# Protecting the Force:
## Reducing Combat Vehicle Accidents via Improved Organizational Processes

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## Reducing Combat Vehicle Accidents via Improved Organizational Processes

*Phase I Final Report*

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## Abstract

Despite extraordinary efforts by leaders at all levels throughout the U.S. Army, dozens of soldiers are killed each year as a result of both combat and motor vehicle accidents. The objective of this study is to look beyond the events and symptoms of accidents which normally indicate human error, and instead study the upper-level organizational processes and problems that may constitute the actual root causes of accidents. Critical to this process is identifying critical variables, establishing causality between variables, and quantifying variables that lead to both resilience against accidents and propensities for accidents. After reviewing the available literature we report on our development of a System Dynamics model, which is an analytical model of the system that allows for extensive simulation. The results of these simulations suggest that high-level decisions that balance mission rate and operations tempo with troop availability, careful management of the work-rest cycle for deployed troops, and improvement of the processes for evaluating the lessons learned from accidents, will lead to a reduction in Army combat and motor vehicle accidents.

# 1. Introduction

Despite extraordinary efforts by Army leaders at all levels, an alarming number of soldiers die or are severely injured each year from accidents that could have been prevented. Two of the major problem areas are vehicle safety (involving both military and privately owned vehicles) and the handling of weapons. While the focus of this study is on prevention of combat and motor vehicle accidents, a secondary goal is to develop a model that can be applied to a wide variety of safety concerns.

Currently, the Army uses a qualitative and methodical risk management process called Composite Risk Management to help manage operational and training risk.[1] While the Composite Risk Management process has produced tremendous improvements in preventing accidents, both it and the results of most Army accident investigations (the primary source of institutional safety learning) tend to focus predominantly on events and symptoms of accidents. Consequently, the results of most safety investigations indicate human error as the primary cause of accidents, and rarely examine the organizational processes and problems that constitute the actual root causes of accidents.

The objective of this study is to develop a model that helps Army policy makers to better understand the effects of various dynamic feedback processes and delays involved with decision making, specifically in regards to accident prevention. *This study focuses on high-level organizational factors that impact safety*, which will help policy makers to better understand which levers in the system play the biggest role in risk mitigation. The general methodology used in this study was first to conduct an extensive review of organizational and behavioral safety literature, System Dynamics modeling literature, and official U.S. Army safety publications and accident reports. Next, a System Dynamics model was developed and calibrated using historical Army accident data, and a number of simulations were then conducted to see what new insights might be learned from the model.

# 2. Background & Context

We begin with a brief discussion of Army vehicle safety, an examination of the key problems in context, a short review of the literature on this subject, and a brief introduction to System Dynamics modeling concepts.

## 2.1 Vehicle Accidents & Investigations

Since the beginning of the war in Iraq in 2003, approximately 20% of the Army's combat casualties have been a result of accidents (over 600 total). Roughly 40% of these deaths (about 250 total) have been caused by combat vehicle or motor vehicle accidents. These numbers are staggering and represent the number of accidents from Iraq only; they do not include other accidents within the Army. Furthermore, as can be seen in Figure 2-1, there has been a sharp

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[1] See U.S. Army Field Manual 5-19 "Composite Risk Management" for an in-depth overview of the Composite Risk Management process.

increase in the number of Class A vehicle accidents since Operation Iraqi Freedom began.[2]  In 2006 the Army undertook new initiatives to reduce vehicle accidents, focusing on both job related and off duty accidents.  Consequently, there was a corresponding decrease in the number of class A vehicle accidents during 2006.  Nevertheless, room for improvement remains.
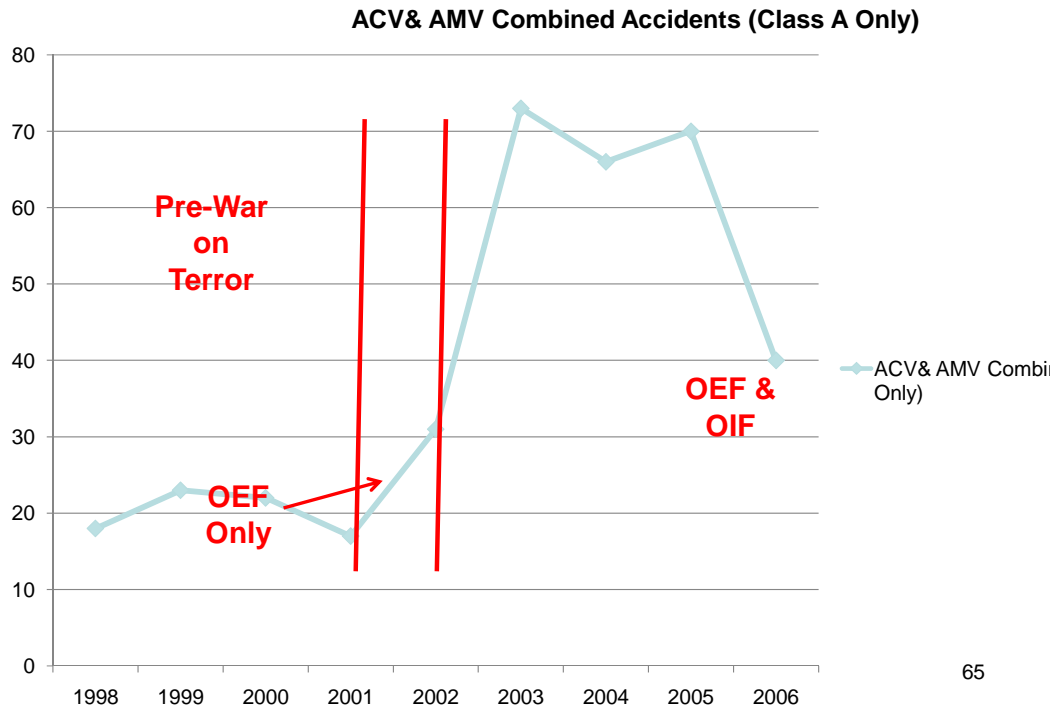
## Accident Data

**ACV& AMV Combined Accidents (Class A Only)**



**Figure 2-1 Army Class A Vehicle Accident Trend**[3]

A review of the archives of Army combat and motor vehicle accident reports reveals that the results of most investigations cite human error as the primary cause of the accident. Furthermore, according to these reports factors such as complacency, poor supervision, fatigue, lack of mission awareness, pressure to perform, and perceived conflicts with operational necessities are often involved in the mechanisms of an accident.  Consequently, leaders at all levels of the Army have undertaken extensive efforts to study these phenomena and implement new policies and procedures to prevent their occurrence in the future.  While almost all accident investigations take into account the events and symptoms of an accident as well as the conditions and surface indicators, only on rare occasions do accident investigations include any Army wide organizational problems which are usually the "root cause" of accidents.[4]  This typical framework for safety analysis can be seen in Figure 2-2 below.

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[2] Class A Accidents are those involving loss of life, permanent total disability, or costing greater than $1M.  Class B Accidents involve costs of $200K or more, but less than $1M, and/or permanent partial disability and/or three or more people hospitalized as inpatients

[3] ACV- Army Combat Vehicle; AMV- Army Motor Vehicle; OEF- Operation Enduring Freedom; OIF- Operation Iraqi Freedom

[4] Leveson, p. 43-53.  According to Leveson, this is a common occurrence in almost all organizations, a tendency to place blame on the operator as opposed to addressing organizational problems.

It is critical to note than many other studies cite this same tendency. In his study of high-hazard industries, John Carroll notes that most accident investigations produce problem diagnoses that are worker centric, resulting in extensive written detailed procedures and discipline. This leads to added job complexity and a reduction in trust between workers and management, which leads to slower work speed, alienation of workers, and a reduced flow of information between supervisors and their subordinates. Naturally, this leads to increased problems and therefore, a cycle of accumulating problems, accidents, and worker resentment.[5] Consequently, it would be beneficial for not only the Army but also civilian industries to undertake studies that look beyond the immediate mechanisms and conditions that lead to accidents (i.e. poor risk assessments, faulty procedures, equipment failure, mechanical breakdown, excessive speed, lack of sleep, etc) and instead, examine the root causes of combat vehicle accidents; such as operations tempo, implications of funding decisions, budget constraints, institutionalized leader training, etc.
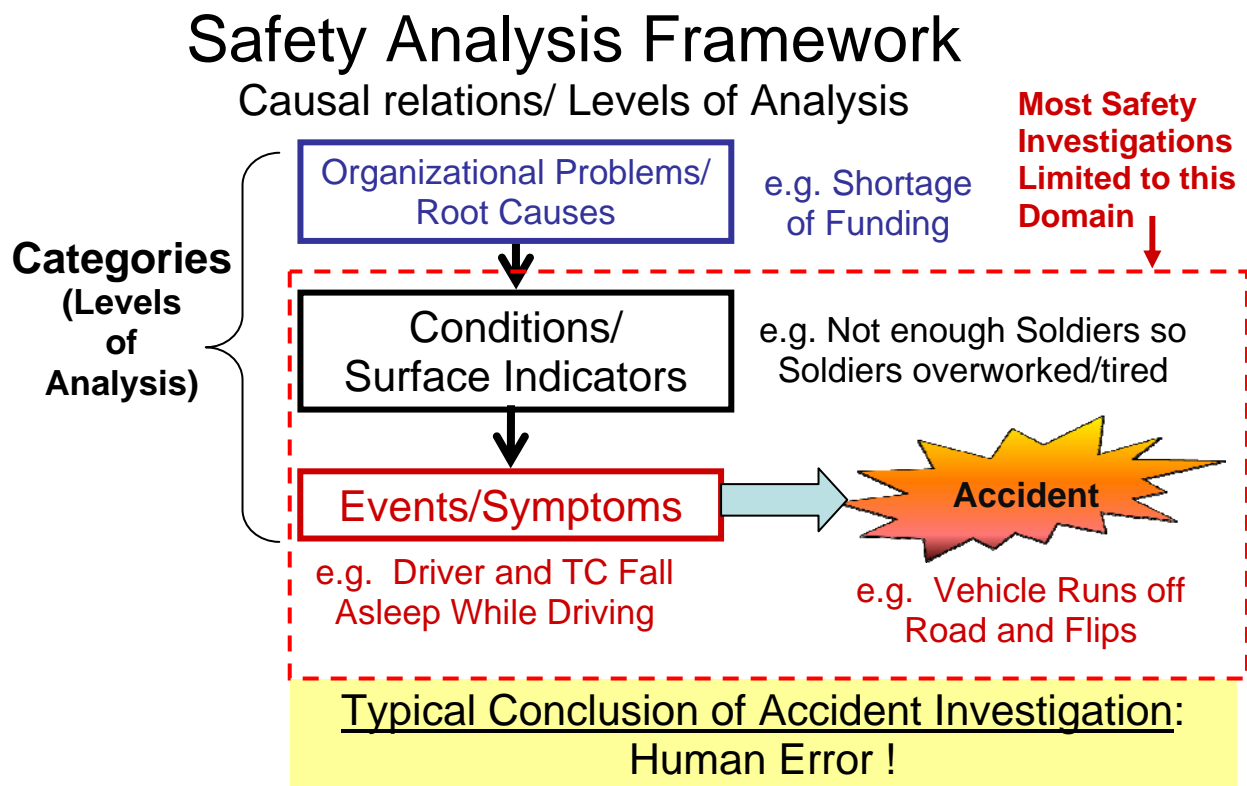
# Safety Analysis Framework
## Causal relations/ Levels of Analysis

