DEPARTMENT OF TRANSPORTATION

Work Zone Intrusion Report Interface Design

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While necessary for roadways, work zones present a safety risk to crew. Half of road workers deaths between 2005 and 2010 were due to collisions with motorists intruding on the work zone. Therefore, addressing intrusions is an important step for ensuring a safe work environment for crewmembers. However, a recent research synthesis at the Minnesota Department of Transportation found that few states had an explicit method for systematically collecting work zone intrusion data. The purpose of this work zone intrusion interface design project was to design an efficient, comprehensive, and user-friendly reporting system for intrusions in work zones. A user-centric, iterative design process was employed to design an adaptable web-based and paper report to account for simple documentation of intrusions not deemed a threat to worker safety and a detailed report for more thorough documentation of serious intrusion events. Final recommendations include organizational changes and support to encourage workers to complete the form and provide valuable data to the state.

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Work Zone Intrusion Report Interface Design

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EXECUTIVE SUMMARY

While necessary for roadways, work zones present a safety risk to work crew. Between 2005 and 2010, 733 road workers died at work zones, half of them due to collisions with motorists intruding on the work zone (FHWA, 2015). Therefore, addressing these intrusions is an important step for ensuring a safe work environment for crewmembers. These intrusions have been documented to occur in most types of work zone operations, including lane and shoulder operations, flagger operations, mobile operations, and traffic control setup and removal operations (Ullman et al., 2011). These statistics are based on work zone crash data, intrusions may be more likely to occur due to weather and lighting factors, road geometry factors, traffic calming measures, and driver factors (e.g., demographics and impairment). However, a recent research synthesis at the Minnesota Department of Transportation (MnDOT, 2015) found that few states had an explicit method for systematically collecting work zone intrusion data. Without this data, any policy or design recommendations made to mitigate intrusions and improve worker safety will not be grounded in significant empirical, verifiable information. The purpose of this work zone intrusion interface design project was to design an efficient, comprehensive, and user-friendly reporting system for intrusions in work zones. The information collected by this system could then be used to examine risk factors and areas of interest to reduce intrusions and risk to workers, disseminate feedback to workers and Department of Transportation administration on safety data, and provide an empirical basis for design changes to work zones and future policy recommendations to the state government.

To design a usable system (Wickens et al., 2004) for work zone intrusions, designers must do the following:

(1) Understand the characteristics of the typical user (in this case, work zone supervisors).
(2) Develop common or typical intrusion scenarios for realistic testing of the system.
(3) Conduct iterative testing with typical users (supervisors and crew) and incorporate revisions based on the results of the tests.

To understand the supervisors and crew, the research team at HumanFIRST conducted semi-structured interviews with work zone supervisors from rural and urban locations across the state (Baxter, St. Cloud, Duluth, and Cedar Ave. stations). Crews and supervisors conceptually understood an intrusion as a vehicle entering the work area cordoned off by cones, but considered an intrusion as practically reportable if the intrusion happened near the activity area threatening active workers or if it threatened a flagger. Furthermore, they considered the primary reportable elements of an intrusion to be the layout, environmental conditions (e.g., weather), location, time, road condition, maneuvers made by intruding vehicle, and work zone operation type. The research team at HumanFIRST extracted the qualitative information from these interviews and codified it into a task analysis of a prototypical intrusion reporting sequence, which informed the initial design of the prototype intrusion report.

The HumanFIRST research team designed four typical intrusion scenarios to test the prototype reporting interface. Those scenarios were reviewed and verified by MnDOT work zone supervisors with minor revisions. The team conducted a series of usability tests across multiple phases with evolving designs of the intrusion reporting interface. The usability test sessions had users input into the intrusion report system either a researcher-generated intrusion scenario or a vividly recalled intrusion event that the crewmember or supervisor directly experienced. In later phases, video recordings of real intrusions on MnDOT roads were used. Participants verbalized their thoughts as they interacted with the interface, and the time to complete each report was recorded. Following the reports, supervisors and crew then answered questions and filled out questionnaires to clarify the difficulty and usability of the intrusion report interface.

Initially, the team tested 6 users across Maple Grove, Cedar Avenue, and Bemidji. This first phase of usability testing led to a finalized prototype, which was implemented by HumanFIRST into a working online beta reporting system hosted by the University of Minnesota. Furthermore, a paper version of the interface was implemented to supplement the online electronic beta interface. A second round of usability tests with 4 work zone supervisors across Minnesota led to a second revision of the beta interface (both electronic and paper). Some takeaway points from the first two phases were: Supervisors liked drop-down menus, comprehensiveness of the reporting system, and that it was relatively quick to use, but they did not necessarily see the rationale for reporting intrusions, particularly minor intrusions in which there was no risk to crew.

In response to the issue with minor intrusions, the HumanFIRST team incorporated a third major revision to the beta interface by splitting up the reporting decision flow into an immediate “basic” report, and a comprehensive “full” report, based on whether there was a reported risk to crew onsite at the work zone. This major revision was incorporated into the online and paper forms, and was then user-tested with a laptop, portable tablet, and the paper form. The final round of user testing on this finalized design version of the reporting interface had good usability scores, difficulty scores, and time to completion scores.

The final version of the work zone intrusion reporting interface should be, based on the results of testing, user-friendly and effective. During implementation by MnDOT, those responsible for administration should be aware that the primary benefit of the online or digital interface is that it should be easy and quick to access in the field, allowing a supervisor or head crewperson on site to rapidly report a work zone intrusion and go about their business. Furthermore, if MnDOT wants reliable and consistent intrusion reporting, an effort to engage work zone supervisors and crewmembers in the benefits, consequences, and decision-making process is essential to the success of the intrusion reporting system. Communication should be made on a widespread and consistent basis about the current and recent data on intrusions, data trends, and what changes are being made as a result of the intrusion reporting.

CHAPTER 1: INTRODUCTION

1.1 LITERATURE REVIEW

Work zone intrusions are a serious safety concern for crew workers, as motorists are known to breach the boundaries of construction, maintenance, and mobile operations. Understanding the factors that contribute to work zone intrusions is largely unknown because the method and standards for capturing data surrounding the events statewide and nationally are not well established, according to a recent transportation research synthesis (CTC, 2015). In the absence of information, little action can be taken to reduce the frequency of intrusions and address this worker safety risk. From 2005 to 2010, the U.S. suffered the loss of 733 road workers, approximately half struck by motorists (FHWA, 2015). Motorists are also injured or killed by intrusion crashes, adding to the urgency for an understanding of intrusion causes.

Addressing intrusions is an important step toward ensuring a safe work environment for work crews on our roadways. Due to the limited data collected regarding work zone intrusion, this review must preliminarily focus on work zone crashes to determine which factors are most likely to be linked to intrusions. The following summary highlights the current practices for defining and documenting work zone intrusions and the current risk factors of work zone crashes and potential intrusions to assist in the identification of which information is most important to collect in documenting intrusions in Minnesota.

1.1.1 Reporting Work Zone Intrusions

A recent transportation research synthesis submitted to the Minnesota DOT (MnDOT, 2015) provided a survey of work zone reporting practices across 19 states. Only three states at the time collected work zone intrusion information (Pennsylvania, North Dakota, and Iowa). The reported information includes incident description, time, date, and location details, a diagram and vehicle count, rate of similar events at the location, and any actions taken. Other details reported by individual states include weather, the presence of law enforcement, and injury/damage. The report (MnDOT, 2015) also noted that work zone intrusion reporting was not as formalized or as complete as reporting for injuries or crashes, and that intrusion reporting was seen as a burden on top of the other responsibilities of safety managers or supervisors.

The primary means of reporting for the three states were by PDF sheets that allowed for electronic entry and submission, although there is some shifting toward handheld devices such as iPads in Iowa. Oregon, although not recording intrusion data at the time of the report, reported that the state will employ smart technologies in the near future. These technologies include high definition cameras that can be date/time stamped and organized with GPS coordinates (MnDOT, 2015).

1.1.2 Defining Work Zone Intrusions

Work zone intrusions can be largely divided into two categories: those that occur intentionally and those that occur unintentionally. A study of work zone intrusion crash reports from New York identified deliberate intrusions when it was reported the driver turned into a driveway, intersection, or exit through a work zone, followed a work vehicle into a work zone, or refused to comply with instructions after interacting with flaggers, for example, driving into the lane after being told to wait (Ullman, Finley, & Theiss, 2011). While risk taking, like drunk driving or speeding, can certainly co-occur with deliberate intrusions, non-deliberate intrusions are often the result of losing control of the vehicle, confusion, distraction or inattention, or avoiding a crash of another kind. The factors that are attributed to these types of intrusions and crashes can vary greatly from environmental conditions to human factors.

1.1.3 Intrusions by Work Zone Type

Various types of work zones and the areas within them can differentially impact the risk of work zone intrusions and crashes. Road segments with narrow lanes, reduce cross sections, closed lanes or otherwise changes to the roadway force drivers to perform maneuvers they may not otherwise perform, and more importantly, may require them to modify their driving in a way in which they may fail to comply (Venugupal & Tarko, 2000; Bella, 2005). Work zone intrusions have been documented and categorized to occur within: lane and shoulder operations, flagger operations, mobile operations, and traffic control setup and removal operations (Ullman et al., 2011).

1.1.3.1 Lane and Shoulder Operations

Lane and shoulder operations are at great risk for intrusion and crash, in part, due to the sheer length of the work area and increased exposure to the travelling public. Long work zones add risk due to the increased exposure; however, shorter work zones may present more extreme speed differentials, which are more likely to disrupt traffic flow and result in crashes (Khattak et al., 2002). Stationary lane and shoulder operations in highways also result in more severe work zone injuries than those in city streets and more than mobile work zones (Wong, Arico, & Rivani, 2011). While precise data is not always available regarding crashes at different points within the work zone, clearly documenting the accurate location can provide useful insight into the different factors at hand throughout the zone. Work areas can be divided into four (MUTCD) to six (MMUCC) areas depending on the criterion being used: -2) Before the First Work Zone Sign, -1) After the First Work Zone Sign, 1) Advanced Warning Area, 2) Transition Area, 3) Activity Area, and 4) Termination Area (Dissanayake & Akepati, 2009). Garber and Zao (2001) reported that 70% of crashes occur in the Activity Area and few occur within the Termination Area, while Dissanayake and Akepati (2009) reported that 40-57% of crashes occur in the Activity Area.

The likelihood of sideswipe crashes increases in the Transition Area, likely due to increased lane changing behavior in this area (Garber & Zao, 2001).

1.1.3.2 Flagger Operations

Flaggers appear to be at greatest risk of being struck compared to other workers in the work zone. In Wisconsin between 2000 and 2010, over twice as many flaggers (i.e., 13) were struck compared to other workers in the work zone (Yu et al., 2013). Of those flaggers, 23% were indirectly struck when one vehicle was pushed into the worker as a result of being rear-ended by another vehicle. Ullman and colleagues (2011) found that 64% of intrusions that occurred at flagger operations were caused by deliberate actions of drivers. Most common were instances where motorists who were instructed to stop decided to unlawfully ignore the directions and drive around the flagger. Otherwise, motorists documented in the report unintentionally entered the work area, most often from being caught off-guard by the traffic conditions.

1.1.3.3 Mobile Operations

Mobile work zone intrusions that result in a crash appear to be infrequent; however, the frequency at which intrusions occur within them without resulting in a crash is unclear. A study of New York work zone crashes from 1993 to 1998 found that only 20% of intrusion crashes occurred in mobile work zones, while stationary work zones accounted for the remaining 80% (Bryden, Andrew, Fortuniewicz, 2000). It is unclear to what extent exposure may influence these percentages since stationary work zones are likely to outnumber mobile operations in both frequency counts and hours of operation. Deliberate intrusions in mobile operations appear to be infrequent; however, the documented cases involving crashes in mobile work zones are rare, providing few data points to draw firm conclusions. Two of the eight intrusion crashes in mobile work zones in New York were deemed deliberate where motorists chose to pull in between two work vehicles in the convoy (Ullman et al., 2011). The remaining unintentional intrusions were the result of motorists misjudging the speed or distance of the convoy or, in one case, being forced into the convoy to avoid a crash.

1.1.3.4 Traffic Control Setup and Removal Operations

However infrequent, workers appear to be at a risk while they are in the process of setting up or removing traffic control devices or work zone boundaries. Two Wisconsin workers were struck while setting temporary traffic control devices between 2000 and 2010 (Yu et al., 2013). Similarly, nine crashes were documented in New York involving setup or removal operations (Ullman et al., 2011). A third was due to deliberate actions by drivers (e.g., choosing to pass the convoy on the shoulder or entered into the convoy during cone retrieval). The remaining two-thirds were unintentional, but largely the result of inattentive driving.

1.1.4 Environmental Risks

1.1.4.1 Lighting and Weather Factors in Work Zone Crashes

Work zones are at a heightened risk under poor visibility conditions, such as at night or during inclement weather (Garber & Woo, 1990). Fatal crash risk in maintenance work zones is greatest under dark conditions, contrasted by construction and utility work zones, which are under greatest risk of fatal crash in daylight (Weng & Meng, 2011) and non-peak daylight hours (Wong et al., 2011). This discrepancy may be attributed to the most likely hours that work tends to occur. Nighttime work has compounding effects with drivers since not only are they operating under poorer visibility, but they are also more likely to be driving fatigued or distracted (McAvoy, Schattler, & Datta, 2007). Drowsy drivers or drivers engaged in a long, boring trip have slower reaction times and are less likely to detect hazards. Moreover, drowsy drivers have been demonstrated to perform equally or worse than drivers at the legally acceptable level of alcohol intoxication (Dawson & Reid, 1997). This is important to note if a long stretch of roadway must be traveled prior to reaching a work zone since drivers who finally reach it may likely be tired, travelling at high speeds, or both.

Approximately 78% of work zone crashes in Minnesota occur during the day and under clear conditions since a majority of work occurs in the summer months when daylight and accommodating weather are maximized (Minnesota Crash Facts, 2013). Adverse weather, however infrequent, does increase the risk of more serious crashes compared to clear weather conditions (Katta, 2013). This is likely due to poor vehicle control on wet surfaces, but may have a protective effect on work zones since drivers are more likely to reduce their speeds in inclement weather.

Investigations of work zone intrusion crashes have shown that when a vehicle intrudes into a work area, the likelihood that it will strike a worker is less (9%) than the likelihood it will strike work equipment or vehicles (53%) (Bryden et al., 2000). However, a follow up investigation for New York from 2000-2005 found the percent of worker strikes increased to 30% of all intrusion crashes if they occurred at night (Ullman, Finley, Bryden, Srinivasan, & Council, 2008).

The lighting conditions of the work zone site itself is also an important factor in the margin of risk. Poorly lit work zones (i.e., limited or no lighting) have been found to be associated with increased fatal crash risk and this is more profound than when compared to poorly lit non-work zone roadways (Li & Bai, 2008; Daniel, Dixon, & Jared, 2000). The safety risk of work zones at night can be ameliorated by increasing the conspicuity of the area through retroreflective materials (e.g., alternating orange and white stripes) to increase the visibility of workers, signs, barrels, and barriers (McAvoy et al., 2007). Properly placing the reflective material on workers and vehicles can help best ensure that motorists properly detect them at night. Simply adding retroreflective striping to workers' thighs significantly increased the distance at which drivers could react to their presence, with the best performing placement being at the vest, elbows, wrists, knees, and ankles (Wood, Marszalek, Lacherez, & Tyrrell, 2014, see Figure 1.1).

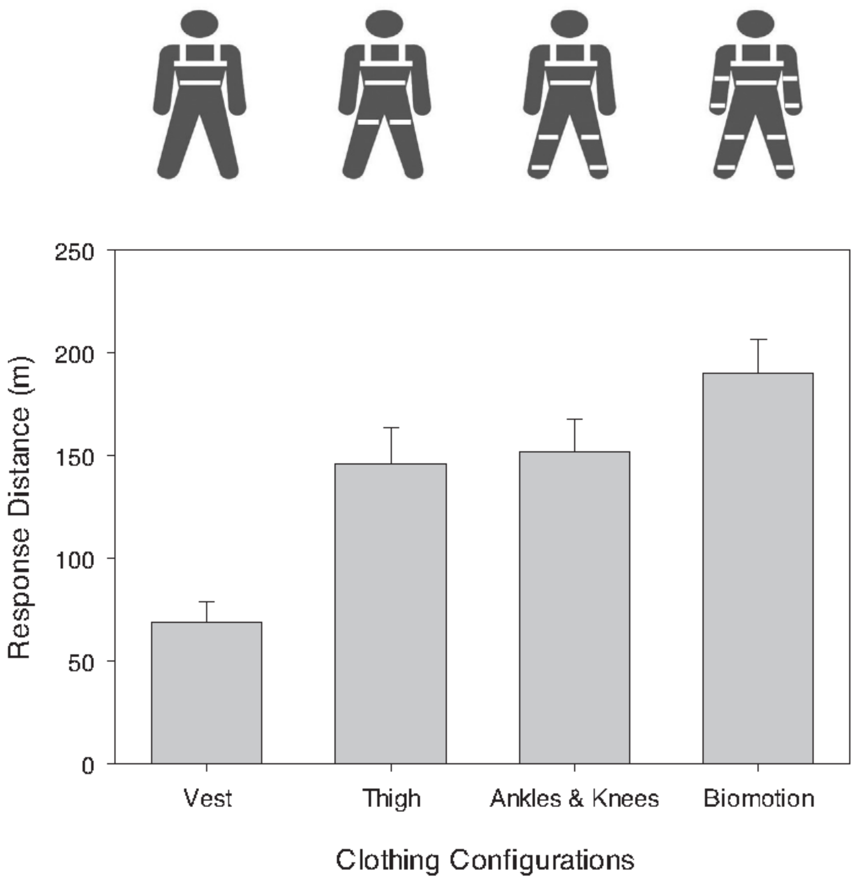


Figure 1.1 Adapted graph and images from Wood et al. (2014) depicting response distances corresponding with four different retroreflective stripping compositions on workers.

