Abstract— Every nine hours a US Army Soldier dies. Each and every death affects the lives and vitality of this great country while reducing our combat power against the current and future enemy. The Army Combat Readiness Center (CRC) has transformed into a knowledge center for all losses and is looking to this research as a means of identifying the most severe hazards in Army ground vehicle operations. To address this issue this research incorporates the values of the Army and its current decision-makers into a systematic and logical decision structure that analyzes existing hazards while identifying the most serious driving mishaps. This paper discusses the data analysis of 11,012 driving mishaps and the methods used to accurately identify the leading hazards in ground vehicle operations. This research confirms that Class A accurately reflects the distribution of the entire population of Army Accidents (Class A-C). Ultimately, this research provides empirical evidence that Motivation is the leading cause in driving mishaps. The results of this research provide the groundwork for the selection of controls to minimize driving mishaps, and preserve one of our country’s greatest assets – the American Soldier.

I. BACKGROUND

The number of Army accidental fatalities has increased dramatically within the past couple of years. Accidental fatalities make up nearly 24% of total military deaths – to include the combat losses incurred during the global war on terrorism. [1] The CRC exists in order to minimize these types of losses. A difficult problem for the CRC is the identification and ranking of present and future hazards in Vehicle Operations. The current analytical methodologies are limited in scope to basic statistical comparisons to identify major safety related hazards risks and controls. This tends to lead to analysis and results that are reactive rather than proactive. Currently, hazards are ranked by one or a few criteria. For instance, the current vehicle accident database, the Risk Management Information System (RMIS), ranks hazards by the number of accidents which are caused by that hazard, total cost of the accidents or a myriad of other categories taken singularly. This is an ineffective and inconsistent manner for ranking hazards. The current system does not provide decision-makers with enough information to make key, necessary tradeoffs for certain risk reduction decisions nor does it provide a baseline to make comparisons between different accidents or hazards. The unstable prioritization of the evaluation criteria leads to an inconsistent and possibly unsupportable decision-making process. [2]
(based on severity); and 2) compare the severity and number of Class A, B, and C accidents and the overall distribution of them. By analyzing the accident data collected to achieve these two objectives, the root causes of these accidents can be easily identified.

Various tools and specific methods were used in order to better understand the problem behind the rising number of driving mishaps. These included producing a system decomposition chart, creating a systems context diagram, identifying the system classification, constructing an input-output diagram, conducting a stakeholder analysis, performing a functional analysis, and generating an affinity diagram. All these tools refined the scope of the research.

The CRC had many initial thoughts as to why there were an increasing number of accidental fatalities throughout the Army. They provided the following puzzle diagram that suggested that there were four crucial factors that impacted one’s performance: Ability, Skills, Knowledge, and Motivation/Emotion. They believed that Motivation was the underlying cause for most of the driving mishaps. However, none of their hypotheses had ever been proven true, nor did they have the factual evidence to back their claims. In fact, the expert data collectors had only been contracted for a limited number of years; and so they did not have the time to analyze the collected data itself. In the process of analyzing the data, this research helps to verify those propositions. Additionally, finding these underlying causes will clear the path towards successfully mitigating those driving mishaps by focusing on those root problems.

Each case referring to a particular driving mishap, was then categorized under a respective heading, so as to provide for further groupings and causal analysis.

After completing the needs analysis portions of the problem definition phase, identifying the clients requirements, and going through the raw data provided by the Combat Readiness Center, a revised problem statement was developed: “To identify the combination of risk mitigation methods, tools, policies, and procedure in the Army designed to minimize ground vehicle accidents.” From here, the team was able to focus more directly on attempting to address the problem.

V. METHODOLOGY

A. Army Mishap Classification System

Initially, the Army Mishap Classification System was used as a method of classifying the data. This system determined the type of investigation, report, and record acquisition. The original data was acquired from the CRC in Microsoft Excel format with a myriad of entities and attributes. Each row referred to a different hazard statement associated with each case provided. All in all, there were over 11,000 hazard statements (91 fields of raw data) provided, covering the last five years of accident investigations.

