	1
Earth/Grass Shoulder Present	0.04	0.30	0	1
Paved Shoulder Present	0.90	0.46	0	1
Right Shoulder Width	8.11	3.77	0	22
Left Shoulder Width	4.65	3.39	0	12
Rumble Strips	0.90	0.50	0	1
Poor Surface Condition	0.31	0.40	0	1
Fair Surface Condition	0.32	0.49	0	1
Good Surface Condition	0.36	0.49	0	1
Slab Thickness (In Inches)	7.51	3.58	0	15
Slope	-0.41	1.07	-6	4.2
Crack Patch (in Inches)	0.15	0.39	0	1.7
International Roughness Index	90.33	72.76	0	475
No Barrier Median	0.10	0.39	0	1
Hard Surface No Barrier Median	0.07	0.32	0	1
Grass Surface No Barrier Median	0.46	0.48	0	1
Grass Surface Barrier Median	0.17	0.36	0	1
Barrier Median	0.2	0.38	0	1
Median Width	59.87	110.73	0	418
Average Annual Daily Traffic	41046.01	31838.03	5081.444	266745

Fig 21*: Work zone 5.1 in October 2015, very wide median; Source: Google Maps*

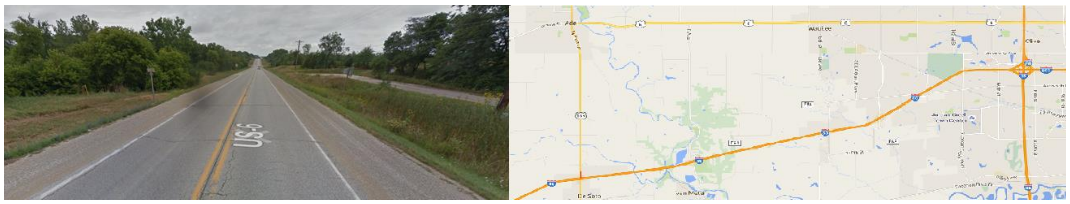


Fig 22*: Work zone segment for 4.3, No Median, No Rumble Strips; Source: Google Maps*

4.5.3 Calculating Crash Frequency

Crash frequency needed to be calculated so as to obtain a count data set of crashes for each work zone location. This parameter was calculated in two different ways for each section of the dataset. A conditional count operation was carried out based on the four given criteria for all the crashes dating between 2006 and 2015:

a. Work zone presence

b. Type of lane closure

c. Duration of each specific category of lane closure

d. Work zone name (and location with respect to work zone)

e. Crash Direction

f. Crash year

Indicator variables were created for the following cases to answer two primary questions of interest associated with work zone speed limit reduction: Are 55 mph speed limit road segments as safe as 55 mph speed limit work zones? Additionally, in the existing database, we observe that all road sections where the originally posted speed limit was greater than 55 mph, the work zone speed limit, if reduced, was lowered to 55 mph, irrespective of the original speed limit. On the other hand, for a few construction sections where the original speed limits were already 55 mph, the work zone speed limits were reduced by 5 mph to 10 mph. In such a scenario, another metric that can possibly be examined in this study would be the safety significance, effectiveness and impact on crash frequency of higher speed limit road segments being reduced to 55 mph.

Important Indicator Variables:

a) Speed Limit: 55 mph; No work zone conditions (Base case with respect to which all the other speed limit conditions would be inspected)

b) Speed Limit: 65 mph; No work zone conditions

c) Speed Limit: 70 mph; No work zone conditions

d) Original Speed Limit: 55 mph; Work zone conditions; Work Zone Speed Limit: 55 mph; No speed limit reduction.

e) Original Speed Limit: 55 mph; Work zone conditions; Work Zone Speed Limit: 50 mph; 5 mph speed limit reduction.

f) Original Speed Limit: 55 mph; Work zone conditions; Work Zone Speed Limit: 45 mph; 10 mph speed limit reduction.

g) Original Speed Limit: 65 mph; Work zone conditions; Work Zone Speed Limit: 55 mph; 10 mph speed limit reduction.

h) Original Speed Limit: 70 mph; Work zone conditions; Work Zone Speed Limit: 55 mph; 15 mph speed limit reduction.

4.5.4 Data Reduction using ATMS log:

ATMS message archives mentioned earlier in the section provided a roster of one minute interval information regarding traffic control plans throughout the state. This database consists of information regarding the starting date and time of various traffic control plans corresponding to a number of highway operational characteristics. In addition, it also enlists the type of traffic control in place within each lane which underwent lane closure or blockage during any time during the construction period. Work zone road plans and evidence for traffic control measures collected from this archive is thus ascertained to be complete for the crash analysis year 2015.

The information contained in this catalogue was also tested for validity against the actual work zone deployment dates and times from the field. This analysis showed that the ATMS archive consisted of traffic control plan data for more than 95% of the crash instances included as a part of the work zone crash analysis. It was also observed that this archive contained temporally higher resolution data for each traffic control procedure. Due to this reason, this database was used as the primary constant for defining work zone presence. This was sourced from real time field message data by the Iowa DOT. Information related to unusual driving circumstances, road obstructions, incident response messages, intimation about road work and work type, delay pertaining to alternate driving routes, headway, parking occupancy, special events, winter driving restrictions, highway line closure, advisory (changed) speed limits, sporting events, advance warning systems, etc. in conjunction to weather related information like precipitation, wind, driver visibility, temperature air quality, snow depth, etc. are sourced from the 511 archive database. Expiry date and time of each of these corresponding traffic control plans are also related through this system.

Data associated with each of the twelve months was concatenated to obtain a database for the entire year. Message signs corresponding to each of the work zone locations in the study were isolated using a spatial query in ARCGIS. This limited the database to a list of traffic control operations for highway road works only. Next, the route names and numbers for each of the work zones under analysis were filtered for. Validations were made for point locations on the road where the work zones on each of these routes were observed to start from. A lookup query was generated to match each crash date and time in the crash database with the respective traffic control operation in place in the ATMS archive. The duration of each lane blockage instance were observed. It was found that it varied from 0 to 247.34 days. Some of these lane closures lasted for less than a day. It was therefore necessary to archive the respective durations in order to standardize and analyze the effect of each of these lane closure combinations. Following this, the data separated into three separate classes according to the direction of the work zone activity each of these messages were based on. The importance of this separation has been established in the previous section. For joining this data to each of the corresponding direction from the crash database, initially, the direction obtained from the crash data was used. But this would entail appending only the work zone activity messages affecting unidirectional work in the ATMS log archive. To account for cases where the work was simultaneously occurring in both the directions, the “rest” category of messages (which included both bi-directional, as well as, non-directional construction activity) was used to join the crash data to.

It should be noted that a major limitation of using this archive was the inability to extract information related to the consolidated periods of continual lane closure. In a lot of instances, lane closures were observed to be occurring only for a few minutes as shown in figure 43. To enable maintaining data quality checks, it is therefore imperative that daily logs of activities be looked into to verify the authenticity of the ATMS logs. These anomalies interfere with the accuracy of the lane closure severity priority rankings, the duration of lane closures associated with each work zone related crash, and also, the very classification of a crash as being work zone related or otherwise.

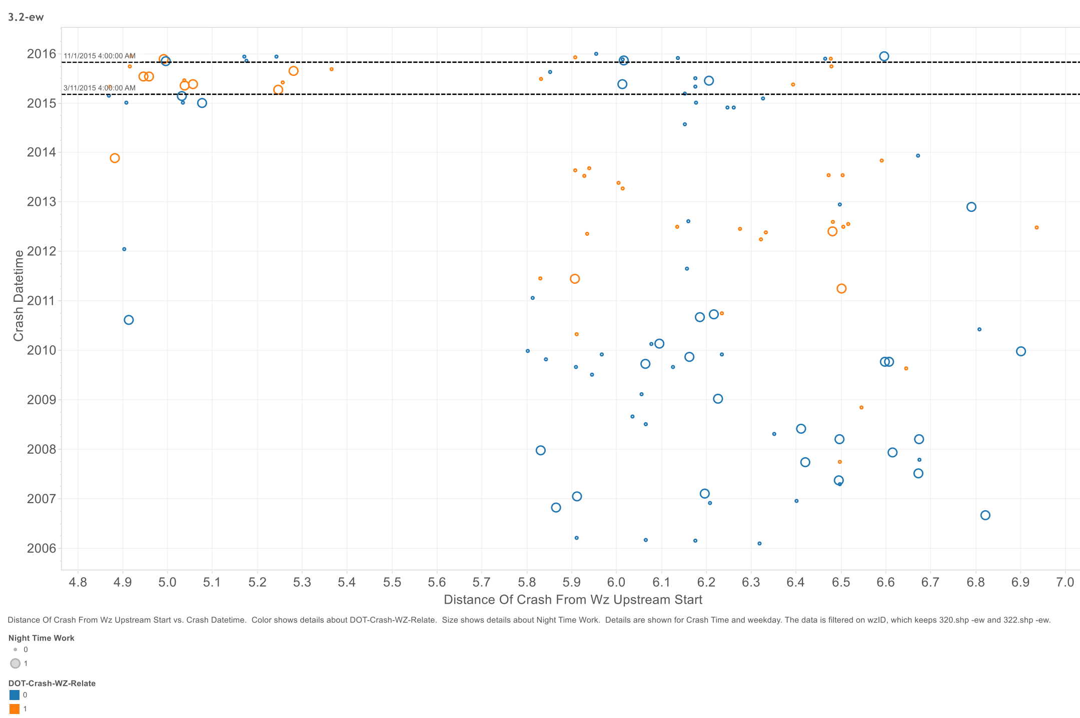


Fig 23*: Sioux City: Space time representation of day time, night time, work zone and non-work zone crashes*

Further, assuming authenticity of the durations obtained from the ATMS logs, and to the purpose of proposing a work zone crash classification methodology, for obtaining the base cases for number of crashes in unit duration of days, time periods where crashes coded as being work zone related in the DOT-sourced database were eliminated. In doing this, a corresponding number for time duration for non-work zone period crashes was also arrived at, which is less in number than the intuitionally assumed 365 days for non-construction periods and years. A typical example of this is shown in figure 42, denoting the work zone 3.1 in Sioux City, Iowa. It is a space time representation of the crash placement occurring from 2006 to 2015, the x-axis representing the distance of the crash from beginning of the work zone. The dotted line represents the construction period obtained from the contractors, the orange dots signifying crashes coded as being work zone related.

The larger circles in figure 23 represent night time crashes. It can be observed that the construction period (year 2015) saw multiple work zone related crashes bound between the dotted lines in the graph. It is also noteworthy that some work zone related crashes occurred in the years 2007 to 2013. Crash timestamps of these occurrences were looked into and time periods preceding a month before the earliest work zone related crash and extending a month later than the last work zone related crash were eliminated from the database, creating a count (or if divided by the respective duration in days begot from this method) data for base case crashes (non-construction related crashes).

For identifying the specific work zone operation during each crash in the data base, a ranking criterion was created based on the severity of each of the lane closure instances found in the database. This severity ranking is given in table 4:

Table 4: Lane Blockage Severity Priority List

Blocked Lanes	Priority Ranking
|RS|LS|ML|ML|	1
|LS|ML|ML| and/or |RS|ML|ML|	2
|RS|LS|ML|	3
|RS|ML| and/or |LS|ML|	4
|LS|ML|RL|	5
|ML|	6
|LS|LS| and/or |RS|LS|	7
|RS| and/or |LS|	8
BLANK (Not Reported)	9

Thus, if any lane closure operation higher up in the priority table is in place at the time of crash even for a smaller duration, the crash will be corresponded to the said lane closure type if in case there are more than one type of lane closure operation at the time and day of the crash. The duration, intuitively, corresponding to the most severe lane closure type is mentioned for each crash record. Also, for identifying the work zone period, only the overlap periods between the active ATMS feed data duration and the total construction period sourced from the DOT bid files were considered. A typical example for this is shown in figure 24. In this case, the middle lane has been closed for a major portion of the expected construction period from March to November, 2015 that is from the beginning of the year 2015 to mid-November, 2015. But any crash occurring on a date where other more severe lane closures were in place, for example, on May 8, 2015, would entail two middle lane closures instead of one, albeit for a shorter period of time (3 days) and the same would reflect in the crash identification table.

In table 5, frequencies only pertaining to the above mentioned time duration intersection and actual crash occurrences have been registered. It should be noted that the actual number of occurrences of the four listed lane closure types was higher than the ones mentioned which would include cases where the intersections between ATMS logs and contractor-sourced construction periods exist but no crashes were found to be occurring. These occurrences of lane closure have been accounted for in the procedure mentioned for calculating time durations associated with zero crash counts are mentioned in Appendix B of the text.

As the total number of unique traffic control operations found correlating to the timestamps in the crash database was only 13 as shown in the severity ranking table, relating the duration to the message itself would have led to a marked reduction in the resolution of the data contained in the "Duration" field, disallowing the analyst from making sound distinction between the impact of different values of traffic plan durations deployed at a stretch at various points of time within the work zone. This distinction is also necessary to account for possible lapse in the influence of these traffic control devices as the drivers get used to their placement on field. This could potentially lead to different values for the coefficients, statistical significance and confidence values for the different traffic control plans in place.

The realistic number of repetitions required on part of each driver to get acquainted with each of these traffic control operations in time and space, therefore, is unlikely to be met. Therefore, a unique combination of direction, type of traffic control operation devised, presence of work zone and year of crash was used as the criteria for counting crashes in order to arrive at the crash frequency table. Also, data pertaining to the field "NUMLANES" found in the crash database were modified accordingly to match the messages related from the ATMS log archive.

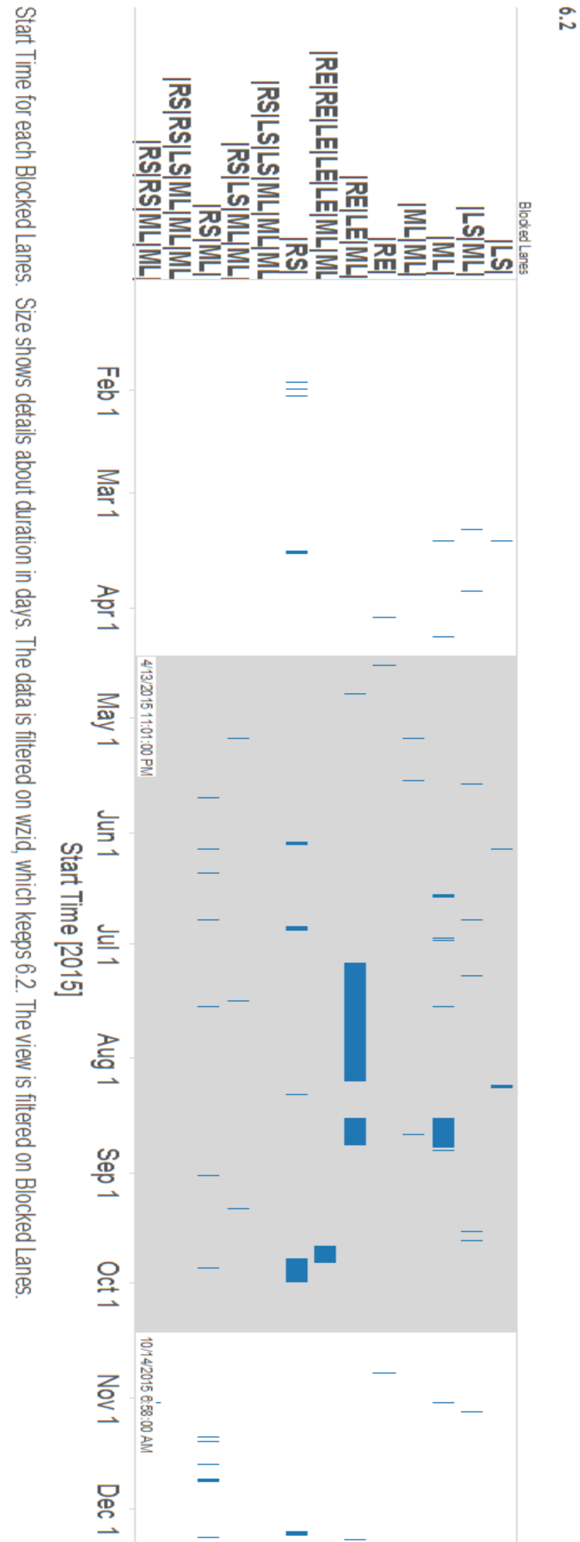


***Fig 24**: Gantt chart for ATMS log representation for different categories of lane closure in Lamoni work zone*

For intersecting time periods of blue bars and gray areas where no crash (work zone related) was observed to be taking place, the crash count should be recorded as being zero. In order to associate a time duration (in days) to these zero count data points, the sum of all such intersecting time periods corresponding to each of lane closure type for every individual work zone needs to be calculated. It should also be kept in mind that these time periods corresponding to zero crash counts should only be a sum of all the instances where each specific lane closure would feature as being the most severe lane closure. To this end, an algorithm was developed to extract the sum of the duration of the most severe lane closure wherein no crash occurred within the construction period duration boundaries for every individual work zone. The code for obtaining this extract is mentioned in the appendix B.

The traffic control operation corresponding to the starting timestamp closest to the crash date was chosen and assigned to each crash using the SUMPRODUCT function in Excel.

A distribution detailing the frequency of each type of lane closures encountered during work zone crashes is mentioned in table 5. It is necessary to observe this frequency distribution so as to ensure and address any existing skew towards a specific discourse of traffic control operation in place during the analysis period. In the following table work zones 1.5 and 4.3 show no closures as no intersections of time duration were found between crash occurrences, contractor construction dates and ATMS-activated lane closure logs. Therefore, the rows associated with these two work zones would only feature zero counts in the crash frequency database, wherein each row would represent the sum of all durations when the corresponding lane closure was found to be the most severe lane closure in place.

Table 5: Lane Closure Distribution Reduced from ATMS Log Database

Work Zones	**Right Shoulder**	**Middle Lane**	**Left Shoulder**	**Two Middle Lanes**
Project 1.2 Polk-DSM Rt. 235 SW Mix_31St	6	7	6	2
Project 1.3 I80 from Des Moines to Newton	18	18	8	4
Project 2.1 I380 in Waterloo	0	1	1	0
Project 3.1 I29 in Sioux City	4	5	5	2
Project 3.2 Woodbury-Sioux City-Bacon River Bridge-Floyd River Bridge	6	3	4	2
Project 4.1 I80/I29 Council Bluffs	42	43	20	14
Project 5.1 Decatur LamoniI-35 Missouri US69	1	2	2	1
Project 6.2 Scott Davenport Rt74 Mississippi River Bettendorf	4	10	3	2
Project 6.3 ScottDavenportRt280	0	4	1	0
Project 4.3 Pottawattamie Council Bluffs Interstate	0	0	0	0
Project 1.5 Polk Des Moines I-80	0	0	0	0

Location of the respective roadwork operations can also be found in this database. These traffic control plans consist of but are not restricted to shoulder restriction and closure information, partial or complete ramp blocking information, lane reductions, rest area closures, etc. A dummy variable was introduced to signify each of the 13 different types of lane closures/blockages associated with each of the crashes for the purpose of creating the statistical analysis model. Duration (the natural log of) was used to offset the crash counts as an extremely important independent variable which would account for the relatively smaller number of crashes occurring at the intersection of the gray area in the chart above (DOT validated construction dates) and the blue areas (lane closure information found in the ATMS log dataset).

4.6 Crash Injury Severity

An important aspect of any crash study is determining the overall impact of crash on the partaking and contributing individual(s), as well as quantifying the assimilated damage suffered. Studying injury severity gives a quantifiable metric to arrive at such desired conclusion. Analyzing the extent of impact of various factors leading up to severally classified crash categories helps to create a higher resolution picture of the degree up to which each influential factor affects crashes as a function of exclusive crash circumstance. To this end, a non-aggregated data set needs to be used which details the crash characteristic of every individual crash, the most important of them being the availability of the informant variable "Crash Severity", which is treated as the dependent variable of interest. Crash Severity is an ordinally classified categorical variable which ranks crashes according to their perceived severity outcomes from 0, denoting fatal crashes to 5, representing property damage only crashes (no injury crashes). Other intermediate severity levels in similar order are disabling injury crashes, evident injury crashes and possible injury crashes.

An alternate method of calibrating the severity of crashes would be to make use of the Equivalent Property Damage Only method, or the "Kentucky Formula". This is, essentially, a weighted average of the total crashes counted multiplied by an empirical factor corresponding to their professed equivalent property damage cost incurred. This is a possible solution to convert the categorical variables of crash severity to a continuous variable with fixed threshold values. However, keeping in mind the extensive discrete outcome models available and widely practiced for modelling crash injury severity data, it was decided to stick with the former form of ordered discontinuous crash injury severity database. Commonly used methods for addressing such discrete category outcome data are Multinomial Logit Model, Ordered Logistic Regression Model, Ordered Probability Model, Nested Logit Model, Random Parameters Logit Model, Dual State Multinomial Logit Model, et al. A more extensive discussion of the grounds on which the Ordered Logistic Regression Model was chosen for this study can be found in the next chapter.

Crashes from 2006 to 2015 for which this information was available in the database were the only observational data points which were considered for this section of the study. Other specific crash features existing in the crash severity database are tabulated in the descriptive statistics table. A comparative overview of the distribution of the crash severity in the database is also outlined. As the primary resolve of this study is to arrive at the most appropriate speed limit reduction measure and detailing other roadway geometric criteria governing the suitability of the proposed speed limit reduction figure, it was sought to zero in at the work zone conditions regulating the adjusted crash aftermath rather than focusing on the driver behavior and other entailing driver attributes. This distinction plays a major role in selecting the appropriate statistical model to estimate crash severity later in the study.