Retroreflective tape on work vehicles can also help to increase conspicuity at night. Motorists may have difficulty, however, determining the stopped or slow status of work trucks at night, in the absence of other visual cues, if the work trucks are parked or travelling parallel to the movement of traffic. Motorists have been shown to have a faster reaction time if vehicles are parked in a diagonal or "echelon" position relative to traffic (Langham, Hole, Edwards, & O'Neil, 2002).

Lastly, proper maintenance of surfaces used to increase visibility is important for safety. Reflective materials and striping can help to increase the visibility of workers, signs, barrels, and barriers; however, dust created by construction activities, road debris, dents and tears in the retro-reflective sheeting, over time, reduce visibility (McAvoy et al., 2007).

1.1.4.2 Road Geometry

Horizontal and vertical curves pose a risk to drivers on all roadways; however, workers have been found to be at an especially high risk of being struck on vertical curve crests compared to the risk of general crashes on other similar road segments (Yu, Bill, Chitturi, & Noyce, 2013). Straight road segments have been shown to be associated with decreased crash severity, further identifying the risk that curves have in work zone safety (Dias, 2015). The role that roadway grade has in work zone crash risk is more unclear with some studies finding a link between crash risk and curved segments (Dias, 2015) and some stating that straight-level roadways present the greatest risk (Harb, Radwan, Yan, Pande, & Abdel-Aty, 2008).

Roadways that may be perceived to be safer tend to result in greater risk because they may actually promote risker driving behaviors, like speeding, since motorists feel safer to do so. This risk-taking behavior is often linked to reasons why average speeds and crash rates are higher on divided roadways compared to undivided roadways (McAvoy, Duffy, & Whitney, 2011). Undivided roadways, however, also experience high-speed crashes since traffic density tends to be light and the perceived risk of traffic enforcement is low (Daniel et al., 2000; Li & Bai, 2008).

Other typical roadway factors that are associated with increased fatal crash risk in work zones include local and arterial roads (rather than interstate highways or freeways), asphalt paved roads, and typically those with speed limits of 60 mph or greater (Harb, Radwan, Yan, Pande, & Abdel-Aty, 2008; Li & Bai, 2008).

1.1.4.3 Traffic Calming Measures

Traditional approaches to speed management have been through the use of clearly marked speed limit signs. Unfortunately, research has found that work zone and speed limit signs are largely ignored by motorists in work zones (Fontaine et al., 2001). Variable Message Signs (VMS) are an alternative approach to alerting motorists to safe travel speeds given the conditions of the road (e.g., crashes, traffic congestion, road surface conditions, etc.; Lin, Kang & Chang, 2004). Moreover, VMS are successful in encouraging better compliance to the posted speed limit, which results in less speed variability and lower crash rates over time (Committee for Guidance on Setting and Enforcing Speed Limits, 1998; Coleman et al., 1996; Lee, Hellinga, & Saccomanno, 2004). The traffic smoothing effect of VMS is even influential in reducing congestion leading to a traffic bottleneck formation of work zones (Lin et al., 2004; Bertini, Boice, & Bogenberger, 2006).

Altering the physical environment through vertical and horizontal deflections has been found to be an effective ecological solution to encouraging lower speeds in work zones. Speed bumps or cushions are effective methods for decreasing speed and crashes in low-speed roadways (e.g., 30 mph; Mountain, Hirst, & Maher, 2005). Similarly, pinch points, traffic islands, and round-abouts provide a protective effect of the roadways by reducing speeds and reducing conflict points between vehicles (Mountain et al., 2005).

Barricades are often implemented to mark construction and maintenance work zones (Daniel et al., 2000), and channeling devices or drums have been demonstrated to help drivers safely navigate through a work zone, in turn, protecting workers and mitigating crash rates (McAvoy et al., 2007). Concrete barriers provide a degree of separation and protection between workers and motorists that can help to reduce the likelihood of intrusions. These barriers, however, are not feasible for all work zone operations.

Incorrect driving responses to traffic-control devices or signage have been documented to result in work zone intrusions in cases where signs were missing or spaced too far apart, which led to confused drivers improperly selecting a lane-change point and inadvertently entering the activity area (Ullman et al., 2011). However, Bai and Lee (2006) analyzed the risk factors to crashes in work zones from crash data in the Kansas Department of Transportation database and found the presence of significant and efficient traffic control can partially mitigate crash rate. With logistic regression analyses, they found that: the presence of flaggers reduced work zone crashes of male drivers by 15% and heavy trucks by 27%; and the presence of stop signs and stop signals reduced crashes caused by misunderstanding traffic control by 20%. These findings suggest that the presence of flaggers, and traffic signs or signals should be accounted for when reporting work zone intrusions.

Finally, the season or time period appears to have a non-negligible impact on the occurrence of work zone crashes. Bai and Lee (2006) report that 18% of total crashes happened during the period of slow construction (December through March). They attribute this to a possible lack of routine inspection of work zones. The public may also have a lower expectancy of work zones, which may lead to unpreparedness upon encountering one. Related to lower expectancy, drivers were more likely to have more severe injuries in work zones for short-term (less than 1 day) stationary zones than longer-term stationary zones (Wong et al., 2011).

1.1.5 Driver Behavior Risks

1.1.5.1 Driver Characteristics

Older drivers represent the second highest fatal crash rate per licensed driver, next to teen drivers on typical roadways and are the leading fatal crash risk group by vehicle mile traveled (see Figure 1.2; FARS, 2010; Cicchino & McCartt, 2014). Unsurprisingly, older drivers are also most likely to be involved in a fatal work zone crash compared to younger drivers (Li & Bai, 2009; Weng & Meng, 2011). Time of day appears to play a role in the likelihood that a driver of a certain age group may be involved in a fatal crash, with older drivers most likely involved between 4:00 pm and 8:00 pm and 35 to 44 year olds between 8:00 pm and 6:00 am (Li & Bai, 2009). Interestingly, middle-aged drivers are at a 1.17 times greater risk to be involved in a fatal or injury crash in a construction work zone than younger drivers (Weng & Meng, 2011). Moreover, male drivers have been found to pose a greater fatal crash risk in work zones than female drivers (Li & Bai, 2009). Even male occupants are more likely to be killed in work zone crashes than their female counterparts (Dissanayake & Akepati, 2009).

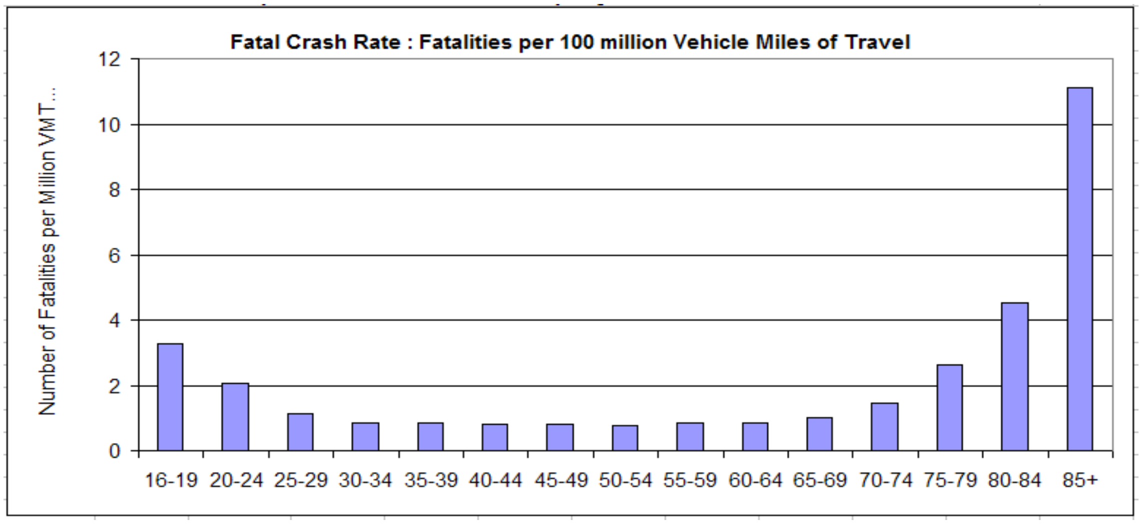


Figure 1.2 National fatal passenger vehicle driver crash involvements per 100 million vehicle miles traveled by age group, 2007. Based on National Household Travel Survey VMT by Age and NHTSA FARS (Cicchino & McCartt, 2014).

1.1.5.2 Vehicle Characteristics

Vehicle type has been found to impact crash risk in work zones. Drivers of older vehicles have been found to have a higher fatal crash risk compared to drivers of newer vehicles (Weng & Meng, 2011). While an overwhelmingly high proportion of work zone crashes involve passenger vehicles, trucks and buses have been shown to have anywhere between a four (Li & Bai, 2009) and ten (Weng & Meng, 2011) times increase in fatal crash risk compared to other vehicles. Moreover, compared to non-work zones, the crashes in work zones are disproportionally more likely to involve trucks than other vehicles (Daniel et al., 2000).

1.1.5.3 Risk-taking Behaviors

Impairments of any kind (alcohol, drugs, fatigue, etc.) are likely to increase the likelihood of other problematic behaviors associated with work zone crashes. Driver impairment was cited in 25% of work zone intrusion crashes in New York (Bryden et al., 2000).

Research examining work zone behaviors in Italy revealed that drivers were more likely to travel closer to the posted speed limit when the travelling lane was narrowed (Bella, 2005). It appears, then, that the drivers were less likely to abide by the posted reduced speed limit if the work zone did not appear to necessitate it, which deemed the signage unreliable or unreasonable. Other studies have similarly shown that drivers will self-select a travel speed, regardless of the posted speed, and will reject artificially low speed limits (McAvoy et al., 2011). This may partially explain why more than 50% of fatal crashes in work zones occur at work zones that are idle (Daniel et al., 2000) since drivers are less likely to feel compelled to abide by speed limits and signage when no workers or activity are present.

Next to impairment, speeding or traveling too fast for conditions is at the forefront of hazardous behaviors that increase crash risk. Both crash risk and crash severity increase with speed (Mountain et al., 2005; Wilson, Hendrikz, Le Brocque, & Bellamy, 2006). Travelling too fast for conditions or speeding was cited as a factor in approximately 17% of worker strikes in Wisconsin analyzed by Yu and colleagues (2013). Additionally, traffic density plays an important role in speed. Free-flowing traffic allows for higher traveling speeds leading to an increase in single vehicle crashes, while denser traffic is more susceptible to the impact of dangerous speed differentials (i.e., increased standard deviation in speed) between vehicles leading to an increase in two vehicle crashes (Daniel et al., 2000; Wilson et al., 2006; McAvoy et al., 2011).

Related to driver speeding, drivers may misjudge distance or the speed of the convoy during mobile operations and end up intruding or impacting the convoy vehicle. Furthermore, drivers can misperceive the distance to traffic channeling devices during traffic control setup/removal, leading to a heightened risk of intrusions and collisions with the convoy (Ullman et al., 2011). Distance perception and rate of approach are key factors in avoiding work zone intrusions, and both are affected by speed of the driver and speed of the mobile convoy.

Following speeding, inattention or distraction is typically the next commonly cited contributing factor to crashes. In 2013, approximately 18% of all work zone crashes in Minnesota cited inattention or distraction as a first or second contributing factor to the crash (Minnesota Crash Facts, 2013). Moreover, approximately 48% of worker strikes in Wisconsin included inattentive driving as a factor (Yu et al., 2013). Drivers who are actively engaged in distraction or passively being inattentive to the task of driving are less likely to appropriately respond to hazards or changing conditions in the roadway, which is especially problematic in work zones where the margin of error is smaller than typical roadways. Perhaps unsurprisingly then, rear-end and sideswipe crashes are more likely to occur in work zones than non-work zones (Khattak et al., 2002). In examining New York intrusion crashes in lane closures, approximately one-fourth of the intrusions occurred because drivers were surprised, likely from inattentive or distracted driving, by stopped or slow traffic and either veered into the work zone to avoid the crash (8%), rear-ended the lead vehicle before entering the work zone (12%), or rear-ended the lead vehicle and consequently pushed it into the work zone (5%). Furthermore, a driver may not be distracted but in an attempt to avoid a sideswipe crash during merging or from the side lanes they may non-deliberately intrude into the work zone (Ullman et al., 2011). A similar pattern was also observed for flagger, mobile, and setup/removal operations, as well.

Finally, drivers may choose to deliberately intrude into the work zone, not because of impairment or distraction, but because of the location of the zone. If the zone is proximate to a roadway exit, intersection, or the driveway of a residence, drivers may choose to intrude into the work zone to reach the location (Ullman et al., 2011). This choice may be due to lower risk perception of intrusions, or the urgency of reaching the exit, intersection, or driveway.

CHAPTER 2: HUMAN FACTORS ANALYSIS

2.1 OVERVIEW

To design an effective interface for reporting work zone intrusions, the designer must have a reasonable understanding of the human factors of the work zone intrusion reporting task. This entails a solid understanding of the task characteristics, and human capabilities and limitations relevant to the job and task. The human factors team conducted interviews with work zone supervisors and workers employed in both urban and rural trucks station locations for day and night shifts to sample most task environments and conditions. Presented here are (1) interview summaries, (2) a task analysis, and (3) relevant human factors issues.

2.1.1 Interview Summaries

Interviews were conducted with supervisors and workers from Baxter, St. Cloud, Duluth, and Cedar Ave stations. Discussions at each truck station typically included multiple workers in the same room to add variety of thought and opinion and expedite the process. Interviews were semi-structured with set questions and follow-up probes, along with brief proposed scenarios to the interviewees for engaging in cognitive walkthroughs. From these interviews, a number of key themes emerged that are relevant to describing the intrusion reporting task and its demands.

2.1.1.1 Reporting Responsibilities and Interface

Supervisors and lead crewmembers are usually notified in the event of an intrusion and perform the formal report to MnDOT. If the intrusion is especially severe, such as obvious drunk driving, workers in the area may call dispatch to immediately address the situation. If necessary, crewmembers could request a paper form (Work Zone Incident Report Form) for reporting from their supervisor. Some interviewees noted that this required step to go through a supervisor may present a barrier to reporting, a step that hinders workers from carrying out the process.

For immediate reporting, a handheld or mobile system for reporting was considered possibly useful, either in the form of a smartphone or a tablet. However, a supervisor may not be on site with a tablet, requiring a reliance on memory for later engaging in the reporting task and details regarding the turn of events. Furthermore, there was concern about being held accountable for damaged tablet or smartphone screens. For reporting purposes, a camera (e.g., GoPro) for capturing either pictures or video could support memory and provide evidence for intrusions, similar to the practice of using cameras for documenting crashes in a work zone.

If the reporting is done at a later date, the crew thought it best be integrated into their daily reporting sequence and prompted, instead of making it an extra step that has to be remembered (and easily forgotten). Suggested sequences include reporting during either their activities timesheet (RCA) or their daily asset management program (the upcoming TAMS). For example, the timesheet could ask if the worker had encountered an intrusion. Any additional reporting related to intrusions should be very simple, short, and straightforward, ideally with box clicking. For crew, the reporting of intrusions is seen as a low priority in comparison with the other demands on their time and energy.

2.1.1.2 Intrusion Definition and Reportable Characteristics

The crew conceptually understood an intrusion as a vehicle entering the area cordoned off by cones. However, an intrusion is thought of as reportable in a practical sense if it occurs close to the activity area and threatens active workers, or if it threatens a flagger during flagging operations. A vehicle that failed to stop before a flagger could be considered an intrusion. Moreover, if aggressive drivers attempt to crowd or slowly advance toward a flagger, requiring the flagger to move or walk backward, this could be considered an intrusion as it forced the flagger to take “evasive maneuvers”.

The key reportable elements of an intrusion from the crew are as follows: layout, environment (lighting and weather), location, time, location road condition, vehicle maneuvers, and operation type. The interviewees did not want to report any elements related to contributing factors focused on driver characteristics such as distraction, as this is an inference that cannot be directly observed, given that the crew frequently cannot see the drivers well and do not want to be liable for uncertain claims. When the crew directly interact with intruding drivers (typically at night), these drivers are either drunk, which typically leads to a call to dispatch, or lost, which normally does not get officially reported.

LAYOUT

Layout of the work zone was identified as an important characteristic to identify during reporting intrusions. Some interviewees reported almost never deviating from the manual layout, and only needed to know the road segment type to consult the manual and report which layout was used for a location. However, if there were enhancements or modifications done, this was typically reported. A typical modification occurs on lane closure at curves due to the nature of that layout, requiring a lengthening of the taper to facilitate merging. This leads to location being a relevant reportable element, as location influences both layout, driver behavior, and rate of intrusion. For example, exit ramps have a higher rate of intrusions due to driver confusion, while operations on bridges have relatively few intrusions. Another directly observable element was road condition, which could possibly contribute to unintentional intrusions due to loss of vehicle control.

ENVIRONMENT

The environment was relevant to the crew, although weather was thought to be somewhat misleading to report. Although the weather can be “clear”, there is usually no way to indicate complicating factors such as the position of the sun leading to glare and disrupting driver vision. Interviewees suggested adding a second reporting attribute in the environment to indicate whether lighting complicates the driving task. Besides time of day elements such as exact time and corresponding lighting levels, workers noted that light salience may be a reportable issue. Drivers’ attention may be drawn to flashing beacons or lit areas at night, causing them to not see workers on foot. These salience elements may need to be added on an intrusion form.

VEHICLE CHARACTERISTICS

Vehicle characteristics, when observed, were thought to be important to report, particularly their maneuvers that are obvious. These include following too close or speeding, that is, behaviors that do not require inference on the part of the worker. Furthermore, the type of intruding vehicle is relevant for reporting as well. Commercial trucks, for example, can present a significant risk to both crew and public safety if intruding in a work zone, relative to a passenger vehicle.

OPERATIONS

Interviewees indicated that another item important to report was the type of operation. As previously described, intrusions during bridge operations and construction operations were infrequent, but non-bridge maintenance operations and mobile operations had more frequent intrusions. Most frequent were intrusions on flagger operations.