IV. NEEDS ANALYSIS

In order to gain a better understanding of the problem, various methods of the engineering design process where employed. The primary tools included System Decomposition, Stakeholder Analysis, and Functional Analysis. These tools were utilized as a means of transferring the provided, raw data into information that could be incorporated into a Severity Hierarchy.

The System Decomposition provided an initial view of the system (ground vehicle accidents), and their specific impact on the ever expanding Army. By decomposing the system, underlying functions, components, and general hierarchical structures were identified. The most significant structure identified was the existing value hierarchy used in Aviation research that was based on years of study and revision. In addition, the primary function of the system was identified: to analyze existing vehicular hazards among Army Motor Vehicles (AMVs), Army Combat Vehicles (ACVs), and Privately Owned Vehicles (POVs), as well as the correlation to the operators, American soldiers.

During the process, a list of the most severe hazards in Army ground vehicle accidents was also identified and taken into consideration. Up to this point, the top hazards believed to have a substantial impact on overall performance were; ability, knowledge, skill, motivation, environment, equipment, and other.

![Factors Impacting Performance](image)

**Figure 2: Factors Impacting Performance**

III. DATA ACQUISITION

The original data was acquired from the CRC in Microsoft Excel format with a myriad of entities and attributes. Each row referred to a different hazard statement associated with each case provided. All in all, there were over 11,000 hazard statements (91 fields of raw data) provided, covering the last five years of accident investigations.
keeping required as a result of the mishap per reference. The system classifies mishaps as “unplanned events or as series of events, which interfere with or interrupt a process or procedure and may result in a fatality, injury, or occupational illness to personnel or damage to property.”[2] Generally, they occur as a result of failing to identify and reduce or eliminate hazards. Mishaps are then classified according to the severity of resulting injury, occupational illness, or property damage. Property damage severity is generally expressed in terms of cost and is calculated as the sum of the costs associated with Department of Defense (DoD) property and non-DoD property that is damaged in a mishap.”[2]

Mishaps are classified by severity. The initial classification of a mishap may change as more accurate information on the severity of the mishap is obtained.

1. Class A Mishap. The resulting total cost of damages to DoD or non-DoD property in an amount of $1 million or more; a DoD aircraft is destroyed; or an injury and/or occupational illness result in a fatality or permanent total disability.
2. Class B Mishap. The resulting total cost of damages to DoD or non-DoD property is $200,000 or more, but less than $1 million. An injury and/or occupational illness result in permanent partial disability or when three or more personnel are hospitalized for inpatient care (beyond observation) as a result of a single mishap.
3. Class C Mishap. The resulting total cost of damages to DoD or non-DoD property is $20,000 or more, but less than $200,000; a nonfatal injury that causes any loss of time from work beyond the day or shift on which it occurred; or a nonfatal occupational illness that causes loss of time from work or disability at any time.[2]

While the Army Mishap Classification System was beneficial for classifying the data, it did not provide the level of detailed analysis needed to identify root causes of driving mishaps.

B. Human Factors Analysis and Classification System (HFACS)

As a result of the Army Mishap Classification System not being detailed enough for our stated objectives, and the fact that close to 80% of all civil and military aviation accidents are correlated to human error, a theoretical framework, known as the Human Factors Analysis and Classification System (HFACS) was used to better identify the leading causes of ground vehicle accidents. Prior to HFACS, most databases (like the Army Mishap Classification System) were not conducive to a traditional human error analysis which made the identification of intervention strategies complex. Therefore, HFACS was developed as a comprehensive human factors analysis and classification system to meet those needs. HFACS has been utilized by the military, commercial, and other sectors of accident investigation to systematically examine “root causes” and the underlying contributory factors of various mishaps. HFCAS is the most current approach to the genesis of human error and was proposed by James Reason in 1990. The model that Reason developed has come to be known as the “Swiss Cheese” model of human error. In his model, Reason breaks human failure down into four varying levels of specificity. The first level, and most general, is titled Unsafe Acts. Here, the classification refers to the acts committed by the operators, ultimately leading to the accident. This level is where most accident investigations focus their effort, which means most causal factors are uncovered. The second level of human failure is referred to as Preconditions for Unsafe Acts. This level involves conditions such as mental fatigue and poor communication and coordination practices. The next level, Unsafe Supervision, refers to the human failure of command. The fourth and most specific level of human error falls under Organizational Influences. The organizational factors referred to here include resource management influences, organizational climate influences, and overall organizational processes and their influences. The logic behind the “Swiss Cheese” model is that mishaps generally occur due to the “holes” in each of these layers.

