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Prevention of Injury in Mine Resistant Ambush Protected (MRAP) Vehicle Accidents

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14. ABSTRACT
This study analyzed causes and outcomes of Mine Resistant Ambush Protected (MRAP) vehicle accidents reported to the Joint Staff Deployments and Operations Task Force (DOTF) and the U.S. Army Combat Readiness/Safety Center (USACR/SC). Accidents reported to the DOTF were reviewed to identify sequences of MRAP accident causes and outcomes. Accidents reported to the USACR/SC were reviewed to identify MRAP accident costs and injury severity outcomes. Causes and outcomes were standardized and weighted to determine their relative contributions to MRAP accident occurrence. During the time period studied (2006-2009), five standardized causes and outcomes classified as road hazard, rollover, vehicle issues, personnel, and driver response contributed to 80 percent of MRAP accidents resulting in injury. Rollovers were the deadliest and costliest Army MRAP accident type. Countermeasures such as materiel solutions and tactics, techniques, and procedures mitigating these top five MRAP accident causes and outcomes with injury are recommended, including continued emphasis on rollover risk reduction in MRAP driver training.

15. SUBJECT TERMS
Mine resistant ambush protected vehicles, MRAP accident prevention, MRAP accidents, MRAP injuries, MRAP injury prevention

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Preface

This study was originally presented in a poster titled "Prevention of Injury in Mine Resistant Ambush Protected (MRAP) Vehicle Accidents" at the 12th Annual Force Health Protection Conference, August 2009, in Albuquerque, New Mexico. Kraig Pakulski, M.Ed., John Johnson, Ph.D., Robert Giffin, M.S.O.H., Parrish Balcena, M.D., M.P.H., Dan Wise, M.Ed., and Paul St. Onge, Ph.D. were poster contributors. This technical report summarizes content presented in the poster, which is included in appendix A of this report. An updated report is planned detailing current efforts to identify and prioritize actionable recommendations addressing specific conditions, causes, and outcomes of MRAP accidents and injuries.

The authors wish to acknowledge Mr. Al Rice of the Deployments and Operations Task Force (DOTF), Joint Staff, J-39 Readiness Division, and the U.S. Army Combat Readiness / Safety Center (USACR / SC), Fort Rucker, Alabama, for granting access to the data used in this study.

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Introduction

The Mine Resistant Ambush Protected (MRAP) family of vehicles was designed to improve survivability of mounted U.S. Warfighters from improvised explosive device (IED) attacks. As of October 2009, more than 16,000 MRAP vehicles had been deployed to Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) (Gansler, Lucyshyn, & Varettoni, 2010). Anecdotal reports from theater indicate the MRAP is an effective countermeasure against IEDs, saving countless Warfighter lives (Rice & Rodriguez-Johnson, 2010).

While multiple MRAP variants have been produced to fulfill different mission profiles, all MRAPs generally incorporate the following design features to withstand the impact of mine and IED blasts: A v-shaped hull to deflect blasts, an armor-plated, blast-resistant undercarriage, a heavy curb weight ranging from 7 to 22 tons, and high ground clearance (GlobalSecurity.org, 2011a; Hambling, 2008; Rice & Rodriguez-Johnson, 2010). However, these features also affect the safe handling and operation of an MRAP. Thus, prior to operating an MRAP, all MRAP drivers receive hands-on training, including specific tactics, techniques, and procedures (TTPs) to mitigate the hazards these design features pose (GlobalSecurity.org, 2011b; Miles, 2008).

An MRAP is prone to roll over on unstable and uneven terrain and come into contact with low-hanging power lines often encountered in theater (Hambling, 2008). Analysis of 420 MRAP accidents occurring from November 2007 through August 2009 showed 178 (42 percent) of these accidents involved some type of rollover, resulting in 215 reported rollover injuries. Additional injuries resulted from falls from the vehicle or from being crushed or lacerated by one of the vehicle's heavy armored components, including doors, ramps, gunner hatches, or the Rhino detonator on the vehicle's front end. Also, 16 (4 percent) of these accidents involved contact with power lines (Rice & Rodriguez-Johnson, 2010).

Because of the MRAP's high public profile and cost, MRAP performance in IED events is closely monitored and reviewed through surveillance of accidents, personnel injuries, and vehicle damage. To support this effort, the Operational Survival Analysis Section (OSAS), an interdisciplinary team funded by the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) Program to provide contract support to the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, analyzed MRAP accident data, focusing on the causes and outcomes of each accident. The objectives of this study were to: (1) identify causative factors[1] contributing to MRAP accidents, (2) identify chronological sequences of events resulting in MRAP accidents, and (3) estimate costs of Army MRAP accidents and identify injury severity outcomes by accident type.

[1] For the purposes of this study, "causative factors," "causes," "contributing factors," "elements," and "events" are interchangeable and refer to causes of MRAP accidents.

Methods

The table below outlines the study methods. The study authors used two data sources:

a. The Deployments and Operations Task Force (DOTF) data set. This is a data set of all U.S. military MRAP accidents collected by the DOTF, Joint Staff, J-39 Readiness Division, and thus represents all Services. We used this data set to analyze contributing factors and event sequences of U.S. military MRAP accidents.

b. The U.S. Army Combat Readiness / Safety Center (USACR / SC) data set. This is a data set of Army only MRAP accidents abstracted from the Risk Management Information System (RMIS) data base. RMIS contains historical information on all accidents investigated and reported to the USACR / SC involving Army personnel and/or materiel. We used this data set to analyze primary causes, outcomes, costs, and injury severity outcomes of Army MRAP accidents.

Appendix B describes the differences between these two data sets and their strengths and weaknesses while complementing each other. For example, the DOTF data set was useful for parsing out circumstantial details from accident investigators' narrative descriptions of each accident to enable reconstruction of accident sequences. On the other hand, the DOTF data set contained limited or incomplete information on accident costs and injury severity, which the USACR / SC data set was able to supply, but only for Army MRAP accidents.

Table.
Methods.