**Most Safety Investigations Limited to this Domain**

**Categories (Levels of Analysis)**

Organizational Problems/ Root Causes — e.g. Shortage of Funding

Conditions/ Surface Indicators — e.g. Not enough Soldiers so Soldiers overworked/tired

Events/Symptoms — e.g. Driver and TC Fall Asleep While Driving

**Accident** — e.g. Vehicle Runs off Road and Flips

Typical Conclusion of Accident Investigation: Human Error !

Figure 2-2 Safety Analysis Framework[6]

[5] Carroll, "Organizational Learning Activities in High-Hazard Industries: The Logics Underlying Self-Analysis." p. 715.
[6] Leveson, 49.

## 2.2 System Dynamics

System Dynamics was developed during the 1950s by MIT Professor Jay Forrester as a method for modeling large real world systems. While System Dynamics is grounded in the rigorous mathematical disciplines of control theory and nonlinear dynamics, it was developed with the intention of becoming "a practical tool that policy makers can use to help them solve the pressing problems they confront in their organizations."[7]

Central to the System Dynamics modeling strategy is the representation of system structure in terms of stocks and flows, which measure the accumulation and dissipation of material or information over a period of time. Feedback loops are connected to these stocks and flows and serve as the building blocks for expressing the relationships between variables and overall dynamic behavior of complex interdependencies on the system. A key aspect of System Dynamics theory is the recognition of complex interdependencies among multiple feedback loops, and a rejection of simple linear cause-and-effect thinking, since in most systems the "effect" might also affect the "cause." System Dynamics has been used to model a wide variety of different systems including state-stability and insurgencies, supply chain management, software development, command and control systems, and dynamics of economic growth.[8]
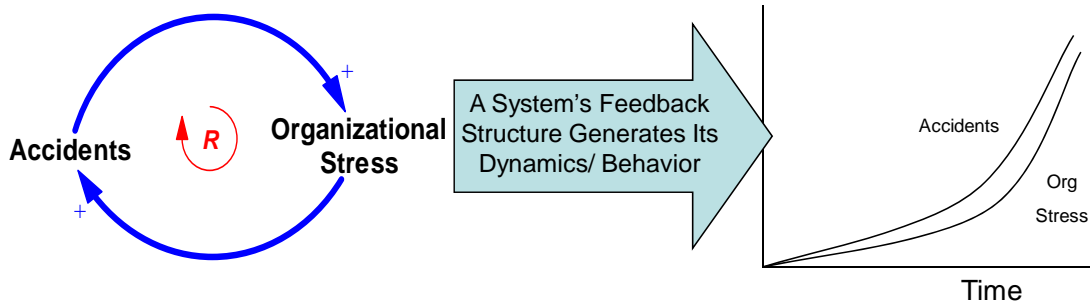
In System Dynamics models a "+" sign indicates a positive polarity between variables (i.e. as in Figure 2-3, as the number of Accidents increases, the level of Organizational Stress also increases). Similarly, a "-" link indicates a negative polarity between variables (i.e. as Safety Precautions increases, the number of Accidents decreases). The loop indicators such as "B1" indicate whether the loop is a balancing (B) or reinforcing (R) feedback loop as well as the loop identifier number (1, 2, 3…) which is used to distinguish between loops. Thus, loop "B1" should be read as "Balancing Loop 1." In reinforcing feedback loops, as seen in Figure 2-3, an increase in one variable (in this case Accidents) produces an increase in another variable (Organizational Stress), which then causes a greater increase in Accidents. Therefore, the effect of a reinforcing loop is to reinforce the effect of an initial external stimulus placed on the system. Reinforcing loops typically produce exponential growth. In balancing feedback loops, however, an increase in one variable (in this case Accidents) produces an increase in another variable (Safety Precautions), which ultimately causes a decrease in the original variable. Thus, the effect of a balancing loop is to balance the effect of an initial external stimulus on the system. Balancing loops typically produce goal seeking behavior.

Figure 2-4 shows the effect of combining balancing and reinforcing feedback loops. In this, case, an increase in Accidents initially leads to an increase in Organizational Stress which causes a rapid increase in the number of Accidents. But over time, the effects of this reinforcing feedback loop are mitigated by the effect of Safety Precautions, which leads to the number of accidents leveling off. This is called S-Shaped behavior, and is typical of systems that combine balancing and reinforcing feedback loops. Finally, a causal arrow with two perpendicular straight lines, ⚡ represents a delay in the system (see Figure 3-1).

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[7] Sterman, p. ix.
[8] See Choucri, Angerhofer, Abdel-Hamid, Minami and Lofdahl for examples of each.

## Reinforcing Loop (Example)



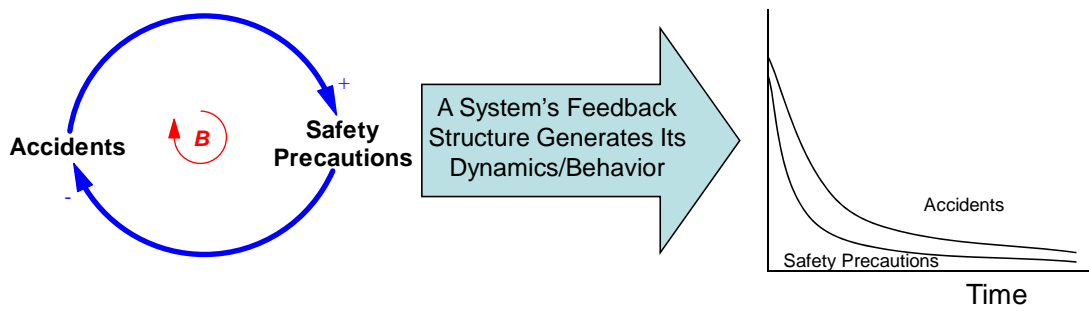A System's Feedback Structure Generates Its Dynamics/ Behavior

## Balancing Loop (Example)



A System's Feedback Structure Generates Its Dynamics/Behavior

**Figure 2-3 Reinforcing and Balancing Loops**

## Combining Balancing & Reinforcing Loops (Example)



A System's Feedback Structure Generates Its Dynamics/ Behavior

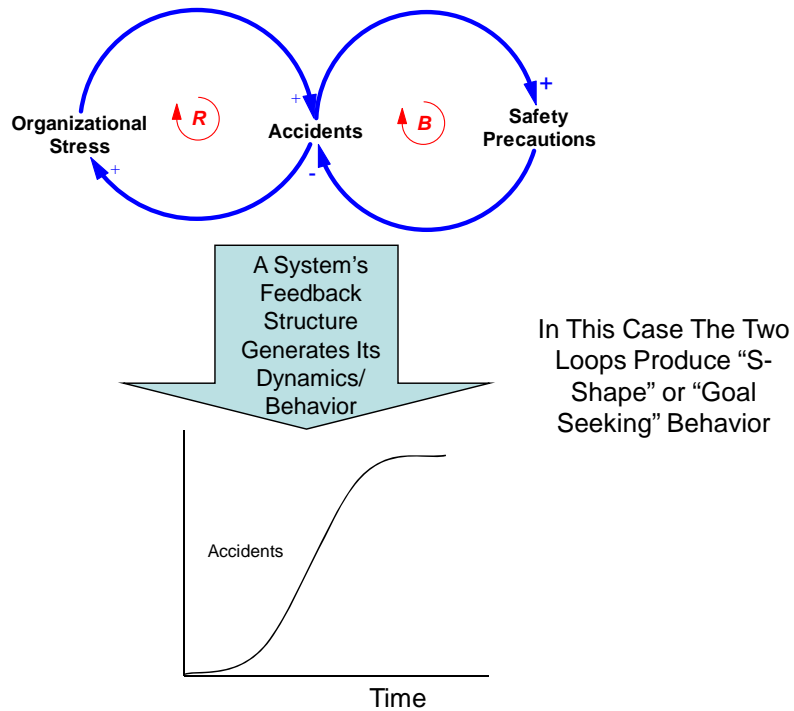In This Case The Two Loops Produce "S-Shape" or "Goal Seeking" Behavior

**Figure 2-4 Combining Feedback Loops**

# 3. Modeling Vehicle Safety

This section describes the process by which the System Dynamics model for this study was created. It began with construction of an initial high-level diagram, followed by data collection. Then a detailed low-level model was developed and validated using historical data.