Flagger operations were particularly prone to intrusions. Flagging is often perceived as a low-level job; however, the flagger is often the first line of defense for crew safety. Flaggers are often physically and mentally exhausted during performance of their task and may be prone to distraction and/or inattention. As opposed to signalized traffic controls that receive high rates of compliance, flaggers often face driver violations and intrusions upon their safety, and interviewed crews suspected that drivers do not attribute significant regulatory authority to the human flagger. Interviewees reported that cameras (e.g., GoPro) for flaggers would be helpful for capturing these driver violations. Furthermore, some crew reported that some work zone signs are often outdated and unreliable, leading to a lack of trust and low compliance in the work zone. Moreover, workers reported that more specific signing regarding work activities (e.g., tree removal) would improve compliance to and trust in signage.

2.1.1.3 Impedances and Incentives

The primary barrier and incentive for reporting intrusions has been the severity of the intrusion itself. Intrusions that directly threatened workers were more likely to be reported in some fashion relative to minor intrusions that involved knocking over cones in the taper portion of the work zone. This is related to the constraint of time and work demands, which precludes reporting as other responsibilities are seen as taking a higher priority in an already demanding schedule. There is also the hierarchical nature of the job, in that, workers feel that they may be required to notify a supervisor who does the reporting instead of direct reporting the intrusion themselves. The perceived organizational structure of making this an extra step in the process could result in making the reporting act less likely.

Lack of information provides a barrier on two fronts, both on the intrusion itself, and the effects of reporting an intrusion. On the first, crewmembers may not observe an intrusion occurring, just its effects, leading to a lack of significant reportable data outside of the appearance of an intrusion. Also, crew members usually do not know any contributing factors related to the driver because they did not directly interact with the driver. On the second, workers may not report because they believe reporting does not have any effect on higher level decision-making and has no immediate impact (especially in terms of legal ramifications for the driver). They are unaware of any of the impacts the information about intrusion rates could have on MnDOT responses or legislation.

The last primary barrier is the complexity and number of forms and entry documents. Forms are frequently marketed as taking a brief time to fill out, while actually taking a substantial amount of time to complete. Any final intrusion reporting form and interface should be as simple and straightforward as possible, while meeting MnDOT needs.

Finally, some crewmembers discussed possible incentives to increase intrusion reporting rates. Reporting must have relevance in the eyes of workers, according to interviewees, which may include disseminating recognition of intrusion documentation and perhaps recognition of who submitted the reports, identifying and communicating action plans based on the data, outlining data trends, and possibly allowing workers to respond with comments and feedback on reports. Other minor incentives include gifts such as food, gift cards, special parking spots, or simple recognition for high volume submitters.

2.1.2 Task Analysis

Given that reporting of intrusions rarely happen outside of the event of a crash, the description of the task steps presented here are necessarily prototypical and suggestive. The description of the task takes the form of a hierarchical task analysis (HTA), which is defined by Stanton (2006) as a way of describing work systems in terms of goals, breaking down sub-steps in a hierarchy in terms of sub-goals, and linking the overall goals and sub-goals in a sequential manner. Once the steps and sub-steps are understood, an analyst can draw conclusions on what steps efficiencies and errors may occur. The information driving this HTA was derived from both the aforementioned interviews and known requirements from MnDOT. Furthermore, the concrete task elements of interacting with the system are omitted because the interface has not been developed yet. The suggested task components are outlined in the HTA representation in Table 2.1.

Table 2.1 Hierarchical Task Analysis of Intrusion Reporting

Super-ordinate	Task component	Notes
1.	*Collect data on intrusion*	
	Plan 1: Supervisor/lead worker collects when ready to report	
	2. Query workers on intrusion occurrence	Plan 1.2. If no intrusion occurred, skip to end
	3. Contact worker(s) who detected intrusion	
	4. Record relevant information for reporting	Plan 1.4. If detecting worker is reporting, they should record the following steps
1.4.	*Record relevant information for reporting*	

	1.4.1. Verify if crash occurred	Plan 1.4.1. If crash occurred, mark that an intrusion occurred and connect to crash report
	1.4.2. Verify severity of risk to crew	Plan 1.4.2. If risk moderate to high, identify if evasive maneuvers took place
	1.4.3. Record layout, environment (lighting and weather), location, time, road condition, operation type, salience, and vehicle type/maneuver	
	1.4.4. Collect evidence of intrusion (pictures/video/documents)	
2.	*Report intrusion*	
	Plan 1: Reporter should skip this step if no intrusion occurred	
	2. Log into reporting system (i.e., TAMS)	
	3. Mark that an intrusion occurred for a hard count	
	4. Indicate worker(s) detecting intrusion	
	5. Mark location, layout, and operation type	Plan 2.5.1. Mark these if reporting system does not automatically populate the fields based on prior records
	6. Enter time and date of intrusion	Plan 2.6. If exact time is unknown, enter estimated time range
	7. Indicate weather, lighting, and road conditions during intrusion	Plan 2.7. If weather is sunny or clear, mark whether glare conditions were present
	8. Indicate the degree of risk to the road crew	Plan 2.8. If risk was higher than minimal, indicate whether workers had to engage in evasive maneuvers
	9. Indicate whether the intrusion involved a flagger	
	10. Indicate intruding vehicle type and observed maneuvers	Plan 2.10. Skip if unknown

2.1.3 Human Factors Issues

The primary human factors issues providing a barrier to reporting intrusions include: time stress, risk perception, mental workload and complexity, and organizational issues. Time stress is present as the crew and those potentially reporting intrusions are already doing many other required tasks, and time spent reporting an intrusion must be weighed against the benefits of performing another task. This goes in hand with risk perception, as the risk of an accident to personnel may be estimated by the worker to be low in the event of a minor intrusion. When estimated personal risk is low, effort is typically not allocated to further reducing the risk (Wickens, 2014). This means that effort may not be spent to report minor intrusions.

Effort may also not be made if the interface is complex and demanding. Information from the interviews suggested that some required forms are complicated and require significant time and mental investment to complete accurately. If the intrusion form is similarly complex, requiring significant time investment, only the most salient and dangerous intrusions may be reported. Therefore, the design must focus on making intrusion reporting simple and short, while capturing as much data as is relevant for MnDOT.

Finally, there may be some organizational and safety culture issues centering on communication about the use of data. Effort spent reporting intrusions may be wasted from the perspective of crew, reporting intrusions is not yet seen as a good safety practice that has beneficial downstream effects. If this is to happen, these potential downstream effects on analysis or policy should be made salient to the crew, to help them feel included and involved in the process.

CHAPTER 3: INITIAL INTERFACE PROTOTYPE AND USER TESTING

3.1 OVERVIEW

After reviewing information gathered from the previous tasks, the research team created an initial prototype of a work zone intrusion report and began user-testing it with relevant personnel across the state, following standard protocol for usability testing (Jordan, 2002). From these tests, the prototype was revised iteratively, resulting in a more complete design to be used in beta testing.

3.1.1 Initial Interface Design

The research team reviewed the materials from the human factors analysis, which comprised of interviews with work zone supervisors and MnDOT central personnel, and created an initial interface incorporating the elements derived from the task analysis presented from Figure 3.1 to Figure 3.4. This design utilized the Justinmind prototyping tool (https://www.justinmind.com), which allowed for testing of the interface and interaction elements as if it were a website or app usable in real-time. The initial design had four screens and was initially planned to be integrated into the TAMS asset management system, therefore the design was made to mimic the TAMS interface. Further, multiple data elements were initially assumed to be derived from the TAMS work order.

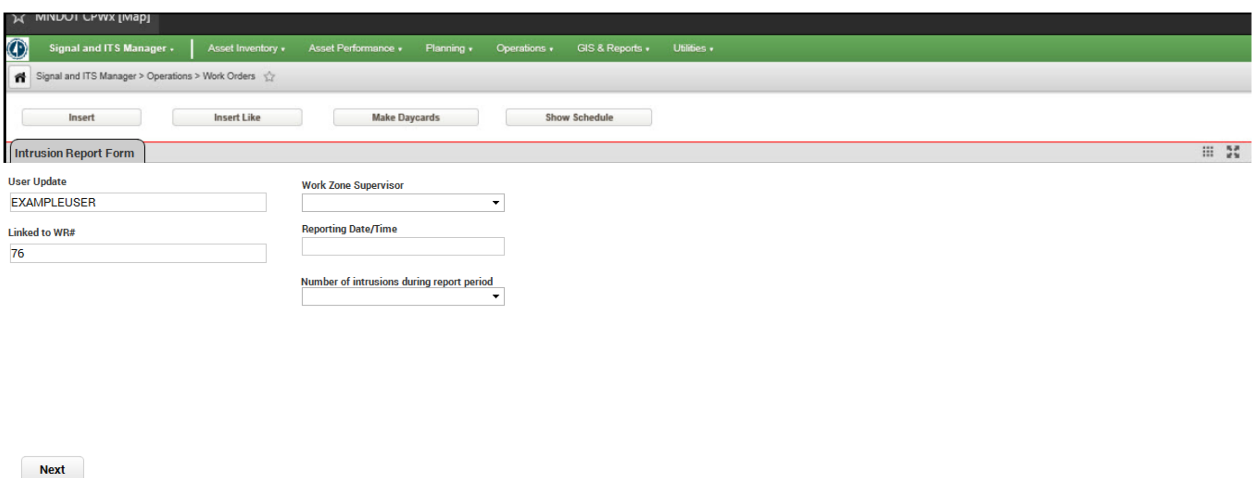


Figure 3.1 Initial Reporting Interface, First Screen.

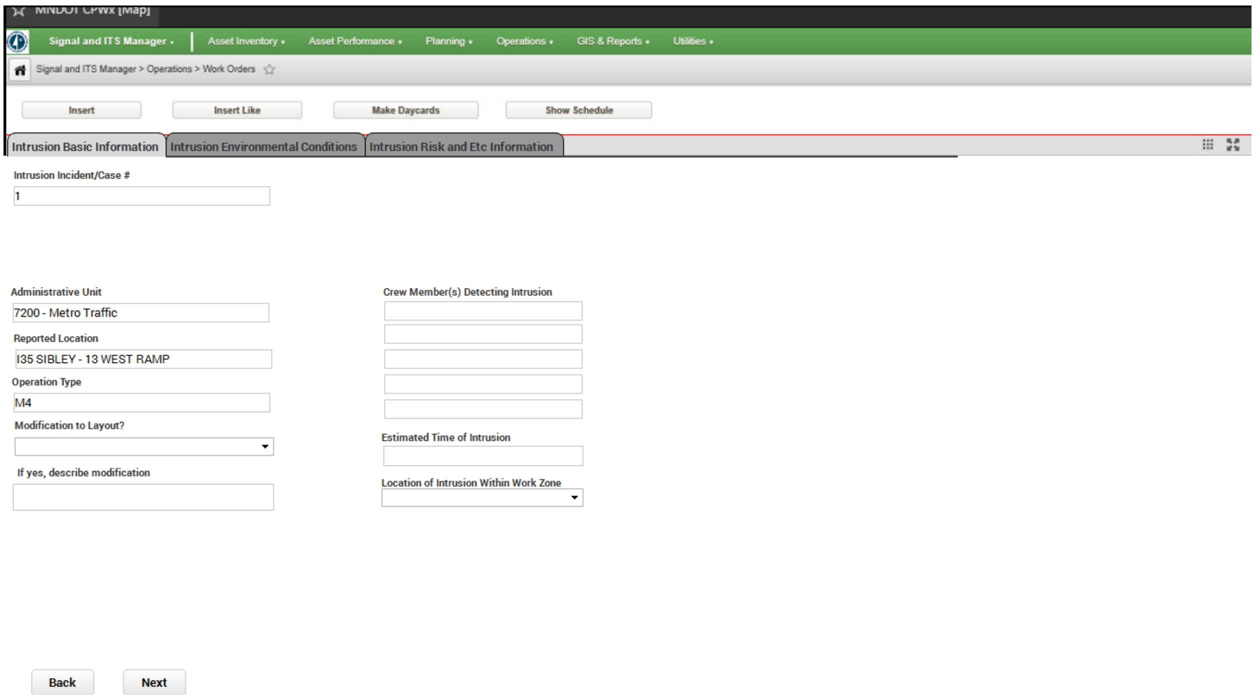


Figure 3.2 Initial Reporting Interface, Second Screen.

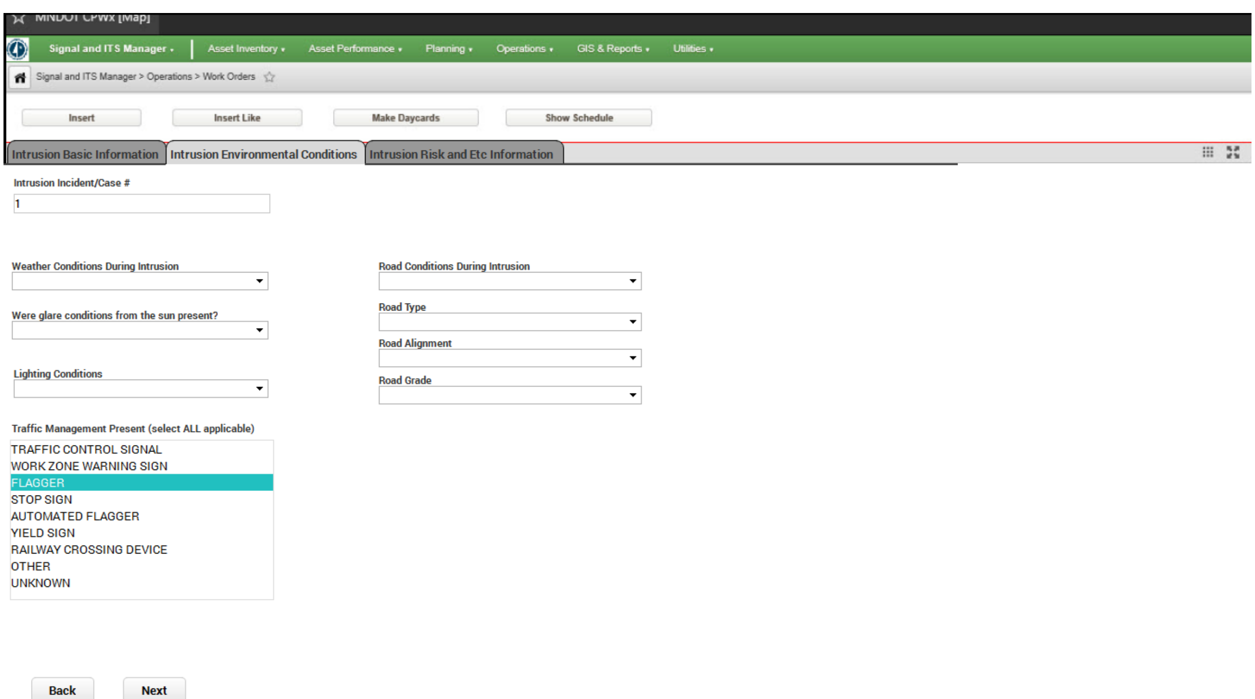


Figure 3.3 Initial Reporting Interface, Third Screen.

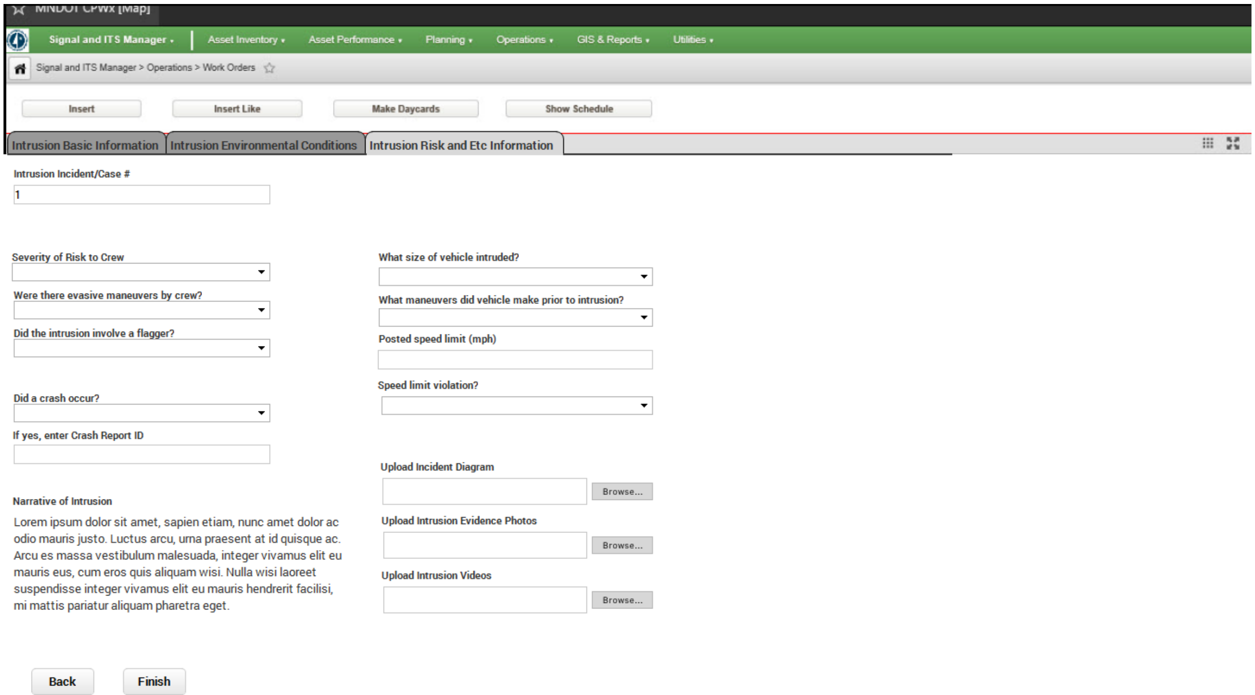


Figure 3.4 Initial Reporting Interface, Final Screen.

3.1.2 User Testing

The usability testing protocol is presented in Appendix A. The protocol had supervisors and workers that performed maintenance duties generate the details of a well-remembered intrusion scenario and indicate which elements of the generated scenario they would most like to be reported to MnDOT. The data elements of these scenarios were included into successive iterations of the prototype design, including vehicle and driver characteristics such as color and suspected driver state. The researchers asked users to input the generated scenario into the interface, along with four researcher-written scenarios that were previously validated by work zone supervisors for face validity (see Appendix A). Workers were asked to “think aloud” as they interacted with the interface to provide feedback about any positive or confusing features of the workflow and system design. The researchers recorded significant comments about the interface, along with the time it took to complete the report. Following the mock data entry activities, the System Usability Scale (SUS; Brooke, 1986) was given to the users to allow them to report their perceived satisfaction with the interface. This data provided a quantitative assessment of the usability of the initial and revised prototypes (Appendix B). Finally, a series of interview questions were used to identify positive elements of the interface and possible areas for improvement.