Study parameter	Description
Study design	Retrospective cohort study
Study population	U.S. military service members, civilians, and local nationals involved in MRAP accidents
Study period	October 2006 through June 2009
Data sources	The DOTF, J-39 Readiness Division; The USACR / SC
Vehicle platform	The MRAP family of vehicles
Incident type	Accidents only
Distribution	Worldwide
Inclusion criteria	MRAP accidents reported to DOTF from all U.S. Armed Services or reported to USACR / SC (Army only)

Variables

We parsed accident descriptions in the DOTF data set into 247 accident elements, where an element is defined as any causative factor deemed to have contributed to an accident sequence. Then, we organized these accident elements into 15 categories (11 contributing factors and 4 outcomes). Appendix C shows a partial listing of these elements and their categories. The 11 contributing factors (independent variables) were the following:

a. *Check point*: A guard shack or guarded check point.

b. *Condition*: Weather conditions, dust, sand, or blackout conditions affecting visibility.

c. *Driver response*: Actions the driver took, such as turns, maneuvers, etc.

d. *Electrical*: Presence or contact with power lines or electrical components of the vehicle (e.g., battery).

e. *Equipment*: Items included with the vehicle for proper operation or safety (e.g., fire extinguishers).

f. *Personnel*: Actions of individuals in or around the vehicle, not operating the vehicle.

g. *Personal protective equipment*: Personal protective equipment (PPE) (e.g., restraints, helmets, gloves) influencing the accident injury outcome.

h. *Road hazard*: Anything on the road affecting the driver's decisions (e.g., barriers, potholes).

i. *Unit activity*: Any group activity with specialized policies (e.g., convoy operations, training).

j. *Vehicle issues*: Issues with the vehicle influencing the accident outcome (e.g., tires blowing out).

k. *Vehicle, local national*: A vehicle driven by a local national.

The four outcomes (dependent variables) were the following:

a. *Collision*: Any instance when a vehicle made contact with something other than the road itself (e.g., a barrier, pothole, another vehicle).

b. *Injury*: Any indication of personal injury regardless of severity.

c. *Rollover*: A vehicle rolling onto its side (90 degrees) or more (on its roof).

d. *Vehicle damage*: Any mention of damage to the vehicle, including fire.

Contributing factors and outcomes

After chronologically parsing accident elements and organizing them into the contributing factors and outcomes described above, we calculated the weighted contribution of each contributing factor or outcome to an accident. This was done by dividing the number of times a contributing factor or outcome occurred within a given accident by the total number of contributing factors and outcomes in that accident. We then calculated the overall weighted contribution of each contributing factor or outcome to the occurrence of all MRAP accidents in the DOTF data set. This was done by summing the weighted contributions of each contributing factor or outcome across all accidents and dividing by the total number of accidents.

As an example of this analysis method, the sum of the weighted contributions of one accident with three contributing factors (*road hazard*, *driver response*, and *collision*)[2] and a second accident with two contributing factors (*road hazard* and *collision*)[3] was calculated as follows:

a. *Road hazard*: 0.33 (one-third of first accident with three contributing factors) + 0.50 (one-half of second accident with two contributing factors) = 0.83 / 321 total accidents = 0.26 percent overall weighted contribution.

b. *Driver response*: 0.33 (one-third of first accident with three contributing factors) / 321 total accidents = 0.10 percent overall weighted contribution.

c. *Collision*: 0.33 (one-third of first accident with three contributing factors) + 0.50 (one-half of second accident with two contributing factors) = 0.83 / 321 total accidents = 0.26 percent overall weighted contribution.

Results

Summary statistics

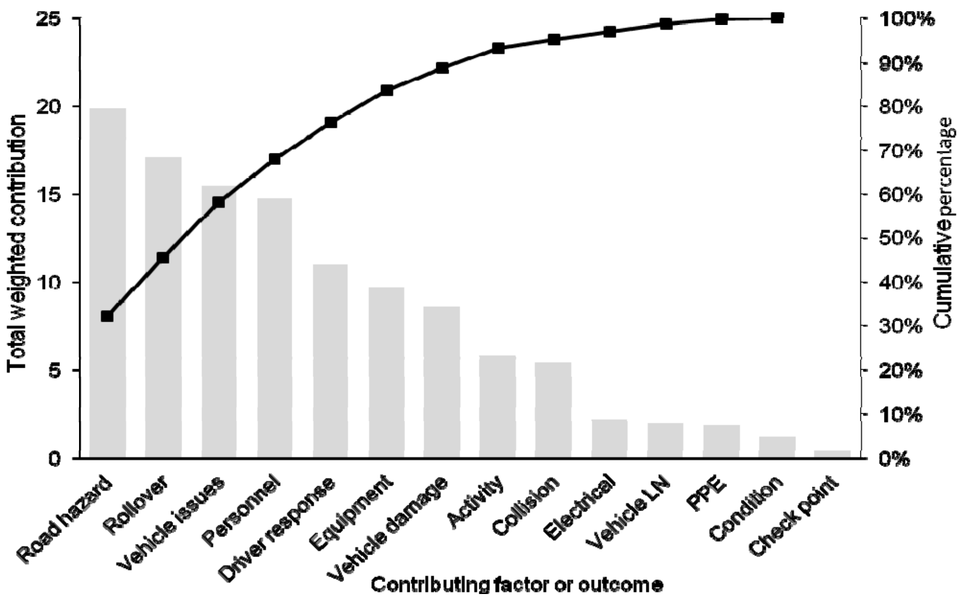
A total of 321 MRAP accidents reported from all U.S. Armed Services were identified in the DOTF data set. In addition, 130 Army MRAP accidents were identified in the USACR / SC data set, which involved 220 Soldiers and Army civilians, 95 of whom were injured, and nine of whom died.

Results derived from Deployment and Operations Task Force data set

Figure 1 highlights the most common contributing factors and outcomes of the MRAP accidents reported in the DOTF data set. Only accidents resulting in injury are shown. The overall weighted contribution of each contributing factor or outcome, which was obtained by

[2] An accident description with three events (for example, "the driver swerved to miss a pothole and collided with a barrier") is sequenced and parsed into its element categories as follows: (1) pothole (*road hazard*), (2) driver swerved (*driver response*), and (3) collided with barrier (*collision*).
[3] An accident description with two events (for example, "the driver ran into a pothole and then collided with a barrier") is sequenced and parsed into its element categories as follows: (1) pothole (*road hazard*), and (2) collided with barrier (*collision*).

summing its weighted contributions across all accidents as described above, was plotted in a descending order column chart. A line chart was then plotted over the column chart, indicating the incremental percentage contributed by each column to the cumulative total weighted contributions. This type of chart, known as a Pareto chart (QFINANCE, 2011), shows *road hazard*, *rollover*, *vehicle issues*, *personnel*, and *driver response* were the cause or outcome of 80 percent of these accidents. This chart does not identify which contributing factors were initial causative factors (primary causes), which are identified in figures 2 and 3 (pgs. 6 and 7).