Table 6: Descriptive Statistics for Crash Severity Data Table

Variable	Mean	Std.Dev.	Minimum	Maximum
Duration in Days	283.918	86.47375	0.01	365
Precipitation	0.000164	0.002281	0	0.1
Right Shoulder Blocked	1	0	1	1
Middle Lane Blocked	1	0	1	1
Left Shoulder Blocked	1	0	1	1
Two Middle Lanes Blocked	1	0	1	1
Work Zone Length	8.204168	7.572502	0.6	24.72

Table 6 continued

Speed Limit Reduction	0.467717	2.368919	0	15
Speed Limit	57.85784	6.074156	45	70
Unidirectional Work in Progress	0.866394	0.340261	0	1
Well Lit Road	0.668611	0.470758	0	1
Poorly Lit Road	0.331389	0.470758	0	1
Daylight Hours	1143.817	214.304	906	1514
Darkness Hours	1196.304	218.0757	746	1454
Annual Average Daily Traffic	46231.03	43763.97	180	325445
Clear Weather	0.427655	0.494787	0	1
Windy Weather	0.251459	0.433894	0	1
Weather with Precipitation	0.245041	0.430153	0	1
Dry Surface Condition	0.543174	0.498181	0	1
Wet Surface Condition	0.16375	0.370084	0	1
Snowy Surface Condition	0.216647	0.412	0	1
Severity	3.570401	0.780527	0	4
Driver Age	40.41676	19.19795	8	99
Female	0.40111	0.490174	0	1
Alcohol Test Result	0.004101	0.027684	0	0.62
Surface Width	33.07514	11.53145	0	60
Asphalt Surface	0.060288	0.238042	0	1
Concrete Surface	0.680475	0.466338	0	1
Composite (Combination) Surface	0.251264	0.433782	0	1
Gravel/Stone Surface	0.002917	0.053937	0	1
No shoulder Present	0.269934	0.443968	0	1
Earth Shoulder	0.073318	0.260683	0	1
Paved Shoulder	0.631855	0.482348	0	1
Left Shoulder Width	6.975605	4.597692	0	22
Right Shoulder Width	3.975995	3.502378	0	12
Rumble Strips Present	0.522248	0.499554	0	1
Slab Thickness in Inches	6.969555	4.363333	0	22
Slope	-0.41343	1.035512	-6	6.9
Crack patch present in Inches	0.152986	0.381825	0	1.7
International Roughness Index	76.99996	77.83311	0	475
Interstate	0.669399	0.470476	0	1
Access Control	0.894223	0.776971	0	4
Truck Route	0.705894	0.471267	0	2
No Barrier Median	0.203617	0.402727	0	1

Table 6 continued

Hard Surface No Barrier Median	0.166083	0.372192	0	1
Grass Surface No Barrier Median	0.266044	0.441931	0	1
Hard Surface with Barrier Median	0.020615	0.142104	0	1
Grass Surface with Barrier Median	0.180086	0.384296	0	1
Hard Barrier Median	0.160054	0.366692	0	1
Median Width	40.89696	77.8444	0	551
Reduced Number of Lanes	4.653637	1.733461	1	9

As evident from table 6, fewer fatalities were observed for work zones set in both directions instead of in just one of the two traveling lane directions. Table 7 specifies the severity level-wise crash separation in the two work zone condition scenarios. Some other variables used for exploratory analysis of the crash severity analysis database are also stated. As a major fraction of the work zones were uni-directional at any given time, larger number of crashes, as well as fatalities, were observed for the same. Further analyzing the effect of directional influence of work zones on fatalities and other crash severities would be carried out by the Ordinal Logistic Regression Model explained in the latter sections.

Table 7: Directional Distribution of Work Zone Crashes reduced from Crash Severity Data Table

Type of Crashes	**Type of Work Zones**	
	Bi-directional	**Uni-directional**
Fatalities	0	0
Disabling Injury Crashes	0	3
Evident Injury Crashes	0	32
Possible Injury Crashes	0	58
Property Damage Only Crashes	7	252

Table 7 continued

4.6.1 Speed Limit Reduction:

Another factor examined was the effect of different values of work zone speed limit reduction on the severity of crashes. As can be interpreted from the following table, the fraction of fatal crashes among all crashes in each particular speed limit reduction scenario seems to be the optimum (least) in case of 10 mph reduction (0.11%). In a similar fashion, disabling injury crashes seem to have been minimized in case of a 5 mph reduction in speed limit (1.13%). It is now a question of trading off the number of fatalities versus that of disabling injury crashes as the sheer numbers of the latter are intuitionally more in any crash prone condition. Further, a 10 mph reduction in speed limit also appears to minimize the susceptibility of evident injury (level 2) crashes, whereas a 15 mph reduction in speed limit brings about the most number of reductions in crashes, although the number of avoided crashes seems to fall under the category of possible injury crashes. Therefore, a higher resolution analysis of the effect of speed limit reduction needs to be carried out to inspect its influence on crash severity and fatalities.

Table 8: Comparison of number of crashes and severity in variant speed limit reduction scenarios

Type of Crashes	Speed Limit Reductions							
	No reduction		5 mph		10 mph		15 mph	
	Count	%	Count	%	Count	%	Count	%
Fatalities	6	0.57	2	0.45	1	0.11	2	0.54
Disabling Injury Crashes	20	1.901	5	1.13	14	1.56	7	1.89
Evident Injury Crashes	96	9.125	34	7.71	53	5.9	26	7.01
Possible Injury Crashes	181	17.21	65	14.7	130	14.5	32	8.63
Property Damage Only Crashes	749	71.2	335	76	701	78	304	81.9
Total	1052	100	441	100	899	100	371	100

CHAPTER 5

CRASH STUDY

As the aim of this study was to recommend the most effective speed limit reduction criteria in order to reduce the number and severity of crashes on Iowa work zones, the variables of interest were crash frequency and crash severity. As mentioned in the previous chapters, an aggregate database for the crash counts for generating the crash frequency variable was created on the mentioned bases of separation. This chapter outlines the different statistical methods widely considered suitable for estimating the variables of interest as well as the path intentioned to arrive at the final statistical model used for associating the crash frequency to traffic and work zone characteristics, in conjunction to the speed limit reduction values.

5.1 Statistical Methods for Crash Frequency

Negative binomial regression model is the most commonly used statistical method for modeling crash count data as opposed to the other widely used count data analysis method, Poisson regression, due to the oft rare and random, or in other words, the "over dispersed" nature of crash data. LIMDEP initially runs a Poisson model when commanded to execute a negative binomial regression model which enables the evaluator to compare the Poisson model with the Negative Binomial Regression Model. The over-dispersion parameter is α, with provision for representing under dispersed data as well, (expected value of the random variable, or the distribution mean, is greater than its variance in case of under-dispersed data, while the vice versa holds true for over-dispersed data set). It is present in the latter model and validates the necessity of using the Negative Binomial

Model. The difference in parameter estimates between these two models can thus be verified. This is because the mean and variance of the variables are significantly different from each other, which is a prerequisite for applying the Poisson Regression Model for analyzing the database. If curative measures are not taken to address dispersion, it is found that a bias is introduced in all the parameter vectors for which this inequality holds true.

The following formulation denotes the difference between the two mentioned count models:

5.1.1 Poisson Model

$$P\ (y_i) = (\text{Exp}\ (-\lambda_i)\ \lambda_i^{y})/\ (y_i)! \qquad (1)$$

Where, λ_i is the Poisson parameter for the direction and year specific work zone (i), representing the expected crash frequency for the stated parameter separators. This Poisson parameter is a function of the independent explanatory variables (the condition of independence of the variables is verified and iterated by observing the variable correlation table of the final conclusive model) [26]. The Poisson parameter is:

$$\lambda_i = \text{Exp}\ (\beta X_i) \qquad (2)$$

Here, X_i is a vector of independent explanatory variables and β is a vector of dependent variable(s).

5.1.2 The Negative Binomial: parameter addresses the stated concern by adding an error term in the equation for the Poisson parameter λ as shown below:

$$\lambda_i = \text{Exp}\ (\beta X_i + \varepsilon_i) \qquad (3)$$

The term EXP (ε_i) is gamma distributed error term with mean of 1 and constant variance α^2. Similarly, the previously discussed α parameter is added to the Negative

Binomial model which tracts the following condition, allowing the variance to differ from the mean:

$$Var\ [y_i] = E[y_i] * (1 + \alpha\ E[y_i]) \tag{4}$$

Where, α, the dispersion parameter with a constant variance, when equal to zero, reduces the Negative Binomial Model to a Poisson Model as previously described.

The variable “Direction” if found significant in the model can be treated as an offset variable with its corresponding β coefficient. The log of Annual Average Daily Traffic needs to be supplied as an offset variable to normalize the crash analysis for changing traffic volumes during the analysis period. Work zone duration was also examined for its role as an offset versus a regular explanatory variable in the model and was used accordingly [23]. The final model equation to be used for arriving at the crash model, therefore, consisted of the AADT offset $X_{AADT(i)}$, calculated intercept β_0, estimated explanatory variable values X_i and their corresponding coefficients β_i:

$$\lambda_i = X_{AADT(i)} * Exp(\beta_0 + \beta_i Xi) \tag{5}$$

The Negative Binomial distribution is given by the following equation, where the term “P (y_i)” depicts the probability of the work zone crash frequency being accounted for, and Γ (.) is a gamma function:

$$P(y_i) = \frac{\Gamma\left(\left(\frac{1}{\alpha}\right) + y_i\right)}{\Gamma\left(\frac{1}{\alpha}\right) y_i!} \left(\frac{\frac{1}{\alpha}}{\frac{1}{\alpha} + \lambda_i}\right)^{\frac{1}{\alpha}} \left(\frac{\lambda_i}{\left(\frac{1}{\alpha}\right) + \lambda_i}\right)^{y_i} \tag{6}$$

5.1.3 Random and Fixed Effects Negative Binomial Model

A concern that might arise while using a negative binomial study model for modeling crash frequency is the possible correlation between crash conditions across the same work zone sites. This situation arises when unexplained heterogeneity is present in the study which stays inexplicable by any of the included explanatory variables. Work zones located next to each other might have certain characteristics similar to each other, while there can also exist some common uncaptured factors exclusive to certain work zones. Some examples of such unobserved variables could be the presence of a visually distracting billboard situated near to the crash location, special geometric conditions of a specific work zone, presence of a scenic route next to a water body, incidental location of a warehouse in the proximity of the crash location, presence of animals, etc. Such factors could trigger similar responses within drivers maneuvering a specific work zone. While it is unknown what significant bearing, if any, such factors possess on crash frequency and severity, it is possible to account for such random variation in experimental or observational units by using a Random Effects Model. Through this method, one can append an additional intercept to the negative binomial equation, as shown in equation 7 below, validating every source of random or unpredictable individual spatial and temporal variation such effects bear on the response *across the groups*, which in context of this study, is defined by a unique identifying variable for every discrete work zone.

$$\lambda_i = X_{AADT(i)} * Exp(\beta_0 + \beta_i Xi + \mu_i) \tag{7}$$

The intercept term accounting for the group effect variation across work zone is μ. Exp (μ) is gamma distributed, with mean 1 and variance k, where k is the over-dispersion parameter. The grouping variable, say φ, is a randomly distributed term which when added to the regular negative binomial equation, introduces the intercept μ as shown above in equation 7. The random variable φ_j can take on a number of distributions, out of which

LIMDEP supports uniform, normal and log-normal. All estimable parameters in the random parameters model now take the following form:

$$\beta_j = \beta + \varphi_j \qquad (8)$$

The Poisson parameter from equation 2, due to equation 8, becomes:

$$\lambda_i/\varphi_j = \text{Exp}\ (\beta X_i + \varepsilon_i) \qquad (9)$$

The corresponding probabilities P (y_i) in the negative binomial model mentioned in equation 6 is substituted by P (y_i/φ_j). Thus, the log likelihood function for the random parameter negative binomial model is:

$$\text{Log Likelihood} = \Sigma_{(Vi)} \ln {}_{\varphi j}\!\int g\ (\varphi_j)^* P\ (n_i/\varphi_j)\ d\varphi_j \qquad (10)$$

Marginal effects of other explanatory factors also need to be tested in order to assess their impact on crash frequency as well as crash severity (discussed in point 4, Ordinal Logistic Model). Marginal effects are calculated for each observation and then averaged across all observations. They are essentially elasticities of the independent variables which compute the change in predicted crash frequency with one-unit changes in each of the explanatory variables.

There are four possible methods of creating the work-zone-specific distinct explanatory variable φ_j. These criteria are enumerated hence:

a.) By treating each direction of the work zone as a separate discrete variable.

b.) By treating both directions of the work zone as a single entity for the purpose of coding the grouping variable.

c.) By treating upstream, downstream and within the work zone location as three separate entities for coding the grouping variable.

d.) By treating the three mentioned locations as a single entity for each specific work zone.

The Fixed Effect Model rationalizes omitted variable bias introduced in the database *within groups* defined by the grouping variable. Any criterion among the four above mentioned methods not used to create the grouping variable or found insignificant in defining the random or fixed variation across and within the groups respectively, could be coded in the database itself as an additional independent explanatory variable in order to observe their effects on the experimental units (crash frequency and severity) instead.

5.1.4 Ordinal Logistic Model

The ordinal logistic model was proposed to be used to analyze the effect of work zone environments and the different speed limit reduction conditions on the severity of crashes. The sample size of crashes used in this study was restricted, as no upstream and downstream crashes were included; also, historic crash data pertaining only to the respective time periods between the construction start and end dates were included to omit skew of non-work-zone period crashes due to factors other than solely road work. This restricted the database further, rendering using nested logit models to analyze crash severity levels unusable due to low variability in the dependent variable [30]. Also, individual driver characteristics are not considered in this study, or at least, that is not the main focus of this analysis as the aim is to enunciate the effect of work zones on traffic safety regardless the behavior of the drivers maneuvering the work zone; the independent indicator variables signifying work zone speed limit reduction criteria were first individually tested for influence on crash severity, and were further supplemented with other significant geometric variables. Other methods used in earlier studies for successfully modeling crash severity are multinomial logit and probit models. These models while accounting for lesser variability in the dependent variable, render the ordinality of the data immaterial, and require inclusion of more parameters in the analysis; effectively for more than three severity levels, the degrees of freedom also get restricted [31, 32].

5.2 Results

In order to investigate the impact of speed limit reduction in work zones, the following questions needed to be answered:

a.) Did reduction in work zone speed limit improve work zone safety as observed in construction conditions in segments with speed limits of 55 mph?

b.) Were there any significant differences between base case crash counts in segments with speed limits greater than 55 mph?

c.) Did lowering work zone speed limits minimize work zone crashes in road segments with speed limits greater than 55 mph, namely, 65 mph and 70 mph?

d.) Are work zones with speed limits of 55 mph safer than any other speed limit criteria, regardless of originally posted speed limits?

The following distribution of original posted and work zone speed limits was observed.

Table 9: Details of posted and reduced Speed Limits in the observed work zones

Work Zone ID	**Originally Posted Speed Limit**	**Speed Limit Reduction**	**Work Zone Posted Speed Limit**
Project 4.1	55	0	55
Project 1.2	55	5	50
Project 1.5	55	10	45

Table 9 continued

Project 3.2	55	10	45
Project 3.3	55	10	45
Project 4.2	55	0	55
Project 4.3	55	0	55
Project 5.1	55	0	55
Project 6.1	55	0	55
Project 6.2	55	0	55
Project 6.3	55	0	55
Project 6.4	55	0	55
Project 1.4	65	10	55
Project 2.1	65	10	55
Project 3.1	70	15	55
Project 1.3	70	15	55

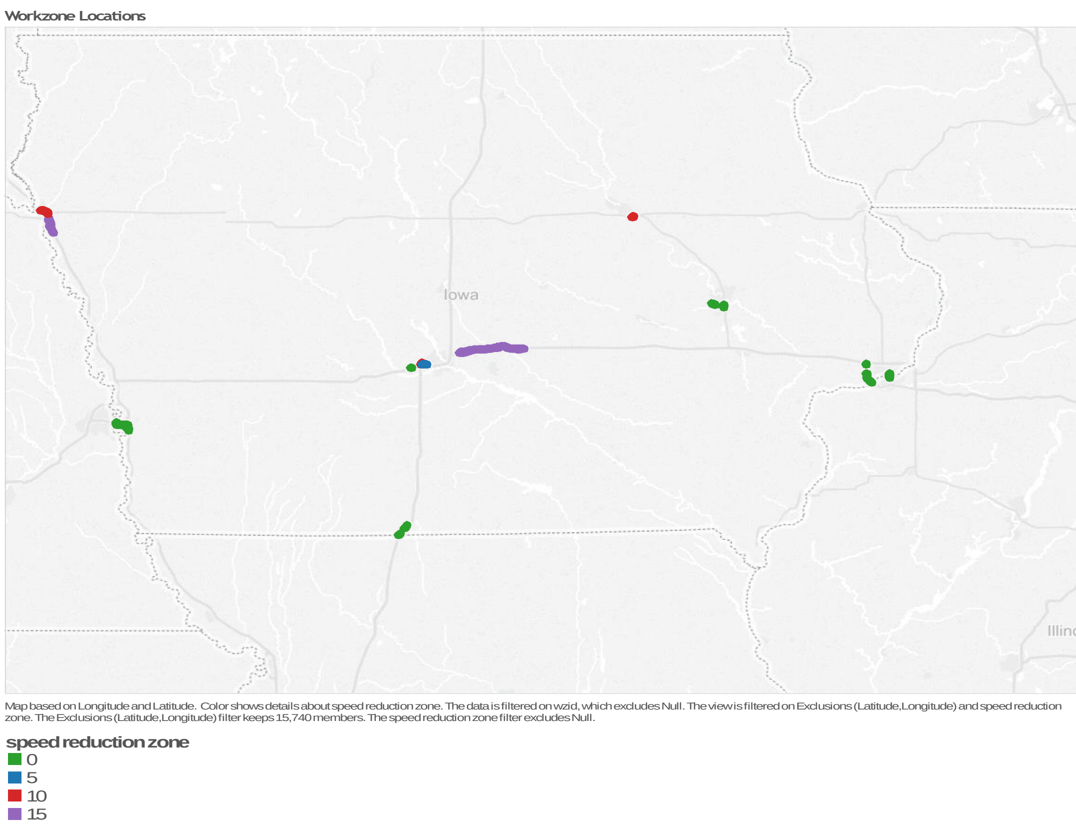


***Fig 25**: Work zones included in the crash study color coded by applied speed limit reduction; Source: Iowa DOT GIMS Database*

5.2.1 Crash Frequency Analysis

Firstly, a variable selection algorithm was run using SAS ® to identify the independent variables most significantly affecting crash frequency using the “countreg” suite corresponding to negative binomial distribution. The countreg procedure in SAS is used to analyze non-negative integer count data occurrences. In count regression, the conditional mean of the dependent variable, y, is assumed to be a function of a vector of covariates, x [35]. This variable selection process is proposed to eliminate independent variables of low significance from the database. The listed variables need to be further examined to identify and consequently reject geometric variables which pose as surrogates for other effects, which in this study would namely be the 8 chief indicator variables of interest signifying the unique speed limit reduction conditions in work zones. The following variables were found to be expressively influencing crash count/frequency in the studied database as shown in table 10. It can be interpreted as the variables corresponding to the lowest possible values of the Akaike Information Criteria parameter, which estimates the relative quality of the respective model as compared to all the other variable combinations run for the same analysis procedure. Table 11 gives the model fit summary of the run procedure:

Table 10: Variable Selection Output

Effect Entered	AIC	SBC
Constant	10799	10810
Annual Average Daily Traffic	10607	10623
Panel Variable-Work Zone Name	10418	10440
Unidirectional Work	10336	10363
Speed Limit	10310	10342

Table 10 continued

Slope	10220	10273
Rumble Strips Present	10189	10264
Left Shoulder Paved	10184	10264
Left Shoulder Earth/Gravel	10176	10262
Right Shoulder Earth/Gravel	10171	10261
Slab Thickness in Inches	10165	10261
Median Width	10150	10262
Curb Shoulder Condition: Fair	10143	10266
Paved Barrier Median	10141	10269
No Median Present	10139	10273
Access Control Points	10137	10276
International Roughness Index	10135	10279
Surface Width	10129	10283
Gravel/Stone Surface	10127	10287
Fair Surface Conditions	10126	10292
Good Surface Cond	10125	10296
Crack patch in Inches	10124	10300
Shoulder Width	10121	10313

Table 11: Model Fit Summary for Variable Selection Countreg Procedure

Model Fit Summary	
Dependent Variable	Crash Count
Number of Observations	561
Data Set	WORK.SET1
Model	NegBin (p=2)
Log Likelihood	-5023
Maximum Absolute Gradient	5.63836

Table 11 continued

Number of Iterations	7
Optimization Method	Newton-Raphson
AIC	10120
SBC	10318

Table 12 delivers the results of the random parameter negative binomial model estimated to investigate work zone versus no work zone condition crash counts under various speed reduction scenarios. It should be noted that these variables were acquired using the data assimilated through the procedure mentioned in the study. The variables found significant in this model may be influenced by data quality issues but an approach similar to the one discussed in this study can be instrumental in generating dependable results if the quality of the data can be assured through the methods mentioned earlier. Thus, assuming the authenticity of the work zone period duration data, the geometric random parameters chosen to test in the model were first examined for their range, spread, standard deviation and means as noted in table 12. In order to prepare the variables “International Roughness Index” and “Surface Width” to be incorporated into the crash frequency table, the average of these variables for every road segment contained in each work zone was calculated, weighted by their segment lengths (identified by their respective MSLINK ID sourced from the GIMS database).