Researchers tested six potential users of the intrusion reporting form across Minnesota’s truck stations, including Maple Grove, Cedar Avenue, and Bemidji. This sampling allowed the research team to capture input from both metro and rural locations. After each session, the interface was modified to reflect the input from the supervisors and workers.

3.1.2.1 Testing Results

The average time for completion of a scenario was just over 5 minutes (*M* = 5 minutes, 5.08 seconds), with a standard deviation of 68.35 seconds, with all users noting that with repeated exposure they felt they would be able to complete the form even more quickly. The System Usability Scale (SUS) of the interface were 80, 85, 87.5, 92.5, 62.5, and 90 with an average of 82.92 (*SD* = 10.89). Scores between 60 and 70 reflect an average interface for usability, while scores higher than 70 reflect an increasingly more user-friendly design. The scores for the interface suggest that the design for the work zone intrusion form were highly usable for most participants.

The most popular aspect of the interface were the drop-down menus, which allowed for ease of selection and rapid completion of the reports for each intrusion scenario. Most of the changes to the interface involved using the appropriate language and terminology with which workers and supervisors were most familiar. Workers reported a desire to document any vehicle information they observed from the intrusion first to limit any memory decay, rather than reporting vehicle information after querying other information, like location details. Further, workers reported a desire to document intrusions shortly after they occurred, on the work site.

When asked how likely they would be to use this system to report intrusion, if it were available, each user expressed with certainty that they would use it, but that was contingent upon several stipulations:

- **The interface had to be available on-site,**
- **The interface was easy to quickly open, and**
- **Employees needed to feel like the data they were entering was going to actually be seen and analyzed.**

The general reasons for the stipulations were that employees, supervisors especially, felt they already spent too much time having to fill out reports and that they only way they would be willing to fill out more reports were if they were quick and easy. They liked that a digital reporting system made it much more likely that the information they were reporting would be seen by someone rather than just filed away as they perceived paper reports were.

3.1.3 First Redesign of Reporting Interface

The completed iterative redesign of the interface is presented in Figure 3.5, Figure 3.6, Figure 3.7, Figure 3.8, Figure 3.9, and Figure 3.10. After discussion, the design was decoupled from the TAMS interface and conceptualized as a standalone website interface to ensure smooth functionality and access across potential users such as supervisors and work zone site forepersons. This decision was largely made from two main research findings. First, a heuristic analysis of the existing TAMS interface suggests that users will have a poor user experience with the system. For instance, the data entry fields lack clear organization, grouping, or flow. Moreover, some design features, such as the size of the buttons for the drop-down menus are inappropriately small and would not meet basic accessibility standards or lend well to any touchscreen interaction on a tablet PC. Ultimately, integrating the intrusion report into the TAMS software appears to be counter to the goals of this project, which are to create a user-friendly interface that will promote, not hinder, quality data collection regarding intrusions. Second, users' strong preference for being able to document intrusions at the work site, just after an intrusion occurs, may be hindered by poor access to the TAMS system remotely or by all workers. With the primary focus of this project being to increase the reporting of work zone intrusions, users were asked roughly how many reportable intrusions they witnessed per day on their shift. Workers all noted that it depended on the type of road work being done as well as location, but on average they saw about one reportable intrusion per day. It is important to note that this does not technically include all work zone intrusions, but rather the types of intrusions that they viewed as reportable. Of the six workers who were interviewed, five reported that if a car were to intrude into a work zone but not damage any property, equipment, or interrupt the work that was being done, they would be unlikely to report it. The frequency of the intrusions occurring coupled with the worker's assertion that reporting of these events would only happen if it were a quick and user-friendly interface necessitated a design that was consistent with the thought patterns of the events from the workers point of view.

The flow of information was reassessed to address users' requests to document vehicle features at the beginning of the reporting process. After employing a card sorting procedure, the interface flow was re-framed as an "inside-out" reporting system, beginning with the intruding vehicle, next to work zone site characteristics, location, and then administrative information. This flow was employed to better fit the worker and supervisor mental model of an intrusion and how they think about reporting. This resulted in the addition of a new screen, along with more user-friendly terminology (e.g., temporary and permanent lane closure, ICR #, etc.). The most recent iterative design features a five-screen interface with a sixth "completion" screen, which provides users feedback that they have successfully submitted their report.

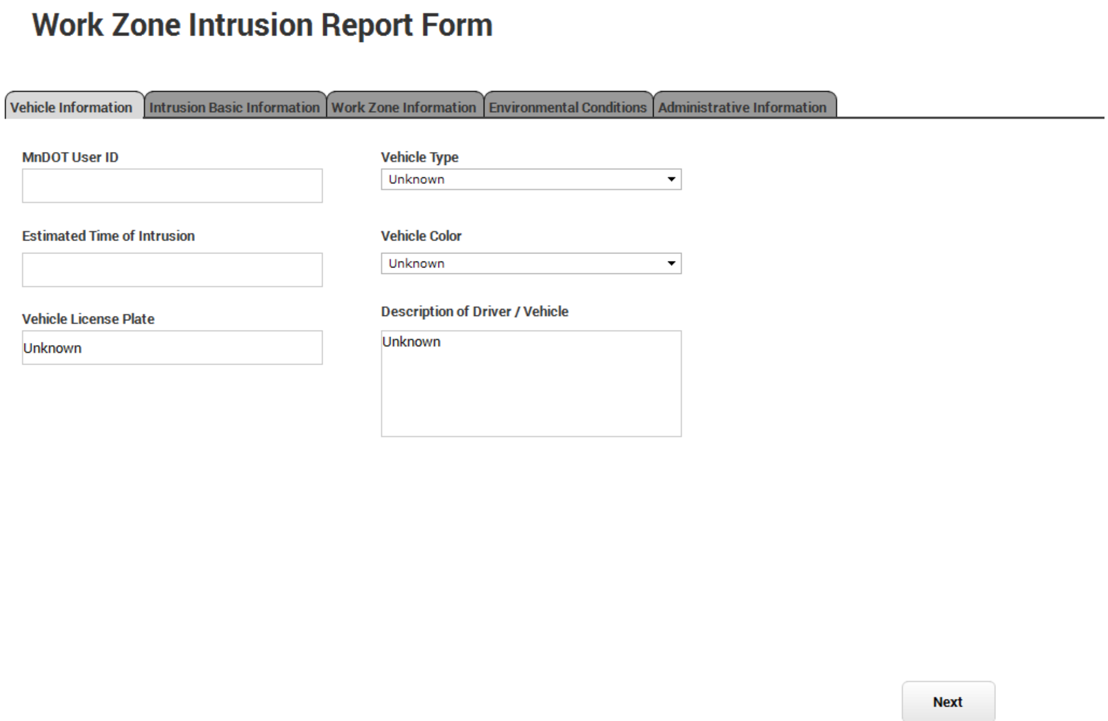


Figure 3.5 Revised Reporting Interface, First Screen.

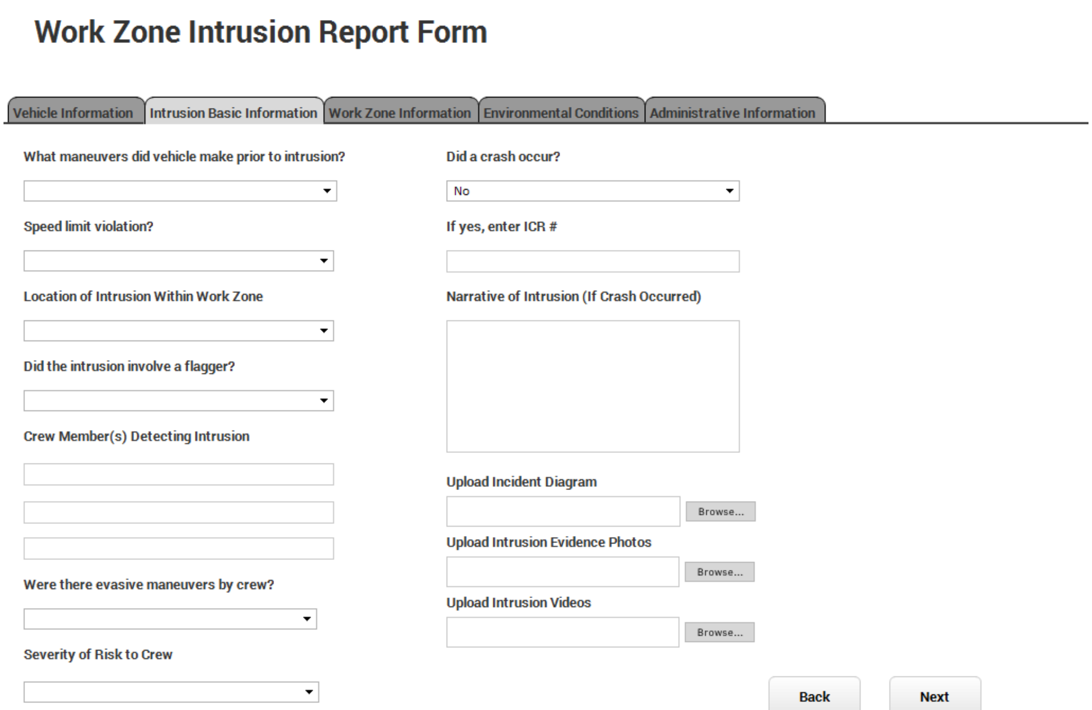


Figure 3.6 Revised Reporting Interface, Second Screen.

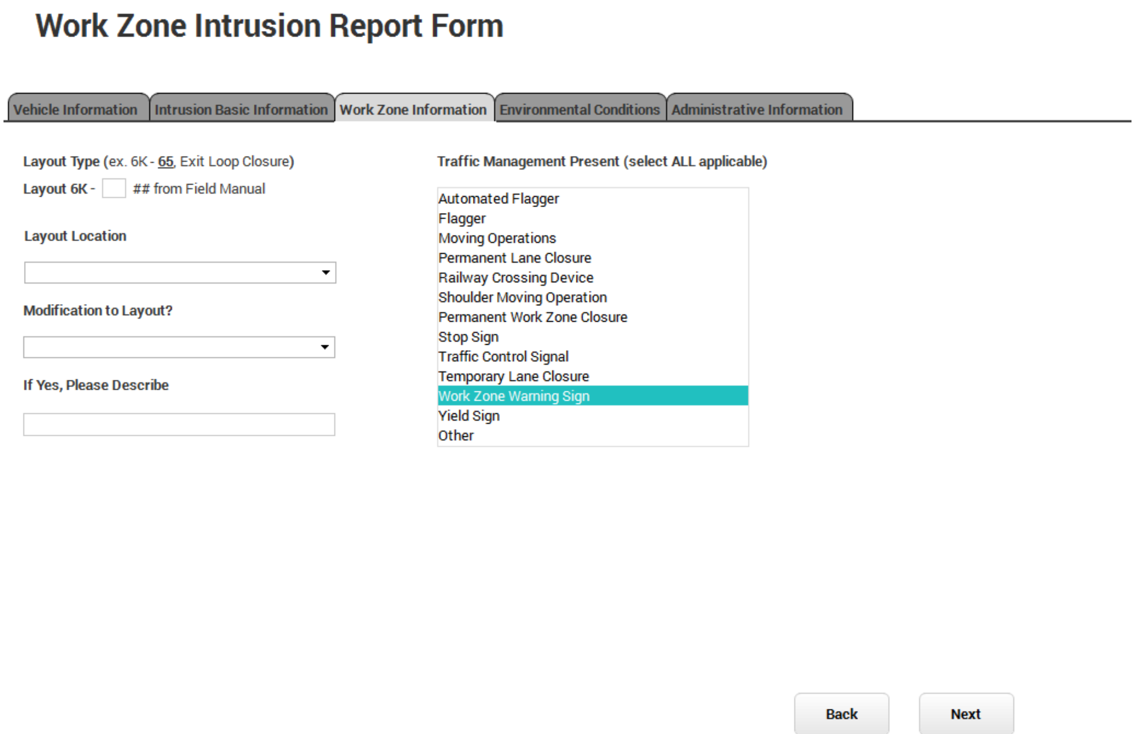


Figure 3.7 Revised Reporting Interface, Third Screen.

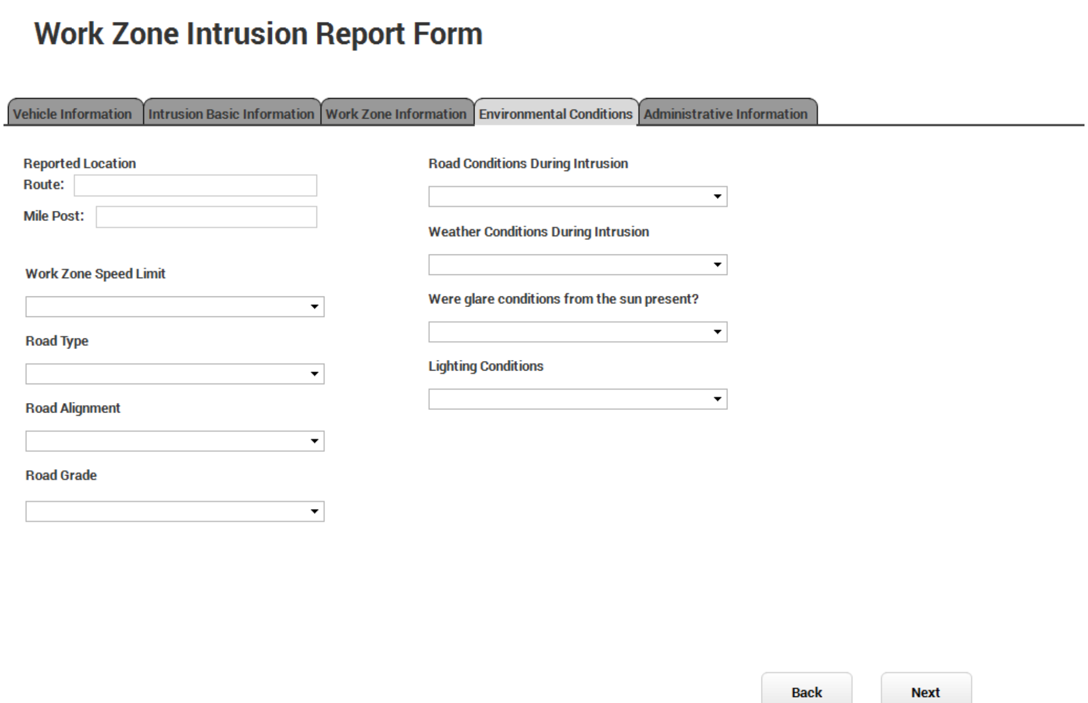


Figure 3.8 Revised Reporting Interface, Fourth Screen.

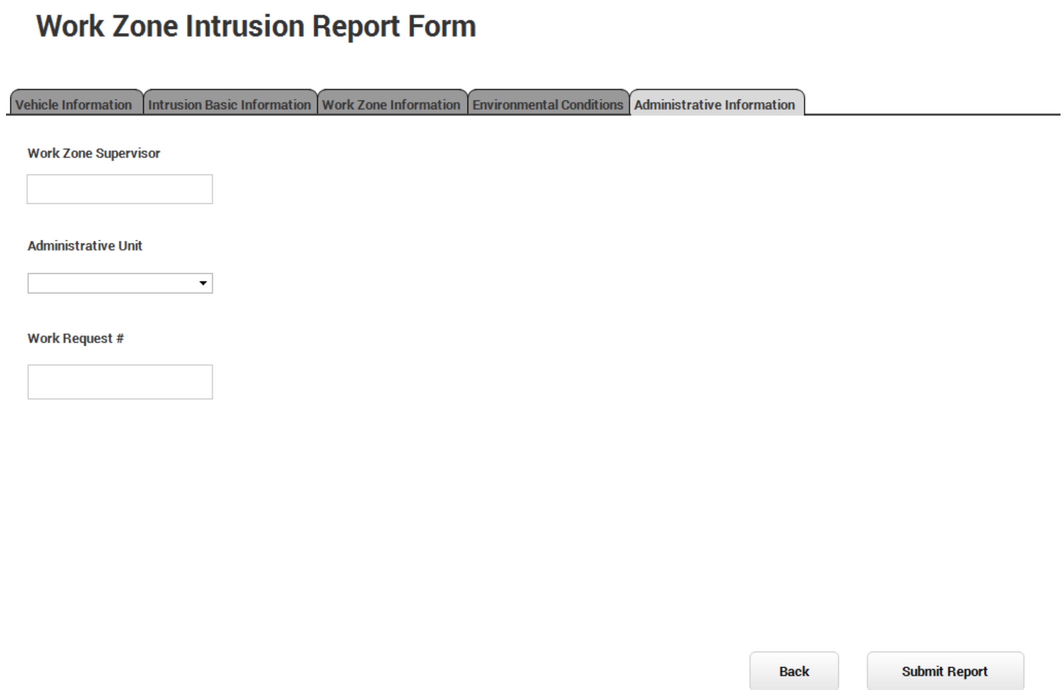


Figure 3.9 Revised Reporting Interface, Fifth Screen.