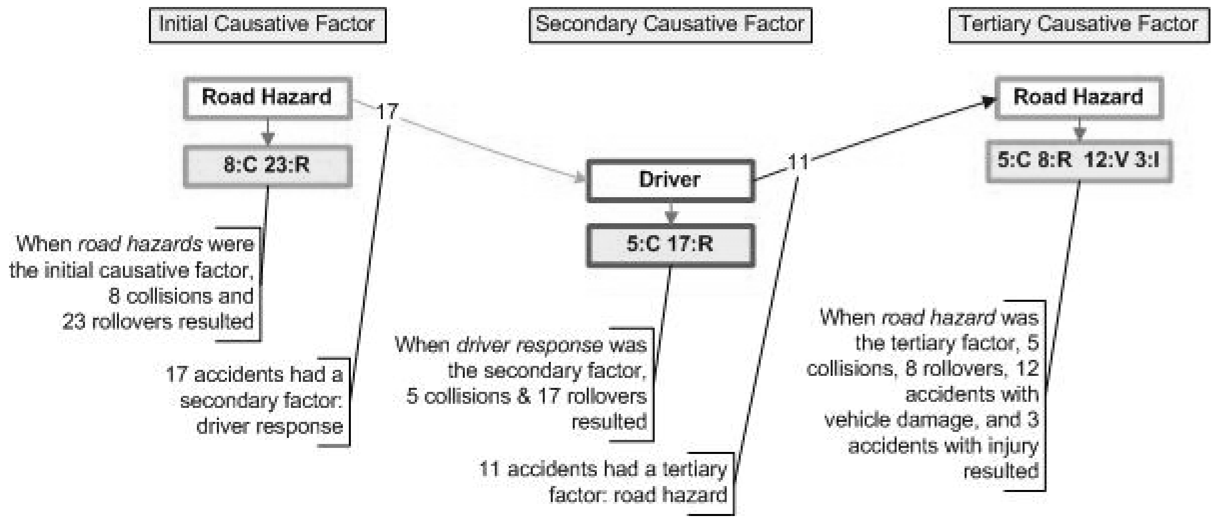


Note: LN = local national; PPE = personal protective equipment.

Figure 1. MRAP accidents with injury.

Figures 2 and 3 show diagrams of causative factor sequence patterns outlining the chronological order of causative factors (events) occurring in MRAP accidents resulting in injury. For ease of analysis, only initial, secondary, and tertiary causative factors were diagrammed. Events were depicted as nodes, and arrows were drawn between them to show the event sequence. The frequency of each outcome identified on page 3 (*collision*, *rollover*, *vehicle damage*, and *injury*) was documented at each node if it occurred. These counts represent the frequency of MRAP accidents resulting in injury as indicated in the DOTF data set, which did not capture sufficient information to evaluate injury severity or accident costs (This was done, as described on page 7, for Army MRAP accidents using the USACR / SC data set.). The outcomes shown at each node were not mutually exclusive. For example, many collisions and rollovers also resulted in vehicle damage. These overlapping outcomes explained why the total number of outcomes at each node was greater than the number of accidents shown on each arrow in these diagrams. Appendix D shows a Venn (set) diagram of these overlapping outcomes.

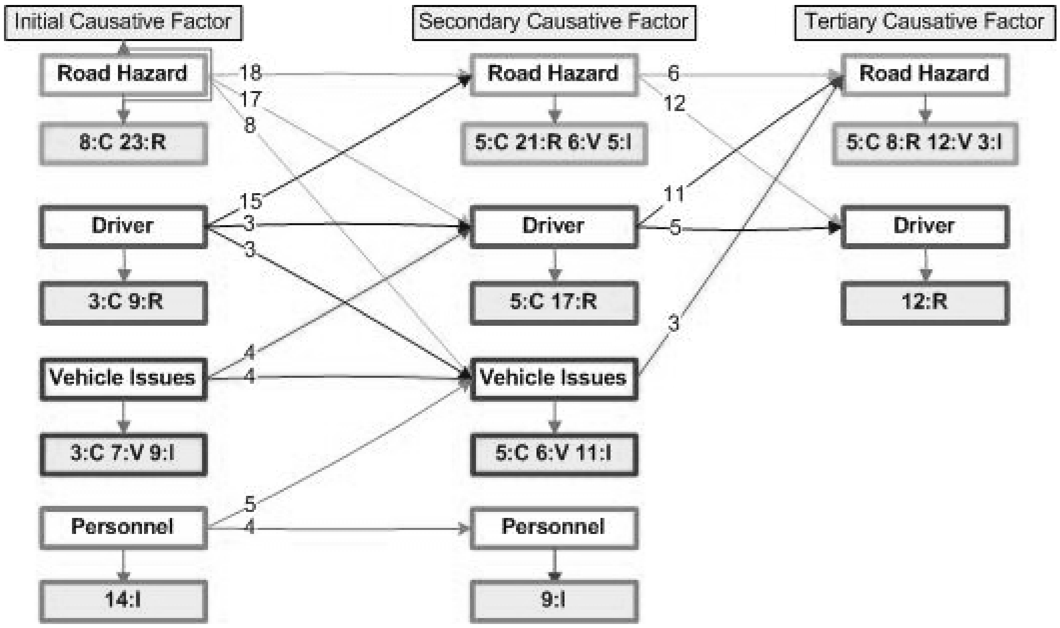
Figure 2 shows a partial causative factor sequence pattern. When *road hazard* was the initial causative factor, 8 collisions and 23 rollovers resulted; the chain of events continued for 17 accidents with *driver response* as the secondary causative factor. When *driver response* was the secondary causative factor, 5 collisions and 17 rollovers resulted; the chain of events continued for 11 accidents with *road hazard* as the tertiary causative factor. When *road hazard* was the tertiary causative factor, 5 collisions, 8 rollovers, 12 accidents with vehicle damage, and 3 accidents with injury resulted, thus ending the chain of events for MRAP accidents occurring according to this sequence pattern.



Note: C = collision; R = rollover; V = vehicle damage; I = injury.

Figure 2. Causative factors example.

Figure 3 shows a full causative factor sequence pattern. Unlike figure 2, this diagram shows a combination of causative factors leading to each secondary and tertiary causative factor. *Road hazard* and *driver response* were the most common initial causative factors setting off the chain of events for MRAP accidents occurring according to this sequence pattern. Collisions resulted directly from *road hazard*, *driver response*, and *vehicle issues* as causative factors in this sequence pattern; injuries resulted directly from *road hazard*, *vehicle issues,* and *personnel*; rollovers resulted directly from *road hazard* and *driver response*; and vehicle damage resulted directly from *road hazard* and *vehicle issues*.