## 3.1 The High-Level Diagram

After a lengthy review of the literature and proper framing of the problem and research objectives, a high-level causal loop diagram was created to help determine the specific domain of the system and to better frame the key variables that might be used in a detailed model of the system. This high-level diagram was necessary for identifying and quantifying key variables which would help to focus efforts for subsequent data collection. Figure 3-1 below is a depiction of the high-level diagram developed for this study.
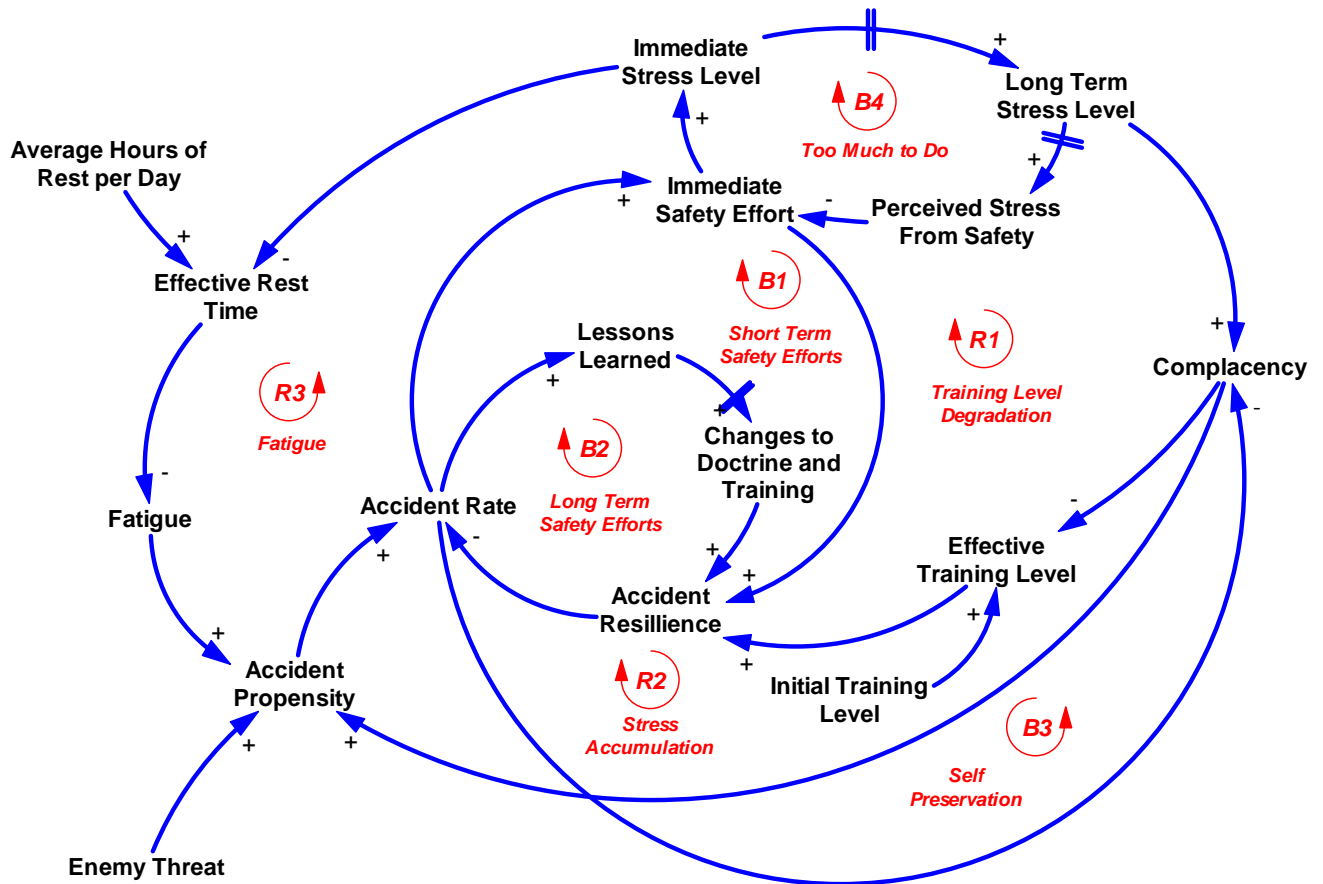


**Figure 3-1 High-Level Model of Vehicle Safety**[9]

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[9] A number of different software applications exist for creating and running System Dynamics models. This study uses Vensim® software. See Sterman 2000 for more information.

Balancing Loop B1 (Short Term Safety Efforts) represents the dynamics of Short Term Safety Efforts on the system. As the Accident Rate increases, the Immediate Safety Effort undertaken by lower-level Army units increases (i.e. actions at Battalion and Company level), which leads to an increase in Accident Resilience and a corresponding decrease in the Accident Rate. As can been seen in Appendix 2, the links between variables in this loop, as well as the other loops in this model, are supported by a number of different independent studies. Loop B1 is specifically interesting because it describes the positive effects of knee-jerk reactions to a safety crisis (in this case an increase in the Accident Rate).[10]

Reinforcing Loop R1 (Training Degradation) represents the unintended consequence of the knee-jerk reaction seen in B1. R1 represents the phenomena where as the Accident Rate increases, the Immediate Safety Effort also increases, which produces an increase in the Immediate Stress Level, Long Term Stress Level, and Complacency, which ultimately increases the Accident Rate. It is important to note that there is a critical delay in this loop between the Immediate Stress Level and Long Term Stress Level. This loop is also critical because it describes how Long Term Stress and Complacency erode an organization's initial training level.[11] Therefore, in isolation loops R1 and B1 will produce some form of S-shaped behavioral dynamics with regards to the Accident Rate.

Next, Reinforcing Loop R2 (Stress Accumulation) is very similar to loop R1, with the exception that it recognizes the direct link between Complacency and Accident Propensity. Thus, it represents the high role that Complacency plays in causing vehicle accidents. Indeed, not only does it decrease Accident Resilience by eroding the training level in an organization, but it also contributes directly to Accident Propensity by decreasing driver awareness of hazards and limiting leader supervision.[12]

Reinforcing Loop R3 (Fatigue) represents another unintended consequence of immediate knee-jerk safety efforts (Short Term Safety Efforts). It represents the situation where as the Accident Rate increases, the Immediate Safety Effort and Immediate Stress Level also increase, which leads to a decrease in the Effective Rest Time and an Increase in Fatigue, which leads to an increase in Accident Propensity and therefore an increased Accident Rate. This loop is significant because it shows that when more work (via increased safety efforts in this case) is created and more stress exists in an organization, workers will not use their rest time effectively and will have a need to "blow off steam" and relax some. In many cases, these burnt out/stressed out Soldiers will spend hours playing video games, talking on the phone and chatting on the internet in lieu of getting some effective sleep.[13]

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[10] See Carroll, Rudolph and Hatakenaka "Learning From Experience in High-Hazard Organizations," Carroll 1998, Dekker 2007, Cook 1999 and Cox 2006.

[11] See Carroll, Rudolph and Hatakenaka "Learning From Experience in High-Hazard Organizations, Carroll 1998, Rudolph and Repenning 2002, Gunther 2002, Dorn "The Effects of Driver Training on Simulated Driving Performance," Dekker 2007, Cook 1999, Murphy 1986, Selzer 1974, Homer 1985 and McKelvey 1988.

[12] See Stave 1998, Slovic 1981, Carroll 1998 and Leveson "What System Safety Can Learn from the Columbia Accident."

[13] See Hefez 1987, Akerstedt 2002, Summala 1994, Dinges 1995, Chau 2002, Kirmil-Gray 1984, Kalimo 2000 and Brown 1994.

Balancing Loop B2 (Long Term Safety Efforts) represents the dynamics of Long Term Safety Efforts or the process of institutional learning.  In this loop, as the Accident Rate increases the Lessons Learned increases which leads to increased Changes to Doctrine and Training, an increase in Accident Resilience, and therefore a decrease in the Accident Rate.  While it appears that B2 is a helpful loop in reducing accidents, it is critical to note that there is a time delay between Lessons Learned and Changes to Doctrine and Training, which places a delay in the time it takes to see a reduction in the Accident Rate following an increase in the Accident Rate through this loop.  In practice, this means it takes a lot longer to rectify safety deficiencies through careful study, consideration, and changes to training and doctrine at the highest levels of the organization.  Therefore, this delay facilitates the tendency to make immediate knee jerk changes at unit level, which in most cases have a number of unintended side effects, are not well thought out solutions to the problem, and lead to increased levels of stress in a unit.[14]

Balancing Loop B3 (Self Preservation) represents the dynamic relationship where as the Accident Rate increases, complacency decreases, which leads to a decrease in accident propensity and a decrease in the Accident Rate.  This loop shows that as accidents occur more frequently, a larger proportion of Soldiers will be immediately impacted by the injuries or deaths that they witness.  The closeness of these events plays an important role in increasing a Soldier's tendency to execute their duties in a safer manner.[15]

Balancing Loop B4 (Too Much to Do) represents the loop where only so much Long Term Stress can build up before Soldiers begin to take matters into their own hands and eliminate the source of stress build up.[16]  It shows that as Immediate Safety Effort increases, the Immediate Stress Level will also increase, which will lead to an increase in the Long Term Stress Level and an increase in the Perceived Stress from Safety, which therefore will cause a decrease in the Immediate Safety Effort.  Finally, it is important to note one of the critical exogenous variables in the model, Enemy Threat, which represents the idea that as the Enemy Threat increases, Soldiers' perception of safety hazards decrease and therefore they are prone to violate safety regulations and procedures, which produces an increase in the Accident Propensity.

## 3.2 Data Collection

After constructing a high-level conceptual model, data was collected to provide quantifiable measures for variables in the model, and to develop critical model parameters and equations.  In collecting the data, we used the hypothesis that no Solider wants to get into an accident, and that all accidents are preventable.  Indeed, in all accident cases reviewed there was clearly something that was responsible for the accidents' occurrence, as evidenced by mechanical errors, poor standard operating procedures, sub-standard training, etc.[17]  Next, we read through the accident

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[14] See Carroll, Rudolph and Hatakenaka "Learning From Experience in High-Hazard Organizations," Garvin 1993, Huber 1991, Kock 1996, Leveson 1995 and Pate-Cornell 2004.

[15] See Stave 2005, Leveson "What System Safety Can Learn from the Columbia Accident," Weinstein 1999, and Slovic 1981.

[16] See Carroll, Rudolph and Hatakenaka "Learning From Experience in High-Hazard Organizations," Carroll 1998, Murphy 1986, Selzer 1974 and Homer 1985

[17] Less than 2% of all accident cases reviewed in this study indicate that the accident was unavoidable.  These atypical cases were all caused by the actions of civilian vehicles, which ran inadvertently into Army vehicles, or by unpreventable mechanical failure.

reports and attempted to walk through the chain of events that lead to each accident to find the underlying conditions that were present in the system that allowed the accident sequence chain to be set in motion.