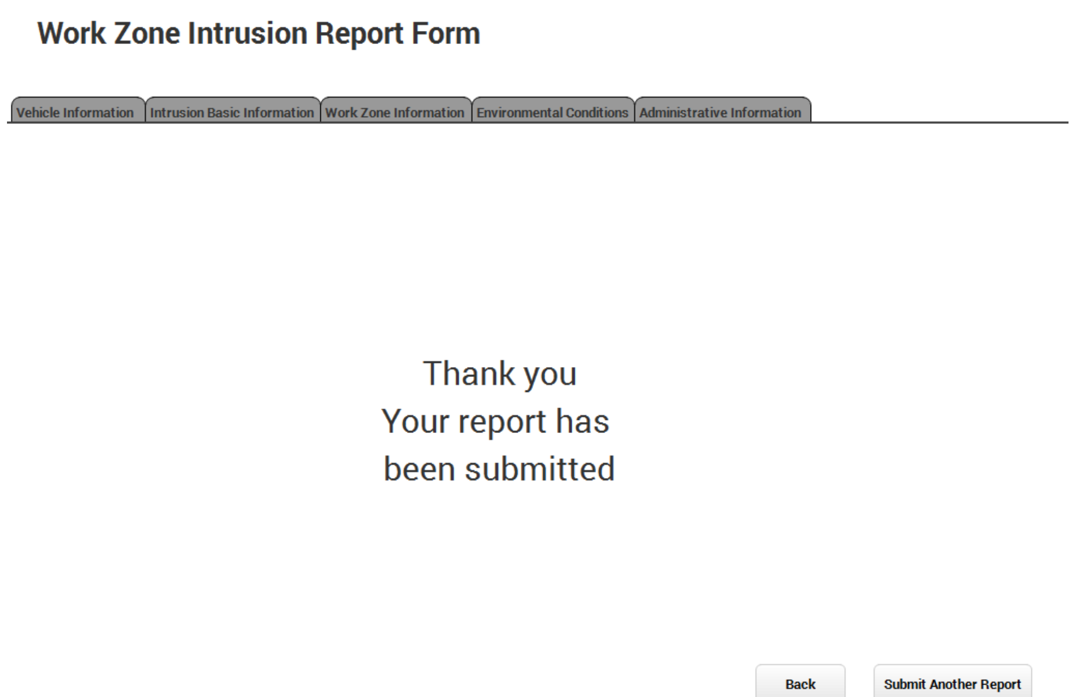


Figure 3.10 Revised Reporting Interface, Submission Screen.

The interface design specs were provided to the software programmer and implemented into a beta test version for further testing and revision. Finally, a paper form was created to mirror the information presentation and flow of the electronic interface. While the research findings strongly support the use of an electronic reporting system, a back-up paper form was considered necessary to provide an alternative means of work zone intrusion documentation in the absence of an electronic device. The paper form (see Figure 3.11), was later user-tested and modified based on feedback.

MnDOT ID ____________ Employee Name ____________

Supervisor ____________ Administrative Unit ____________

Intrusion Date & Time ____________ Work Request # ____________

MnDOT: *Work Zone Intrusion Report*

Vehicle Information

License Plate: ____________ **Description of Driver/Vehicle:** ____________

Vehicle Type: ____________

Vehicle Color: ____________

Intrusion

Vehicle Maneuver Prior to Crash ____________

Speed Limit Violation? ☐ Yes ☐ No ☐ Unknown

Flagger Involved? ☐ Yes ☐ No ☐ Unknown

Crew Evasive Maneuvers? ☐ Yes ☐ No ☐ Unknown

Crash Occur? ☐ Yes ☐ No

Location of Intrusion
- ☐ Taper
- ☐ Activity Area
- ☐ Advance Warning
- ☐ Termination
- ☐ Unknown

Risk to Crew?
- ☐ None
- ☐ Mild
- ☐ Moderate
- ☐ Severe

Narrative: ____________

State Patrol ID (if crash) ____________

Crew Witnessed: ____________

Work Zone

Layout Type: ____________

(ex. 6K – 65, Exit Loop Closure)

Layout Modification?

☐ Yes ☐ No

If yes, please describe:

____

Location of Layout:
- ☐ Right Shoulder
- ☐ Right Lane
- ☐ Multiple Lanes (Right)
- ☐ Center Lane(s)
- ☐ Multiple Lanes (Left)
- ☐ Left Lane
- ☐ Left Shoulder

Location and Environment

Route: ____________

Mile Post: ____________

Work Zone Speed Limit: ____________

Road Alignment:

☐ Straight ☐ Curve Lt ☐ Curve Rt

Road Grade:

☐ Level ☐ Hillcrest ☐ Sag (bottom)

☐ Uphill ☐ Downhill

Road Condition: ____________

Glare Conditions (sun)?

☐ Yes ☐ No

Road Type:
- ☐ Intersection
- ☐ 2-way Undivided
- ☐ 2-way Unprotect. Med.
- ☐ 2-way Med. Barrier
- ☐ One-way
- ☐ Intersection
- ☐ Entry / Exit Ramp
- ☐ Intersection
- ☐ Driveway
- ☐ Railroad Crossing
- ☐ Other

Weather:
- ☐ Clear
- ☐ Cloudy
- ☐ Fog/Smog/Smoke
- ☐ Rain
- ☐ Sleet/Hail
- ☐ Snow
- ☐ Severe Crosswinds
- ☐ Blowing Sand/Oil/Dirt
- ☐ Unknown

Lighting Conditions:
- ☐ Daylight
- ☐ Sunrise/Dawn
- ☐ Sunset/Evening
- ☐ Dark w/ Streetlights
- ☐ Dark w/ No Streetlights
- ☐ Dark Lighting Unknown
- ☐ Unknown

Signature: ____________

Date: ____________

Figure 3.11 Initial Paper Prototype for Intrusion Report

CHAPTER 4: BETA TESTING AND ITERATIVE DESIGNS

4.1 OVERVIEW

After testing an interface prototype for supervisors to report work zone intrusions online, and constructing a beta system of the interface prototype, HumanFIRST researchers began testing this beta system with users. This beta testing was done to further refine the design of the intrusion reporting system and test how it works in a setting more similar to real-world scenarios. This chapter describes the initial design, testing methods, results, and iterative re-designs.

The initial implemented beta design closely resembled the revised design of the interface prototype reported in Chapter 3. This beta was dissociated from the TAMS system to ensure that it was portable and not constrained by any possible usability limitations of TAMS. The beta site was stored on a personal university website and comprised of six webpages, five of which comprised the reporting interface and a sixth page notifying users of a successful submission. Each page in the report includes multiple drop-down menus and manual entry items allowing supervisors to report informative details about the work zone intrusion.

4.1.1 Initial Beta Design User Testing

The usability testing protocol is presented in Appendix A. It consists of an introductory period where the system and testing procedure was explained. Instead of using the user-generated scenarios as previously done, videos of real intrusions captured on camera by MnDOT were used. The volunteering supervisor would watch a video of an intrusion in a Minnesota work zone, and fill out the report using the beta system. The time to completion for reporting the intrusions in the first two videos was recorded to measure both intuitiveness and learnability of the beta. During the third video report, the supervisor was asked to verbalize his or her thoughts on the beta system, to assess preferences and mental processes as he or she used the system. Afterwards, three questionnaires were administered, including the System Usability Scale (Appendix B), the Rating Scale Mental Effort (Appendix C) and a researcher designed questionnaire titled “Intrusion Form Survey” about the beta system (Appendix D). Finally, a series of free-response questions were asked (Appendix A). The testing procedure was iterative, therefore, after every testing session, the researchers would evaluate the results and update the design of the beta system accordingly.

For the videos, the researchers used camera footage supplied by MnDOT. The three videos used different work zone types (i.e., ramp closure, shoulder work), two on Interstate 35W South, and one on Highway 36. The first intrusion was minor, involving no risk to any crewmembers. The second intrusion was moderate in the risk to crewmembers, while the third was quite high regarding the risk level to the maintenance crew on site. Researchers tested four potential users of the intrusion reporting form. The supervisors reflected urban and suburban areas in Minnesota, and worked day and night shifts.

4.1.1.1 Initial Beta User Testing Results

The average time for completion of the first report was 6 minutes and 18 seconds. The average time for completion of the second report was 3 minutes and 9.3 seconds. The first report time reflects moderate to high intuitiveness of the beta interface. While ideally it would initially take under 5 minutes to complete, taking a little over six minutes reflects an acceptable time investment. Furthermore, the learnability of the beta system was high, as the second time to complete was considerably lower at approximately 3 minutes. Reporters easily figured out the system and rapidly filled out the report with the beta system on their second use.

The System Usability Scale (SUS) scores of the interface was fairly good, as scores between 60 and 70 represent average system usability, and the average SUS scores for the beta was 86.875 (*SD* = 13.288). RSME scores measuring self-reported mental effort reflected an average of 36.25 (*SD* = 7.5), which indicates a degree of mental demand between "some", and "a little", which reflects satisfactorily low demand imposed by the beta.

The Intrusion Form Survey averages are reported in Table 4.1, with the first three questions scored on a 1 (Strongly Disagree) to 5 (Strongly Agree) scale, and the last question scored on a multiple choice (7-point) option of: Worst Imaginable, Awful, Poor, Ok, Good, Excellent, and Best Imaginable.

Table 4.1 Intrusion Form Survey Scores

	Average	***Standard Deviation***
Information Entered Accurately	3.75	*0.50*
Confidence While Using Form	4.50	*0.58*
Interface Has Annoying Features	2.25	*0.50*
Overall User-Friendliness	5.50	*0.58*

As reflected in Table 4.1, supervisors were moderately confident in the accuracy of the information entered in the form, and highly confident in their ability to complete the form. Most users reported relatively low annoyance with the form, although there may be room for improvement in later designs. Finally, overall user-friendliness was highly rated, the average score somewhere between "Good" (score of 5) and "Excellent" (score of 6).

The most popular aspects of the interface were the drop-down menus and the comprehensiveness of the form. This allows for quick use of the form and the ability to enter in and report most useful points of data about a work zone intrusion. The least popular aspects was whether it would be reasonable to use the form for minor intrusions that supervisors did not consider a risk to crew, especially if the supervisor could not fill out a form on site with a portable electronic device (e.g., iPad, tablet). Multiple supervisors noted their discomfort with reporting whether they thought the intruding vehicle was committing a speed limit violation, as they did not feel confident they would be able to report speed limit violations accurately. This issue may need to be revisited. Some supervisors also reported wanting a clear explanation of the rationale for the form when the final version is rolled out, to provide motivation for filling out reports on work zone intrusions, especially minor ones.

4.1.1.2 Initial Beta Revisions

There were several changes and adjustments made to the beta from its original design. A number of these changes are described in the following Table 4.2.

Table 4.2 Minor Initial Revisions to Beta Design

Website Interface	Changed “MnDOT User ID” to “Employee ID”, which is a consistent and permanent identification number.	Certain fields were made not mandatory to provide ease in completing the report in case of incomplete information.	Work Request Number was changed to Work Order Number to reflect common terminology with the TAMS system.	Administrative Unit was changed to District Unit to reflect consistent MnDOT terminology.
	District Unit was made into a drop-down menu with the following items: (CO, D1, D2, D3, D4, D6, D7, D8, METRO).	Location Route changed to Location Route Number, and Mile Post Number changed to Location Description.	Auto filling multiple options with “Unknown” to improve efficiency of filling out the form as often some of the details of the intrusion will not be known.	
Paper Interface	“MnDOT ID” was changed to “MnDOT Employee ID”.	Administrative Unit was changed to District Unit	Work Request Number was changed to Work Order Number	Crew Witnessed was changed to Original Witness(es)

The initial revisions to the beta design were implemented prior to a significant revision. The layout of the initial revisions are presented in Figure 4.1 through Figure 4.6.

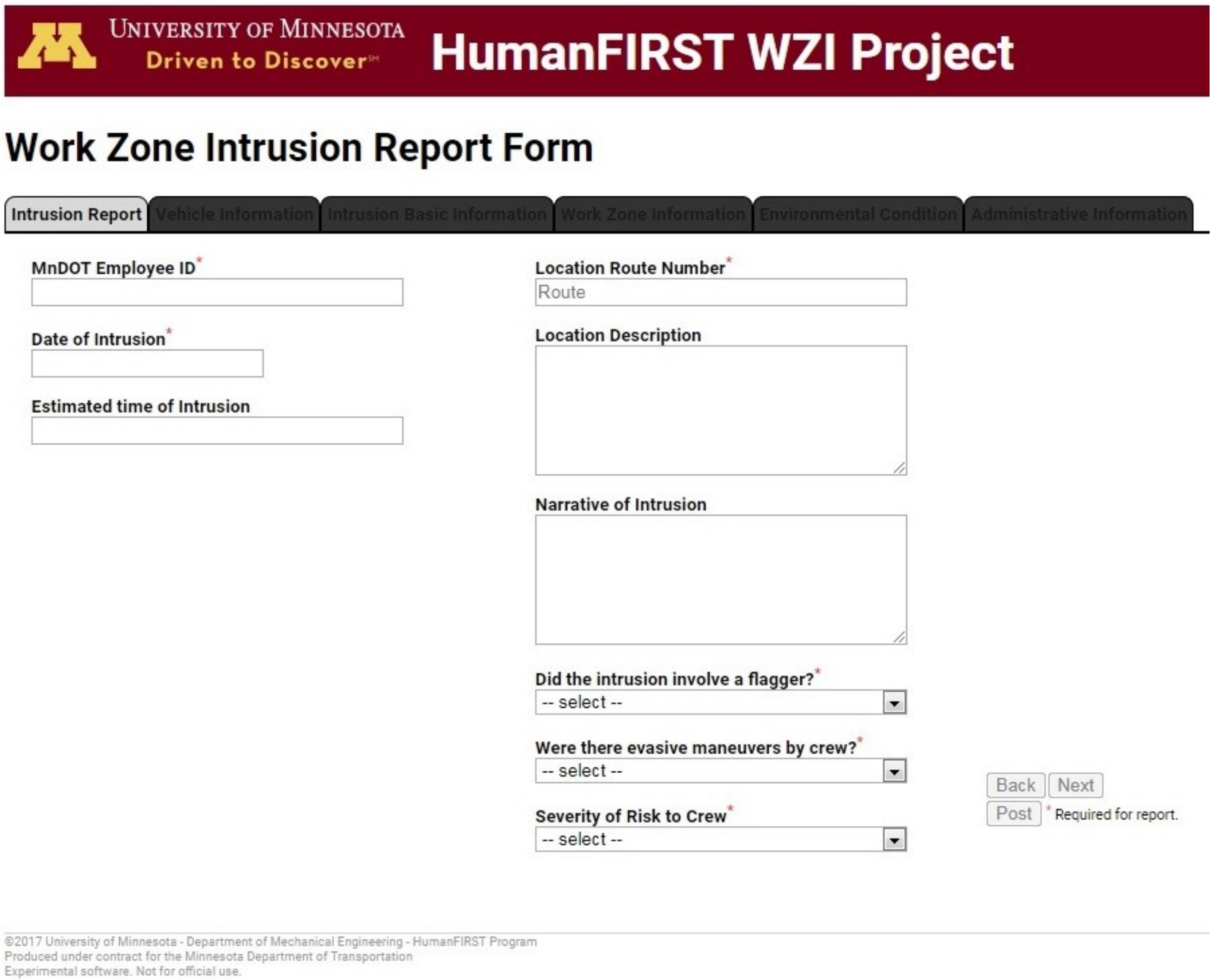


Figure 4.1 Revised Beta Interface, First Screen.

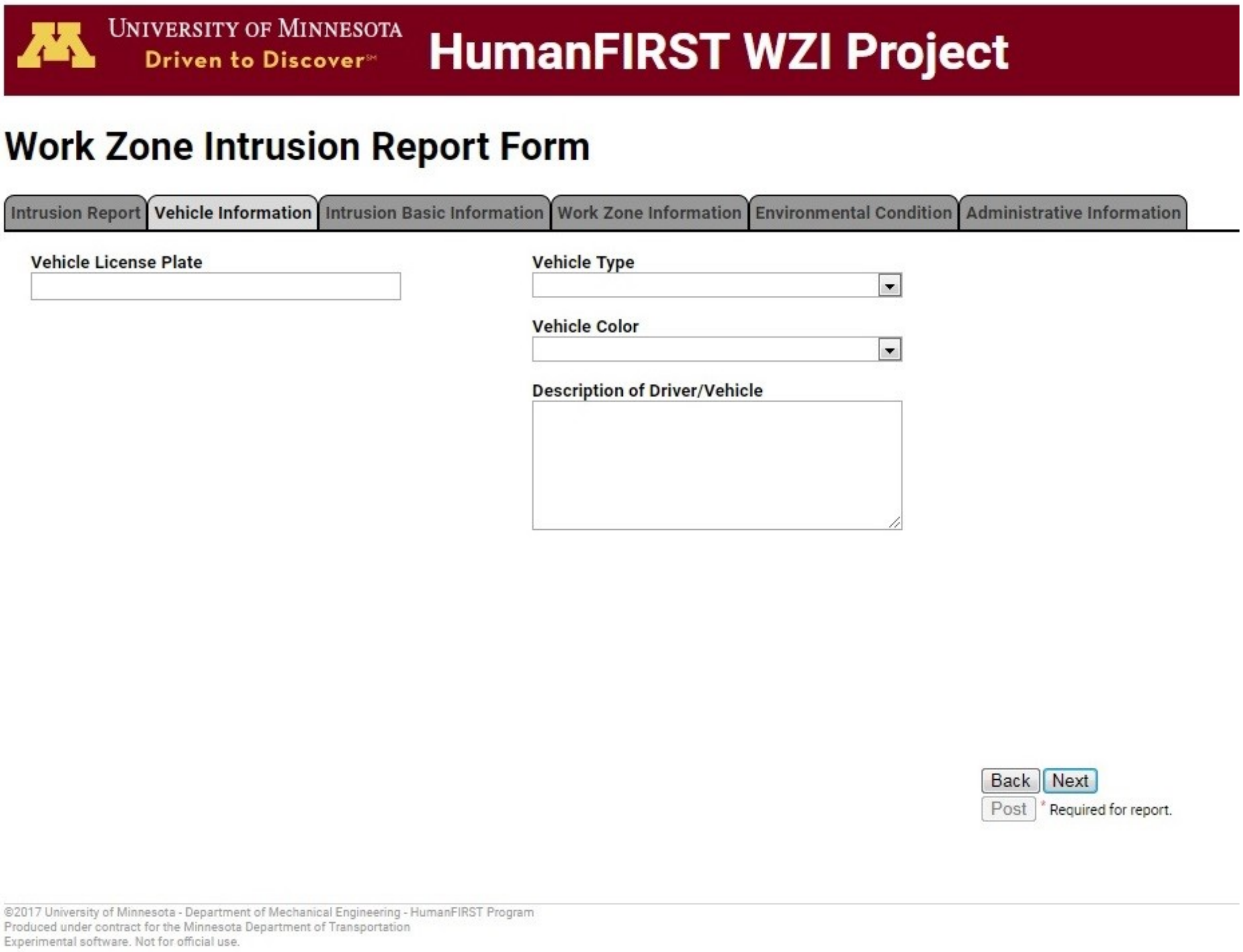


Figure 4.2 Revised Beta Interface, Second Screen.