Table 12: Examining Spread of Significant Geometric Variables

Geometric Variable	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Number of Lanes	3.05	0.7519	2	5

Table 12 continued

International Roughness Index	91.02	28.2394	50.7	168.86
Surface Width	31.41	5.4916	24	41

Table 13: Negative Binomial Model Result for Crash Count

Dependent Variable: Crash Count				
Variables	**Coefficient**	**Standard Error**	**Z-Value**	**P-Value**
Non Random Parameters				
55 mph Speed Zone with 10 mph Reduction	-0.34346	0.31692	-1.08	0.2785
65 mph Speed Zone without Work Zone	-0.29414	0.19209	-1.53	0.1257
70 mph Speed Zone without Work Zone	1.73122 ***	0.20723	8.35	0
55 mph Speed Zone with no reduction	-0.90747***	0.23886	-3.8	0.0001
55 mph Speed Zone with 5 mph Reduction	-1.49302***	0.4044	-3.69	0.0002
65 mph Speed Zone with Work Zone Limit: 55 mph	-2.35295**	0.04842	-2.24	0.0248
70 mph Speed Zone with Work Zone Limit: 55 mph	-1.16525***	0.41242	-2.83	0.0047
Number of Lanes	-0.58955***	0.10917	-5.4	0
International Roughness Index	-0.01259***	0.002	-6.28	0
Means for Random Parameters				
Intercept	2.04119**	0.91988	2.22	0.0265
Natural Log of Annual Average Daily Traffic	0.11681	0.08537	1.37	0.1712
Natural Log of Work Zone Length	-0.26390***	0.06306	-4.19	0
Natural Log of Work Zone Duration in Days	0.18838***	0.02742	6.87	0
Surface Width	0.02687*	0.01612	1.67	0.0956
Scale Parameters for Distributions of Random Parameters				
Intercept	0.12970***	0.04257	3.05	0.0023

Table 13 continued

Natural Log of Annual Average Daily Traffic	0.00713	0.00445	1.6	0.1095
Natural Log of Work Zone Length	0.31559***	0.03908	8.08	0
Natural Log of Work Zone Duration in Days	0.10448***	0.01069	9.77	0
Surface Width	0.03569***	0.00215	16.56	0
Dispersion Parameter for Negative Binomial Distribution (Alpha)				
Scale Parameter	3.39666***	0.22106	15.37	0
Log Likelihood Function = -1162.4954				
Restricted Log Likelihood = -5529.01532				
Chi-Squared (5 degrees of Freedom) = 8733.03984				
McFadden Pseudo R-Squared = 0.7897464				
AIC Value = 4.238				

As can be interpreted from the results table 12 and table 13, the random effects model suggests that with respect to the base case of a 55 mph speed zone with no work zone, statistically significant increase in crashes was registered for speed zones of 70 mph even without the presence of work zones. This fact tallies with earlier studies which enlist high speeds as one of the most influential factors in combination with high speed variance for increasing crash and/or near crash risk. As expected, the offset variable duration in days proved to be proportional to the number of crashes experienced; these day-durations signify the total time period in days for which each entry in the crash count column was calculated, both for work zone as well as no construction conditions. As the work zone duration was assumed to be only the intersection of time between the contractor sourced start and end date, and the activity periods logged in the ATMS database, it was imperative to include the duration variable as an offset in the crash count model to account for much greater entries for this variable associated with the no-construction periods to minimize the risk of omitted variable bias.

Another offset, work zone length (natural log of) was observed to have an inversely proportional effect on the crash counts, as interpreted from the negative coefficient for the mean of the random parameter. It may be reflective of the possibility that as drivers tend to maneuver longer work zones, they get used to driving in the updated driving conditions. Qin, Xiao, Ivan and Ravishanker [33] found that segment lengths have the least effect as an exposure variable on crash counts and are therefore generally used as the chief exposure variable. High standard deviation in crash counts, and by extension, crash risk was noted as work zones started appearing in higher speed zones, which consequently mandated steeper reduction in speed limits at the construction sites. The negative nature of the coefficients associated with speed limit reductions at higher speed limit zones, versus the positive coefficients for the same sites without work zones shows the effectiveness of reducing crash risk by a considerable margin by lowering speed limits in such cases.

It should be noted that the data for this study was extracted from multiple relatively poor quality data sources, which could have introduced inaccuracies in the obtained results. Assuming the validity of the data, the following inferences can be made. It essentially signifies that as compared to the base case of 55 mph speed zones with no work zone, the crash risk is considerably higher in segments of higher speed limits, which regardless of the reason for limiting speeds decreased crash risk by considerable percentages as detailed herein. These respective crash frequencies were observed to have significantly reduced by approximately 8% in 65 mph work zones when speed limit reductions of 10 mph were employed. On the other hand, 70 mph speed limit work zones, when converted to 55 mph zones (15 mph reduction), lowered work zone related crash odds by nearly 18%. For speed zones with originally posted speed limits of 55 mph, on the other hand, a 0.4% reduction in crash count was observed with no change in speed limit. This counter intuitive reduction in crashes could be attributed to the propensity of more cautious driving in presence of work zones in lower speed zones, a fact iterated in the study carried out by Yi, Edara and Sun [4] wherein the natural speed selection of experienced drivers proved to be a major influencer of arriving at 85th percentile speed figures than any other regulatory speed control measure in certain specific driving environments. The fact that most work zones where speed limit reduction is deemed unnecessary are usually low traffic/low speed/non-interstate/short term activity zones/presence of higher population of experiences and/or cautious drivers underlines the likelihood of lower crash risks in such construction affected road segments with restricted access to driving channels.

A 10 mph reduction in speed limit was found to be insignificant for the purpose of this analysis. This could be due to the fact that 10 mph reduction in speed limit in a 55 mph speed zones were seldom found in interstate environments in the collected database. Nevertheless, a 5 mph reduction in speed limit was found to have significantly increased the reduction in work zone related crash frequency by nearly 4%, with a slightly higher standard deviation in the observed number of work zone related crashes. The said standard deviation was noted to be increasing in construction period crashes in higher speed limit segments, limiting the interpretation of the model.

All offsets and/or exposure variables were observed to be significant when treated as random parameters due to the number of data points in each of the respective categories. Another random parameter found significantly affecting crash frequency is surface width, which was found to be increasing with surface width with an exponential coefficient of 0.026. The data for surface width used in the study was the original surface width prior to construction as listed in the GIMS geometric road information database. The possible correlation between this variable and the variable "reduced number of lanes" was verified for, as the number of reduced lanes might be a function of the original surface width (a surrogate for number of lanes) for any construction zone. This index was found to be 0.0000625 (<0.5) which primarily alleviated calculable correlation between the two variables. International Roughness Index (coefficient: -1.02%) and the number of operational lanes were found to be two other non-random geometric parameters, both inversely affecting crashes, with lane counts having a more pronounced effect on crashes bringing down crash frequency by 1.64%.

5.2.2 Crash Severity Analysis

The other very important metric of quantifying traffic safety, crash severity is discussed in this section. The effect of different speed zones and speed limit reduction scenarios on crash severity was studied through the ordinal logistic model. The five crash severity levels described above was treated as an ordinally varying factor impacted by the various criteria of work zone speed limit reduction. Assuming the accuracy of the data, the study showed that as compared to the base case of 55 mph speed limit road segments with no work zones, 5 mph speed limit reduction increased severity in crashes by nearly 3.3%, but a reduction of 10 mph saw a significant reduction in crash severity by 2.14% for work zones with original posted speed limits of 55 mph. For speed zones of 65 mph, which inherently saw more severe crashes than lower speed zones even in the absence of construction zone conditions, a significant decrease in severity was observed on lowering the speed limits to 55 mph. Speed zones of 70 mph showed no statistically significant changes in crash severity levels on account of reducing speed limits. Table 14 provides the analysis results for the ordinal logistic crash severity model.

Table 14: Ordinal Logistic Model Analysis Result for Crash Severity Study

Dependent variable: Severity (Severity varying from 4: Property Damage Only Crashes to 0: Fatal Crashes)	**Coefficient**	**Standard Error**	**Z-Statistic**	**P-Value**
Constant	6.23167***	0.13265	46.98	0
65 mph Speed Zone without Work Zone	-.39917**	0.1782	-2.24	0.0251
70 mph Speed Zone without Work Zone	0.23571	0.16967	1.39	0.1648
70 mph Speed Zone with Work Zone Limit: 55 mph	0.28832	0.31352	0.92	0.3578
55 mph Speed Zone with no work zone speed limit reduction	0.11431	0.18781	0.61	0.5428
55 mph Speed Zone with 5 mph Reduction	-1.20611**	0.51922	-2.32	0.0202
55 mph Speed Zone with 10 mph Reduction	.75964**	0.37352	2.03	0.042
65 mph Speed Zone with Work Zone Limit: 55 mph	-.75840*	0.44059	-1.72	0.0852
Median Width	.00298***	0.00077	3.85	0.0001
Natural Log of Annual Average Daily Traffic	.00063***	0.0001	6.03	0
Work Zone Length	0.00022	0.00042	0.52	0.6036
Surface Width	-0.00085	0.00095	-0.9	0.3701
Threshold Parameters				
Mu(01)	.31854***	0.04796	6.64	0

Mu(02)	3.05153***	0.10773	28.33	0
Mu(03)	5.39302***	0.11827	45.6	0
Log likelihood function -2329.52672				
AIC/N = 1.963				

A closer examination of the marginal effects of the ordinal logistic model, the details of which are listed in Table 15, revealed that fatal, major and minor injury crash probabilities are significantly decreased by lowering speed limit by 10 mph in 55 mph work zones as opposed to other factors of reduction or no reduction at all. This effect needs to be tested for a safety tradeoff between the actual number of fatal work zone crashes and work zone crashes of different severity levels. It appears that a 10 mph reduction in higher speed zones of 65 mph limits is also capable of significantly reducing property damage only crashes by 28%. This inference might insinuate that the number of higher severity crashes increases in the event that a 10 mph reduction is applied in speed zones of 65 mph. This effect was therefore checked for in the partial effects model of higher severity levels and no significant increase for the corresponding speed limit reduction scenario was observed in the results. Elasticities of these variables were then examined to find the direct relationship between unit values of independent and dependent variables. A 10 mph drop, which is the most widely followed value of work zone speed limit reduction in case of higher speed zone road segments is also revealed to be the most effective reduction across lower (limited to 55 mph) speed limit sections. These model results need to be further verified with higher resolution work activity and better quality data due to the effects of the aforementioned issues.

Table 15: Partial Effects Table for Ordinal Logistic Model Analysis Results for Five Crash Severity Levels

Independent Variables	Partial Effect	Elasticity	z	P(|z|>Z*)
Partial effects on Fatal Crash Probability				
55 mph Speed Zone with 10 mph Reduction	-.00091***	-0.5366	-2.8	0.0048
Median Width	-.50520D-05***	-0.1634	-3.6	-0.0003
Log of Annual Average Daily Traffic	-.10672D-05***	-0.0065	-5.6	0
Partial effects on Major Injury Crash Probability				
55 mph Speed Zone with 10 mph Reduction	-.00034***	-0.536	-2.8	0.0048
Median Width	-.18863D-05***	-0.163	-3.6	-0.0003
Log of Annual Average Daily Traffic	-.39846D-06***	-0.0064	-5.6	0
Partial effects on Minor Injury Crash Probability				
55 mph Speed Zone with 10 mph Reduction	-.01708***	-0.5273	-2.8	0.0056
Median Width	-.92949D-04***	-0.1576	-3.6	-0.0003
Log of Annual Average Daily Traffic	-.19635D-04***	-0.0062	-5.6	0
Partial effects on Possible Injury Crash Probability				
55 mph Speed Zone with no work zone speed limit reduction	.06883**	0.28984	2.15	0.0315
65 mph Speed Zone with Work Zone Limit: 55 mph	.21081***	0.88773	2.66	0.0078
55 mph Speed Zone with 10 mph Reduction	-.10561**	-0.4447	-2.5	0.0142
Median Width	-.00049***	-0.1135	-3.7	0.0002
Log of Annual Average Daily Traffic	-.00010***	-0.0045	-5.9	0
Partial effects on Property Damage Only Crash Probability				
55 mph Speed Zone with no work zone speed limit reduction	-.08439**	-0.116	-2.1	0.0351
65 mph Speed Zone with Work Zone Limit: 55 mph	-.28269**	-0.3884	-2.2	0.0272
55 mph Speed Zone with 10 mph Reduction	.12394**	0.17029	2.51	0.0122
Median Width	.00059***	0.04456	3.75	0.0002
Log of Annual Average Daily Traffic	.00012***	0.00176	5.97	0

5.3 Conclusion

To summarize, this crash exploration study aimed at proposing a methodology for approaching and analyzing work zone crash data included in this study. This methodology would help answer the research questions of interest: whether speed limit reduction in work zones help in reducing significantly crashes in work zones and their effect on the severity of crashes. Given ideal data collection resources, sufficient overlap between construction periods and lane closure operations, accurate flagging of crashes as work zone related and/or otherwise, the suggested methodology can be potentially applied to isolate crash counts corresponding to work zones and draw conclusion regarding effect of work zones on normal trend of crashes. In the current study, work zone crash flagging is a major issue which needs to be addressed in future studies. There can be several instances of a crash, for example, a night time crash occurring within the work zone boundaries which is unrelated to construction activity. In spite of the attempt made to address this issue by using the Active Traffic Management System database, the outcome is rendered incoherent due to unrealistic discontinuities in the lane closure operation durations found in the logs. These time durations of any specific type and severity of lane closure operations in the work zone are each expected to possess a unique degree of influence on crash risk. These results therefore need to be verified by a higher quality data source and accordingly suitable analysis models.

According to the current database, crash counts were found to be generally more in higher speed limit road segments in non-work zone conditions through the random effects negative binomial model, which provided markedly better fit and revealed significant differences between the various speed limit reduction conditions.

Namely, in 70 mph and 65 mph speed zones, dropping of speed limits to the DOT prescribed 55 mph was found to be effective in bringing down work zone related crashes to count figures not only below the average count for the respective segments in non-construction conditions, but also lower than the base case condition, that is, 55 mph speed limit road segments in the absence of work zones, ergo, no speed limit drops.

On the other hand, no reduction in speed limits for lower limit speed zones, that is, 55 mph segments, showed significant work zone crash count reduction both in the absence and presence of speed limit drops. The speed limit drop associated with the maximum decline in crashes was 5 mph in such lower original speed limit work zones, albeit with a larger standard deviation (0.4044, as opposed to 0.2389). It can thus be concluded that unless a 55 mph road segment exhibits very high crash counts, speed limit reduction is not necessarily mandated.

It is noteworthy that earlier studies have stressed on the relation between increasing speeds and crashes, a conclusion supported by the findings of this study. Maycock [34] found a 2% increase in crash risk odds with every 1 mph average increase in speed. Other variables like access points, roadway grades and curves, etc. which were found to further impact crash counts in earlier studies [33] were determined to be insignificant when modelling solely for work zone related crashes.

Increase in number of operational lanes in a work zone (calculated by identifying the lane closure in place) reduced crash counts irrespective of construction conditions; similarly, increase in roughness index significantly decreased crashes on highways under similar circumstances through increased traction and frictional forces. The random parameter surface width was found to increase crash counts, possibly acting as a surrogate for higher traffic volumes. Length of the work zone was also found to be a random parameter with a negative coefficient, or an inverse relationship with the crash counts. This counter intuitional relationship can be possibly explained by the number of border bridge construction activities included in the work zone crash data base where the physical extent of the work zone might indeed be limited but major rehabilitation operation carried out on the bridge might lead to significant increase in the crash frequency during the construction period.

The crash severity study revealed distinction between different speed limit reduction scenarios for each of the crash severity levels. A 10 mph speed limit reduction proved to be the most effective way to decrease severity of crashes in lower limit speed zones and also seemed influential in reducing severity for moderately higher limit speed zones. Due to the inherent issues with the data quality available for modeling, these results may possibly be erroneous and need to be further substantiated.

Arriving at a prime speed limit reduction number is therefore based on multifold criteria. The combination of existing speed limits, roadway geometry, weather conditions, construction duration, etc. is inimitable for every work zone. This study proposes one methodology for setting a roster of guidelines for fixing work zone speed limits based on these unique work zone characteristics and the trends observed in the given speed limit reduction setups. Increase in speed limits employed by certain DOT's in recent years warrant further studies in the field to establish expected outcomes of such policies. These verdicts could have a domino effect on work zone crash counts as existing posted speed limits drive decisions to lower construction area speed limits as well. This necessitates a thorough examination of the data quality as well as the work zone characteristics, the uniqueness of which dictates the criteria and the quantitative measure of the speed limit reduction to be employed in any work zone. The major focus corresponding to any site is to be either reducing the frequency of crashes or the severity level of majority of the crashes or a practical tradeoff between the two metrics, exclusive to the work being undertaken and location of each site.

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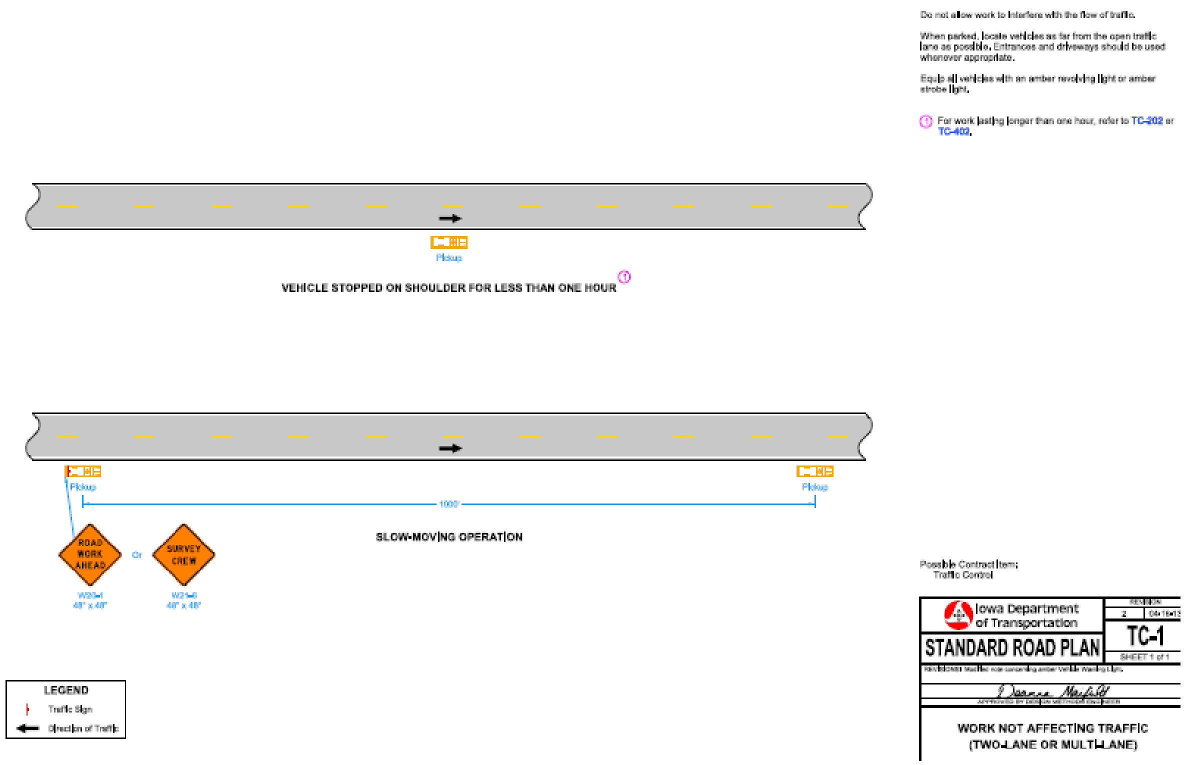
APPENDIX-A