A hypothetical example of an accident sequence chain depicting various levels of analysis is shown in Figure 3-2.
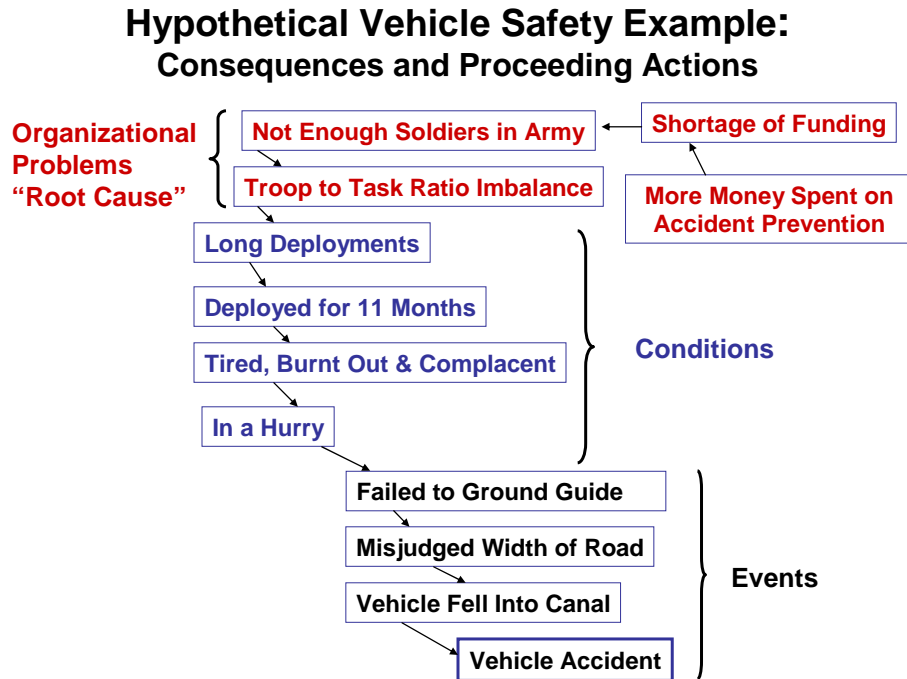
## Hypothetical Vehicle Safety Example:
### Consequences and Proceeding Actions



**Figure 3-2 Hypothetical Accident Sequence Chain**

In this example, a vehicle accident occurred because a vehicle fell into a canal, which was caused because a soldier misjudged the width of the road, which was the direct result of a leader failing to dismount the vehicle and ground guide the vehicle through the hazardous stretch of road on foot. These elements of the accident chain are the "Events" of the accident. It would be easy to stop the investigation at this point, and assign blame on the vehicle commander (TC) for not dismounting and ground-guiding the vehicle. A deeper analysis, however, would reveal more insights. By asking why the TC failed to ground guide, we might find that the TC or convoy commander was in a hurry, and this is because he was feeling tired, burnt out and complacent. While now it might seem even easier to assign blame, a further inquiry might find that the TC was tired and complacent because he was in the 13th month of a 15 month deployment, which is a direct result of long deployments throughout the Army. These new elements of the accident sequence chain are the "Conditions" of an accident, or those elements that cause the actual events of an accident. These conditions, however, are not the root causes of the accident. By further inquiry, we might find that the long deployments are the result of a troop to task ratio imbalance, which is caused by having too many missions to accomplish and not enough Soldiers in the Army, and perhaps the Army cannot afford enough Soldiers because of a shortage of funding, which may partially be a result of too much money being spent on accident prevention and replacing lost/damaged vehicles and Soldiers from these accidents. Naturally, this example is describing a reinforcing feedback loop, which while hypothetical, is quite plausible. In

addition, as described in Figure 2-2, almost all accident reports only focus on the events and some of the conditions of an accident, and therefore one would not be able to find this much information from an accident report or investigation, which limits institutional learning.

Therefore, in examining the actual data as contained in the accident reports, we followed a similar process as described in the hypothetical example above. Once the events and conditions of each accident were identified, we then attempted to determine what the organizational root causes were that led to these hazardous conditions in the system. Wherever there appeared to be a high correlation between specific hazardous conditions and accidents, we then went back and examined the civilian literature of private and public industries to see if these same phenomena existed outside the military. A sample of the Army accident data collected is in Figure 3-3.[18]
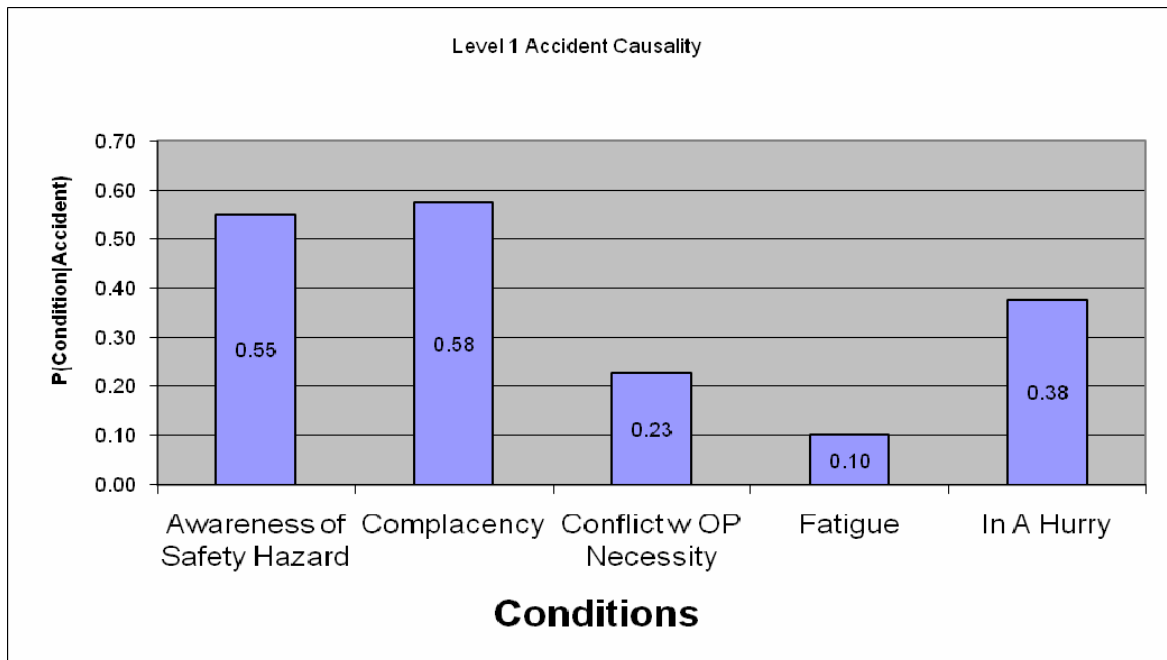


**Figure 3-3 Example Level One Accident Factors**

As seen in Figure 3-3, some of the most common conditions that lead directly to accidents are Awareness of Safety Hazards and Complacency, followed by units that tend to be In A Hurry or perceive a Conflict with Operational Necessity.[19] These are just a few of the level one accident factors that were found in the literature, there were many others. For each level one factor, the safety reports were then carefully scrutinized to determine the level two factors that caused the level one factors to occur. This same iterative process was conducted out to levels four and five

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[18] These are the results of our analysis of the data by category, and are not in all cases explicitly cited as the causes of accidents within the accident reports. P(Conditions/Accident) refers to the probability that a certain condition was present, provided that an accident occurred. In approximately 95% of the cases, more than one condition was involved.

[19] Awareness of Safety Hazards refers to cases where for various reasons, the Soldiers immediately involved in the accident appeared to be completely unaware that the safety hazard that led to the accident existed. Complacency refers to the cases where Soldiers seemed to be careless in their actions usually because of routine actions that they had done many times over. Cases where Soldiers were In a Hurry mainly refers to cases where Soldiers were driving too fast for the existing conditions

(i.e. where each higher "level" of analysis describes how an element within the lower level of analysis occurred).  Next, as per Figure 2-1, an extensive analysis of Army Accidents during the years 1998 through 2006 was conducted to determine a variety of statistics, including pre-war and war accidents rates.  Some of this data can be seen in Table 3-4 below.

| Accident Type | Time Frame | Ave Monthly Accident Rate |
|---|---|---|
| **ALL** | 1998-2001 | 64.6 |
| | 2002 | 61.83 |
| | 2003-2006 | 73.04 |
| **Class A** | 1998-2001 | 1.67 |
| | 2002 | 2.58 |
| | 2003-2006 | 5.19 |
| **Class A & B** | 1998-2001 | 2.81 |
| | 2002 | 3.5 |
| | 2003-2006 | 7.54 |

**Table 3-4 Sample Accident Data[20]**

## 3.3 Proof of Concept Model

After collecting the data a Proof of Concept Model was created.  This process transformed the high-level concept model of Figure 3-1 into a low-level and more detailed model that uses model parameters for exogenous variables and equations for endogenous variables to create a mathematical model of the system that can be simulated by changing various exogenous variables over time.  Figure 3-5 shows a depiction of the low-level model.[21] Appendix 1 provides a larger scale version of the diagram and shows the various parameters and equations that are used in the model.

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[20] As seen in the table, there was not a significant increase in the total number of accidents of all categories when comparing the pre-war and war periods.  There was, however, a significant increase in the Class A and B accidents. We believe this is because in times of war, not all Class C & D accidents (those involving only minor injuries and damage) are reported due to other demanding requirements.  Thus, our analysis used Class A & B reports only.