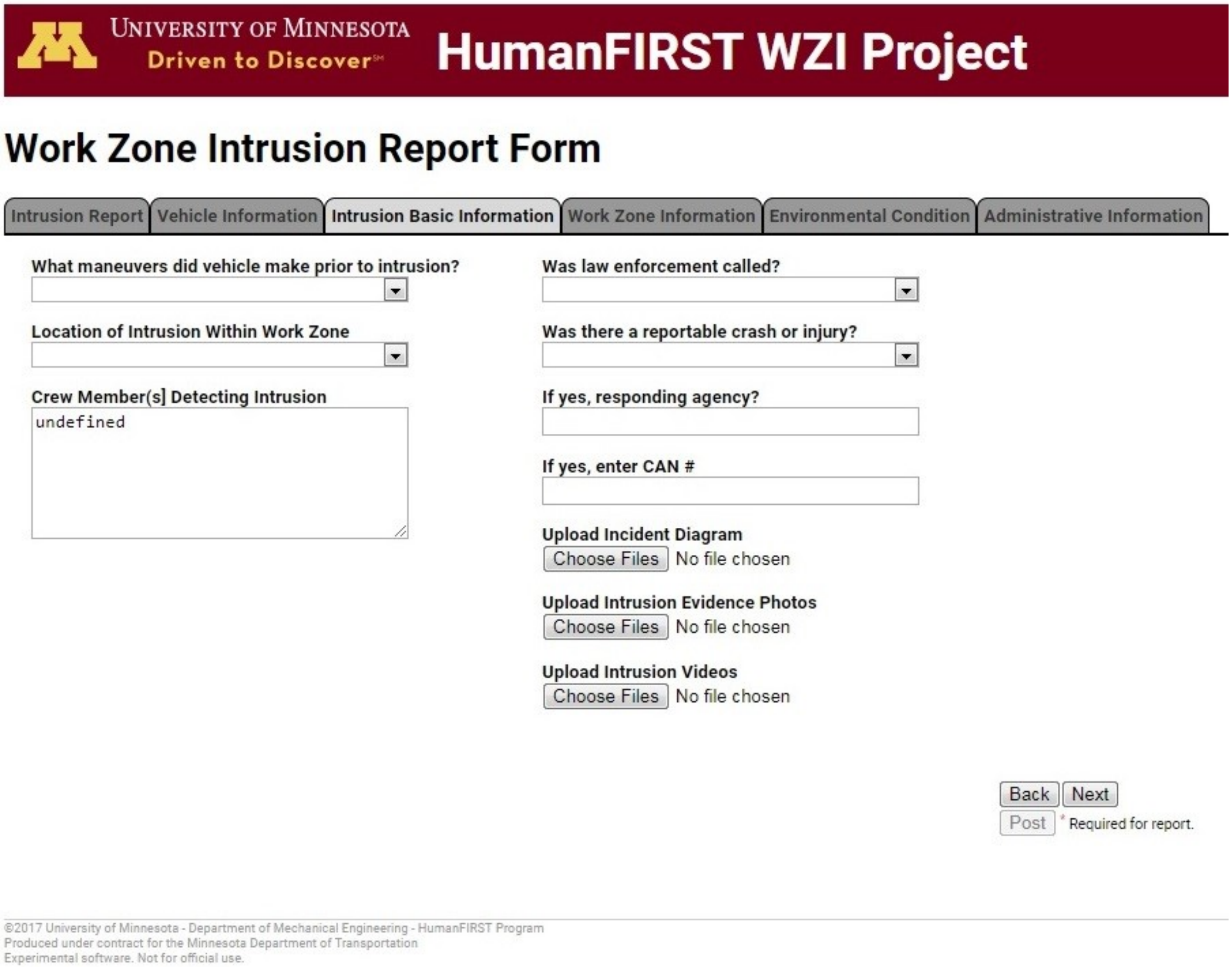


Figure 4.3 Revised Beta Interface, Third Screen.

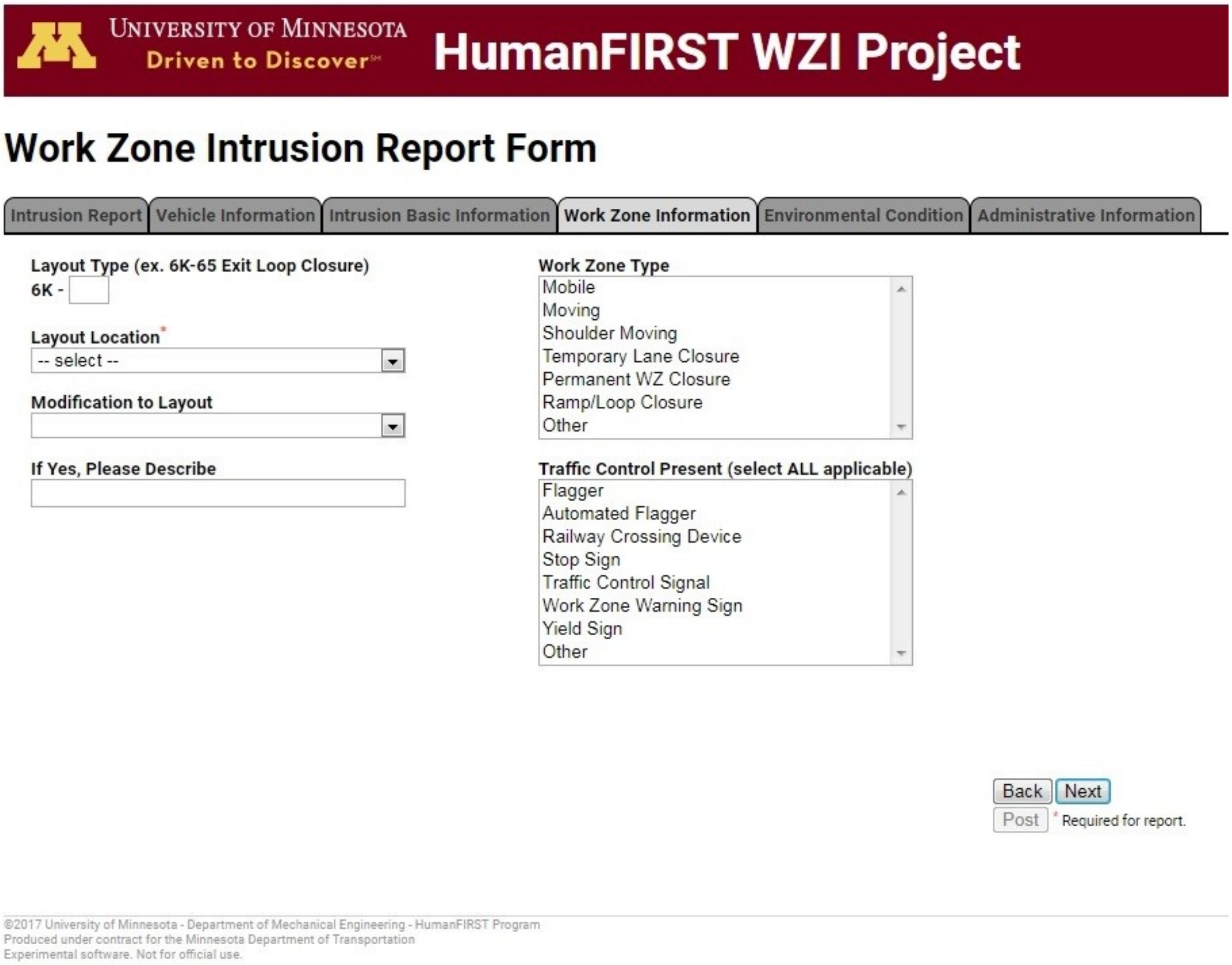


Figure 4.4 Revised Beta Interface, Fourth Screen.

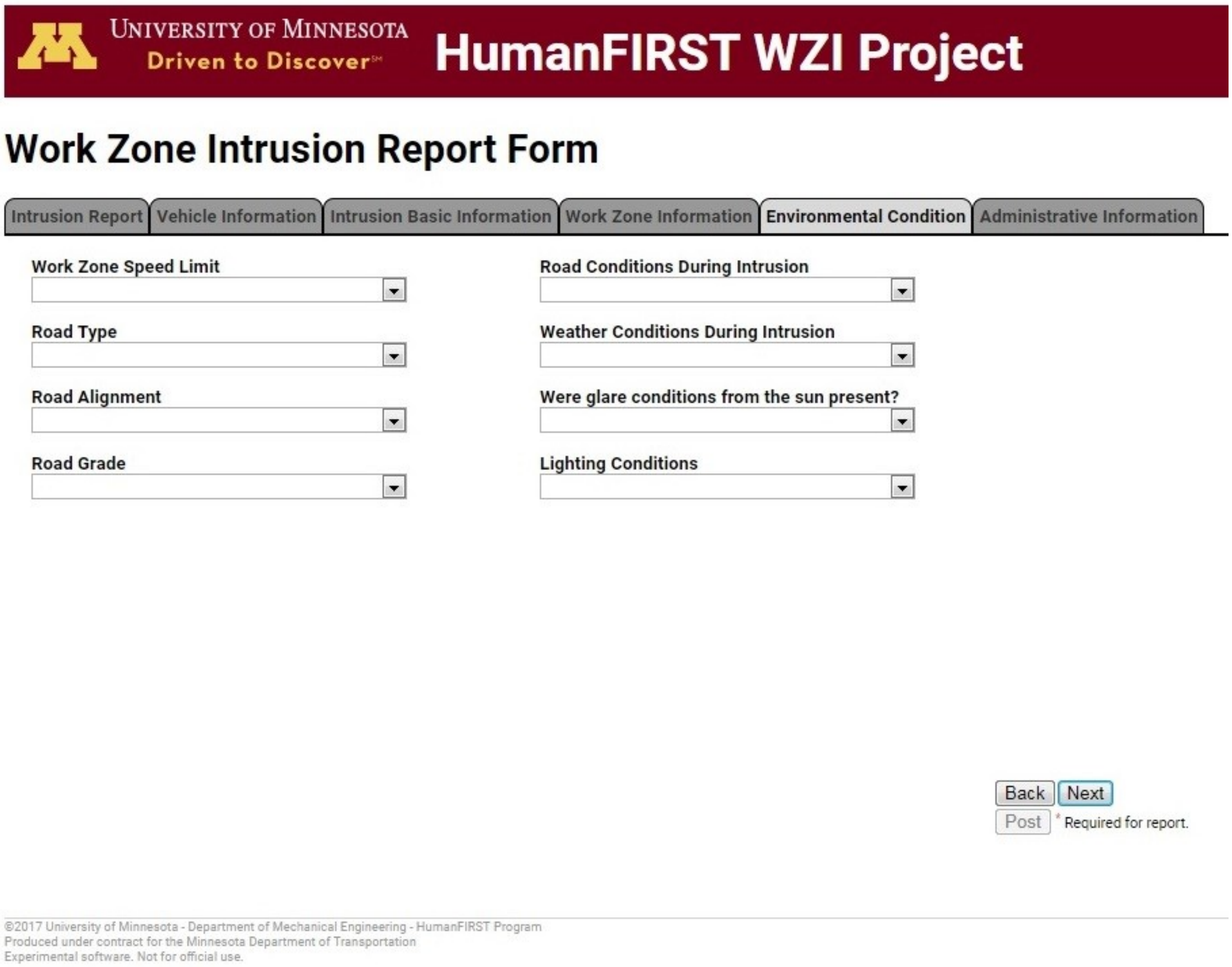


Figure 4.5 Revised Beta Interface, Fifth Screen.

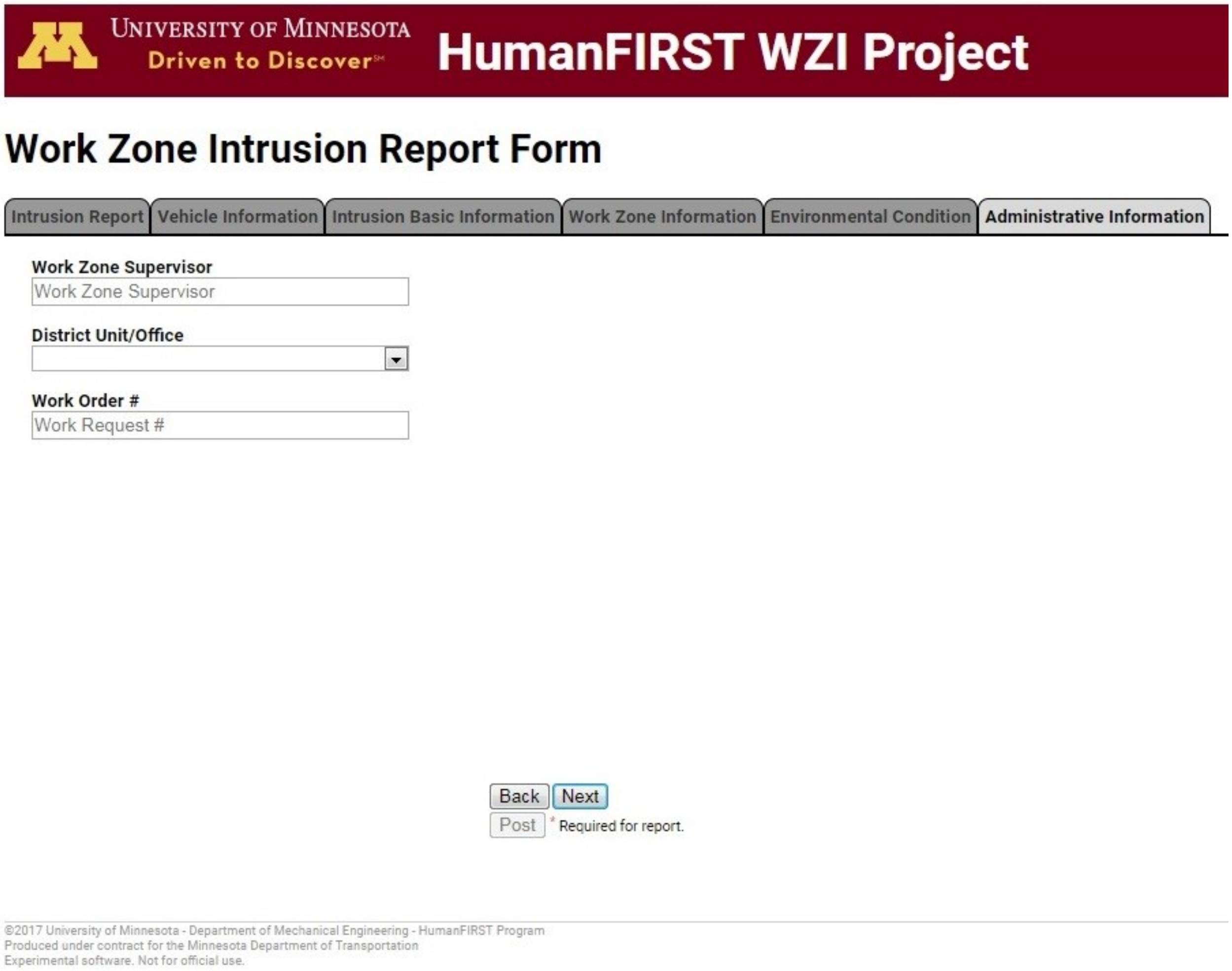


Figure 4.6 Revised Beta Interface, Sixth Screen.

4.2 MAJOR REVISED DESIGN AND TESTING

The research team at HumanFIRST followed up the initial redesigns to the beta website and paper prototype with (1) a major revision to the reporting logic by splitting up the report into an immediate "minor" report, and a more comprehensive "major" intrusion report, and (2) user testing the modal effects of the reporting interface by utilizing the usability protocol (Appendix A) and videos with a laptop, a tablet, and the paper form. Researchers tested the three versions of the intrusion reporting form interfaces with three technical advisory panel employees.

The first page of the website version now contained three drop-down menus regarding the severity of the intrusion. Beneath these drop-down's is a notice to users filling out the report that if they select no/none to all three options regarding the intrusion severity, they may submit the form immediately. This was done to allow users to quickly fill out a brief report for minor intrusions that contain the basic location, date, and narrative information. A similar change was made and is reflected in the paper form as well. This major change was implemented due to repeated comments by users that they would be unlikely to report minor intrusions unless the reporting requirements were very brief and efficient.

4.2.1 Second Beta Design User Testing

Table 4.3 shows the average results of the System Usability Scale (SUS) for all three interfaces on the newly redesigned layout, as well as the Rating Scale Mental Effort (RSME), and the average time to complete the task for each interface. There was little difference between the laptop and paper form, while the tablet took users an average of over two minutes longer to complete relative to the laptop and paper form. All users indicated that they felt their completion time would decrease significantly for all three forms once they had used them again.

The System Usability Scale (SUS) scores of the interface was generally good, as scores between 60 and 70 represent average system usability, with the SUS scores for the laptop version of the form was 71.67 (*SD* = 3.21). The laptop version also received the lowest RSME scores measuring self-reported mental effort reflected an average of 38 (*SD* = 7.21), which indicates a degree of mental demand between "some", and "a little", which reflects satisfactorily low demand imposed by the beta version of the electronic report.

Table 4.3 Average Satisfaction & Mental Workload Scores

	Laptop	**Tablet**	**Paper Form**
SUS	71.67	63.33	65
RSME	38	54	46.5
Completion Time (min.)	5:30	7:22	5:27

The Intrusion Form Survey averages are reported in Table 4.4, with the first three questions scored on a 1 (Strongly Disagree) to 5 (Strongly Agree) scale, and the last question scored on a multiple choice (7-point) option of: Worst Imaginable, Awful, Poor, Ok, Good, Excellent, and Best Imaginable.