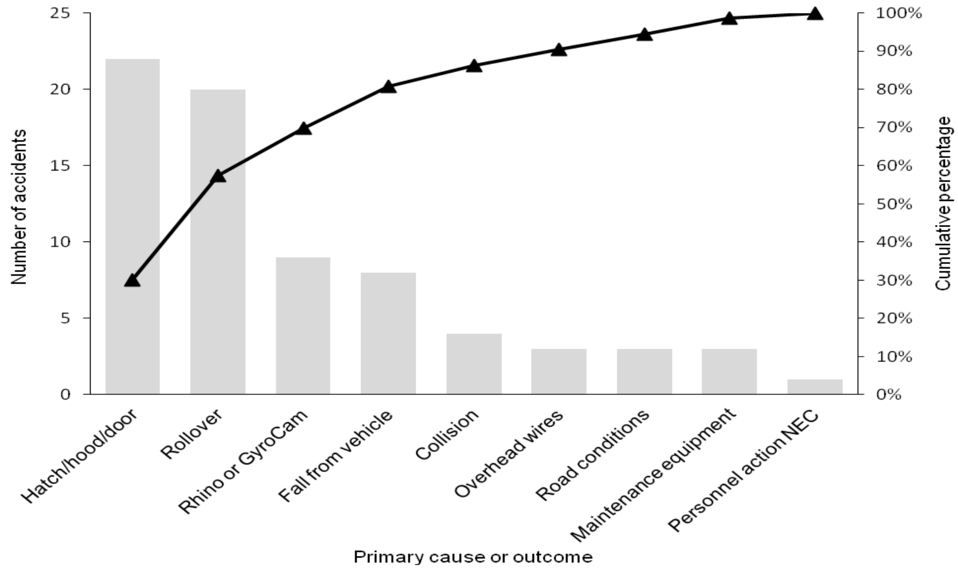


Note: C = collision; R = rollover; V = vehicle damage; I = injury.

Figure 3. Causative factors with injury.

Results derived from U.S. Army Combat Readiness / Safety Center data set

Figure 4 shows primary causes and outcomes of 73 Army MRAP accidents resulting in injury out of the 130 total Army MRAP accidents recorded in the USACR / SC data set. For ease of analysis, only the primary causes or outcomes of these accidents were identified. To determine the unweighted contribution of each cause or outcome to the occurrence of these accidents, the raw number of accidents associated with each cause or outcome was plotted in a descending order column chart. A line chart was then plotted over the column chart, indicating the incremental percentage contributed by each column to the cumulative total number of accidents. Like figure 1, this type of chart is a Pareto chart (QFINANCE, 2011), which shows *hatch/hood/door*, *rollover*, *Rhino or GyroCam*, and *fall from vehicle* were the primary causes or outcomes of 80 percent of these accidents.



Note: NEC = not elsewhere classified.

Figure 4. Vehicle damage and injuries frequency.

Figure 5 shows total costs by accident type of the 130 total Army MRAP accidents reported in the USACR / SC data set. Appendix E shows average costs per accident by accident type. To streamline analysis, causes and outcomes of these accidents were collapsed into the following four accident types: *rollover, collision*, *vehicle moving*, and *vehicle stationary*. Costs were separated into damage and injury costs, which were equal in the *rollover* and *vehicle stationary* accident types. However, damages were approximately three times more costly than injuries in the *collision* accident type and six times more costly in the *vehicle moving* accident type. Approximately $900,000 of the $1.84 million in rollover injury costs (49 percent), were due to drowning fatalities resulting from rollovers into bodies of water.

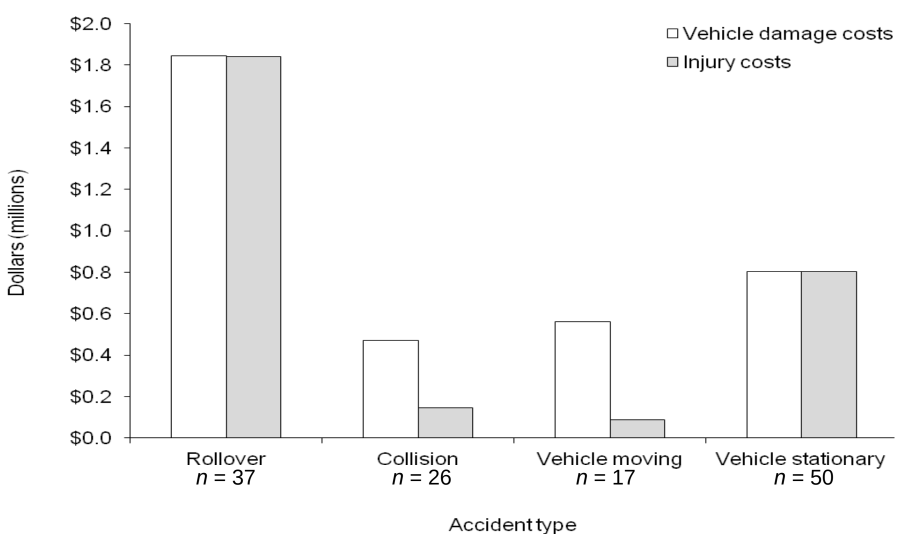


Figure 5. Costs – injuries and vehicle damage.

Figure 6 shows injury severity outcomes by accident type of the 220 Soldiers and Army civilians involved in the 130 Army MRAP accidents reported in the USACR / SC data base. Most of these personnel required only first aid, were not injured, or lost a day of work. All nine fatalities resulted from rollovers, of which five (56 percent) were drowning fatalities resulting from rollovers into bodies of water.

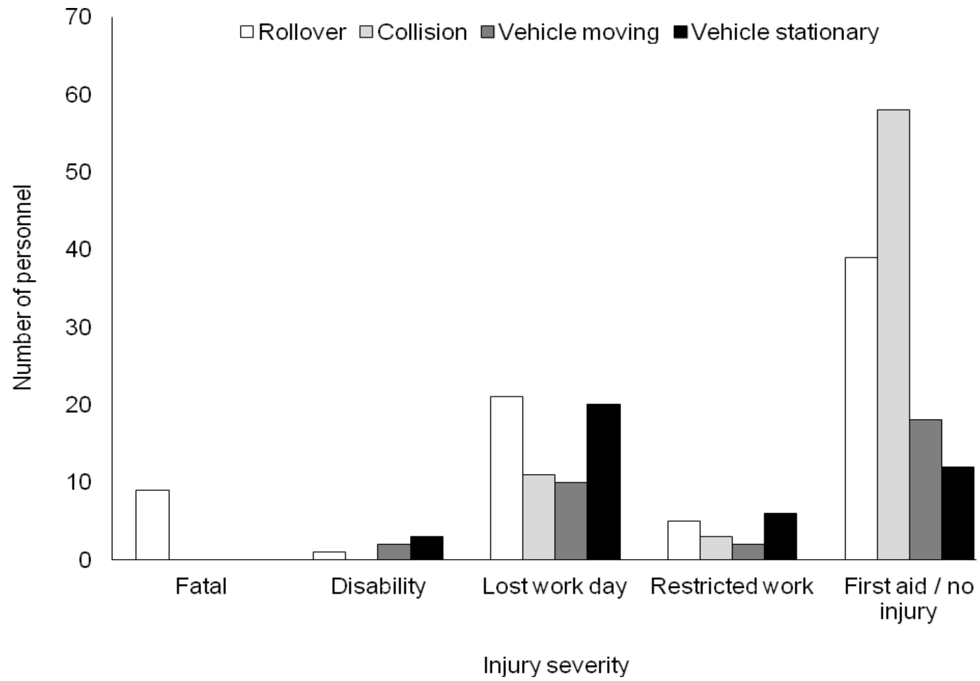


Figure 6. Severity of injury and accident types.