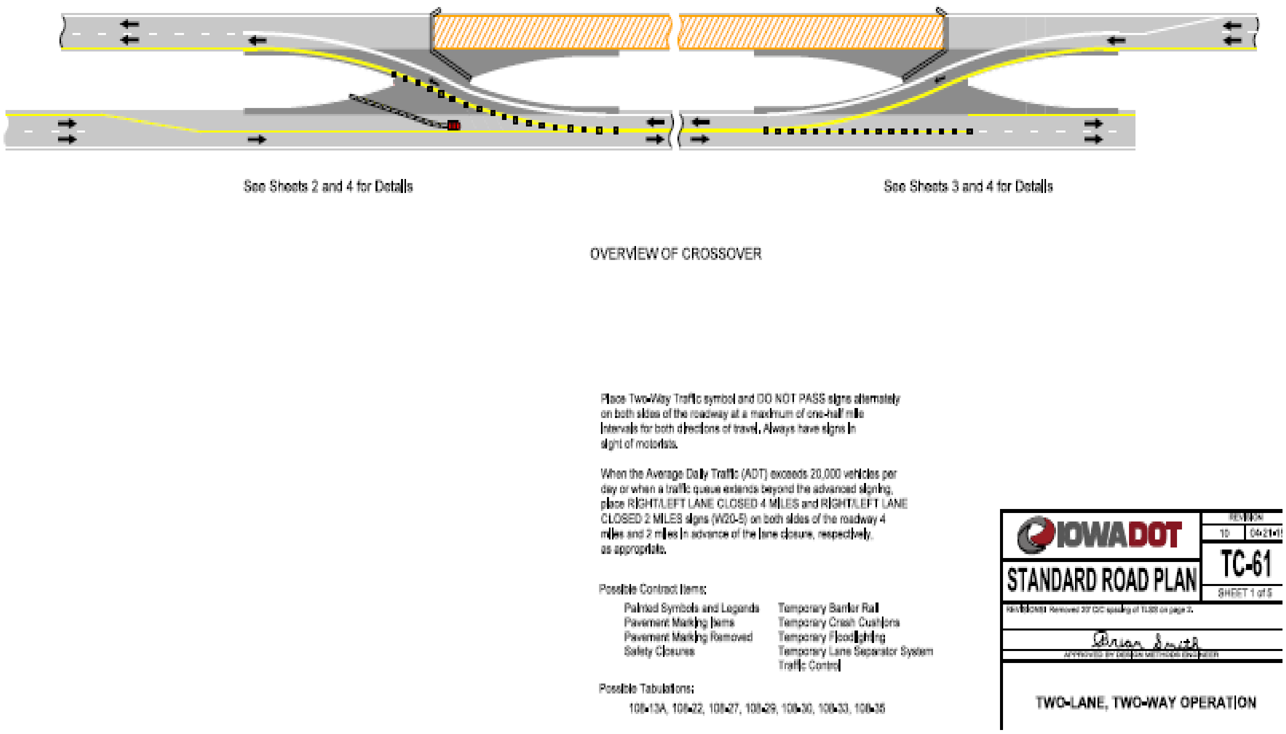
LIST OF TRAFFIC CONTROL PLANS DEPLOYED ON WORK ZONES IN DATABASE

Traffic Control Plan-001

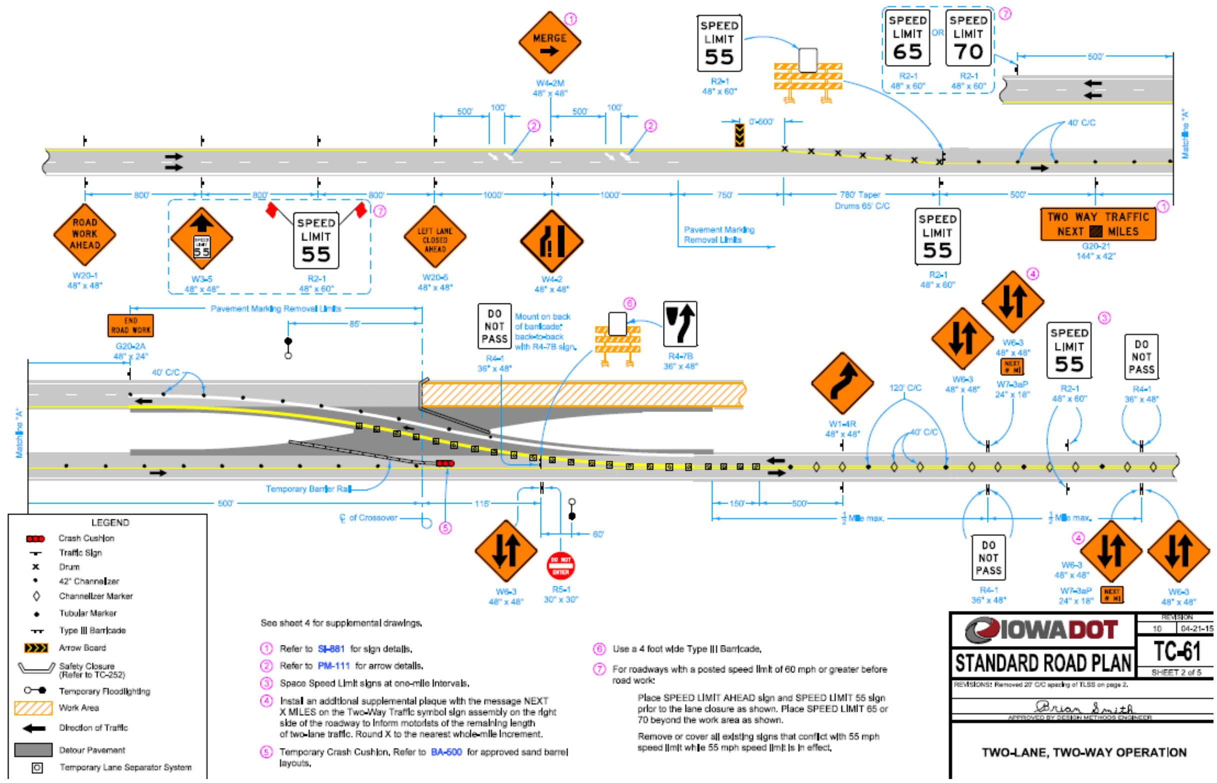


Slow moving work zone operations

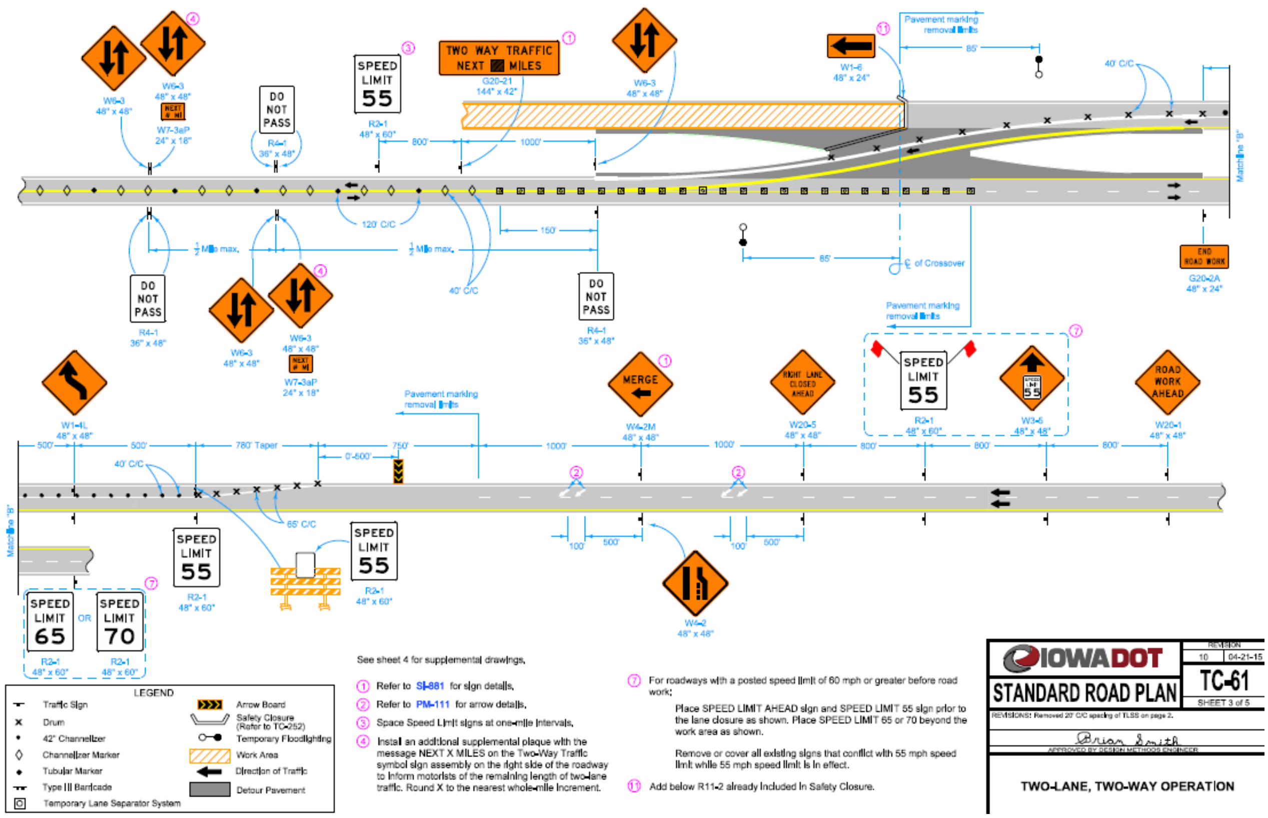
Traffic Control Plan-061



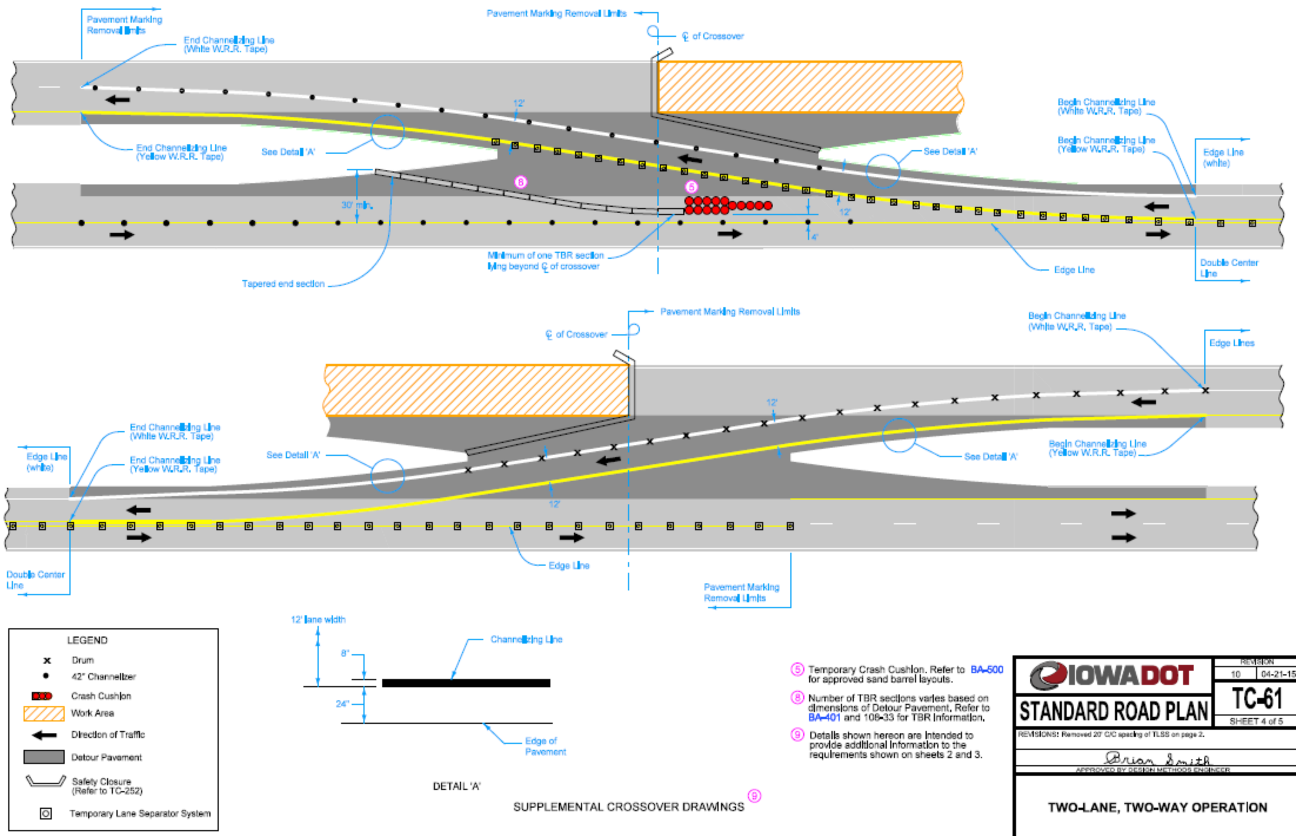
Targeted at two-way operations and ramp movements and regulations



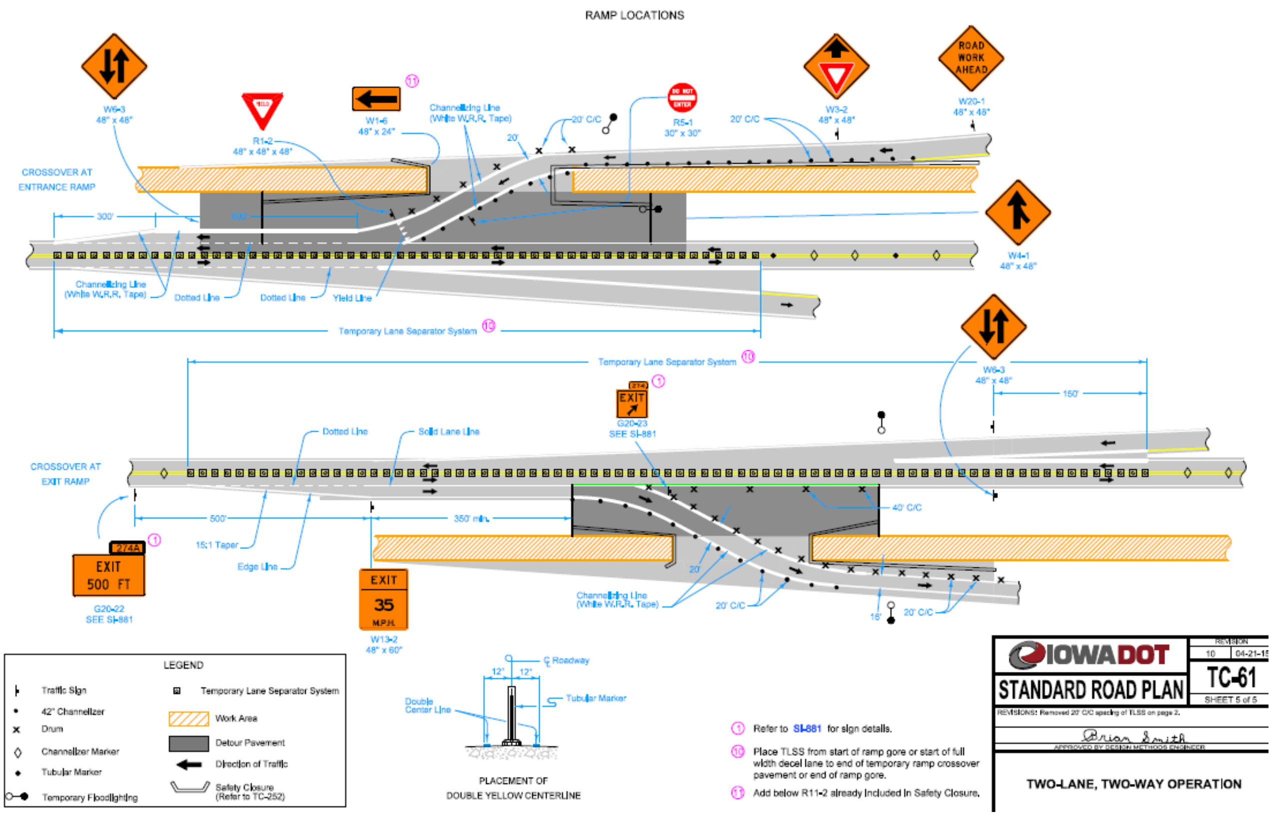
Targeted at two-way operations and ramp movements and regulations



Targeted at two-way operations and ramp movements and regulations

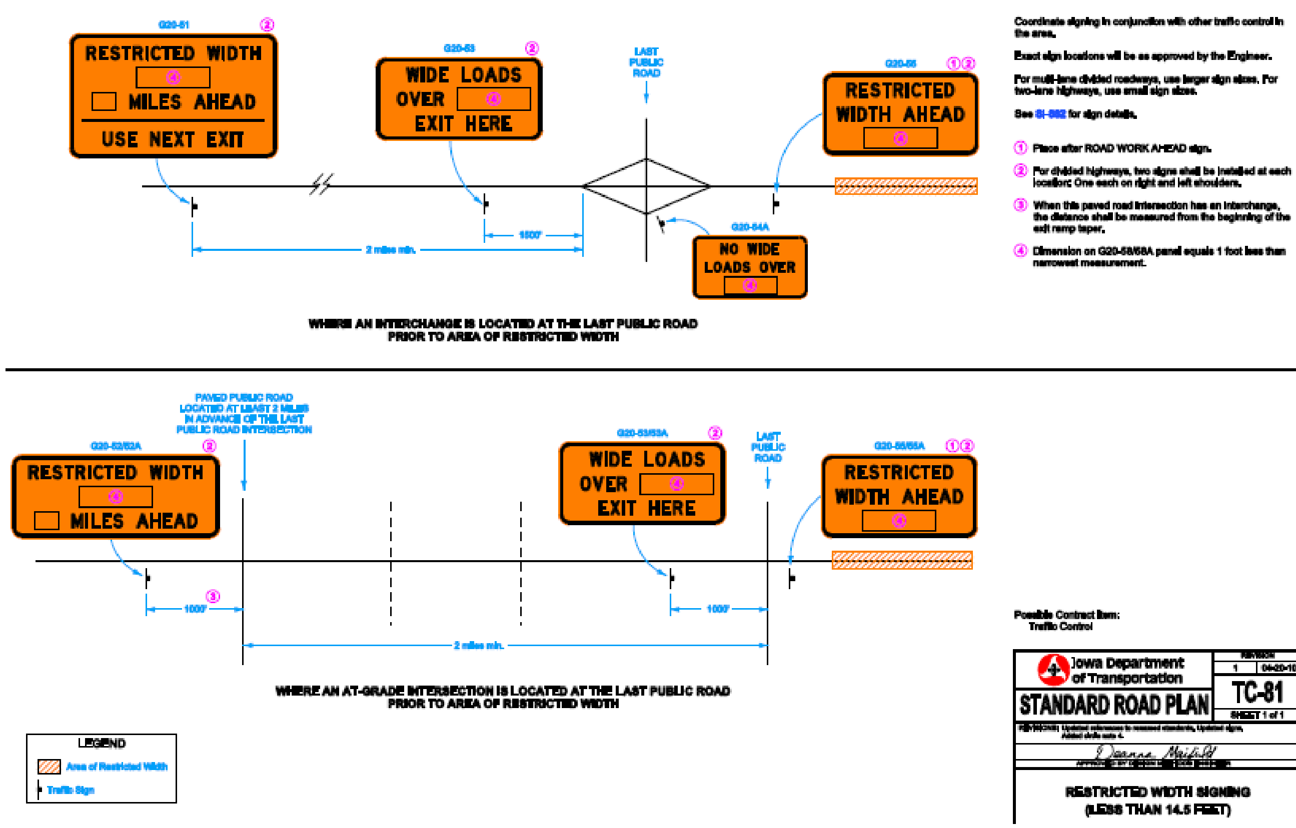


Targeted at two-way operations and ramp movements and regulations



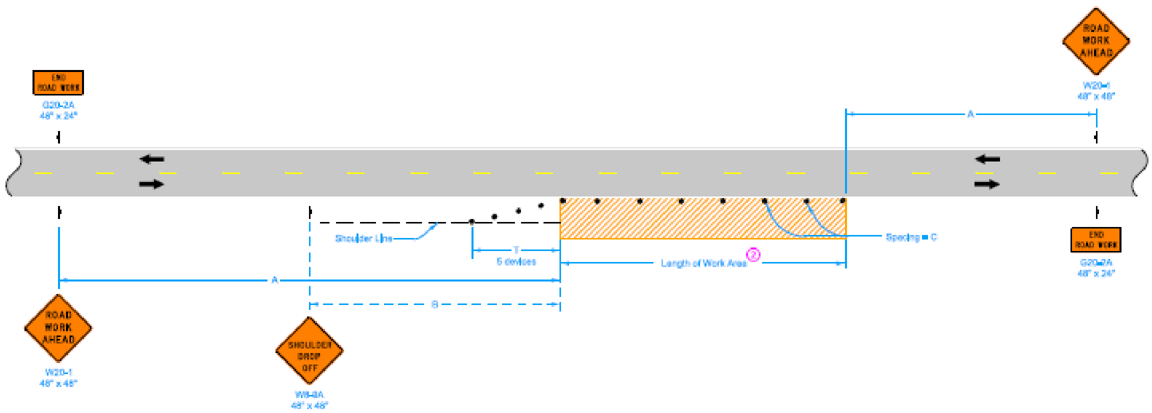
Targeted at two-way operations and ramp movements and regulations

Traffic Control Plan-081



Restricted Width Operations

Traffic Control Plan-202



LEGEND

- Traffic Sign
- 42" Channelizer
- Work Area
- Direction of Traffic

SPEED LIMIT (mph)	A	B	C ②	T
35 or less	500'	250'	40'	100'
40 - 45	700'	350'	80' ①	200'
50 or greater	1000'	500'	100' ①	200'

When a pavement edge drop-off exists, install a SHOULDER DROP-OFF sign.

No pavement edge drop-offs greater than pavement depth will be allowed during non-working hours.

Shoulder edge drop-offs shall be mitigated according to Article 1107.08,L,2 of the Standard Specifications.

For work lasting less than one hour, refer to TC-1.

① When the length of a pavement edge drop-off is 1000 feet or less, the temporary fillet requirement of Article 1107.08 of the Standard Specifications does not apply. Reduce channelizer spacing to 40 feet.

② For work areas less than 200 feet long, use channelizers spaced at 20 foot centers or use a vehicle with an amber revolving light or amber strobe light.