[21] For brevity we will not explain all of the details of the low level model.  The System Dynamics structures used are explained in Sterman 2000.  Functionally, the low-level model in Fig 3-5 exhibits the same behavior as the high-level model in Fig 3-1.
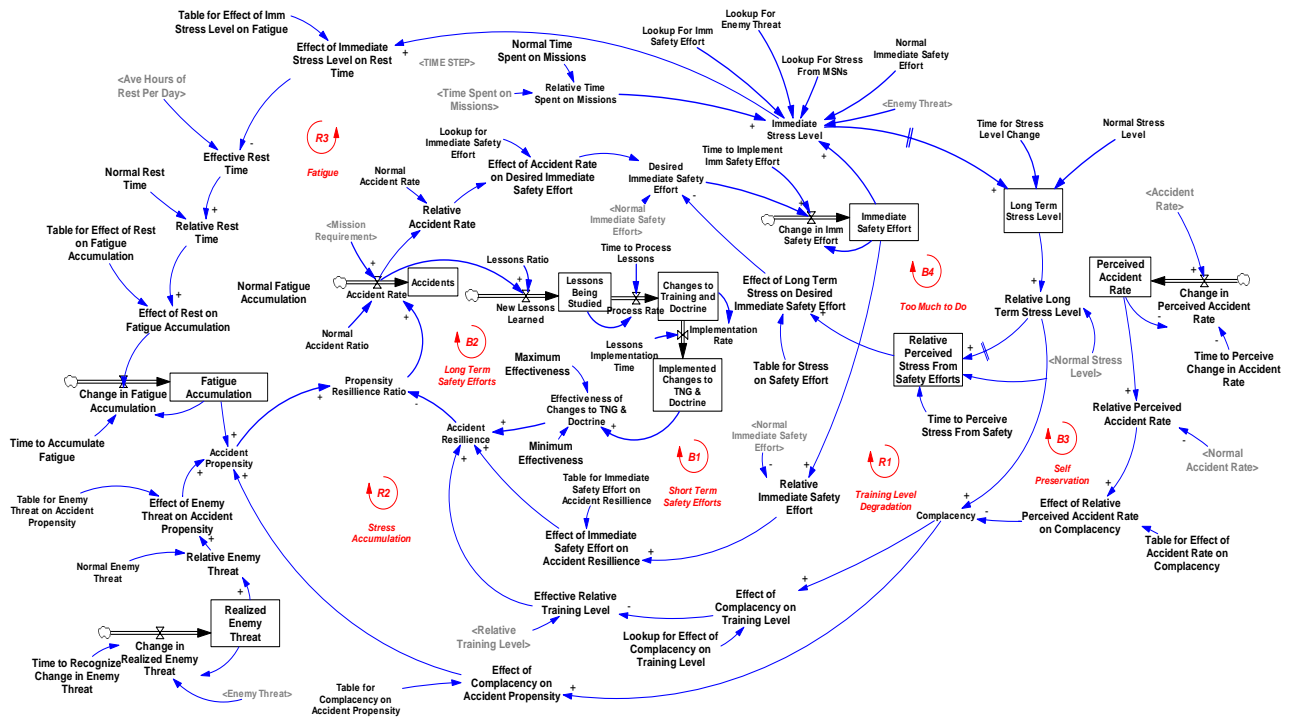
**Figure 3-5  Low-Level Model**

## 3.4 Calibrating the Proof of Concept Model

Once the model was built a number of tests were conducted including sensitivity testing and extreme conditions testing to ensure the model exhibited plausible behavior. Once the model was deemed sound, a final calibration was conducted in order to achieve two goals. The first goal of calibration was to make minor adjustments to any equations or parameters in the model as necessary. The second goal was to confirm that when exogenous stimuli are applied to the system in accordance with historical data, the model will generate behavior that is consistent with the historical evidence. This can be seen in Figure 3-6 below. In doing this calibration, the time period from 1998-2006 was used to validate the model. Time Step 12 represents the rise of the Kosovo (KFOR) mission in 1999, time step 48 represents the invasion of Afghanistan (OEF-Operation Enduring Freedom) in 2002, and time step 60 represents the invasion of Iraq (OIF-Operation Iraqi Freedom) in 2003. Arrays of data were used to adjust the exogenous variables Enemy Threat, Mission Requirements, and Number of Soldiers Deployed across each of the three time steps. As can be seen in Figure 3-6, the simulated accident rate (the blue line) is very close to the actual historical accident rate (the red line). It is important to note that the historical data represents the annual average accident rate for each year, and therefore in reality would be more stochastic in nature.

# Calibration Results

## Accident Rate
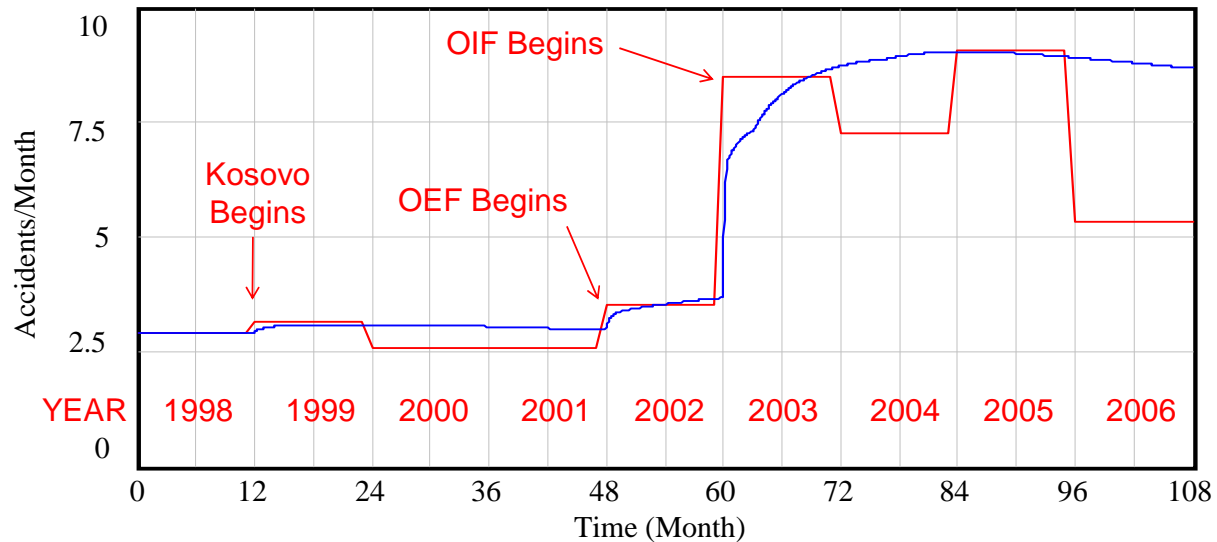


Accident Rate : Simulation Results
Accident Rate : Actual Accident Data

NOTE: Simulation uses step increase at times 12, 48 & 60 for KFOR, OEF & OIF. Step Increase array values for: Enemy Threat (.0062,.0125,.1), Mission Requirements (1250, 2500, 37500), and # Soldiers Deployed (3750, 7500, 100000) 71

**Figure 3-6 Model Calibration Results**

## 4.  Learning from the Model

After constructing and calibrating the model, we then conducted a number of simulations to see what could be learned from the model.  We began using one variable at a time testing, then experimented with various oscillations and stochastic stimuli in the model.  We then conducted several multivariate experiments, where several exogenous variables were manipulated simultaneously.  We then concluded with a hypothetical example, or test case, where the model might be used to assess the impact of a real policy change.

## 4.1 One Variable at a Time

First we began with one variable at a time testing, where one variable was manipulated under "everything else is equal" circumstances.  As can be seen in Figure 4-1 below, step increases in Enemy Threat and Mission Requirements cause severe increases in Accident Rate, with the Accident Rate then slowly declining over time as it does in the equilibrium case (grey line).  A onetime step increase in the Number of Soldiers Deployed, however, counter to what may seem intuitive, actually decreases the Accident Rate.  This is because deploying more Soldiers, with everything else being equal, provides more Soldiers to share the Mission Requirements and

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therefore produces less fatigue and stress on the system.  This is an important finding, and suggests that careful management of the troop-to-task ratio can be critical in reducing Vehicle Accidents.
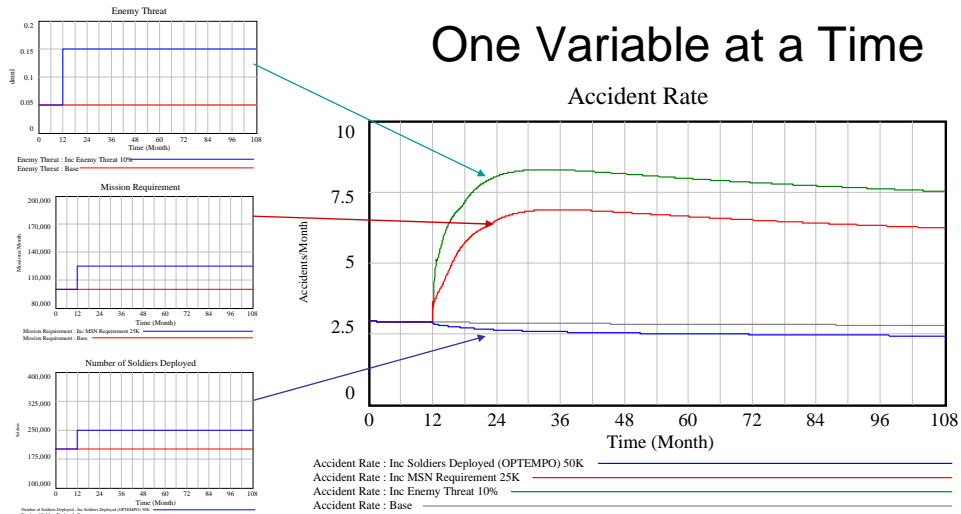


- Increasing the Enemy Threat produces an increase in the Accident Rate
- Increasing the Mission Requirement produces an increase in the Accident Rate
- Increasing the Number of Soldiers Deployed <u>DECREASES</u> the Accident Rate

**IMPORTANT Finding:  More Soldiers Deployed means that accidents will decrease, this is because fatigue is reduced by more Soldiers sharing the workload.**

**Figure 4-1  One Variable at a Time Experiments**

Another key one variable at a time experiment was conducted with the variable Lessons Ratio. This variable represents the percentage of accidents that actually produce an effective lesson learned that can be translated into effective policy, training, and doctrinal changes that improve safety.

As can be seen in Figure 4-2 below, the Lessons Ratio was manipulated from the Base Level of 10% (equilibrium level), to 0%, 50% and 100%. As expected, this test showed that as the Lessons Ratio increases, the Accident Rate decreases. But more significant, is the finding that there are differentiating levels in the rate of improvement. As seen below, it is clear that more accidents are prevented by improving the Lessons Ratio from 0% to 10%, as opposed to improving it from 50% to 100%. As in most endeavors, it is usually more difficult and requires a much greater level of investment to improve from 50% to 100% vs. 0% to 10%. This finding suggests that it is the initial lessons learned that are most important, specifically when the Army is operating in a new environment. It also suggests that because of diminishing rates of return, it may be beneficial to strive for the 70% solution vs. the 100% solution with regards to institutional learning, depending on what the costs are to attain this level.