Table 4.4 Intrusion Form Survey Scores for Multiple Interface Types

	Laptop	**Tablet**	**Paper**
1. Information Entered Accurately	4.5	4	4
2. Confidence While Using Form	4.5	4	4

3. Interface Has Annoying Features	3	2.5	1
4. Overall User-Friendliness	5.5	5	6

As reflected in Table 4.4, users were moderately confident in both the accuracy of the information entered in their ability to complete the form for all three interfaces. Most users reported relatively low annoyance with the form, although there may still be more room for improvement in later designs. Finally, overall user-friendliness was highly rated, with the average score somewhere between “Good” (score of 5) and “Excellent” (score of 6) for all three interfaces.

The most popular aspects of the interface were the drop-down menus, the comprehensiveness of the form, and the ability to quickly report a minor intrusion that did not require users to fill out the entire form. This allows for quick use of the form and the ability to enter in and report most useful points of data about a work zone intrusion. The least popular aspects were regarding the duration it took to complete the form as well as the likelihood that on-site workers would complete the form for minor intrusions. There were also several interfaces design issues for the tablet version of the form regarding the tablet keyboard blocking the input fields.

CHAPTER 5: FINAL DESIGN AND RECOMMENDATIONS

5.1 OVERVIEW

After testing the beta version of the website and paper intrusion forms with work zone employees and supervisors and making another round of changes to the form based on user feedback, HumanFIRST researchers began testing the final version of the form with users. This final phase of testing was done to further refine the design of the intrusion reporting system and test how it works in settings more similar to real-world scenarios. This chapter describes the final design, testing methods, results, and recommendations.

The final version of the design was similar to the beta version with minor changes to the layout and wording of the content. The final version of the electronic form was stored on a private university website and comprised of seven webpages, six of which comprised the reporting interface and a seventh page notifying users of a successful submission. Each page in the report includes multiple drop-down menus and manual entry items allowing supervisors to report informative details about the work zone intrusion. Some of the entry fields were required for submission. All of these fields had markers that indicated they were required and users were not able to submit the form until all of the required fields were completed.

5.1.1 Final Design and User Testing

The protocol used in the final version of the testing was identical to the second beta testing of the form. The usability testing protocol is presented in Appendix A. It consisted of an introductory period where the system and testing procedure was explained. Instead of using the user-generated scenarios as done previously, videos of real intrusions captured on camera by MnDOT were used. The volunteering workers then watched a video of an intrusion in a Minnesota work zone and filled out the report using the final system. For each video, users completed the form using one of three methods: a paper version, a laptop with a mouse, or a Dell tablet used by MnDOT employees. The time to completion for reporting the intrusions recorded to measure both intuitiveness and learnability of the final design. Afterwards, three questionnaires were administered, including the System Usability Scale (Appendix B), the Rating Scale Mental Effort (Appendix C) and a researcher designed questionnaire titled “Intrusion Form Survey” about the beta (Appendix D). Finally, a series of free-response questions were asked (Appendix A).

For the videos, the researchers used the previously administered camera footage supplied by MnDOT (see section 4.1.1). These three videos featured a minor, moderate, and severe intrusion reflecting urban and suburban areas in both day and night shifts. Researchers tested three potential users of the intrusion reporting form.

5.1.1.1 Final Design User Testing Results

The average time for completion of the report using the paper version was 5 minutes and 17 seconds. The average time for completion of the report using the website version on a laptop was 5 minutes and

42 seconds. The average time for completion of the report using the website version on a tablet was 6 minutes and 24 seconds. While ideally it would initially take under 5 minutes to complete, taking a five to six minutes reflects an acceptable time investment. Furthermore, the learnability of the system was high, each user got faster after each time they completed the form, regardless of the order, was indicative of the overall intuitiveness of the forms, with users averaging under 5 minutes each for the final form they completed, regardless of whether it was using paper, laptop, or tablet. Users reported easily figuring out the system and rapidly filled out the report on their final use.

The System Usability Scale (SUS) scores of the interface was fairly good, as scores between 60 and 70 represent average system usability, and the average SUS scores for the beta system was 86.875 (*SD* = 13.288). RSME scores measuring self-reported mental effort reflected an average of 36.25 (*SD* = 7.5), which indicates a degree of mental demand between "some", and "a little", which reflects satisfactorily low demand imposed by the beta system.

The Intrusion Form Survey averages are reported in Table 5.1, with the first three questions scored on a 1 (Strongly Disagree) to 5 (Strongly Agree) scale, and the last question scored on a multiple choice (7-point) option of: Worst Imaginable, Awful, Poor, Ok, Good, Excellent, and Best Imaginable.

Table 5.1 Intrusion Form Survey Scores for Multiple Interface Types

	Paper	**Laptop**	**Tablet**
Information Entered Accurately	4.67	4.33	4.33
Confidence While Using Form	4.33	4	3.67
Interface Has Annoying Features	2	2	2.33
Overall User-Friendliness	5	4.67	4.67

As reflected in Table 5.1, supervisors were moderately confident in the accuracy of the information entered in the form for all three interfaces, and highly confident in their ability to complete the form, also for all three interfaces, although they consistently rated the tablet version, the slowest for completion time, as their least preferred of the three (see Table 5.2). Most users reported relatively low annoyance with the form. Finally, overall user-friendliness was highly rated, the average score for all three forms being at or close to "Good" (score of 5).

The most popular aspects of the interface were the drop-down menus, the comprehensiveness of the form, and the ability to quickly report a basic intrusion (one that did not involve any evasive maneuvers by crew or risk to the crewmembers on-site) that did not require users to fill out the entire form. This allows for quick use of the form and the ability to enter in and report most useful points of data about a work zone intrusion. One of the least popular aspects were regarding the duration it took to complete the form, although users widely indicated they thought they would be able to complete it much faster after a couple times through the form, especially for the “Basic Report.” Users also reported that they were skeptical of the likelihood that on-site workers would complete the form for basic or minor intrusions. There were also several interfaces design issues for the tablet version of the form regarding the tablet keyboard blocking the input fields when it is used in the landscape mode. These issues do not arise when the tablet is in portrait mode, however, which is the mode users indicated they felt they would typically use it when filling out the report.

Table 5.2 Average Satisfaction & Mental Workload Scores

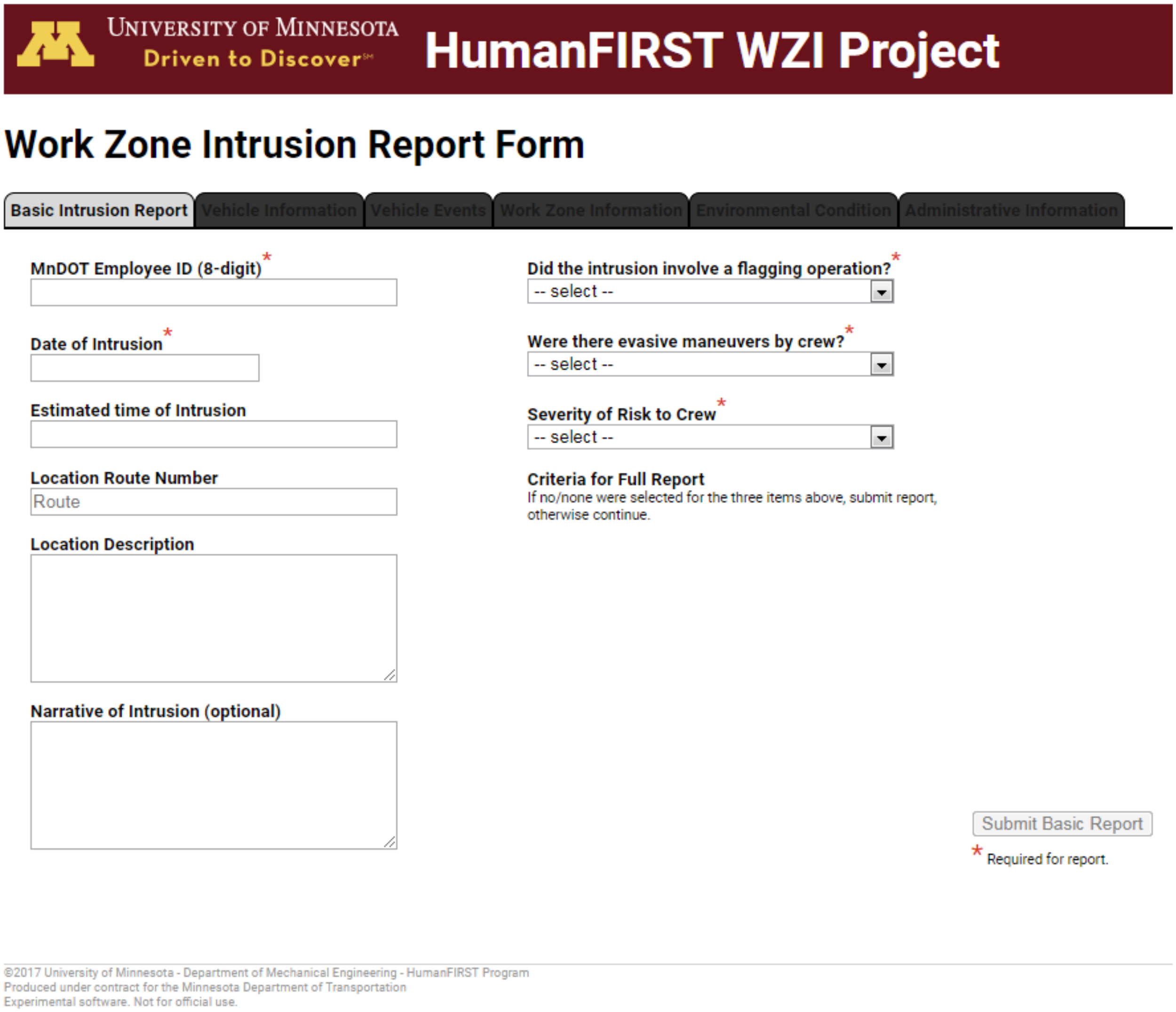
	Laptop	**Tablet**	**Paper Form**
SUS	70.33	61	78.67
RSME	29.67	38	20.67
Completion Time (min.)	5:42	6:24	5:17

5.1.1.2 Final Design Revisions

There were several changes and adjustments made to the final version from the beta design. A number of these changes are described in the following Table 5.3. Screenshots of the final version are presented in Table 5.1 through Table 5.3. The final paper version of the interface is presented in Figure 5.4. The final online interface is, at the time of writing this report, was hosted on a private server and files made available to the sponsor.

Table 5.3 Minor Revisions to Final Design

Website Interface	Changed the title of the tab from "Minor Report" to "Basic Intrusion Report", which was meant to make it more intuitive to users that if there was no risk to crew, further information was not required.	Changed the title of the tab "Intrusion Basic Report" to "Vehicle Events", which was meant to make the tab title more intuitive and not confusing relative to the change of the first tab name.	Changed the button titles from "Submit Minor Report" and "Submit Major Report" to "Submit Basic Report" and "Submit Full Report," respectively.	Certain fields were made mandatory for the full report to ensure enough information was collected to properly analyze the intrusion.
	Added more options to several fields for more accurate and detailed reporting of events	Changed the location of several field items to better reflect the flow of thought of the user		


University of Minnesota
Driven to Discover℠
HumanFIRST WZI Project

Work Zone Intrusion Report Form

Basic Intrusion Report | Vehicle Information | Vehicle Events | Work Zone Information | Environmental Condition | Administrative Information

MnDOT Employee ID (8-digit)*

Date of Intrusion*

Estimated time of Intrusion

Location Route Number
Route

Location Description

Narrative of Intrusion (optional)

Did the intrusion involve a flagging operation?*
-- select --

Were there evasive maneuvers by crew?*
-- select --

Severity of Risk to Crew*
-- select --

Criteria for Full Report
If no/none were selected for the three items above, submit report, otherwise continue.

Submit Basic Report
* Required for report.

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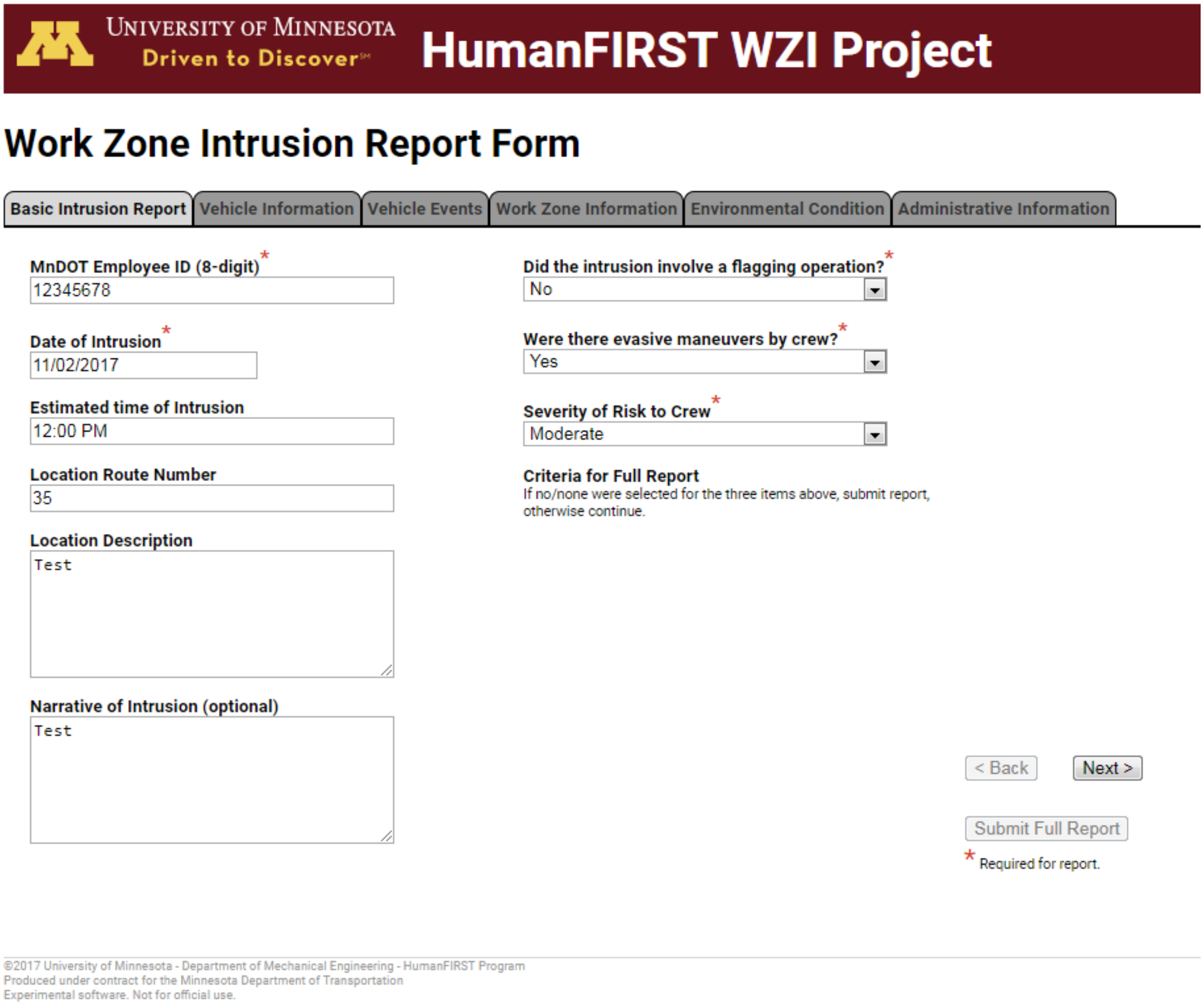
Figure 5.1 Final Interface, Basic Report Screen.


UNIVERSITY OF MINNESOTA
Driven to Discover℠
HumanFIRST WZI Project

Work Zone Intrusion Report Form

Basic Intrusion Report | Vehicle Information | Vehicle Events | Work Zone Information | Environmental Condition | Administrative Information

MnDOT Employee ID (8-digit)*
12345678

Date of Intrusion*
11/02/2017

Estimated time of Intrusion
12:00 PM

Location Route Number
35

Location Description
Test

Narrative of Intrusion (optional)
Test

Did the intrusion involve a flagging operation?*
No

Were there evasive maneuvers by crew?*
Yes

Severity of Risk to Crew*
Moderate

Criteria for Full Report
If no/none were selected for the three items above, submit report, otherwise continue.

< Back | Next >

Submit Full Report

* Required for report.