Discussion

Using a joint military data source (DOTF data set), we identified causative factors contributing to the occurrence of U.S. military MRAP accidents worldwide from October 2006 through June 2009. To analyze these accidents systematically, we devised a methodology to parse accident sequences chronologically into their component causes and outcomes. These causes and outcomes were classified into 15 accident element categories, weighted to determine their relative contributions to the occurrence of MRAP accidents, and plotted in Pareto charts to rank them for the purposes of MRAP accident analysis and prevention. We then applied Pareto's Law, also known as the 80-20 rule (QFINANCE, 2011), to identify the top categories that were the cause or outcome of 80 percent of the MRAP accidents analyzed in this study. This methodology found *road hazard*, *rollover*, *vehicle issues*, *personnel*, and *driver response* were the cause or outcome of 80 percent of U.S. military MRAP accidents resulting in injury, and 36 percent of all U.S. military MRAP accidents occurring during the study period. Furthermore, injuries resulted directly from *road hazard*, *vehicle issues*, and *personnel* as causative factors.

Using an Army-specific data source (USACR / SC data set), we also analyzed the primary causes and outcomes of 73 Army MRAP accidents resulting in injury, as well as costs and injury severity outcomes by accident type. Pareto chart analysis showed *hatch / hood / door, rollover, Rhino or GyroCam*, and *fall from vehicle* were the primary causes or outcomes of 80 percent of these accidents. Contact with hatches, hoods, and doors was the leading cause of these accidents, accounting for 22 (30 percent) of these accidents and $1 million in accident costs. Consistent with the findings of Rice & Rodriguez-Johnson (2010), rollovers were the deadliest and costliest accident type, accounting for all nine fatalities and $3.7 million (56 percent) of $6.6 million in total accident costs. Yet, rollovers made up only 37 (28 percent) of the 130 Army MRAP accidents occurring during the study period. Of particular concern are rollovers into bodies of water, trapping occupants inside the submerged vehicle. Drowning fatalities from such rollovers comprised 56 percent of total fatalities and 49 percent of rollover injury costs.

Several materiel solutions currently exist that could mitigate rollovers and accidental submersion. Electronic stability control (ESC) systems, widely available in civilian passenger vehicles, but available only in the Caiman Light MRAP variant and planned for the RG-31 variant, could mitigate rollovers if mounted in all MRAPs (BAE Systems, 2008; Ferguson, 2007; U.S. Army Contracting Command, 2011). Civilian passenger vehicles with ESC systems are estimated to have 70 to 90 percent fewer fatal rollover crashes than do vehicles without ESC systems (Ferguson, 2007). If ESC systems had been mounted in military motor vehicles, 20 percent of crashes involving these vehicles might have been prevented (Chervak, 2011). Likewise, rollover detection warning systems currently in civilian use could also be adapted for military use to warn MRAP vehicle occupants of an impending rollover to take preventive action (Sanborn, 2010). Finally, Helicopter Emergency Egress Devices (HEEDs), used by all U.S. Armed Services to provide mounted personnel with short-term emergency spare air for breathing during egress from submerged aircraft, watercraft, or ground vehicles, could mitigate rollover drowning fatalities and costs (Submersible Systems, 2013).

Limitations

This study analyzed causative factors contributing to MRAP accidents, accident costs, and injury severity outcomes using two independent data sources – the joint service DOTF data set and, for Army MRAP accidents only, the USACR / SC data set. Each data set uniquely recorded MRAP accident sequences, damages, and injuries sustained. Because these data sets recorded this information differently, they could not be combined. The DOTF data set captured accident sequences, but incomplete cost estimates and injury outcomes. The USACR / SC data set captured accident sequences, cost estimates, and injury outcomes for Army MRAP accidents only, accounting for approximately 30 percent of all U.S. military MRAP accidents reported during the study period (October 2006 through June 2009). Other limitations include the following:

a. Limitation 1 (DOTF data set): Accident reports often did not specify the number of individuals injured in an MRAP accident. Rather, the reports only indicated injuries had occurred, but did not specify how many and which individuals (driver, gunner, vehicle commander, passenger, etc.) were injured.

b. Limitation 2 (USACR / SC data set): Army MRAP accident costs cannot be extrapolated to the other Armed Services due to differences in mission profiles and MRAP variants used.

c. Limitation 3: Damage and injury cost estimates were not consistent between the two data sets.

d. Limitation 4: No data were available on non-accidents; for example, the number of times road hazards did not contribute to an accident is unknown.

Conclusions

Based on the study results, we make the following conclusions:

a. This study found *road hazard*, *rollover*, *vehicle issues*, *personnel*, and *driver response* were the cause or outcome of 80 percent of U.S. military MRAP accidents resulting in injury. Based on this finding, strategies to prevent these accident causes and outcomes would have the greatest impact, potentially reducing MRAP accidents resulting in injury by as much as 80 percent. Efforts are currently underway to identify and prioritize actionable recommendations addressing specific conditions, causes, and outcomes of MRAP accidents and injuries. We will describe these efforts in a future report.

b. This study found rollovers were the deadliest and costliest Army MRAP accident type, accounting for 56 percent of total accident costs. Based on this finding, strategies to prevent this accident type could potentially reduce total Army MRAP accident costs by as much as 56 percent.

c. This study also found contact with hatches, hoods, and doors was the leading cause of Army MRAP accidents resulting in injury, accounting for 30 percent of these accidents. Based on this finding, strategies to prevent this accident cause could potentially reduce the occurrence of Army MRAP accidents and associated injuries by as much as 30 percent.

d. Current MRAP accident data sources (DOTF and USACR / SC data sets) are not standardized. Furthermore, the DOTF data set does not capture key information, such as the number and position of individuals injured within the vehicle, accident costs, and injury severity.