# One Variable at a Time
## (Mitigating The Accident Rate)
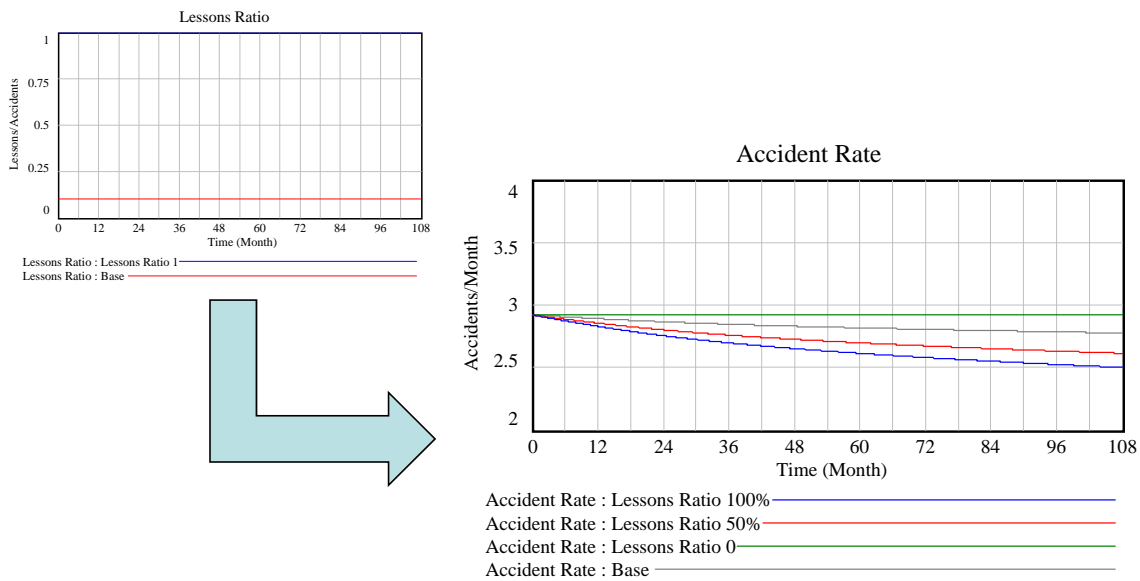


**IMPORTANT Finding: Improving the Lessons Ratio, or ensuring that lessons are learned and appropriate doctrinal and training changes are made, is critical to reducing the accident rate- diminishing payoffs with increased Lessons Ratio**

75

**Figure 4-2 Lessons Ratio**

## 4.2 Oscillations in Enemy Threat

The next simulation conducted was also a one variable at a time experiment, but this time with the aim of determining what effect an oscillation in the magnitude of the enemy threat would have on the system. These simulations were conducted with the intention of replicating how enemy activity is exhibited in many extended conflicts such as Iraq, Afghanistan, and Vietnam. For example, in all of these conflicts, historical evidence indicates that enemy activity normally increases and decreases over time. Especially in low-intensity warfare, it is very difficult for the

insurgent to maintain a constant level of offensive operations, as they periodically need to rest, refit, and develop new strategies and tactics.

Therefore, experiments were conducted to assess the effect of variations in both the amplitude and period of the threat, and to see what effect a stochastic threat would have on the system. As seen in Figure 4-3 below, oscillations in the Enemy Threat can produce fewer accidents over time even when the average enemy threat over time is equal. To better understand this phenomenon, a close examination of the Long Term Stress Level is in order. As can be seen on the graph in Figure 4-3, the Long Term Stress Level never reaches the same level as it does when a constant Enemy Threat is applied to the system. This is because the system has time to recover and "burn off" stress when the Enemy Threat level is lower. Although not shown on the graphs below this same phenomenon occurs with fatigue in the system.
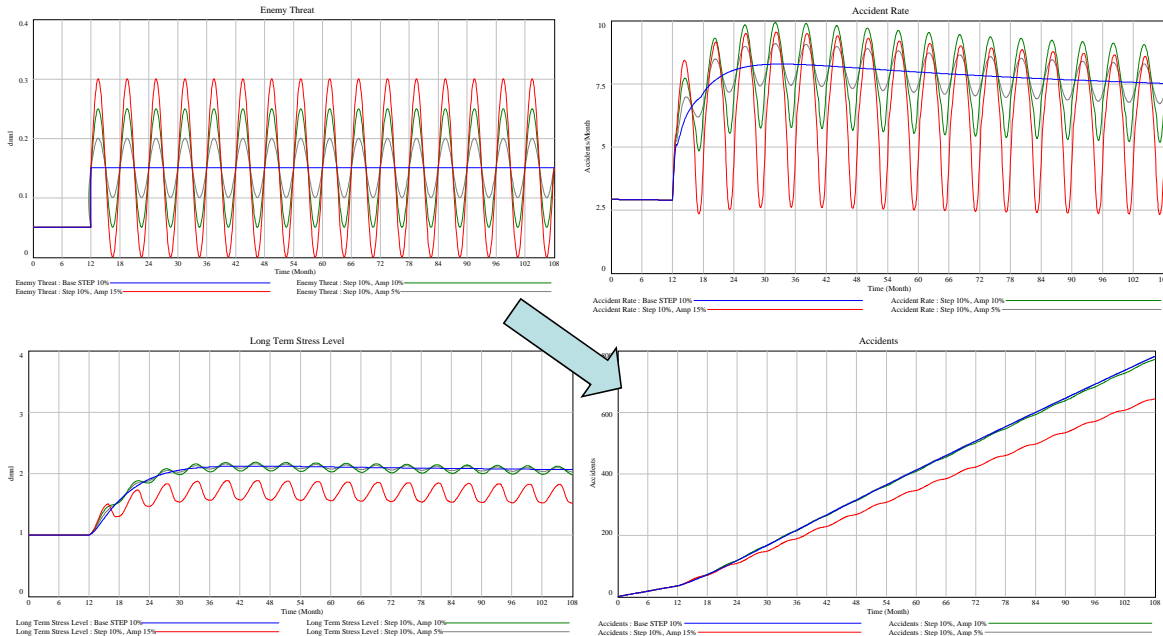
# Oscillations in Enemy Threat
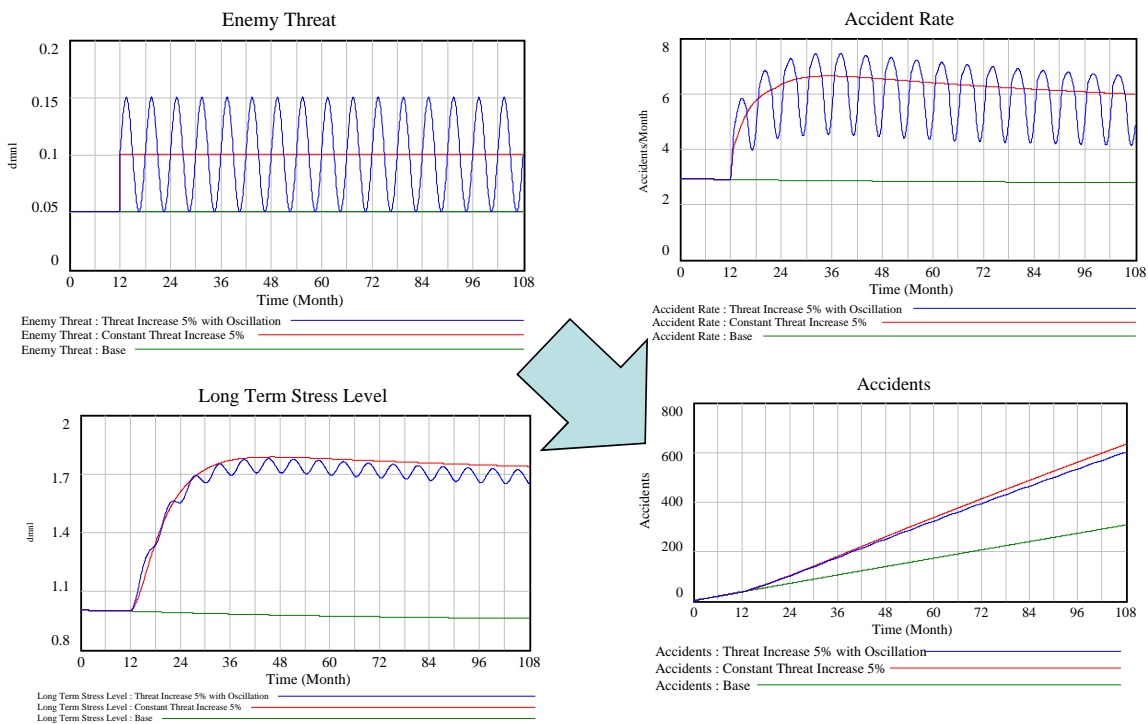


**IMPORTANT Finding:** An Oscillating Enemy Threat produces less accidents despite the same average enemy threat over time…Why? Because Long Term Stress and Fatigue do not reach the same level as they do when the system remains constant

76

**Figure 4-3 Impact of Oscillations in Enemy Threat**

Figure 4-4 is an extension of this idea and shows that the same basic results apply among a wide range of values for amplitudes. It is important to note, however, that the greatest improvements in the system occur when the greatest amplitudes are applied. This finding seems to suggest the importance of rotating Soldiers "off the line" and home on leave more frequently. It shows that Soldiers who are exposed to high levels of enemy threat followed by equal periods of rest, where rest is in this context defined as non-exposure to an enemy threat, will be less likely to have accidents.



## Oscillations in Enemy Threat (Increasing Amplitudes)

**IMPORTANT Finding: The same behavior is shown with increasing magnitudes in enemy threat AND increased oscillations. Here Enemy Threat increases by .1 vs. .05 previously, and amplitudes are 0, .05, .10, and .15. Thus, despite the same total amount of enemy threat over time in all cases, those with increased oscillations in enemy threat clearly exhibit fewer accidents.**

77

**Figure 4-4 Impact of Larger Oscillations in Enemy Threat**

Next, simulations were conducted to see what would happen to the system when the period of oscillation was varied.  As seen in Figure 4-5, the greater the period of oscillation the fewer the total number of accidents.  As with the experiments involving variations in amplitude, the same total enemy threat was present over time; the only aspect of the variable that was manipulated was the period of oscillation.   It should be mentioned that the results of these experiments as demonstrated by the results shown in Figure 4-5 suggest that the period of oscillation is not as important as the amplitude of oscillation.