While this model and the concept of human error has primarily been applied to aviation accidents, it served as a beneficial framework for analyzing the vast amounts of data provided by the Combat Readiness Center. Ultimately, the Human Factors Analysis and Classification System (HFACS) “bridges the gap between theory and practice by providing investigators with a comprehensive, user friendly tool for identifying and classifying the human causes of accidents.”[3]

![Figure 3: The “Swiss Cheese” model of human error causation (adapted from Reason 1990).](image)

VI. DEVELOPMENT OF SEVERITY HIERARCHY

Prior research and information collected from the Combat Readiness Center (CRC) were incorporated into the severity hierarchy. This research included information from Army doctrines such as FM 100-14 “Risk Management” and the senior leadership at CRC. This hierarchy was then modified and tailored to the specific problem utilizing the swing weighting and marble techniques.

The “Risk Management” manual explained the proper procedures, principles, and responsibilities to affectively
apply the risk management process in order to preserve the Army soldiers and resources. This manual provided the four primary elements in order to identify the criteria for measuring accident severity. As a result, the top tier of hierarchy included the following components – Degree of Injury/Illness, Loss of Damage to Equipment/Property, Environmental Damage, and Other Mission Impairing Factors. Currently, no government agency, including the CRC, gathers any data concerning environmental effects. Therefore, it is important to note that Environmental Damage was completely omitted during data analysis due to nonexistent data.

Using the single dimensional value curve, each evaluation measure was identified with an associated value of severity. For example, under the evaluation measure “Loss of Life,” losses were identified with a value ranging from 0 to 5 fatalities. The dimensional curves allowed for weights to be associated with different severities based on the category. An example of this can be seen through the values associate fatalities. The value given to cases with 0-1 fatalities is significantly greater than cases with more than 1 fatality because so much emphasis is placed on preventing death in the first place. Once assigned, these values were then implemented into the hierarchy in order to calculate the overall severity score for each case.

The associated top tier is shown below:

![Accident Severity Hierarchy Diagram]

Ultimately, this hierarchy made it possible to calculate the severity score of each case. Scoring of each case would further the research by showing trends and distributions.

After identifying the top tier of the hierarchy, each of the primary components needed to be further detailed. Using the same methodology in identifying the remaining three components, various Army manuals were applied. The most helpful resource, however, was provided by the senior leadership and prior research conducted at the CRC. The prior research involved a project concerning aviation, so minor changes were needed in order to adapt the existing sub-components to measure accident severity in Army vehicles. The following sub-components for each primary component in the top tier are noted:

a. Degree of Injury/Illness: Loss of Life, Permanent Disability (to include Total Disability and Partial Disability), Time Incapacitated, and Injury Cost
b. Loss of Damage to Equipment/Property: Repair/Replace Cost
c. Other Mission Impairing Factors: Unit Morale (to include Days Restricted Duty and Lost Workdays) and Equipment Replacement Time (to include Vehicle Total Loss)

After all the components and sub-components were identified, the severity hierarchy was approved by the stakeholders. The resultant hierarchy exclusively captures all the necessary means to measure accident severity.

VII. SINGLE DIMENSIONAL VALUE FUNCTIONS

In order to adjust the values of the raw data, Single Dimensional value functions were created for each metric. Such was done in order to standardize the raw data. The functions would convert the raw data into a value between 0 and 1. This hierarchy will determine the severity of hazards, not value; therefore 0 is set as the most desirable and 1 the least. The functions itself were created using a curve. The maximum value of each metric was set so that it received a value of 1 and the minimum value of each metric was set so that it received a value of 0. All the values in between were assigned a value determined by a curve.

This curve differed among the different single dimensional functions because of the assumption made to use linear graphs. This assumption was made under justifiable research and previous work revealed by the CRC.