Recommendations

Based on the study results and conclusions, we make the following recommendations:

a. Leaders should identify, implement, and evaluate materiel solutions and tactics, techniques, and procedures (TTPs) to prevent the top five MRAP accident injury causes and outcomes (*road hazard*, *rollover*, *vehicle issues*, *personnel*, and *driver response*), in consultation with the Joint Program Office (JPO) MRAP, Rollover Risk Reduction Team (R3T), and other related Department of Defense (DOD) components. We currently support R3T efforts to identify and prioritize actionable recommendations addressing specific conditions, causes, and outcomes of MRAP accidents and injuries. We will describe these recommendations in a future report.

b. Trainers should continue to emphasize rollover risk reduction in MRAP driver training outlined in Training Circular No. 7-31 (Department of the Army, 2011) and Graphic Training Aid No. 07-09-001 (U.S. Army Infantry School, 2009), in consultation with the U.S. Army Infantry School, Center for Army Lessons Learned (CALL), and other related DOD components. In addition, materiel solutions currently available, such as ESC systems, rollover detection warning systems, and HEEDs, should be mounted in all MRAPs to mitigate rollovers and accidental submersion.

c. Leaders and safety officers should continue to emphasize the need for all MRAP occupants to exercise extreme caution when entering, exiting, or working around MRAP hatches, hoods, and doors, to prevent injury from these heavy armored components.

d. MRAP accident data collection should be standardized across all U.S. Armed Services to improve MRAP accident analysis and prevention.

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Prevention of Injury in Mine Resistant Ambush Protected (MRAP) Vehicle Accidents

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Introduction

The MRAP family of vehicles was designed to improve survivability from Improvised Explosive Devices (IED) attacks. To date, over 16,000 MRAP vehicles have been deployed to OIF / OEF. Given high public profile and costs, MRAP performance in IED events is closely monitored and reviewed. Comparable surveillance of personnel injury and vehicle damage due to accidents is lacking.

The Operational Survivability Analysis Branch, USAARL, Fort Rucker, Alabama, conducted a comprehensive review of MRAP vehicle accident data, focusing on the causes and outcomes of morbidity and mortality. This poster highlights three areas of MRAP accidents: 1) qualitative review of causative factors; 2) event sequences; and 3) quantitative review of prevalent outcomes. Causative factors and event sequences were identified from available DoD data. The cost and severity of personnel injuries and vehicle damage experienced by the Army are presented.

This poster provides a starting point for discussion of preventive and occupational modalities to identify inter-relationships of critical nodes in the accident sequence and propose countermeasures to disrupt the chain of events that lead to accidents. We will highlight recommendations that address both accident causative factors and outcomes, including materiel solutions, training, and command emphasis.

Methods

Study design:	Cross-sectional study
Population:	US Servicemembers and Civilians involved in MRAP accidents
Dates:	October 2006 through June 2009
Data Sources:	Deployments and Operations Task Force (DOTF), J-39, Readiness Division U.S. Army Combat Readiness / Safety Center (USACR/SC)
Vehicle platform:	Mine Resistant Ambush Protected (MRAP) family of vehicles
Incident type:	Accidents only
Distribution:	Worldwide
Inclusion criteria:	MRAP accidents data-mined by DOTF from multiple sources or reported to USACR/SC

Variables

Data was parsed into 247 accident elements, where an element is defined as any contributing factor deemed significant in the accident sequence.

Accident elements were organized into 15 categories.

<u>Independent Variables</u> (11 Contributing Factors)

Unit Activity	Check Point	Condition	Vehicle, Local National
Electrical	Equipment	Personnel	Driver
Road Hazard	Vehicle	Personal Protective Equipment (PPE)	

<u>Dependent Variables</u> (4 Outcomes)

Rollover	Collision	Injury

Vehicle Damage (not by collision or rollover)

Summary Statistics

- ❑ 321 accidents reported from all Services (DOTF)
  - ❑ 130 Army accidents reported (USACR / SC)
    - ❑ 220 Soldiers and Army Civilians
      - ❑ 95 individuals sustained injuries
        - ❑ 9 fatalities

Derived from DOTF data set

Contributing Factors

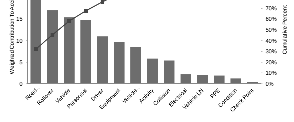
Accident descriptions were parsed into a chronological sequence of events; events were assigned an element category, weighted based on the number of times it occurred and divided by the total number of elements within each accident.

For example, the sum of one accident with three elements (Road Hazard, Driver and Collision) and a second accident with two elements (Road Hazard and Collision) is calculated as follows (n = 321 accidents):

Events	Element contrib.	% contribution per accident	Overall contribution
1. Road Hazards	0.33 + 0.50 = 0.83	0.83	0.83 / 321 = 0.26%
2. Driver	0.33	0.33	0.33 / 321 = 0.10%
3. Collision	0.33 + 0.50 = 0.83	0.83	0.83 / 321 = 0.26%

Figure 1 highlights the most commonly occurring contributing factors with equal weighting of all elements. The primary, initiating events were not determined.

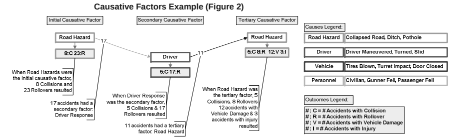
MRAP Accidents with Injury (Figure 1)



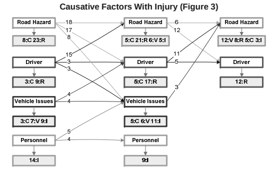
Causative Factors with Injury (Figure 3) identifies the following:

- Sequence of events and critical nodes
- Outcomes at each node, such as collisions, rollovers, vehicle damage, and injuries
- Represents frequency count of accidents with injuries; no evaluation of injury or damage severity / costs

Causative Factors Example (Figure 2)



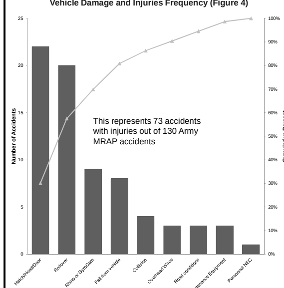
Causative Factors With Injury (Figure 3)



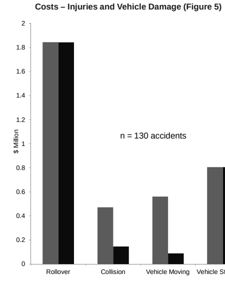
- Most common initial Causative Factors are Road Hazard and Driver Response
- Causes for Injury and the following are:
  - ❑ Collision – Road Hazard, Driver Response and Vehicle Issues
  - ❑ Rollovers – Road Hazard and Driver Response
  - ❑ Vehicle Damage – Road Hazard and Vehicle Issues