Possible Contract Item:
Traffic Control

IOWA DOT

STANDARD ROAD PLAN

REVISION: 8 — 04-21-15

TC-202

SHEET 1 of 1

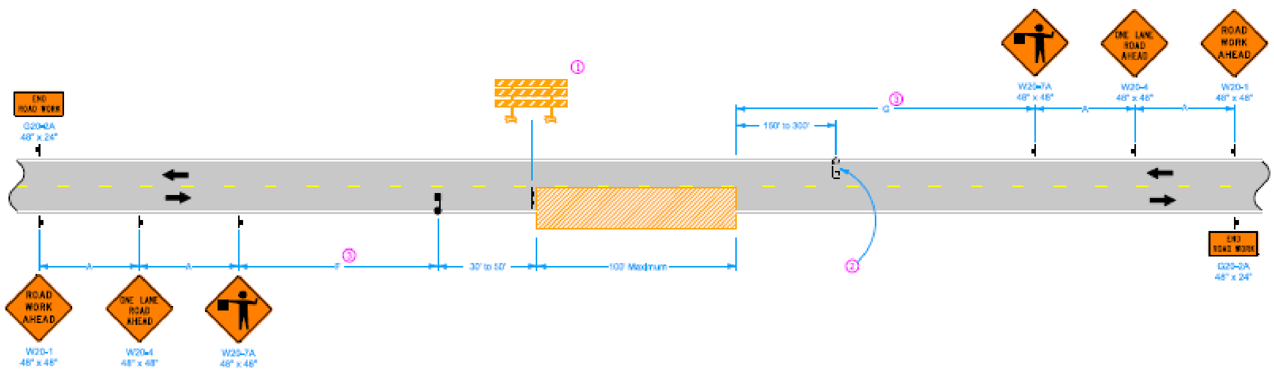
REVISIONS: Modified general notes, changed title and replaced the DOT logo in the title block with the new version.

APPROVED BY DESIGN METHODS ENGINEER

WORK WITHIN 15 FT OF TRAVELED WAY

Pavement Edge and Shoulder Drop Offs

Traffic Control Plan-212



LEGEND

- Traffic Sign
- Flagger
- Work Area
- Type II Barricade
- Direction of Traffic

SPEED LIMIT (mph)	A	F and G Range (3)	F + G Max.
35 or less	250'	250'-3250'	3500'
40 - 45	350'	350'-3350'	3700'
50 or greater	500'	500'-3500'	4000'

(1) A vehicle with an amber revolving light or amber strobe light may be substituted for the Type III barricade.

(2) Provide a second flagger if:

The flagger's view of approaching traffic in the open lane is less than 1/4 mile or the work site is in an area of restricted sight distance (such as a "No Passing" zone); or

Excessive traffic delays are encountered.

(3) F and G distances are to remain as near minimum values as work permits. However, to be able to move the work area without moving the advance signing, F and G distances may be varied within the limits of the table. Maximum movement can be achieved by setting one F or G value at the minimum and the other value at its maximum.

Possible Contract Items:
Flaggers
Traffic Control

Iowa Department of Transportation

STANDARD ROAD PLAN

REVISION 4 04-16-13

TC-212

SHEET 1 of 1

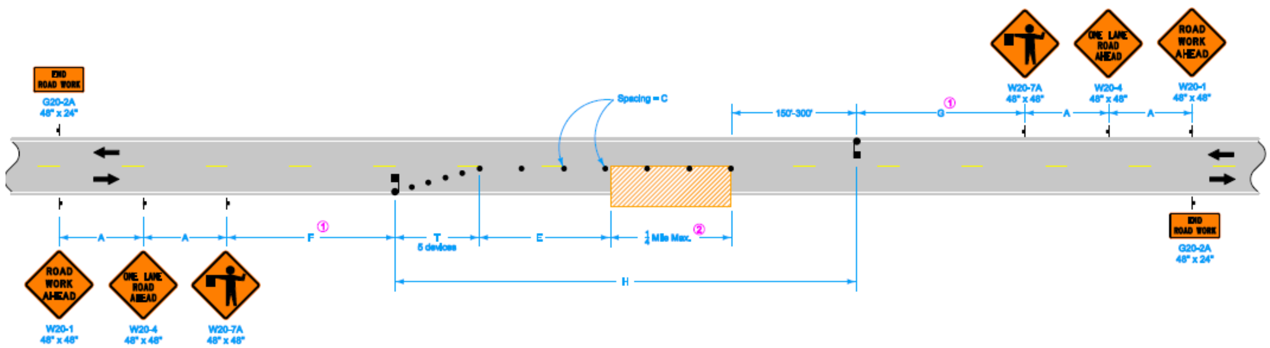
REVISIONS: Modified circle note 1.

APPROVED BY DESIGN METHODS ENGINEER

SPOT LOCATION LANE CLOSURE WITH FLAGGERS

Less-Width and One Lane Operations

Traffic Control Plan-213



SPEED LIMIT (mph)	A	C	E	F and G Range (1)	F + G Max.	H Max.	T
35 or less	250'	40'	0'-200'	500'-3000'	3500'	2000'	50'
40 - 45	350'	80'	0'-200'	700'-3000'	3700'	2000'	100'
50 or greater	500'	100'	200'-300'	1000'-3000'	4000'	2000'	100'

(1) Keep F and G distances as near to minimum values as work permits. However, to allow advancement of the work area without moving signs, F and G distances may be varied within the limits of the table. Maximum movement can be achieved by setting one F or G value at the minimum and the other value at its maximum.

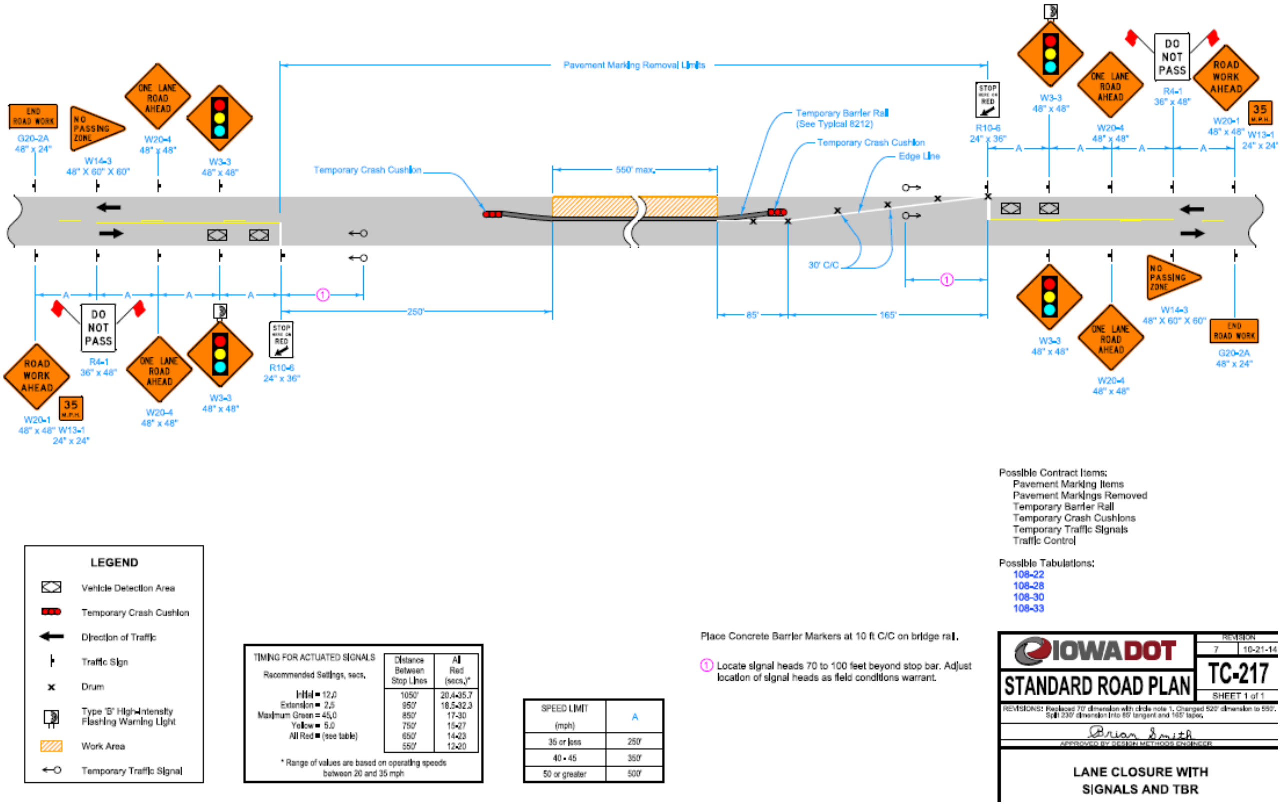
(2) If length of work area exceeds 1/4 mile, use TC-214.

Possible Contract Items:
Flaggers
Traffic Control

Iowa Department of Transportation
STANDARD ROAD PLAN
REVISION 3 04-17-12
TC-213
SHEET 1 of 1
REVISIONS: Removed "or Vertical Panel" from 42" Channelizer in Legend.
Deanna Maifield
APPROVED BY DESIGN METHODS ENGINEER
LANE CLOSURE WITH FLAGGERS

Regulations for Lane Reductions and Taper Lengths

Traffic Control Plan-217



TIMING FOR ACTUATED SIGNALS

Recommended Settings, secs.

Initial = 12.0
Extension = 2.5
Maximum Green = 45.0
Yellow = 5.0
All Red = (see table)

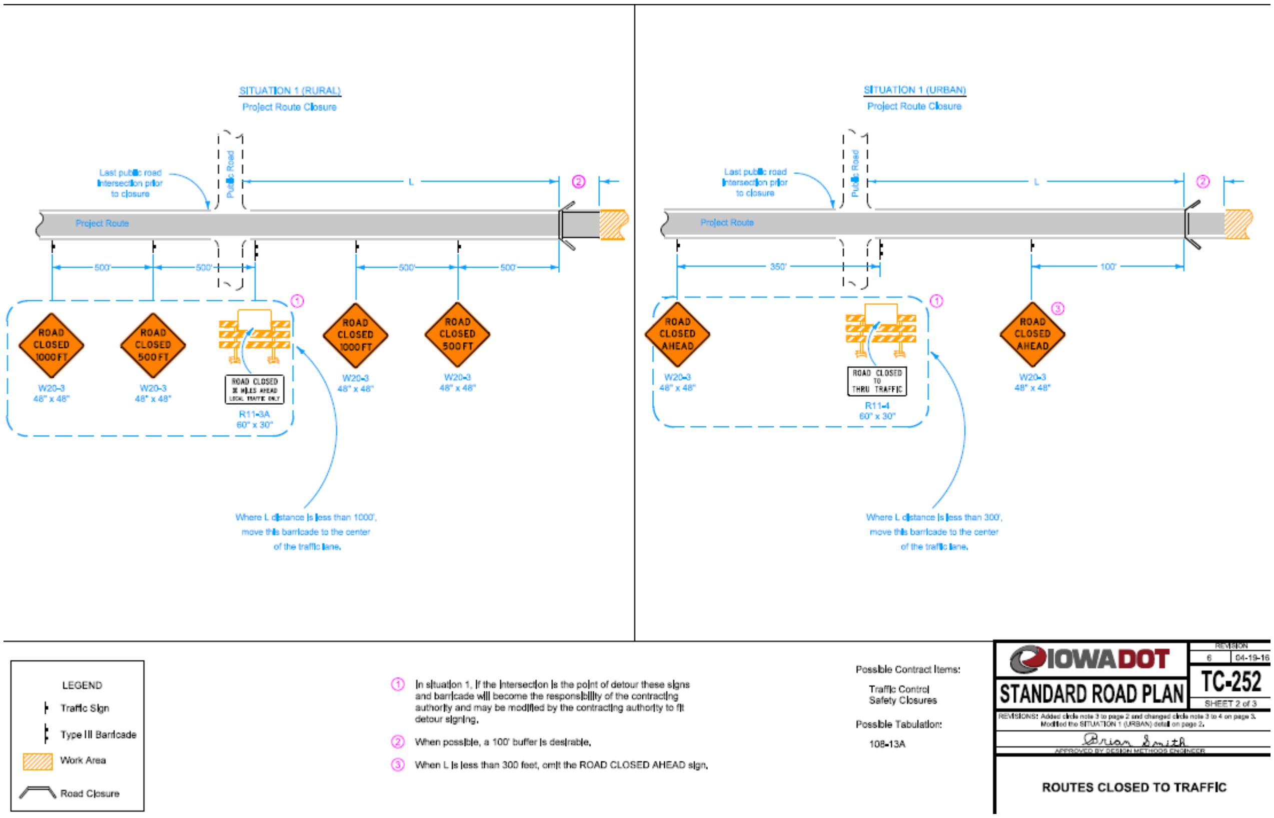
Distance Between Stop Lines	All Red (secs.)*
1050'	20.4-35.7
950'	18.5-32.3
850'	17-30
750'	15-27
650'	14-23
550'	12-20

* Range of values are based on operating speeds between 20 and 35 mph

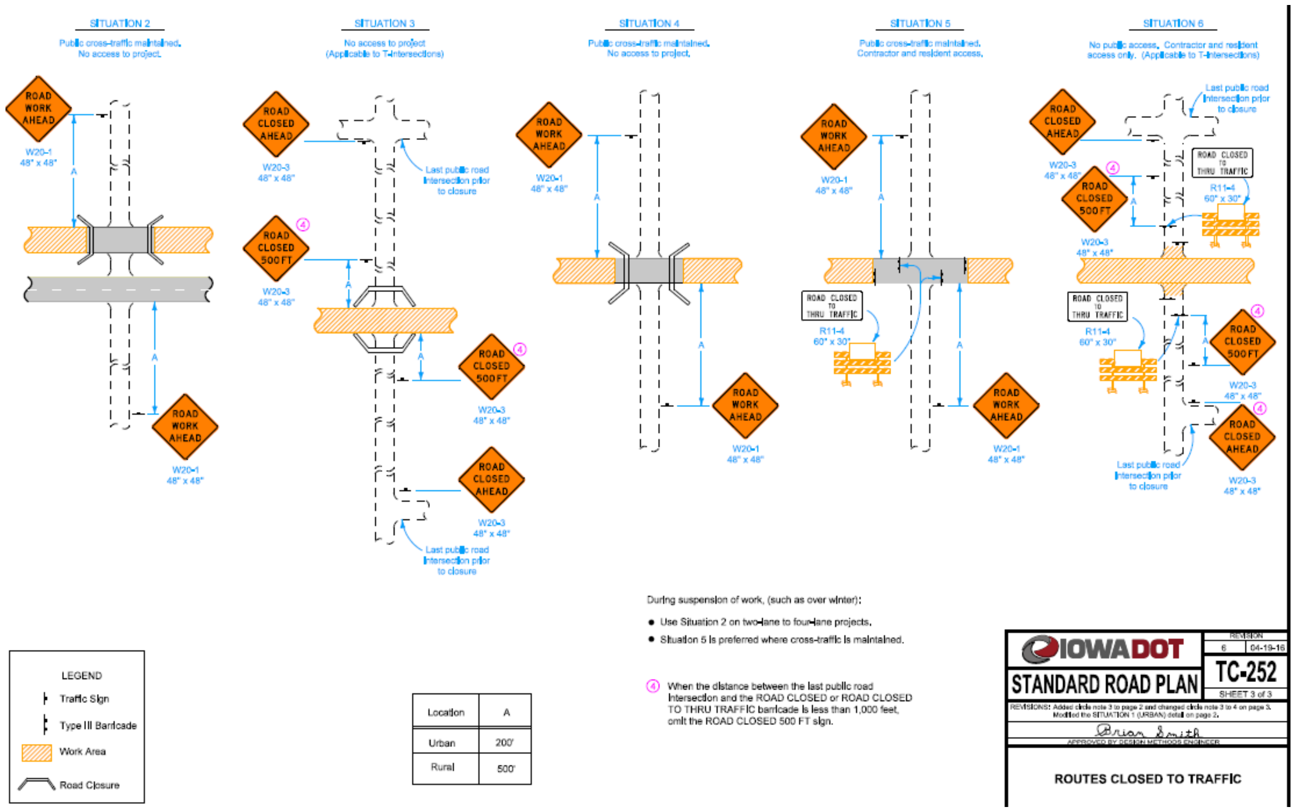
SPEED LIMIT (mph)	A
35 or less	250'
40 - 45	350'
50 or greater	500'

Concrete Barrier Operations

Traffic Control Plan-252

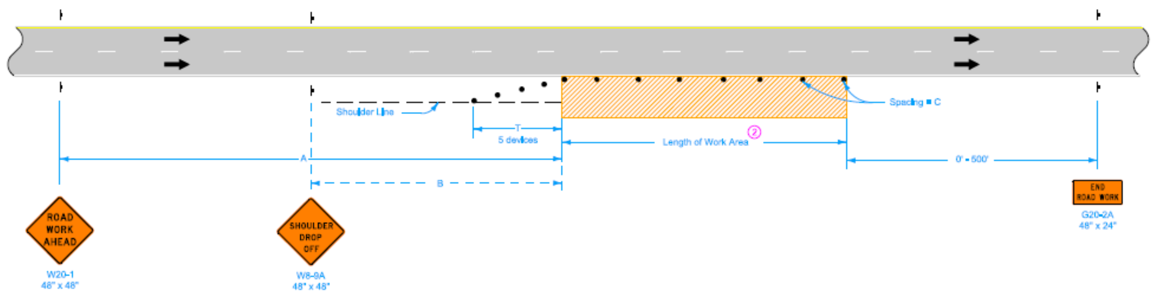


Sign Placements and Barricade Operations



Sign Placements and Barricade Operations

Traffic Control Plan-402



When a pavement edge drop-off exists, install a SHOULDER DROP-OFF sign.

No pavement edge drop-offs greater than pavement depth will be allowed during non-working hours.

Shoulder edge drop-offs shall be mitigated according to Article 1107.08,L2 of the Standard Specifications.

For work lasting less than one hour, refer to TC-1.

Possible Contract Item:
Traffic Control

LEGEND

- Traffic Sign
- 42" Channelizer
- Work Area
- Direction of Traffic

SPEED LIMIT (mph)	A	B	C (2)	T
40 or less	500'	250'	40'	100'
45 - 50	700'	350'	80' (1)	200'
55 - 60	1500'	500'	100' (1)	200'
65 - 70	1500'	500'	100' (1)	230'

(1) When the length of a pavement edge drop-off is 1000 feet or less, the temporary fillet requirement of Article 1107.08 of the Standard Specifications does not apply. Reduce channelizer spacing to 40 feet.

(2) For work areas less than 200 feet long, use channelizers spaced at 20 foot centers or use a vehicle with an amber revolving light or amber strobe light.

IOWA DOT | REVISION 8 | 04-21-15

STANDARD ROAD PLAN | TC-402 | SHEET 1 of 1

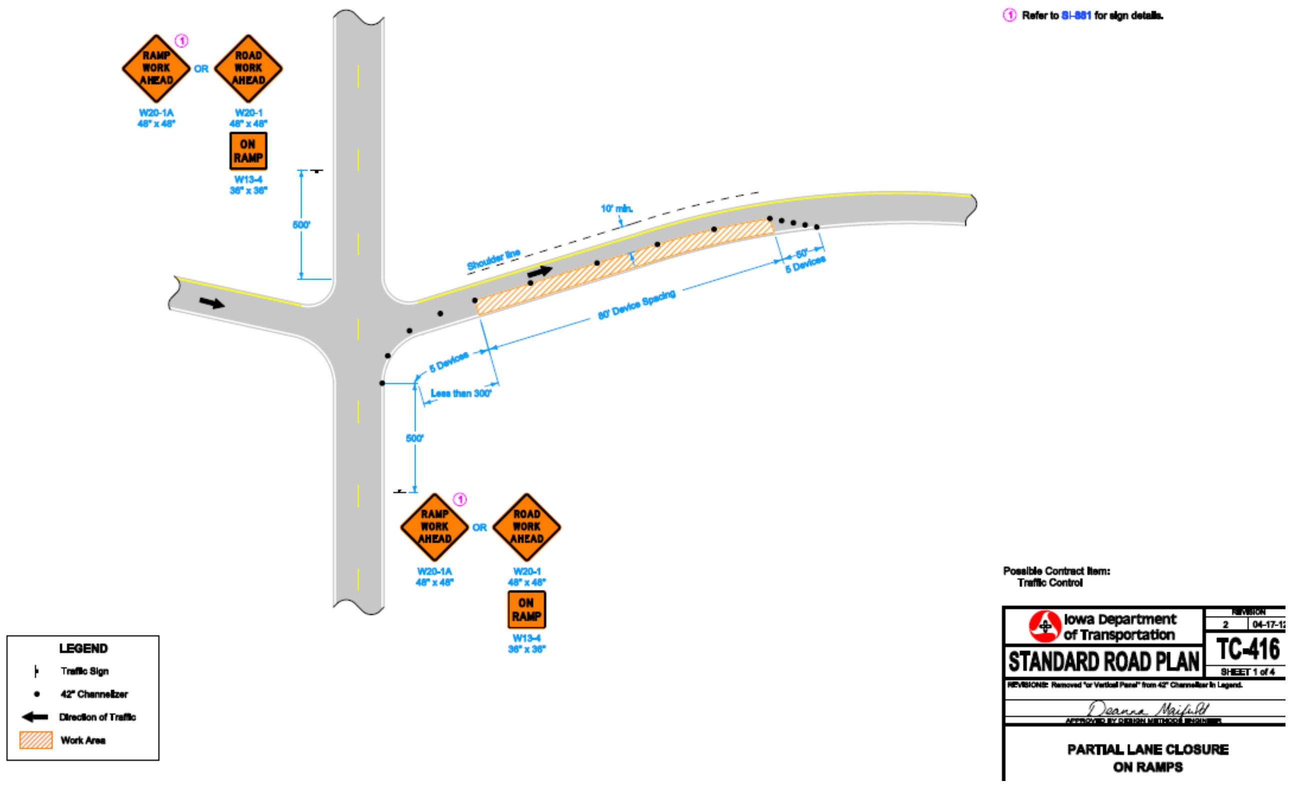
REVISIONS: Modified general notes, changed title and replaced the DOT logo in the title block with the new version.