VIII. CALCULATIONS AND ANALYSIS

The severity calculations were done using simple mathematical procedures. To find the total severity of each case, the following equation was used:

\[ \text{Total Severity} = \sum \text{Associated Severity Hierarchy Weight} \times \text{Adjusted raw value} \]

In this equation, the Associated Severity Hierarchy Weights were determined by the following formula:

\[ \text{Associated Severity Hierarchy Weight} = \sum \text{Metric weight} \times \text{global weight} \times \text{local weight} \]

Multiplying all of these weights would calculate the metric’s overall weight within the scheme of the whole severity hierarchy.

An example of the procedure above is as shown below:

\[ \text{Total disability weight} = \text{Permanent Disability weight (global weight)} \times \text{Degree Injury Illness weight (Local weight)} \]

All of the calculations up to this point were done using interlaced excel sheets. This allowed unity within our calculations.

After calculating the total severity, the cases were separated according to hazard classifications. Assigning the correct hazard to the appropriate cases was done using
Microsoft access. This allowed for easy recall of data through use of queries.

In the final steps of connecting the appropriate puzzle letters to the appropriate cases allowed us to analyze which puzzle letters led to the absolute and average maximum and minimum severity.

The resulting analysis showed that motivation was the key factor affecting the severity of an accident, in both total number of cases and in averages. This translates into saying that an accident caused by motivation will on the average cause the most severity and motivation was the leading cause to accident severity during the observed years.

The causes that led to the highest total amount of severity are listed below:

![Pareto Analysis of Class A-C Accidents](image)

Careful analysis of the graph shows the importance of motivation as the leading cause of the accidents.

From here, it was believed that class A accidents could best model the population (Class A-C) as a whole. Proving such hypothesis would allow the team to focus on the Class A accidents, which contained the most detailed data.

Graphing the Class A accidents validated the hypothesis as seen below:

![Pareto Analysis of Severity Score](image)

Using this as the foundation the team focused on the Class A accidents and further calculated the causes that led to the highest amount of severity on the average:

![Average Severity of Each Hazard](image)

Every time an accident occurs, it is most likely to be the most severe if it is attributed to motivation as its cause. These were the calculations.

IX. CONCLUSION

In summary, motivation has been proven to be the most severe ground vehicle hazard in the Army. This conclusion is based on both severity and overall averages. The overall distribution of severity between each class of accidents can be represented by a single class (i.e. Class A accidents). This is justified by the fact that motivation drastically causes most of the severity in each of the cases, generally being at least four times larger than the second cause.

The initial objective of this research was to incorporate the values of the Army and its current decision-makers into a systematic and logical decision structure which analyzes existing hazards and develops a list of the most severe hazards in Army ground vehicle operations. Based of this information, initial research reflected current systems in the Army, particularly the Army Mishap Classification System and then branched out to HFACS as a primary source of data analysis. From there, the data was grouped into hazard categories (to better understand the cause of accidents). Once the 11,000+ cases were classified, the newly categorized cases were run through a severity hierarchy. This provided an overall severity score for each hazard statement and allowed for further data analysis.

The results of the data analysis indicate that based on totals, Motivation received a severity score of 343.9, outpacing the next largest hazard cause, Knowledge, at 33.6. Motivation also doubled the severity of the next largest hazard cause when analyzed based on averages. This is important because it shows that a lack or void of motivation creates the most severity as a total, as well as per accident. In regards to the overall distribution of hazards, the results indicate that the distribution of severity between each class can be represented by Class A accidents alone. Ultimately, these finding have never been proven before and if used to their potential, could seriously assist the Army developing new ways to preserve America’s greatest asset – the American Soldier.
X. FUTURE WORK

Using the knowledge that “Motivation” was proven to be the leading hazard in Army vehicle mishaps, future work will target this hazard category. In addition to this, continued analysis will solely examine Class A accidents, ultimately identifying alternatives to minimize the number of accidents related to motivation. Finally, continued research and analysis will select the optimal solution to provide to the decision makers and to the future American soldier. Examples of such alternatives will be generated through systems analysis – using various methodologies, such as existing systems, modified existing systems, prepackaged designs, and new system designs. Outside suggestions will also be factored into account and will be valuable during the alternative generation process. While the end state of the project will involve the implementation of the optimal solution, success can only be measured by a decrease in soldier fatalities.

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REFERENCES