Derived from USACR / SC data set

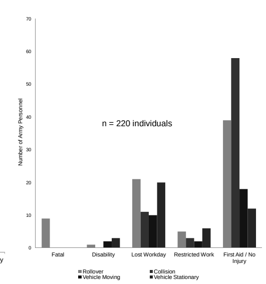
Vehicle Damage and Injuries Frequency (Figure 4)



Costs – Injuries and Vehicle Damage (Figure 5)



Severity of Injury and Accident Types (Figure 6)



Discussion

<u>Factors identified as common to MRAP accidents from DOTF dataset</u>

1. Road Hazard, Rollover, Vehicle, Personnel, and Driver Response factors:
   - Common to 36% of all reported MRAP accidents
   - Contributing factors are associated with 80% of the accidents with injury
   - Improved recognition of road hazards and appropriate driver response training could mitigate a large number of accidents
2. Most common causative factors of injury in MRAP accidents included Road Hazard, Vehicle Issues, Personnel, and Driver Response

<u>MRAP accident vehicle damage and injury costs from USACR / SC dataset</u>

1. Rollovers account for 30% of accidents and $3.6M in costs
   - Fatalities (drownings) comprised the bulk of the costs; these fatalities/costs could be minimized by improving survivability in underwater scenarios
2. Hatches, Doors, and Hoods account for 30% of accidents and $1M in costs
   - These occur during maintenance, not operational missions
3. Injuries are associated with accidents initiated by Road Hazard, Contact with Energized Utility Lines and Personnel factors

Limitations

This study qualitatively and quantitatively assessed factors and costs associated with MRAP accidents by systematic analyses of two independent data sources. Each data source uniquely recorded accident sequence and damage and injuries sustained. Differences between the information available in the datasets did not permit combining them. DOTF dataset provided accident sequences but did not link accidents with damage / injury outcomes and costs. USACR / SC data included crash sequence events and damage / injury outcomes and costs but for US Army only, accounting for approximately 30% of all MRAP accidents.

Limitation 1 (DOTF): number of people injured in a single accident was often not specified in the accident report; rather, the report indicated that injuries did occur but not how many and to which position.

Limitation 2 (USACR / SC): extrapolating MRAP accident costs to other Services based on Army MRAP accidents is not suggested because mission profiles and vehicles differ between Services.

Limitation 3: damage and injury cost measures were not consistent between datasets.

Recommendations

<u>Materiel solutions</u>

1. Injuries could be mitigated by using safety devices and improved practices such as maintenance platforms while servicing vehicles
2. To address costs associated with Rollovers, develop systems to counteract / identify rollover conditions the following could be developed and implemented:
   - Electronic stability control system
   - Vehicle rollover warning sensor
   - Road edge detection systems will provide advantage in degraded visual environments
3. Provide secondary measures to reduce injuries sustained during Rollovers
   - Crew Spare Air and emergency breathing devices
   - Appropriate equipment to secure loose items to the vehicle

<u>Tactics, Techniques and Procedures</u>

1. Implement safety procedures to address injuries by enforcing:
   - Two person lift when engaging Rhino
   - Rear ramp clearing procedure prior to operating
2. Mitigate vehicle damage and injuries associated with rollovers by:
   - Implementing field canal / road calculator
   - Providing off road recovery / rollover prevention classes
3. Implement advanced training
   - Recurrent crew coordination drills and expanded drivers' training
   - Develop and distribute best practices maintenance policies
4. Field reports suggest the need for improved enforcement of PPE and restraint use

For reprints or questions, please contact usaarl.osab@us.army.mil

<u>Appendix B.</u>

<u>Differences between DOTF and USACR / SC data sets.</u>

Data set parameter	DOTF data set	USACR / SC data set
Data sources	Multiple sources including service safety centers and CIDNE reports	USACR / SC
Data set formats	One table with nine columns, including a brief accident narrative description	Relational data base of 24 tables with 313 total columns linked by case number
Inclusion criteria	U.S. military MRAP accidents	Army MRAP accidents reported on DA Form 285 or AGAR
Unique data elements captured	MRAP accident elements (appendix C) can be parsed chronologically from brief accident narrative descriptions in data set	Damage costs, injury costs, and injury severity
Strengths/weaknesses	Includes all U.S. military MRAP accidents (strength)	Includes Army MRAP accidents only (weakness)
	Circumstantial details can be parsed from brief accident narrative descriptions to enable reconstruction of accident sequences (strength)	Circumstantial details are derived from longer accident narrative descriptions to populate separate data base columns (strength or weakness depending on analysis needs)
	Contains limited or incomplete quantitative information on costs and injury severity (weakness)	Contains quantitative information on costs and injury severity (strength)

Note: CIDNE = Combined Information Data Network Exchange; DA = Department of the Army; AGAR = Abbreviated Ground Accident Report.

Appendix C.

Classification of MRAP accident elements.