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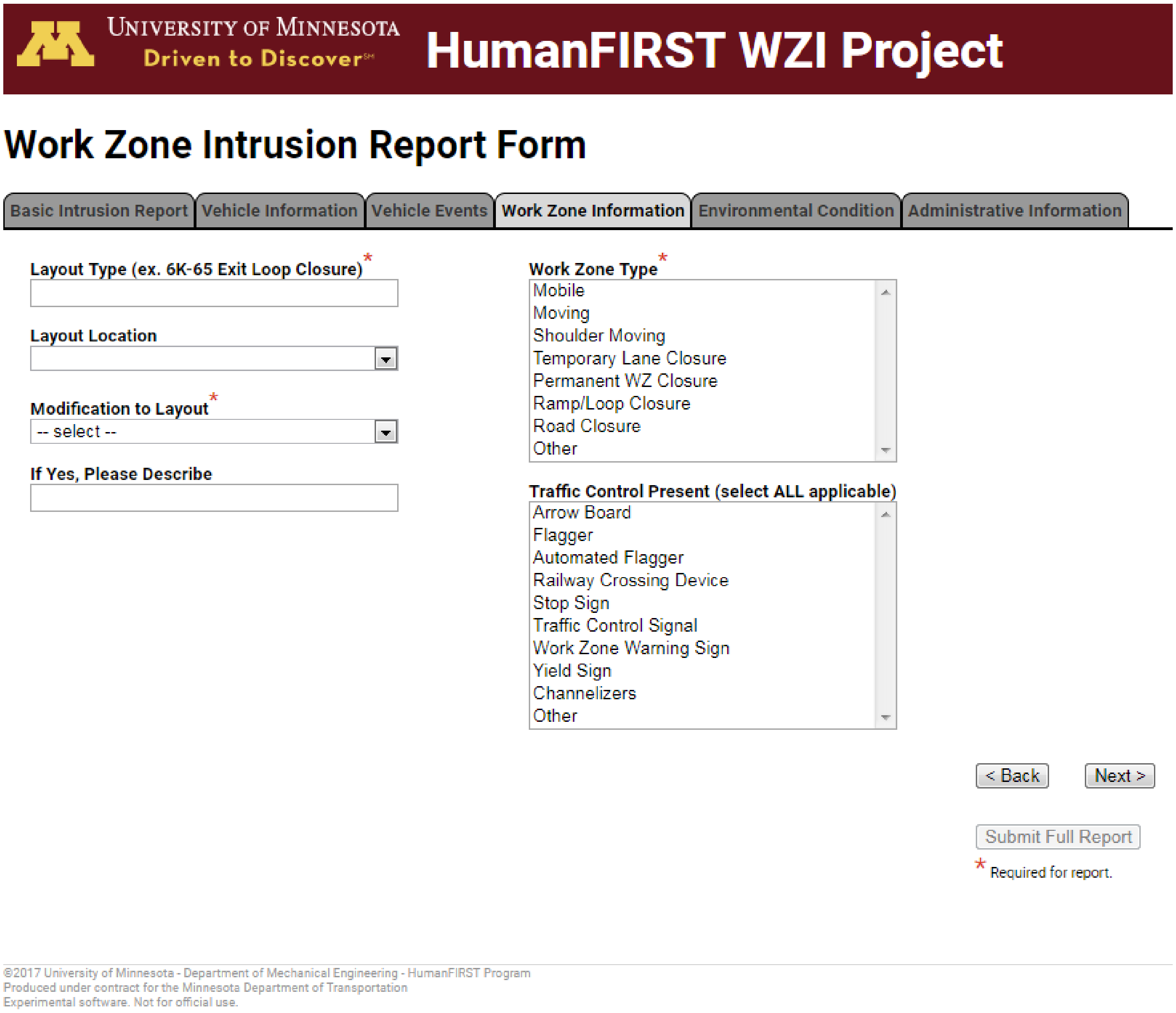
Figure 5.2 Final Interface, Full Report First Screen.



University of Minnesota
Driven to Discover
HumanFIRST WZI Project

Work Zone Intrusion Report Form

Basic Intrusion Report | Vehicle Information | Vehicle Events | Work Zone Information | Environmental Condition | Administrative Information

Layout Type (ex. 6K-65 Exit Loop Closure) *

Layout Location

Modification to Layout *
-- select --

If Yes, Please Describe

Work Zone Type *
- Mobile
- Moving
- Shoulder Moving
- Temporary Lane Closure
- Permanent WZ Closure
- Ramp/Loop Closure
- Road Closure
- Other

Traffic Control Present (select ALL applicable)
- Arrow Board
- Flagger
- Automated Flagger
- Railway Crossing Device
- Stop Sign
- Traffic Control Signal
- Work Zone Warning Sign
- Yield Sign
- Channelizers
- Other

< Back   Next >

Submit Full Report

* Required for report.

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Figure 5.3 Final Interface, Full Report Fourth Screen.

Employee Name: ______________________ Work Order #: ______________

*MnDOT Employee ID: ______________________ District/Office: ______________

Work Zone Supervisor: ______________________

MnDOT: Work Zone Intrusion Report

*Intrusion Date: ________________ Intrusion Time: _______________

Location

Route Number: _______________________ Location Description:____________________________

Narrative (optional): ____

____

____

Intrusion Severity

*Flagger Involved?

- ☐ Yes
- ☐ No
- ☐ Unknown

*Did Crew Make Evasive Maneuvers?

- ☐ Yes
- ☐ No
- ☐ Unknown

*Risk to Crew:

- ☐ None
- ☐ Mild
- ☐ Moderate
- ☐ Severe

Directions

IF: You marked one of the above items in GRAY, turn page over and fill out the second page of form.

If you did not mark one of the gray items, only fill out this front page, sign, and date.

Signature: ___________________________________

Date: ______________________________________

*Required for basic report

Figure 5.4 Final Paper Interface, First Page.

Vehicle Details

License Plate: ________________ **Description of Driver/Vehicle:**______________________________

Vehicle Type: ________________ ____

Vehicle Color: ________________ ____

Vehicle Maneuvers Prior to Intrusion: ____

Intrusion Details

*__Was law enforcement called?__

☐ Yes ☐ No

If yes, what agency? _____________

Reportable crash or injury occur?

☐ Yes ☐ No

If yes, crash report #: _____________

Original Witness(es), if known:

____

____

____

____

*__Location of Intrusion:__

☐ Advance Warning Area
☐ Transition / Taper
☐ Activity Area Buffer
☐ Active Activity Area
☐ Termination
☐ Unknown

Work Zone Details

*__Layout Type:__ ____________
(ex. 6K-65, Exit Loop Closure)

*__Layout Modification?__
(including additional layout)
☐ **Yes** ☐ **No**

If yes, please describe:

____

____

*__Work Zone Type:__

☐ Mobile
☐ Moving
☐ Shoulder Moving
☐ Temporary Lane Closure
☐ Permanent WZ Closure
☐ Ramp/Loop Closure
☐ Road Closure

Traffic Control Present:

☐ Flagger
☐ Automated Flagger
☐ Railway Crossing Device
☐ Stop sign
☐ Traffic Control Signal
☐ Work Zone Warning Sign
☐ Yield Sign
☐ Other___________

Roadway Location:

☐ Right Shoulder
☐ Left Shoulder
☐ Right Lane
☐ Left Lane
☐ Center Lane(s)
☐ Multiple Lanes (Right)
☐ Multiple Lanes (Left)

Environment Details

WZ Speed Limit: _______

Road Alignment:

☐ Straight
☐ Curve Lt
☐ Curve Rt

Road Grade:

☐ Level
☐ Hillcrest
☐ Sag (bottom)
☐ Uphill
☐ Downhill

Road Type:

☐ Intersection
☐ 2-way Undivided
☐ 2-way Unprotect. Med.
☐ 2-way Med. Barrier
☐ One-way
☐ Intersection
☐ Entry / Exit Ramp
☐ Intersection
☐ Driveway
☐ Railroad Crossing

Weather:

☐ Clear
☐ Cloudy
☐ Fog/Smog/Smoke
☐ Rain
☐ Sleet/Hail
☐ Snow
☐ Severe Crosswinds
☐ Blowing Sand/Oil/Dirt
☐ Unknown

Lighting Conditions:

☐ Daylight
☐ Sunrise/Dawn
☐ Sunset/Evening
☐ Dark w/ Streetlights
☐ Dark w/ No Streetlights
☐ Dark Lighting Unknown
☐ Unknown

Glare Conditions (sun)?

☐ Yes
☐ No

Road Condition: _______________

Signature: ________________________________

Date: ________________________________

*Required for full report

Figure 5.5 Final Paper Interface, Second Page.

5.2 FINAL RECOMMENDATIONS

Our final recommendations are segmented into three categories: 1) direct implementation issues, 2) near-future human-system integration, and 3) organizational engagement. Direct implementation relates to immediate items that MnDOT and MNIT should consider while converting the research prototype intrusion reporting system built by HumanFIRST. Near-future human-system integration issues reflects the ongoing task and design considerations as MnDOT deploys the system. Organizational engagement centers around how the central office could best coordinate and communicate with supervisors and workers on the field to make the reporting dynamic successful.

5.2.1 Direct Implementation

There are two primary issues and one minor issue that MnDOT and MNIT should be aware of while converting the reporting system for use by MnDOT. First, the converted system should be quality assurance tested with all browsers, especially Internet Explorer, to ensure functionality before deployment. Second, the uploading options for incident diagrams, pictures, and video in the current build by HumanFIRST are placeholders due to security reasons for the University of Minnesota. The research platform created for data storage demonstration is in an unsecured website. No files are allowed to be uploaded at present time for this reason. When implemented for MnDOT user, security would be handled internally to ensure data privacy is appropriately addressed, and the uploading capabilities should be made functional by MnDOT and MNIT. Finally, there is a minor limitation on the Work Zone Information page in the online reporting form: the work zone type, and traffic control present option are currently only multi-selectable by pressing CTRL + the left mouse button. This places a limitation on full use of the multi-selectable function by touchscreen or tablet users. Further coding should be done to make the options multi-selectable by pressing the data attribute option and having that option remain selected unless deliberately de-selected by having the user press the same option again.

5.2.2 Human-System Integration

A primary selling point of using the online or digital interface is that it should be easy and quick to access in the field, allowing a supervisor or crew leader on site to rapidly report a work zone intrusion and resume primary job duties. Furthermore, some supervisors thought that digital data might get more attention from analysts than paper data that "collects dust in a locked storage room". Therefore, ease of access and analysis are moderate selling points for the new system, and an effort should be made to actually make the reporting system easily accessible on tablets and other portable electronic devices in the field. In addition, as the system is deployed, the responsible office should continue to consider how to best implement the intrusion reporting process in the everyday workflow of supervisors, so that even if the intrusion is not reported immediately, there is part of the supervisor routine in which they are prompted to report any intrusion that occurred that workday.

5.2.3 Organizational Engagement

Reporting work zone intrusions, especially minor ones, is seen as a low priority by many supervisors and workers, as “just another report for the pencil-pushers that doesn’t change anything”. Given that they consider reporting minor intrusions as low priority, if MnDOT wants reliable and consistent intrusion reporting, an effort to engage work zone supervisors and crewmembers in the benefits, consequences, and decision-making process is essential to the success of the intrusion reporting system. Communication should be made on a widespread and consistent basis about the current and recent data on intrusions, the data trends, and what changes are being made as a result of the intrusion reporting.

Given this, the office or team responsible for managing the intrusion reporting data should have at least three areas of focus with a different team member handling each area:

1. Intrusion data and how it should impact *state and local government* policy,
2. Intrusion data and how it should influence *MnDOT policy* on work zone use and design, and
3. Supervisor and *crewmember coordination* and outreach.

Through the creation of an organizational structure and plan regarding the received work zone intrusion data, MnDOT can design a plan around the data, propose policy at the state level, consider current work practices, and communicate to work zone crews how their reporting is having a real impact.

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APPENDIX A

WORK ZONE INTRUSION PROTOCOL #1

Introduction

- Thank you for meeting with us today
- Brief explanation about work zone intrusions
- Brief explanation about how our role is to communicate their needs and wants back to the state

Tasks

- Today we are going to have you complete 2 tasks
    - Which is faster, writing or typing?
- First, we would like you to write down (or type up) a detailed story about a real work zone intrusion that you can remember well and would be likely to report if it occurred if there were an easy option to do so. Describe the important details about the work zone setup (e.g. lane closure, vehicle convoy, traffic control setup & removal) Try to be as detailed as possible about the information that you do remember regarding the vehicles actions, and any evasive action by the crew. Also, try to include any information you can recall about the weather and road conditions.
    - Now that you have written out the intrusion account you've experienced, please underline (or highlight) what information in the story you think would be important details you would want reported to your truck station, MnDOT, and and/or other authorities?
- Next, we are going to read to you a few brief scenarios about a work zone intrusion. After we have read each report, we would like you to fill out the intrusion report with the prototype interface. We would like to encourage you to please think aloud as you fill out the form and provide any verbal feedback you can think of regarding your thought process and expectations or concerns as you fill the form out.
    - Each scenario will be filled out as its own report, multiple intrusions not implemented yet
    - This is to be implemented with TAMs, so it will be part of a work order, so some details will already be included, such as a Username and Work Zone location

Scenarios

1. Flagger in daytime, SUV, angry driver, intrudes near taper/merge, evasive maneuvers by flagger, driver skips queue.

"Donald Morrison is the flagger for a daytime work zone site on a straight level one-way road. He reports to you that yesterday afternoon around 2:00 PM he was flagging a series of cars to wait and form a queue. A driver in an SUV pulled up to the front of the line, yelled at him, and deliberately maneuvers around him, skipping the queue to continue driving into the work zone. It was a cloudy day with normal road conditions and the local speed limit was 40 mph."

2. Driver enters activity area, swerves to avoid sideswipe, in active work zone. Debris in road, glare conditions. Driver merges back into roadway.

"Gregory Wise is a crewman in a lane closure work zone on a left curving uphill two-way undivided road near a stoplight. He reports to you that today, in the morning, he saw a driver of a small car swerve to avoid another car about to sideswipe and hit it, and because of this swerve, the car entered an activity area and an active work zone. There was debris in the roadway as well as quite bad glare conditions on a sunny day. The driver then left the activity area and merged back onto the roadway. "

3. Driver moves in-between mobile convoy at night, rainy weather, swerving a little, perhaps inattentive or drunk. Driver moves off into exit ramp.

"Issac Patrick drives part of a mobile operation. He reports to you that a driver moved in-between the operation (the gore point) at night during rainy weather. The driver was swerving a little and was perhaps drunk or being inattentive. Shortly after, the driver moved out from the convoy and off into an exit ramp. The speed limit in the area was 35 mph."

4. Unseen intrusion. Knocked over cones and skid marks, on a long straight rural road. Late night clear weather conditions.

"Coming to the work zone in the morning, you find that a series of barrels along a long, straight, four lane rural highway that are blocking off a lane have been knocked over, as well as tire skid marks near the end of the disturbed barrels in the middle of the termination area, where a vehicle seems to have veered back onto the roadway. There was clear weather the night before, and road conditions seemed normal."

Closing Interview

- Administer SUS and any other potential surveys
- Closing Interview
    - "Thank you for completing the intrusion reports. We would like to hear from you your experience using the prototype reporting interface. We want to hear your thoughts so we can design the most user-friendly interaction possible."
    - Possible Questions for the guided interview

1. What elements of the interface worked well for you, that we may want to keep?

2. What part of the interface or task did you find frustrating or hard to do?
3. Did you have any problems with the organization of the interface, where things were?
4. What elements should we include in the next version of the interface? Are we missing things we should have in the report?
5. If an intrusion occurred but nothing was damaged and no one was hurt, how likely do you think you would be to report it if this form was available to you. Why or why not?
6. In your experience, about how many work zone intrusions (may need to specify again what we consider intrusions) would you estimate occur a day? Does it seem to vary based on the location (rural vs. urban vs. highway)?
7. In your experience, what seems to be the most common type of work zone intrusion? Why do you think that is?
8. Do you have any other thoughts about the interface or the possibility of beginning to report and record work zone intrusions?

How would you define a work zone intrusion? What would be the threshold to classify an intrusion as something “reportable”?

APPENDIX B

SYSTEM USABILITY SCALE (SUS)

Statement	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this system frequently	☐	☐	☐	☐	☐
2. I found the system unnecessarily complex	☐	☐	☐	☐	☐
3. I thought the system was easy to use	☐	☐	☐	☐	☐
4. I think that I would need the support of a technical person to be able to use this system	☐	☐	☐	☐	☐
5. I found the various functions in this system were well integrated	☐	☐	☐	☐	☐
6. I thought there was too much inconsistency in this system	☐	☐	☐	☐	☐
7. I would imagine that most people would learn to use this system very quickly	☐	☐	☐	☐	☐
8. I found the system very cumbersome to use	☐	☐	☐	☐	☐
9. I felt very confident using the system	☐	☐	☐	☐	☐
10. I needed to learn a lot of things before I could get going with this system	☐	☐	☐	☐	☐

APPENDIX C

RATING SCALE MENTAL EFFORT (RSME)

Rating Scale Mental Effort

Please indicate, by marking the vertical axis below, how much effort it took for you to complete the task you've just finished

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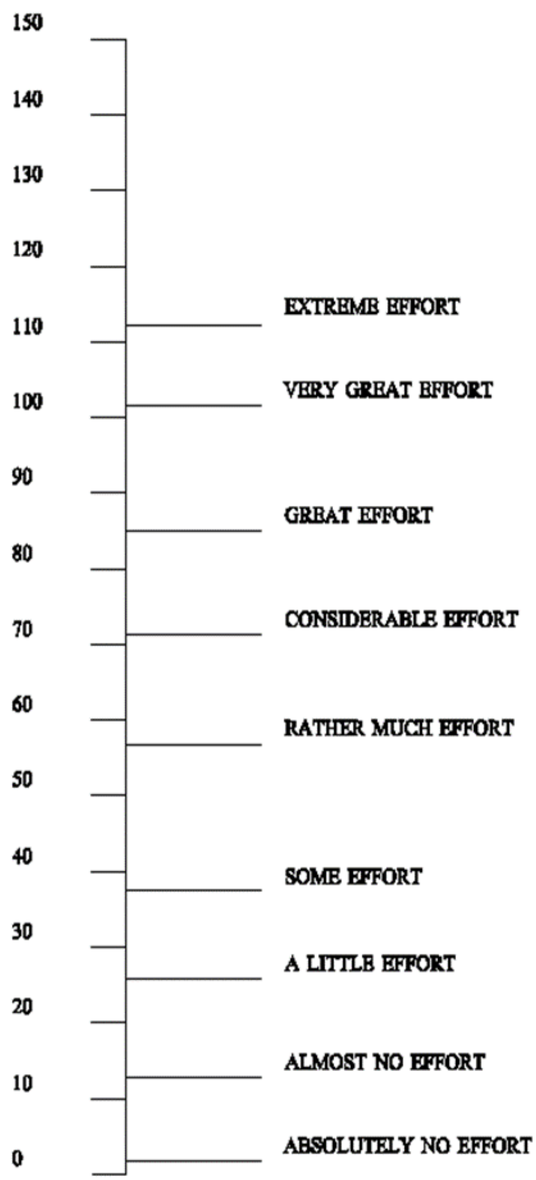

APPENDIX D

INTRUSION FORM SURVEY

For each of the following questions, place an "X" through the one number to indicate your response.
"1" for strongly disagree, "3" for neutral- neither agree nor disagree, "5" for strongly agree.

1. I was accurate with the information I entered on this interface

Strongly Disagree		Neutral		Strongly Agree
①	②	③	④	⑤

2. I felt confident completing this form

①	②	③	④	⑤

3. This interface had some annoying features

①	②	③	④	⑤

4. Overall, I would rate the user-friendliness of this device:
    - Worst Imaginable
    - Awful
    - Poor
    - Ok
    - Good
    - Excellent
    - Best Imaginable