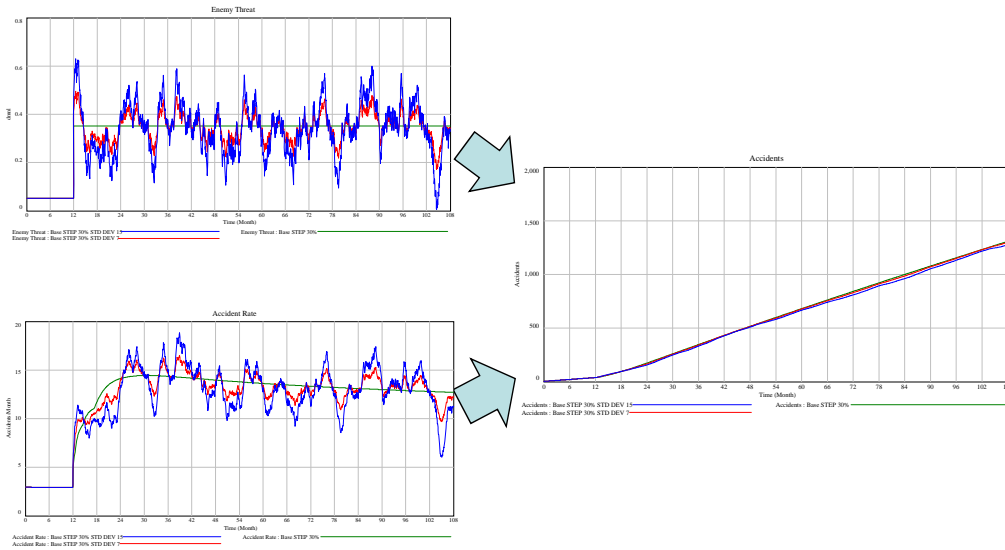# Oscillations in Enemy Threat (Increasing Periods)
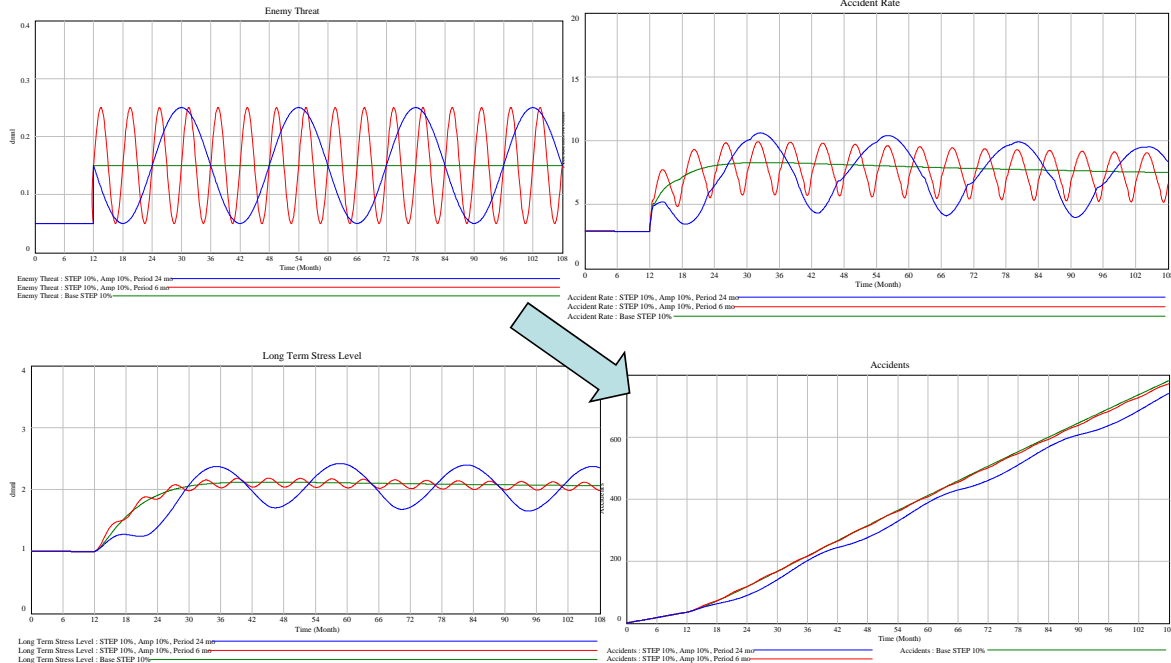


**IMPORTANT Finding:  The length of the period has only a small effect on total accidents.  For example, with Step inc of .10 and amplitude of .10, no oscillation yields 781 accidents over 108 months, a period of 6 months yields 771 casualties, and a period of 24 months 740 casualties.**

78

**Figure 4-5 Impact of Increasing Periods Oscillations in Enemy Threat**

Finally, experiments were conducted to test the results of a stochastic threat on the system (i.e. a threat that is entirely random and varies in intensity at a high and unexpected frequency). Contrary to what was expected following the results of the oscillating experiments, a stochastic threat had no impact on the system; see Figure 4-6. This is important, as it reinforces the finding previously mentioned regarding rotating Soldiers out of combat on regular and expected schedules in order to reduce stress and fatigue. This also suggests that it is important to consider shorter deployments with longer rest cycles, which ultimately requires careful management of the troop-to-task ratio.

# One Variable at a Time (Stochastic Enemy Threat)



**IMPORTANT Finding: A stochastic Enemy Threat, unlike a fluctuating enemy threat, produces roughly the same number of accidents over time as a constant threat level.**

79

**Figure 4-6 Impact of stochastic Oscillations in Enemy Threat**

21

Figure 4-7 demonstrates why this is the case, as increased amplitudes in the enemy threat translates to more time being spent in smaller slope areas on the graph of Relative Enemy Threat vs. Effect of Relative Enemy Threat on Accident Propensity. Because the relationship between these two variables is non-linear, there is a distinct tradeoff advantage for obtaining frequent periods of rest in return for similar periods of greater exposure to Enemy Threat.

# One Variable at a Time
## (Insights From an Oscillating Enemy Threat)
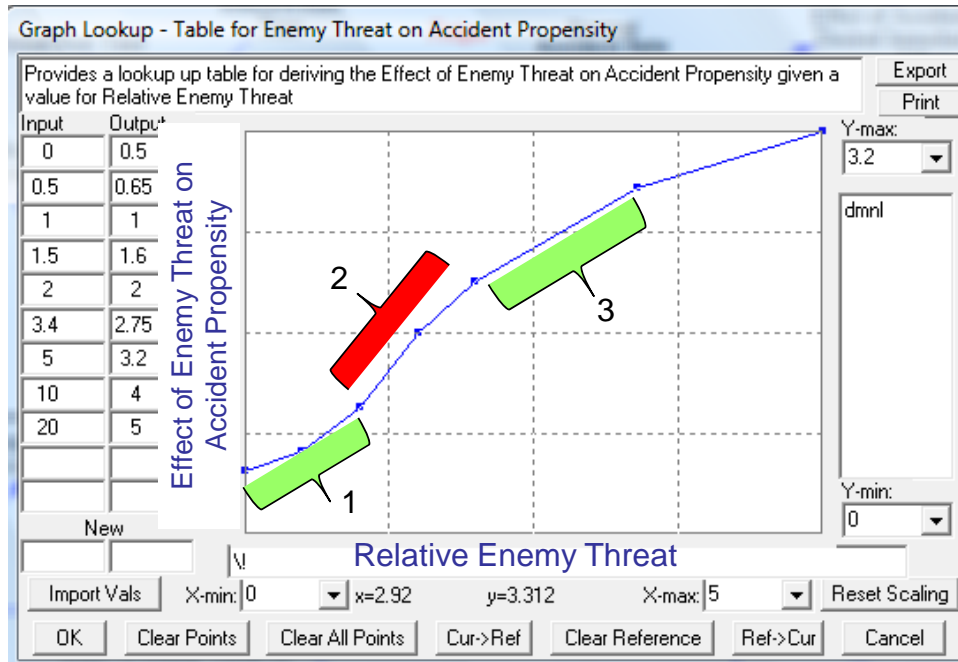


**IMPORTANT Finding:** **Oscillating Enemy Threats with high amplitudes produce less accidents because they spend a roughly equal amount of time in zones 1-3, where zones 1 and 3 have smaller slopes than zone 2. Threats with smaller amplitudes are mostly in zone 2 only, where the slope is higher. Therefore, the system never has time to recover where small oscillations occur as compared to threats with greater amplitudes.**
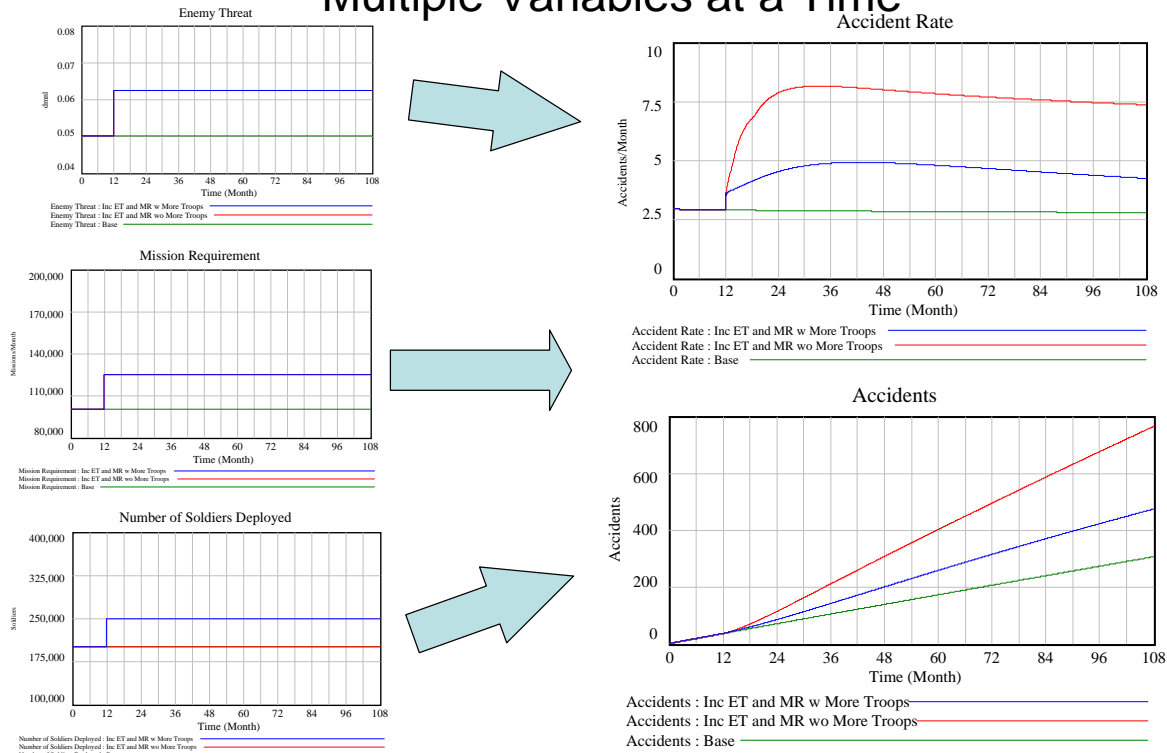
80