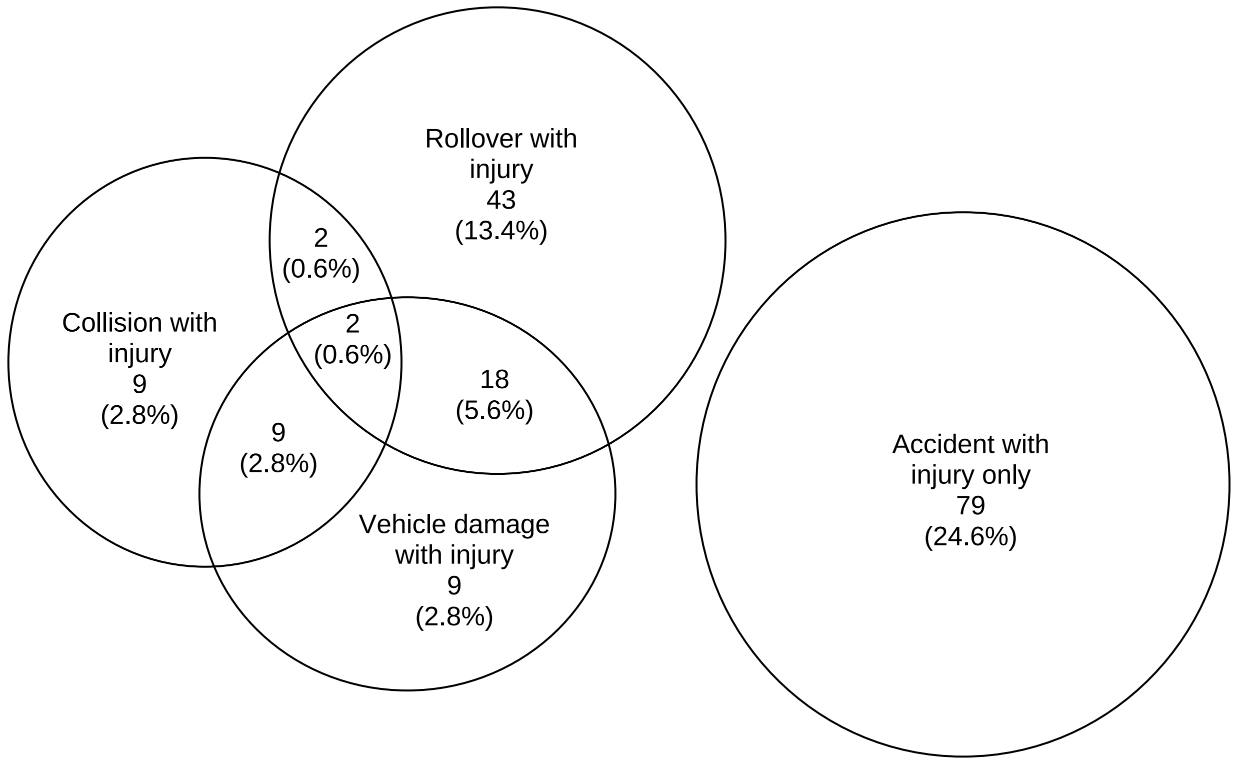
Element category	Element	Element category	Element
Check point	Guard shack	*Road hazard* (continued)	Bump
			Canal
Collision	Object or vehicle		Curve
			Ditch
Condition	Blackout		Embankment
	Night operations		Hole
			Narrow road
Driver response	Driver lost control		Overpass
	Driver maneuvered		Pothole
	Driver overcorrected		Road collapsed
	Driver reversed		Uneven terrain
	Driver slid		Water
	Driver stopped		Wire
	Driver swerved		
	Driver turned	*Rollover*	Rolled 180° on roof
			Rolled 90° to left
Electrical	Electrical short		Rolled 90° to right
	Electrical spark		Rollover
	Power lines		
		Unit activity	Convoy
Equipment	Fire extinguisher succeeded		Maintenance
	GyroCam		Towing
	Mine roller		Training
	Ramp		
	Rhino lowering	*Vehicle damage*	Damage to vehicle
			Fire
Injury	Personnel injury		Vehicle in water
Personnel	Civilian	*Vehicle issues*	Battery box
	Gunner fell		Door closed
	Passenger fell		Fire suppression system failed
	Passenger dismounted		
			Tires blown
Personal protective equipment (PPE)	Restraints worn		Turret
	Restraints not worn		
		Vehicle, local national	Privately-owned vehicle
Road hazard	Barrier		

Note: Only a partial listing of MRAP accident elements is shown. A total of 247 elements were identified from accident narrative descriptions and classified into these 15 element categories.

Appendix D.

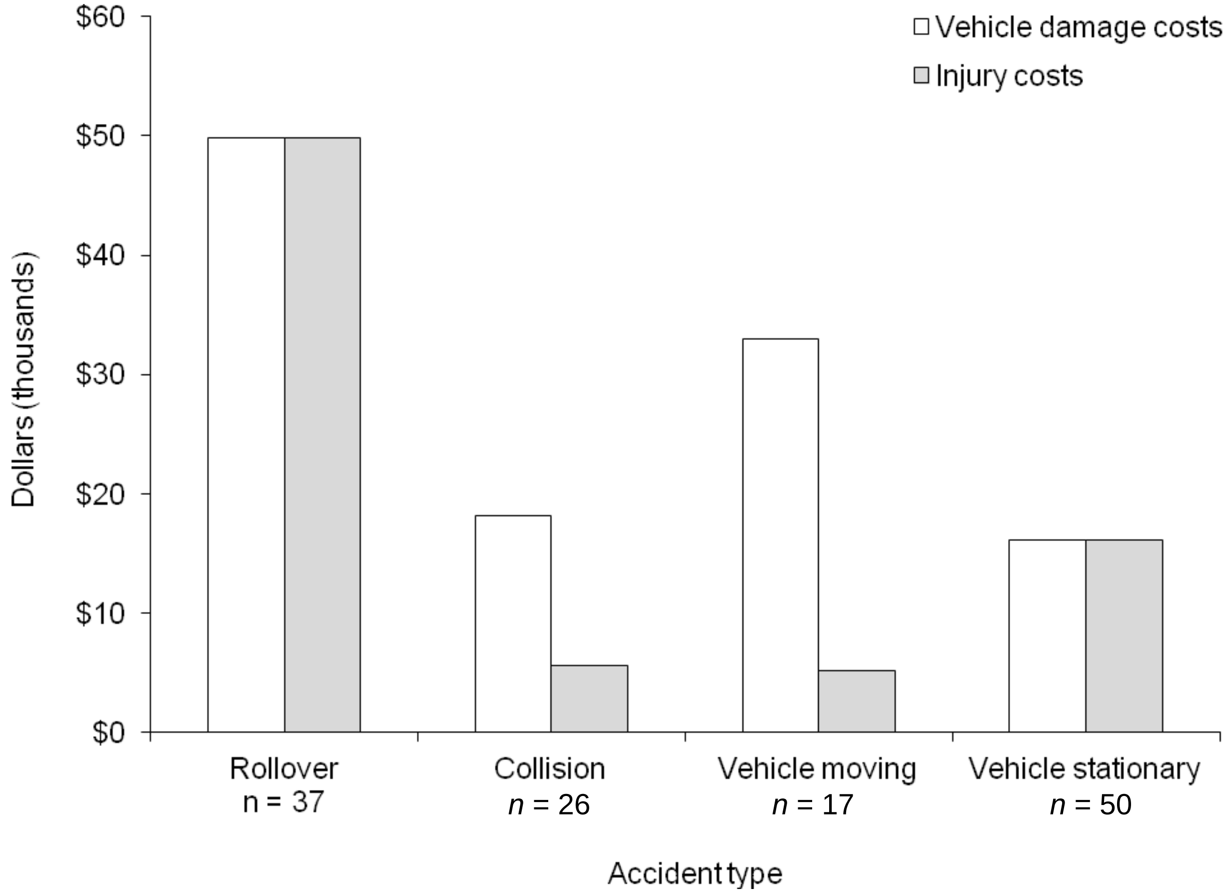
Venn diagram of overlapping outcomes of MRAP accidents with injury.

N = 171 accidents



Appendix E.

Costs per accident – injuries and vehicle damage.



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