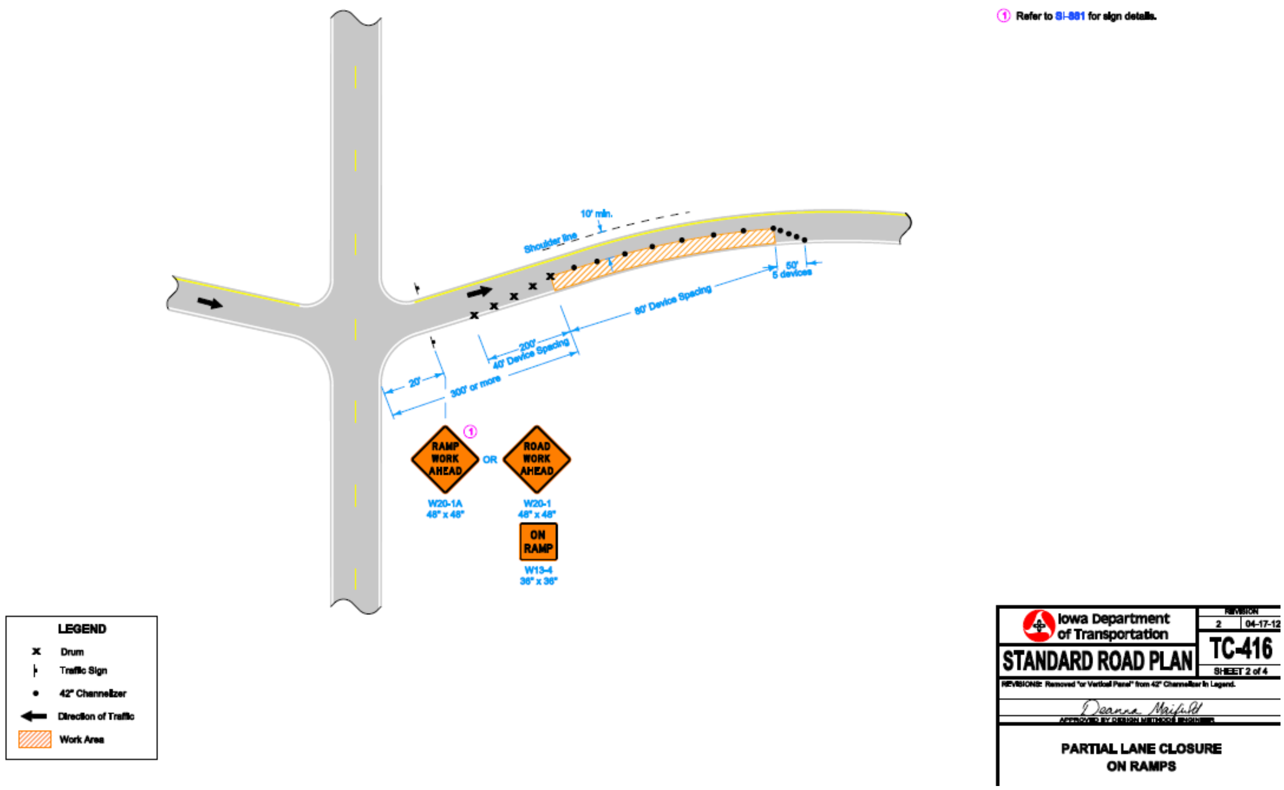
Brian Smith
APPROVED BY DESIGN METHODS ENGINEER

WORK WITHIN 15 FT OF TRAVELED WAY

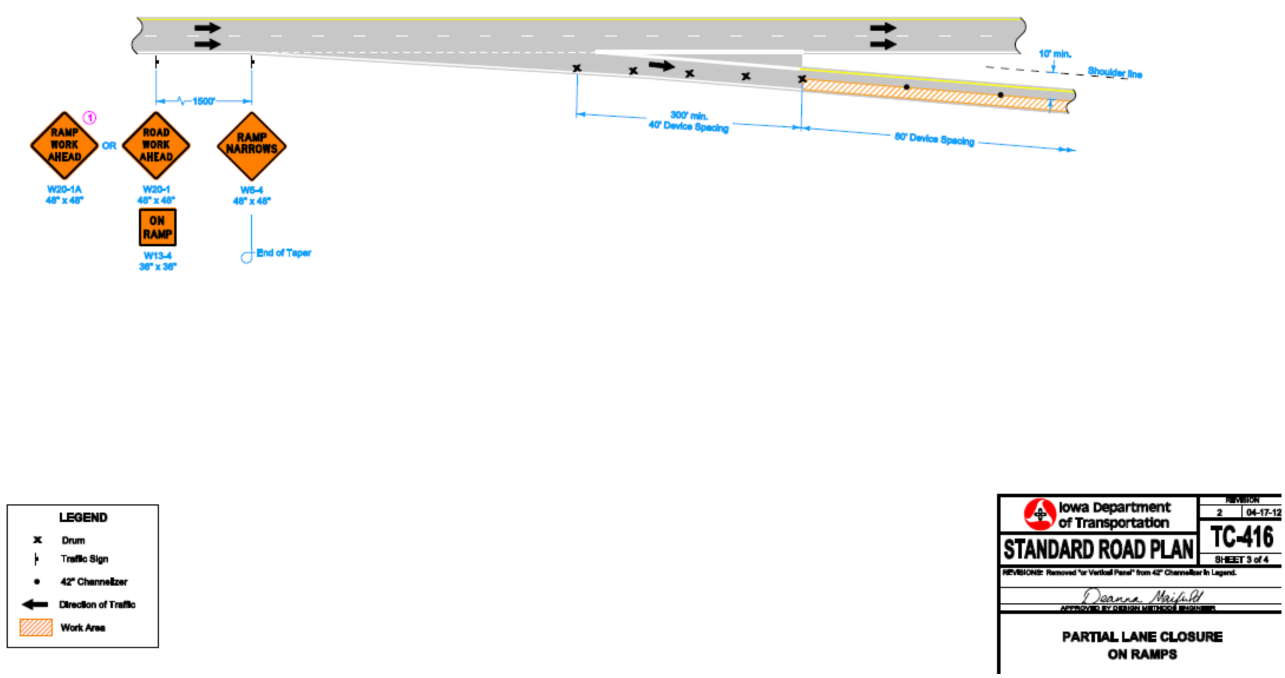
One Lane Pavement Edge and Shoulder Drop-offs

Traffic Control Plan-416

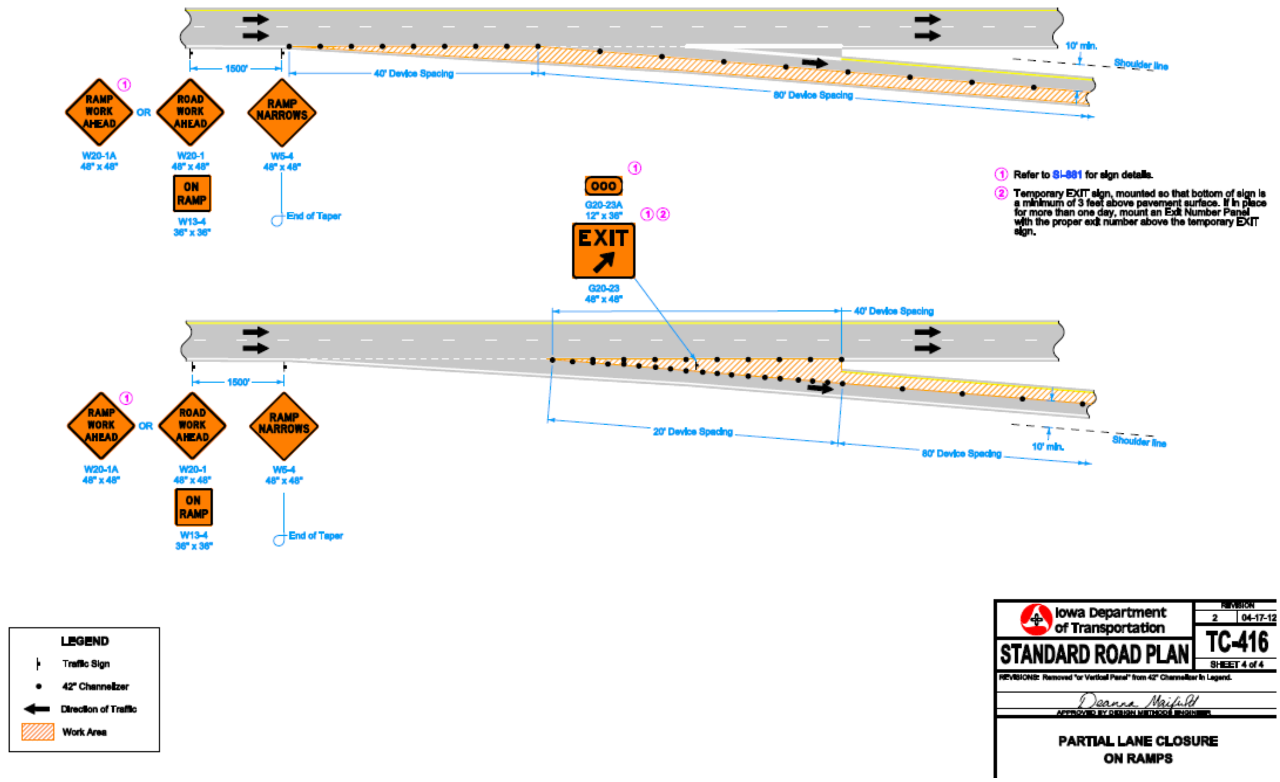




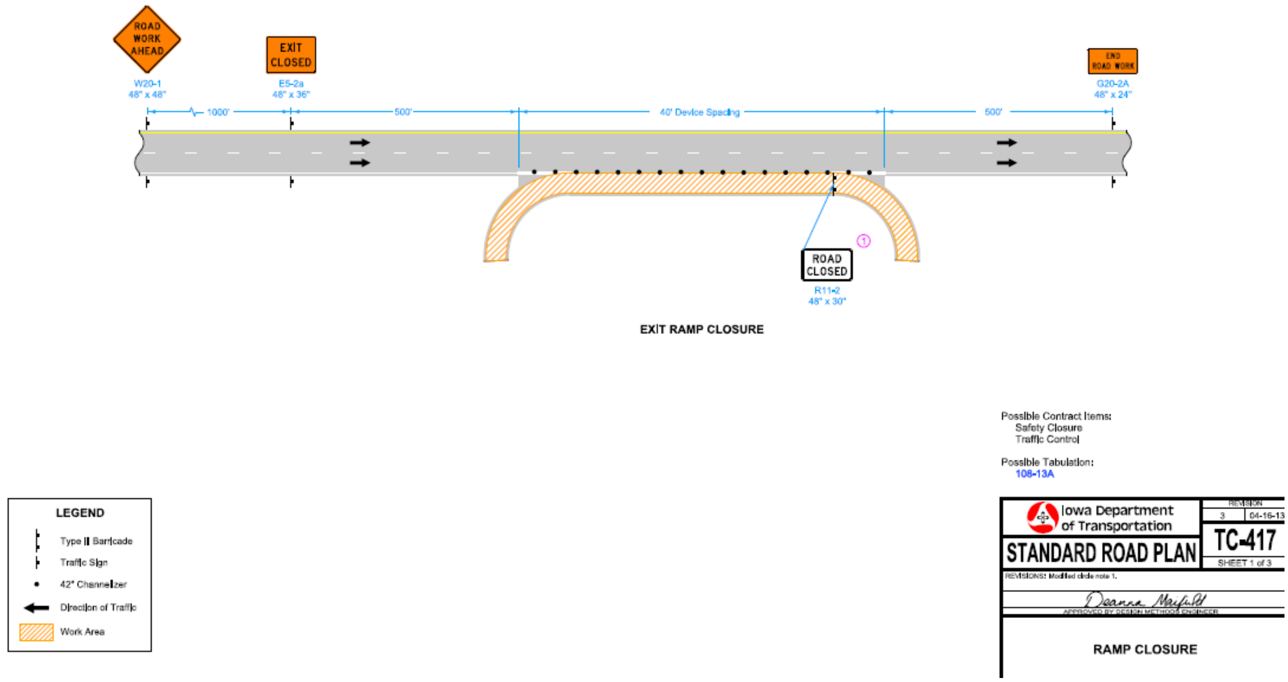
Ramps and Interchanges



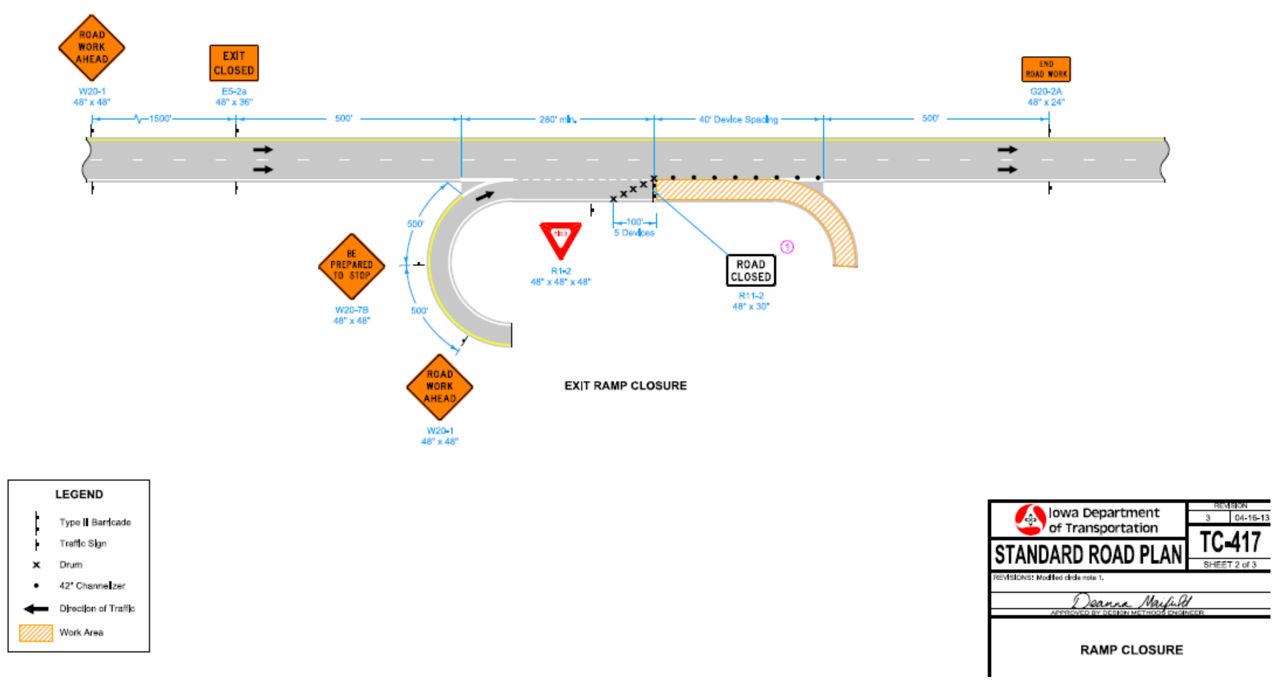
Ramps and Interchanges


RAMP WORK AHEAD
OR
ROAD WORK AHEAD
RAMP NARROWS
W20-1A 48" x 48"
W20-1 48" x 48"
W5-4 48" x 48"
ON RAMP
W13-4 36" x 36"
End of Taper
1500'
40' Device Spacing
80' Device Spacing
20' Device Spacing
10' min.
Shoulder line
000
G20-23A 12" x 36"
EXIT
G20-23 48" x 48"
1 Refer to SI-881 for sign details.
2 Temporary EXIT sign, mounted so that bottom of sign is a minimum of 3 feet above pavement surface. If in place for more than one day, mount an Exit Number Panel with the proper exit number above the temporary EXIT sign.
LEGEND
Traffic Sign
42" Channelizer
Direction of Traffic
Work Area
Iowa Department of Transportation
STANDARD ROAD PLAN
REVISION
2 04-17-12
TC-416
SHEET 4 of 4
REVISIONS: Removed "or Vertical Panel" from 42" Channelizer in Legend.
APPROVED BY DESIGN METHODS ENGINEER
PARTIAL LANE CLOSURE ON RAMPS

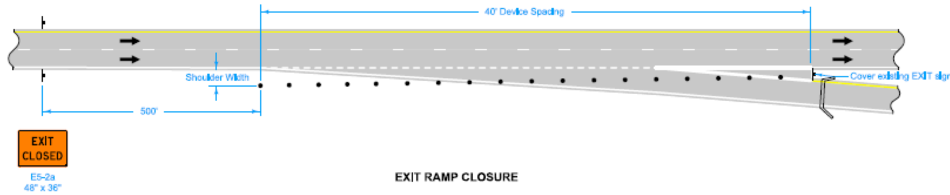
Traffic Control Plan-417



Exit and Entrance Ramp Closures



Exit and Entrance Ramp Closures

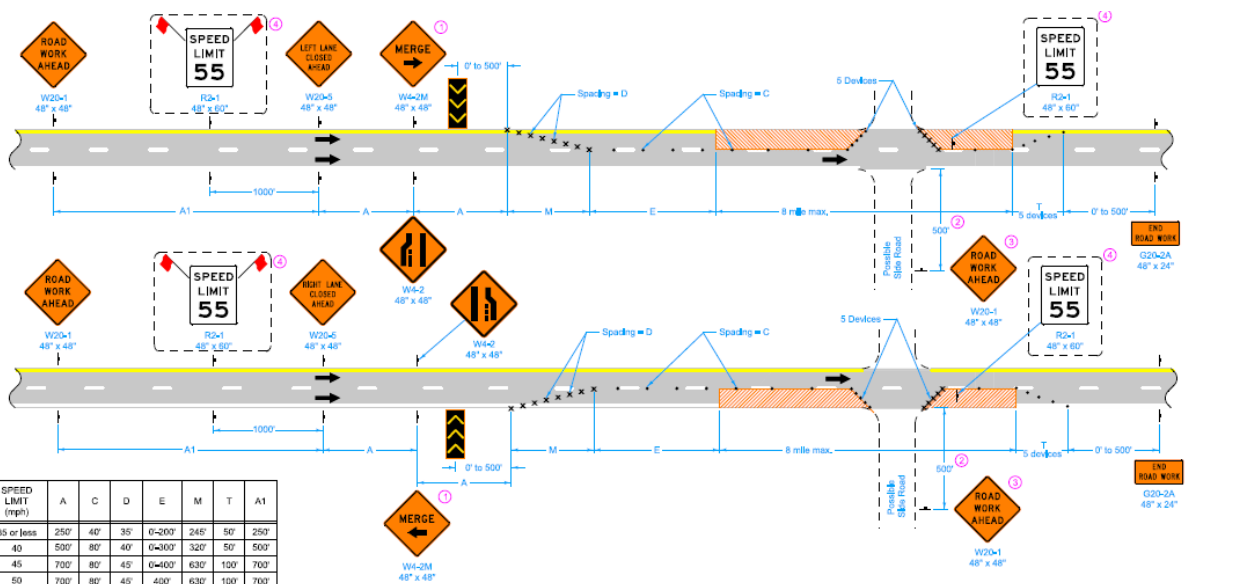


LEGEND
- Road Closure
- Traffic Sign
- 42" Channelizer
- Direction of Traffic

Iowa Department of Transportation
STANDARD ROAD PLAN TC-417
SHEET 3 of 3
RAMP CLOSURE

Exit and Entrance Ramp Closures

Traffic Control Plan-418



SPEED LIMIT (mph)	A	C	D	E	M	T	A1
35 or less	250'	40'	35'	0'-200'	245'	50'	250'
40	500'	80'	40'	0'-300'	320'	50'	500'
45	700'	80'	45'	0'-400'	630'	100'	700'
50	700'	80'	45'	400'	630'	100'	700'
55 - 60	1000'	100'	55'	600'	770'	100'	2000'
65 - 70	1000'	100'	65'	700'	910'	100'	2000'

LEGEND
- Direction Of Traffic
- Traffic Sign
- Drum
- 42" Channelizer
- Arrow Board
- Work Area

When the Average Daily Traffic (ADT) exceeds 20,000 vehicles per day or when a traffic queue extends beyond the advanced signing, place RIGHT/LEFT LANE CLOSED 4 MILES and RIGHT/LEFT LANE CLOSED 2 MILES signs (W20-5) on both sides of the roadway 4 miles and 2 miles in advance of the lane closure, respectively, as appropriate.

Where there is a lane line drop-off or rise, do not allow traffic to cross over the drop-off or rise, except for ramp locations where a BUMP (W8-1) sign is placed.

Lane line drop-offs greater than a nominal 4 inches are not allowed during non-working hours.

1. Refer to SI-881 for sign details.
2. Where side road speed limit is 40 mph or less, a distance of 200 feet is allowed.
3. Place a ROAD WORK AHEAD sign on the opposite side of the intersection in a similar location.
4. For roadways with a posted speed limit of 60 mph or greater before road work:

   Place SPEED LIMIT 55 signs prior to the lane closure as shown.

   When the length of closure is greater than 1 mile, install SPEED LIMIT 55 signs in the closed lane at 1-mile intervals.

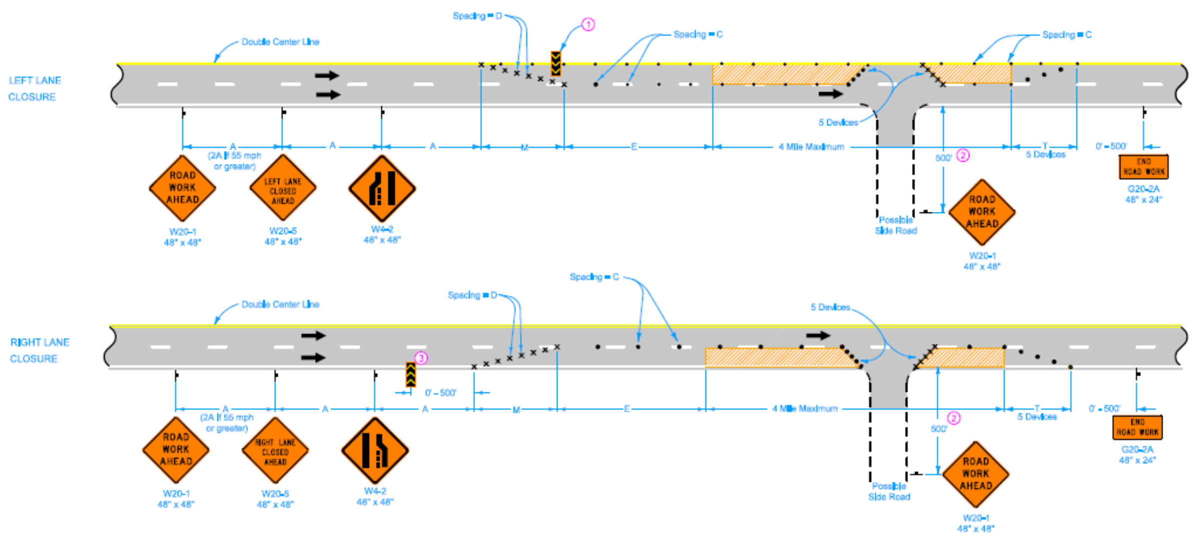
   Remove or cover all existing signs that conflict with 55 mph speed limit while 55 mph speed limit is in effect.

Possible Contract Item:
Traffic Control

Iowa Department of Transportation
STANDARD ROAD PLAN TC-418
SHEET 1 of 1
LANE CLOSURE ON DIVIDED HIGHWAY

High Volume Lane Closures and Speed Limit Reductions

Traffic Control Plan-419



LEGEND

- Traffic Sign
- Drum
- 42" Channelizer
- Arrow Board
- Work Area
- Direction of Traffic

SPEED LIMIT (mph)	A	C	D	E	M	T
35 or less	250'	40'	35'	0'-200'	245'	50'
40	500'	80'	40'	0'-300'	320'	50'
45	700'	80'	45'	0'-400'	630'	100'
50	700'	80'	45'	400'	630'	100'
55 - 60	1000'	100'	55'	600'	770'	100'

Where there is a lane line drop-off or rise, do not allow traffic to cross over the drop-off or rise, except for ramp locations where a BUMP (W8-1) sign is placed.

Lane line drop-offs greater than a nominal 4 inches are not allowed during non-working hours.

(1) Place arrow board within the closed lane behind the drums and as close to the beginning of the taper as practical.

(2) Where side road speed limit is 40 mph or less, a distance of 200 feet is allowed.

(3) When there is no shoulder, place arrow board within the closed lane behind the drums and as close to the beginning of the taper as practical.

Possible Contract Item:

Traffic Control

IOWA DOT
STANDARD ROAD PLAN

REVISION 7 04-19-16

TC-419

SHEET 1 of 1

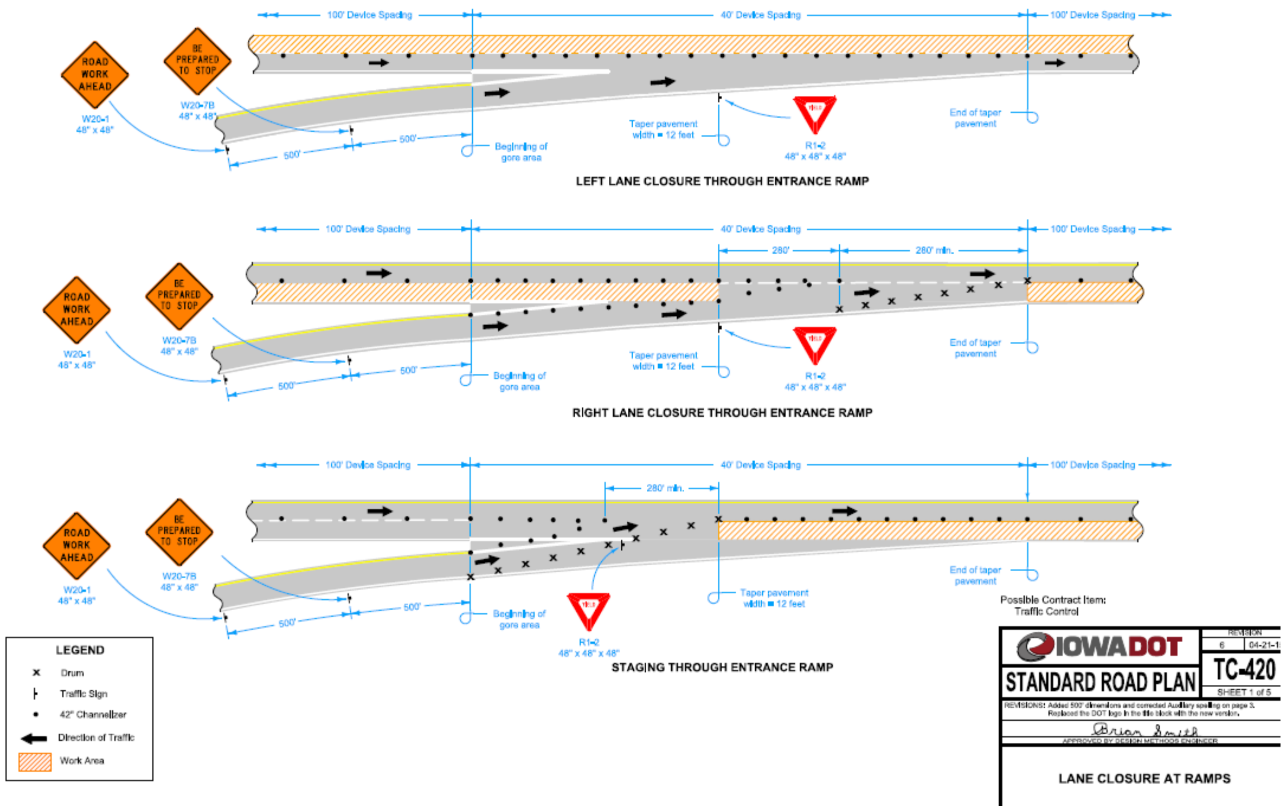
REVISIONS: Added circle note 3.

Brian Smith
APPROVED BY DESIGN METHODS ENGINEER

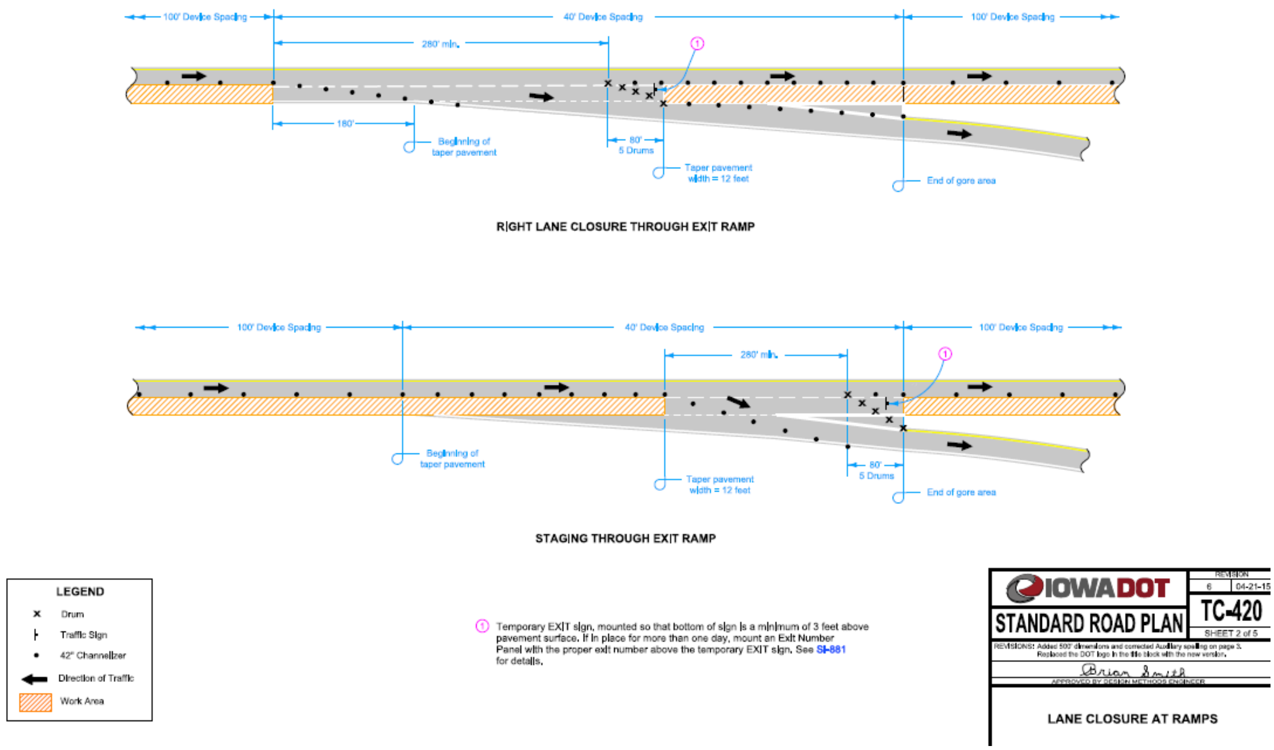
LANE CLOSURE ON UNDIVIDED HIGHWAY

Lane Closures and Drop Offs

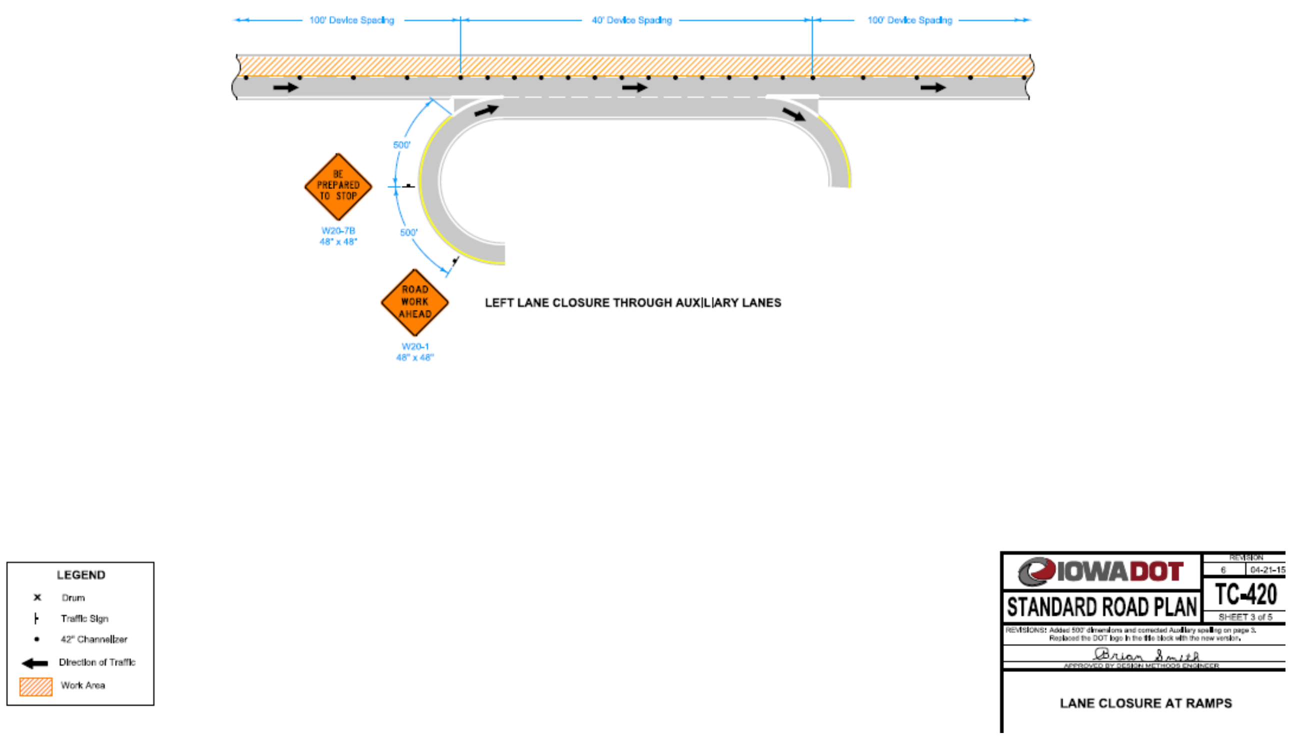
Traffic Control Plan-420



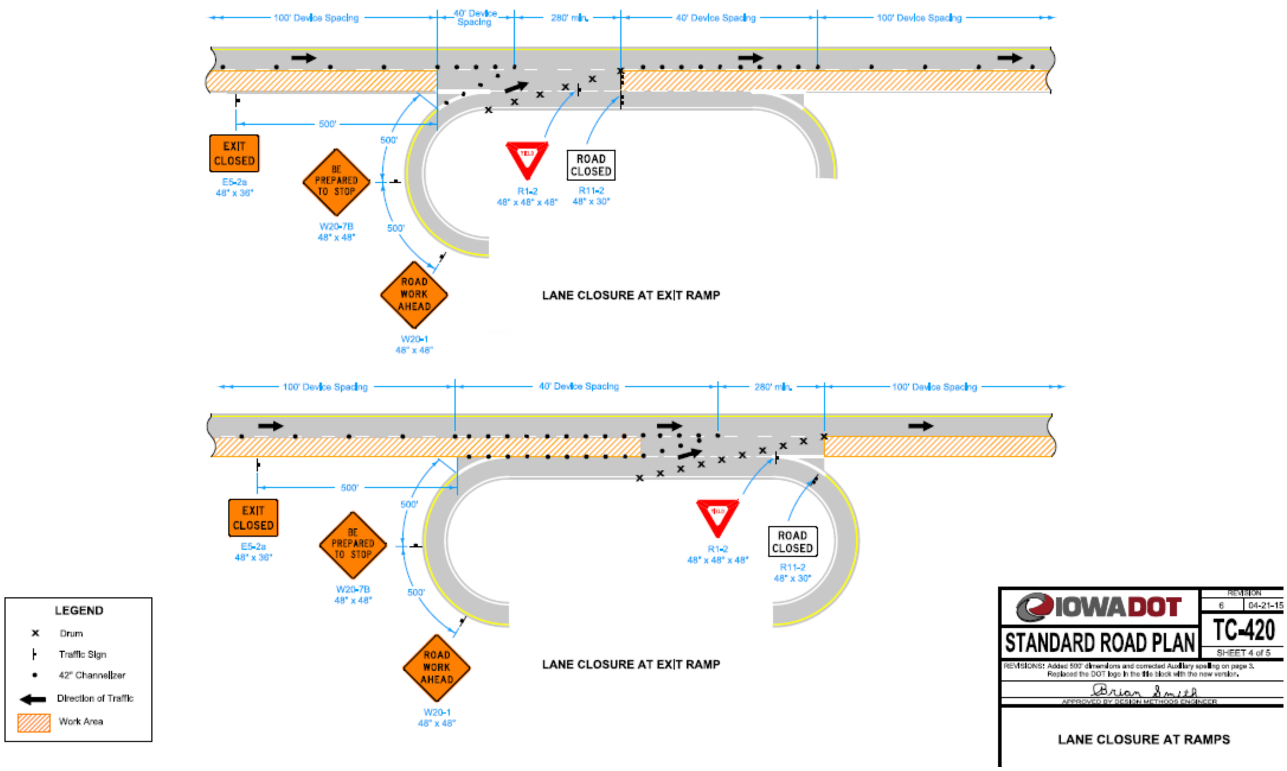
Lane Closures at Ramps



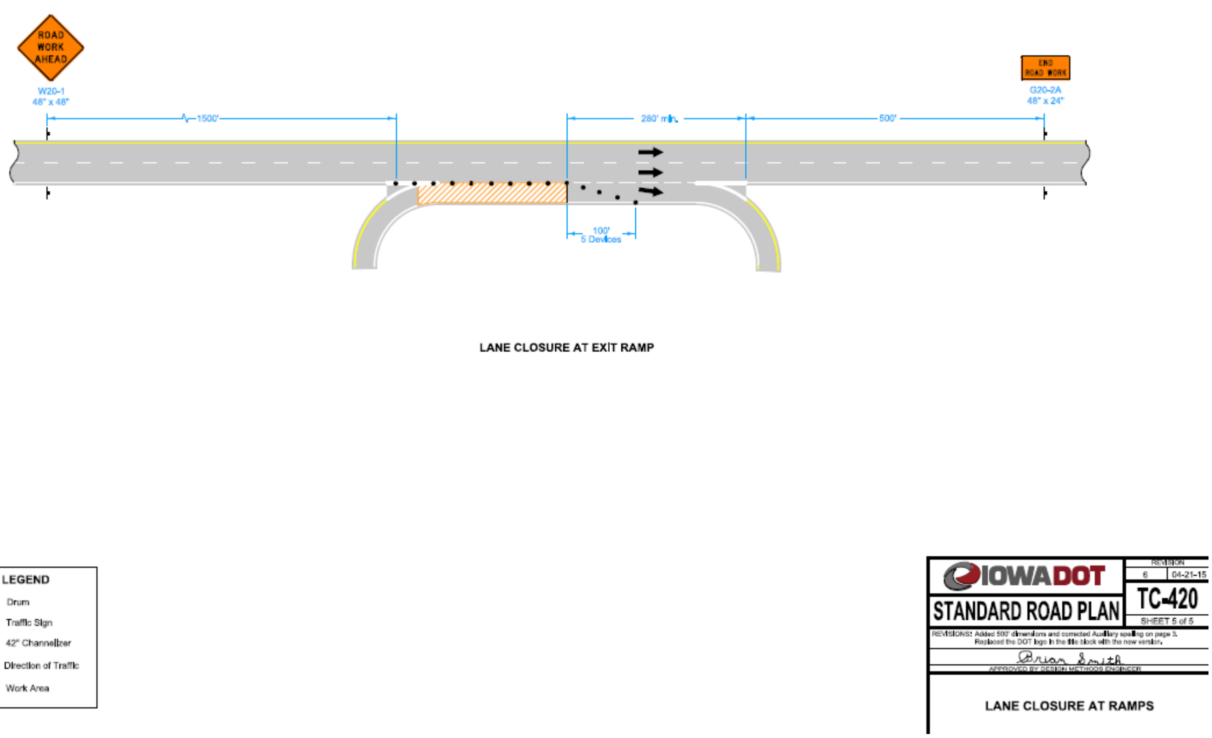
Lane Closures at Ramps



Lane Closures at Ramps

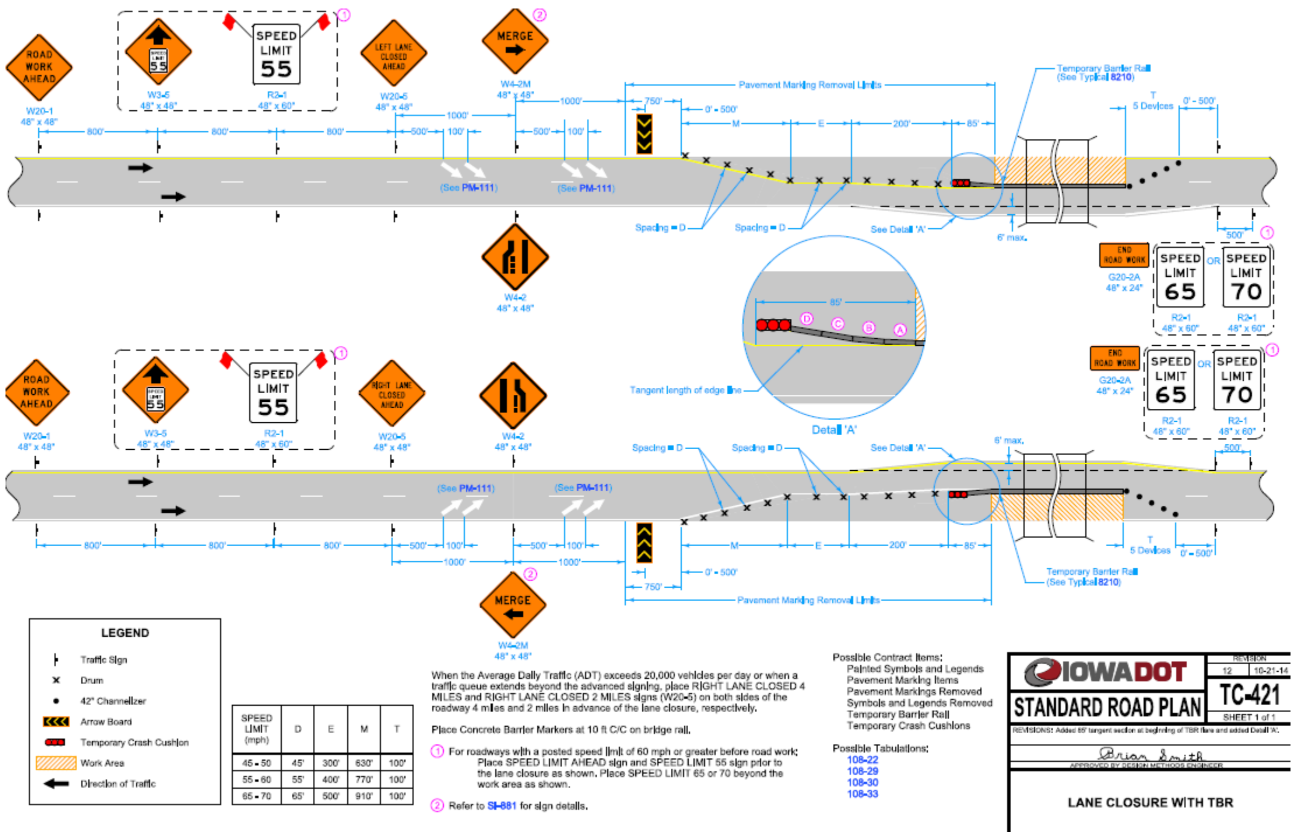


Lane Closures at Ramps



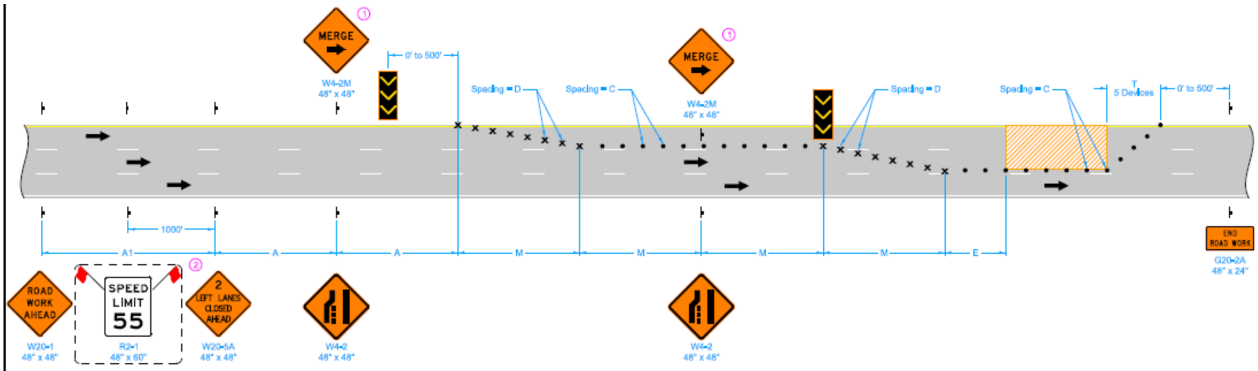
Lane Closures at Ramps

Traffic Control Plan-421



High Volume Tapers and Sign Placement

Traffic Control Plan-422



When the Average Daily Traffic (ADT) exceeds 20,000 vehicles per day or when a traffic queue extends beyond the advanced signing, place RIGHT/LEFT LANE CLOSED 4 MILES and RIGHT/LEFT LANE CLOSED 2 MILES signs (W20-6) on both sides of the roadway 4 miles and 2 miles in advance of the lane closure, respectively, as appropriate.

Where there is a lane line drop-off or rise, do not allow traffic to cross over the drop-off or rise, except for ramp locations where a BUMP (W8-1) sign is placed.

Lane line drop-offs greater than a nominal 4 inches are not allowed during non-working hours.

Possible Contract Item:
Traffic Control

LEGEND

- Direction Of Traffic
- Traffic Sign
- Drum
- 42" Channelizer
- Arrow Board
- Work Area

SPEED LIMIT (mph)	A	C	D	E	M	T	A1
35 or less	250'	40'	35'	0'-200'	245'	50'	250'
40	500'	80'	40'	0'-300'	320'	50'	500'
45	700'	80'	45'	0'-400'	630'	100'	700'
50	700'	80'	45'	400'	630'	100'	700'
55 - 60	1000'	100'	55'	600'	770'	100'	2000'
65 - 70	1000'	100'	65'	700'	910'	100'	2000'

(1) Refer to SI-881 for sign details.

(2) For roadways with a posted speed limit of 60 mph or greater before road work;

Place SPEED LIMIT 55 signs prior to the lane closure as shown.

When the length of closure is greater than 1 mile, install SPEED LIMIT 55 signs in the closed lane at 1-mile intervals.

Remove or cover all existing signs that conflict with 55 mph speed limit while 55 mph speed limit is in effect.

Iowa Department of Transportation

STANDARD ROAD PLAN	TC-422
REVISION	8 — 10-15-13
	SHEET 1 of 1

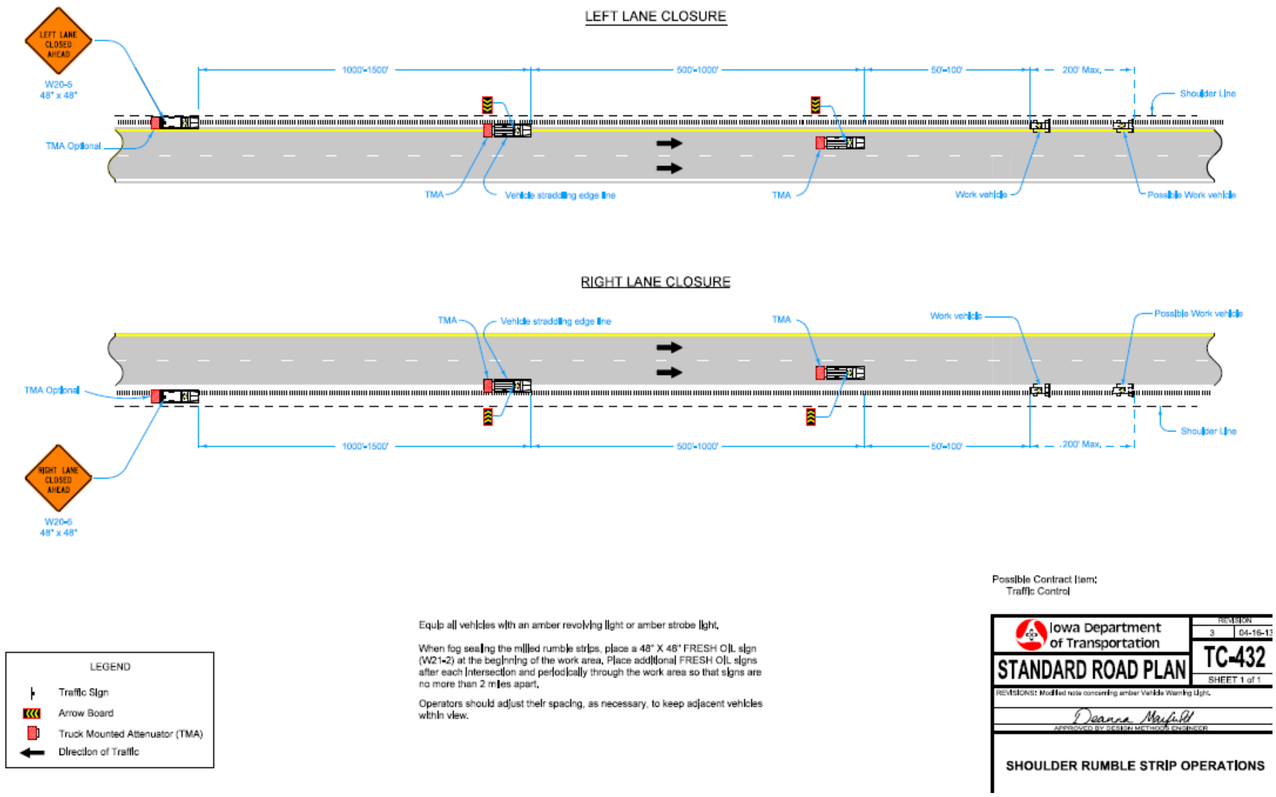
REVISIONS: Clarified lane line drop-off in the general notes.

Brian Smith
APPROVED BY DESIGN METHODS ENGINEER

CLOSURE OF TWO ADJACENT LANES ON DIVIDED HIGHWAY

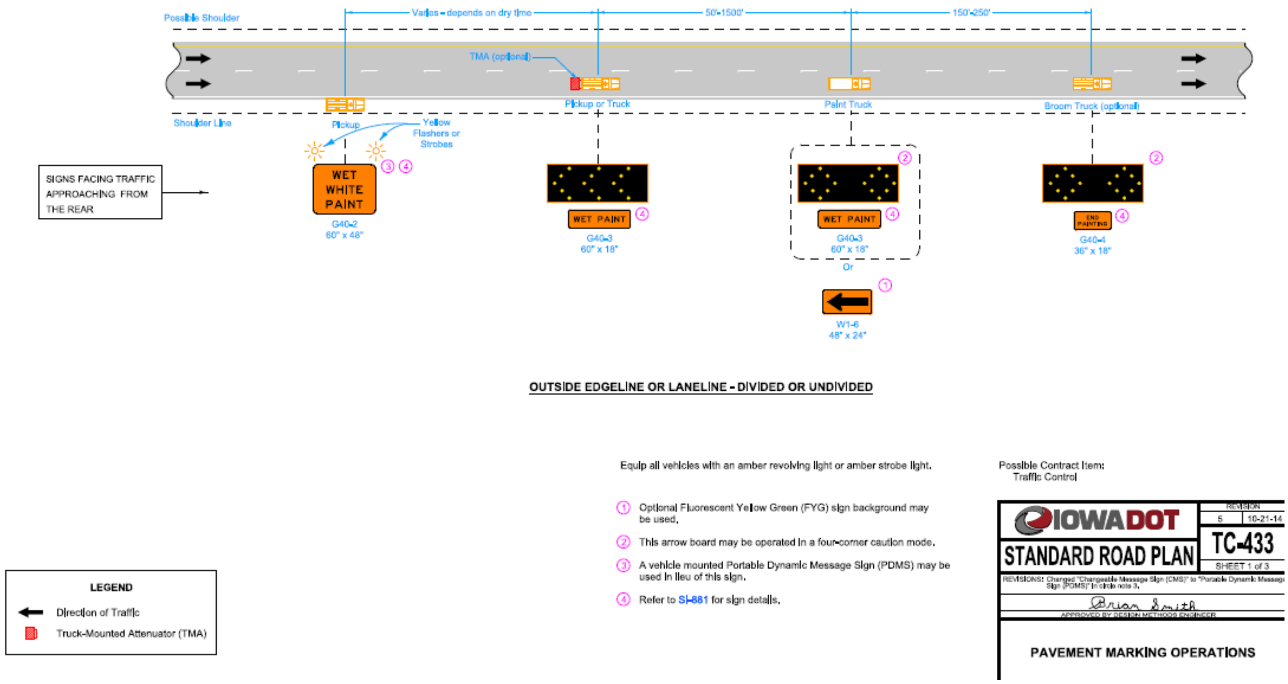
High Volume Lane Closures

Traffic Control Plan-432

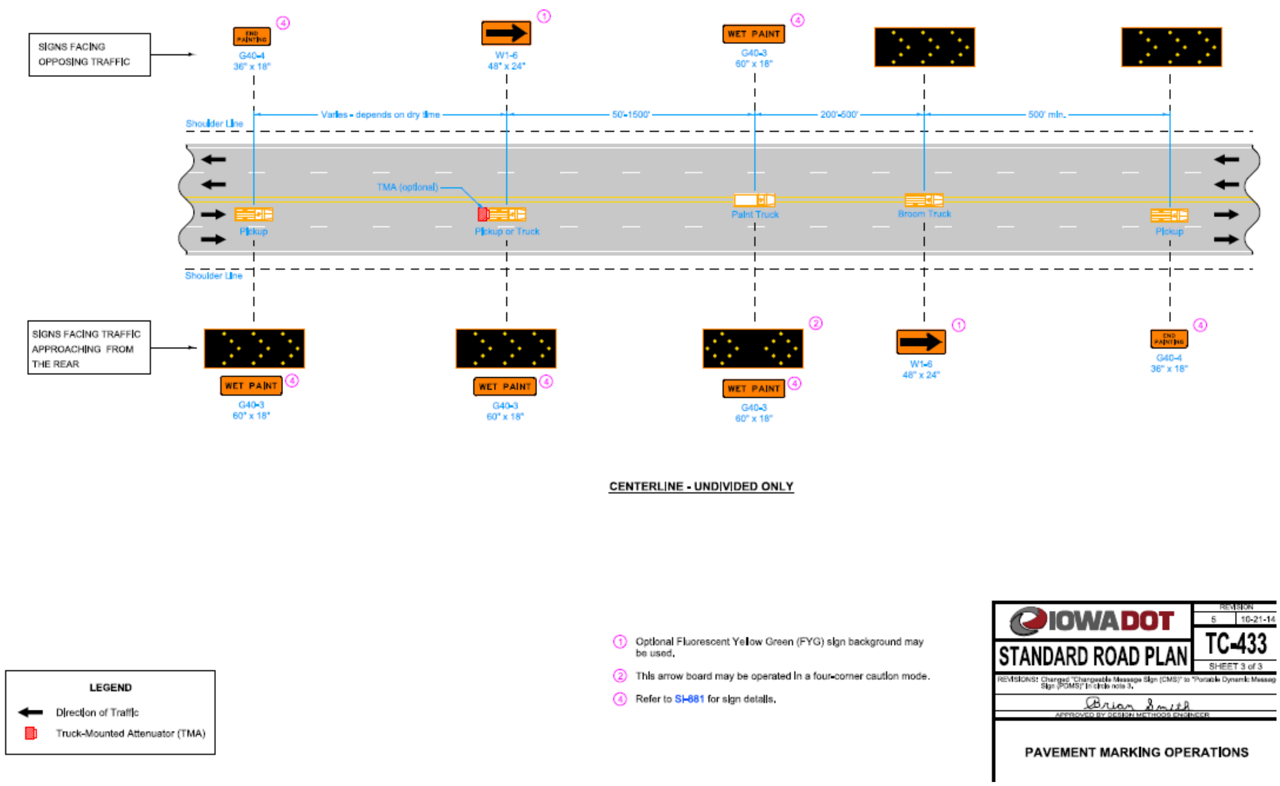


Direction Specific Lane Closures

Traffic Control Plan-433

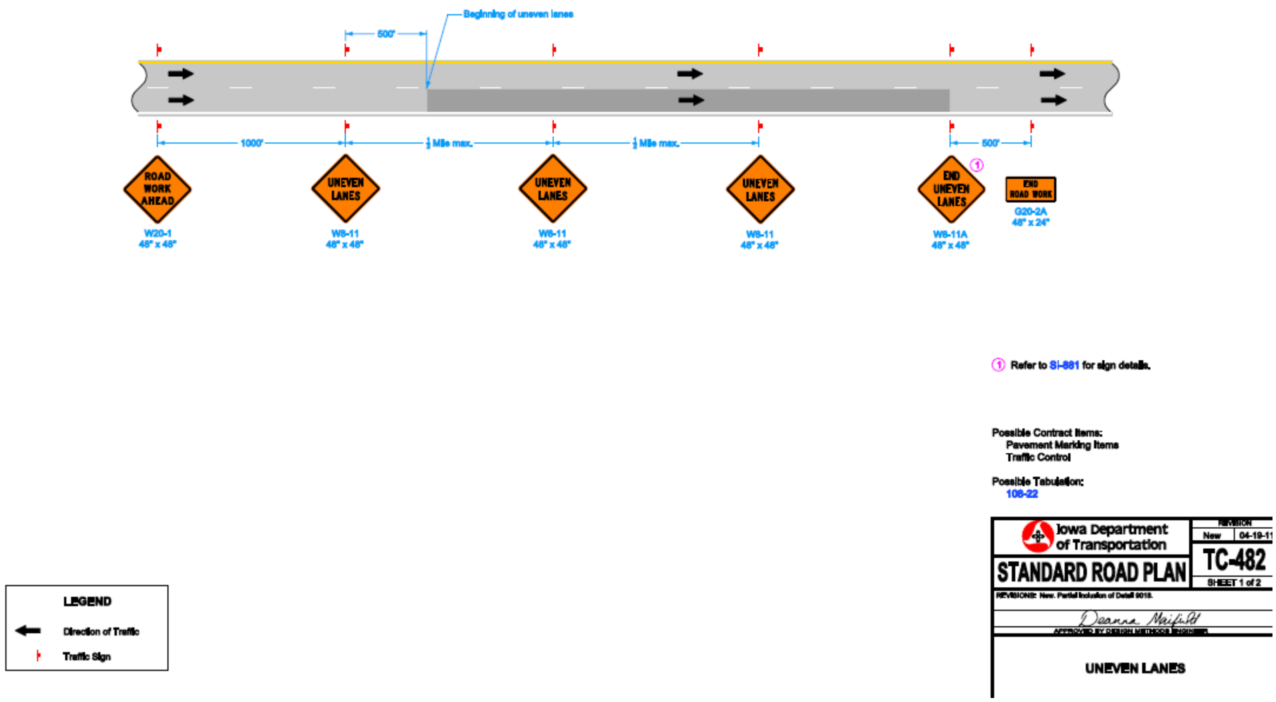


Edge Line Markings

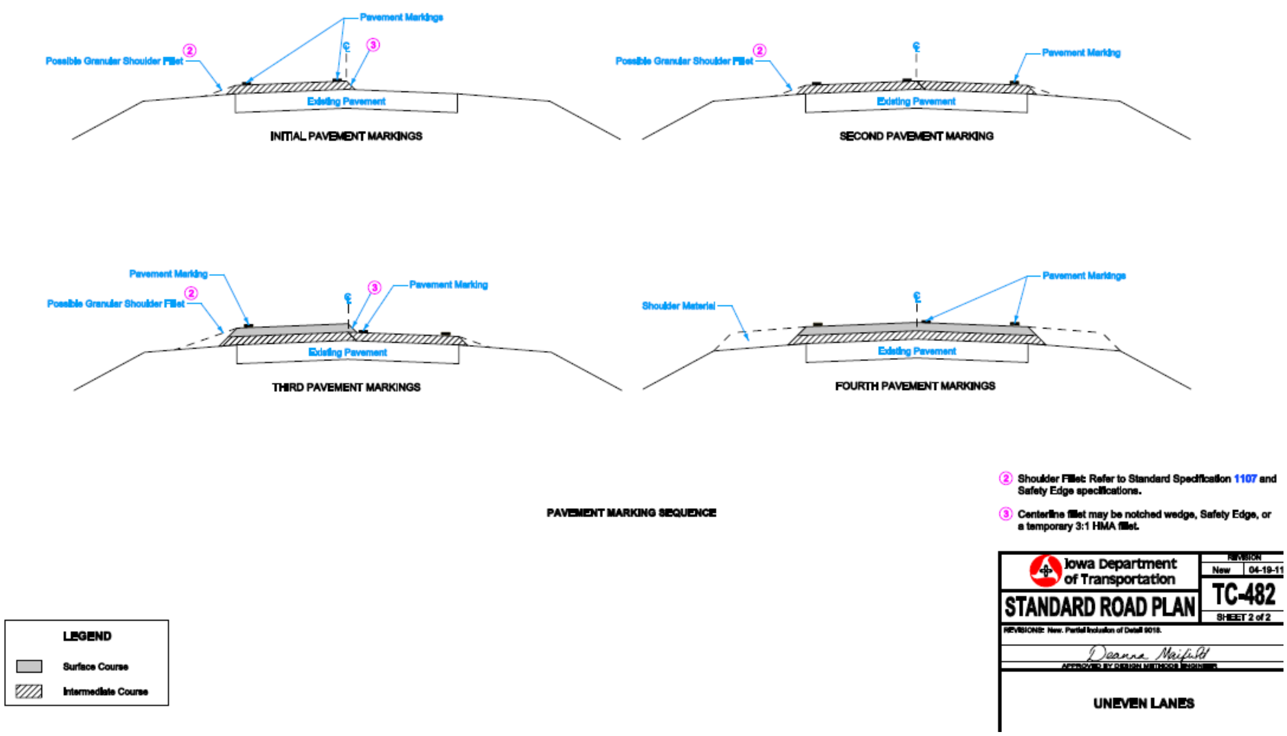


Edge Line Markings

4.4.1 Traffic Control Plan-482



Operations involving Uneven Lanes



APPENDIX B

CODE FOR REDUCING ZERO CRASH COUNT TIME DURATIONS OF MOST SEVERE LANE CLOSURE AT ANY GIVEN TIME DURING THE CONSTRUCTION PERIOD:

[Written in MATLAB]

```
Working_matrix=horzcat(workzone_name,message_starttime,
message_endtime,lane_blocked_lane);
unique_blocked_lane_ids=unique(blocked_lane);
for i=1:length(unique_blocked_lane_ids)
    workdata_new=Working_matrix(Working_matrix(:,4)== unique_blocked_lane_ids (i),:);
     k=size(workdata_new,1);
    for j=1:k
        refer(workdata_new(j,2):workdata_new(j,3),i)= unique_blocked_lane_ids (i);
    end
end
refer(~refer(:))=100;
l=size(refer,2);
for i=1:size(refer,1)
    refer(i,l+1)=min([refer(i,1) refer(i,2) refer(i,3)]);
end
refer(refer(:,l+1)==100,:)=[];
for i=1:length(unique_blocked_lane_ids)
    refer(i,l+2)=sum(refer((refer(:,l+1)== unique_blocked_lane_ids (i)),l+1))/
unique_blocked_lane_ids (i);
    refer(i,l+3)= unique_blocked_lane_ids (i);
end
```

APPENDIX C CRASH REDUCTION METHODOLOGY