**Figure 4-7 Key Insight: The Dynamics of Threat Amplitudes**

## 4.3 Multivariate Simulation

Next, we conducted several multivariate experiments to determine the impact that changing multiple variables simultaneously has on the system, and what might be learned from it. As can be seen in Figure 4-8, we increased the Enemy Threat, Mission Requirements and Number of Soldiers Deployed simultaneously to see what effect it would have on the system. One important finding is that even minor increases in the enemy threat and mission requirements can cause salient behavior regarding the Accident Rate, if the Number of Troops Deployed is not increased proportionately. This reinforces the earlier finding that careful management of the troop-to-task ratio at a macro level of control is requisite to reducing combat vehicle accidents. It suggests that if commanders on the ground are given too many missions to accomplish under hostile

conditions, without enough troops to effectively share the burden, an unnecessary number of vehicle accidents will occur.



**Figure 4-8  Multiple Variables at a Time**

## 4.4  Troop Reduction Example

Finally, a hypothetical but plausible example of how this model might be used to assess the effects of a potential policy alternative is shown below.  The following simulations, with results shown in Figures 4-9 and 4-10, was conducted to see what the results of various options are for withdrawing troops from a combat zone.  The green line in Figures 4-8 and 4-9 represents the system in equilibrium, while the red line represents the results of a phased troop withdrawal over a period of 24 months that is proportional to a reduction in the Enemy Threat and Mission Requirements over that same period of time.  The blue line represents the effects of an un-scaled troop withdrawal that is proportional to the decrease in Enemy Threat and Mission Requirements, but the decrease in Enemy Threat and Mission Requirements has a delay of 12 months while the troop withdrawal begins immediately.  In essence, this replicates two very different policy alternatives.  In the first case, the mission is scaled down simultaneously with the troop withdrawal, in the second case the overall mission remains the same for the first 12 months as the troop withdrawal begins, and then scales down at a faster pace during the last 12 months of the withdrawal.

23

# Hypothetical Example (Troop Reduction)
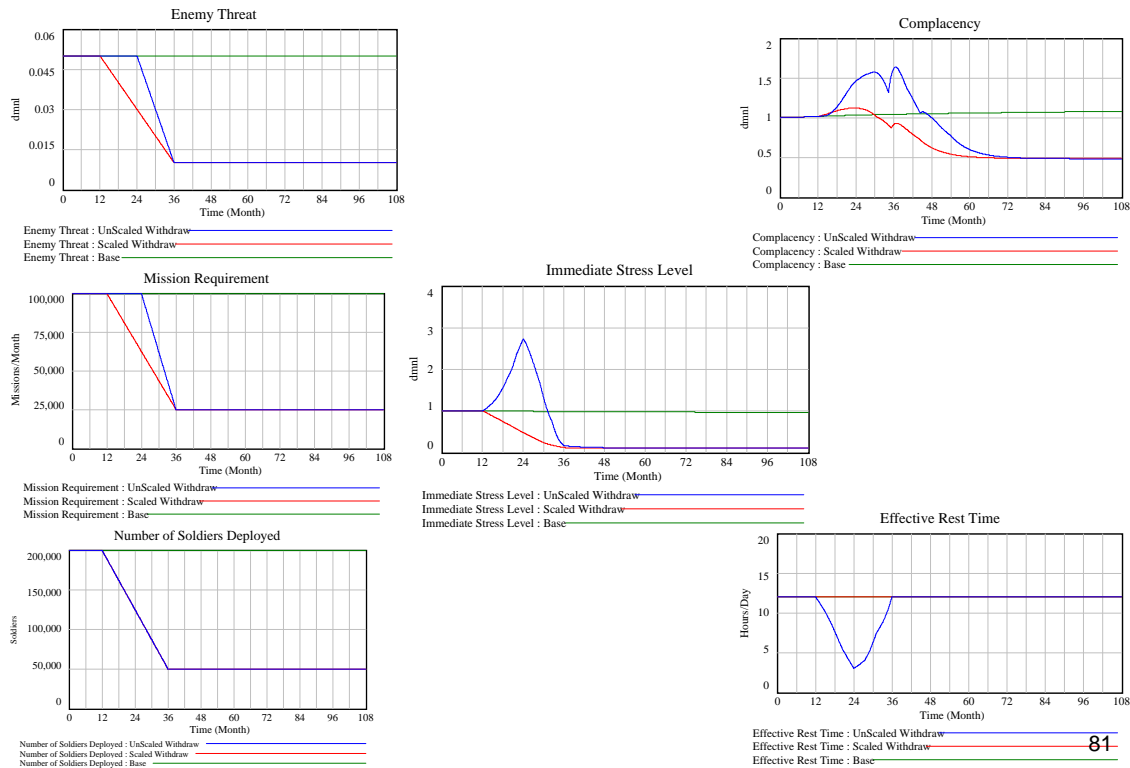


**Figure 4-9  Simulation Results of Troop Reduction:**
**Impact on Complacency, Stress Level, and Effective Rest Time**

As the graphs in Figures 4-9 and 4-10 show, there are serious unintended consequences involved with conducting a troop withdrawal that is not phased proportionately with a decrease in Enemy Threat and Mission Requirements.  The graphs of Enemy Threat, Mission Requirements and Number of Soldiers Deployed shows the exogenous changes for each of the simulations.  The graphs of Complacency, Immediate Stress Level and Effective Rest Time shows the difference between each of the scenarios with respect to the two different simulations.  For each variable, it is clear that Stress and Complacency are much greater in the case where the withdrawal is un-scaled.  It is also clear that the Effective Rest time for the un-scaled withdrawal is much less than the case for the scaled withdrawal.  As can be seen in Figure 4-10, this translates to a much greater Accident Rate for the un-scaled withdrawal, as opposed to the scaled withdrawal, and the total number of accidents caused by the 24 month withdrawal is approximately 75% greater in the un-scaled case.  It is also interesting to note that when the model is simulated for a troop withdrawal with a reduction in Mission Requirements only, and no reduction in Enemy Threat (a factor that normally cannot be controlled), the model still exhibits the same behavior.  The only exception occurs when the Enemy Threat is not reduced; in this case the total number of Vehicle Accidents will be greater than when the Enemy Threat is reduced over time.

This model could be useful to a policy maker who is contemplating whether or not to conduct a troop withdrawal, and if so, how to conduct it.  The result of this simulation would suggest that any troop withdrawal must be carefully scaled with a concurrent and proportional decrease in

24

mission rate and enemy threat in order to avoid excessive complacency and fatigue that leads to accidents.

# Hypothetical Example (Troop Reduction)

Accident Rate
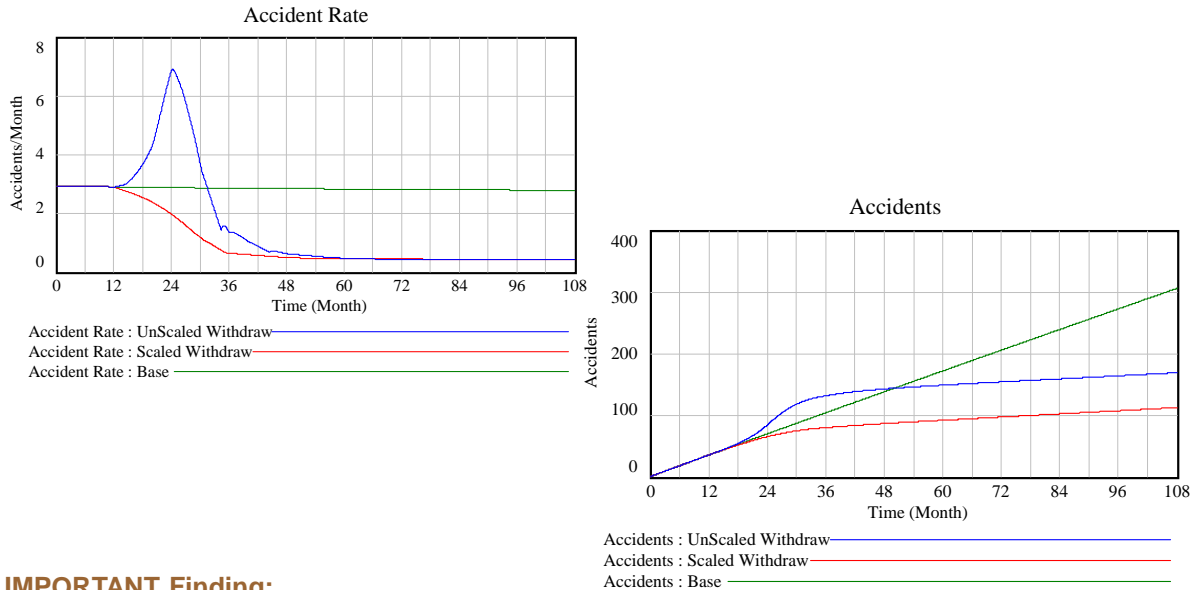
Accidents

IMPORTANT Finding:
• **Any troop withdraw must be carefully scaled with a concurrent and proportional decrease in mission rate and enemy threat in order to avoid excessive complacency and fatigue that lead to accidents**
• **The same model behavior occurs with constant enemy threat as with decreasing enemy threat, only exception is constant enemy threat (i.e. no reduction of enemy threat) produces a greater number of accidents proportionately)**

82

**Figure 4-10  Simulation Results of Troop Reduction:
Impact on Accident Rate and Accidents**

## 5. Conclusions & Recommendations

The following recommendations are consistent with the findings in this study.  The findings are derived from three sources; the literature review, construction of the model, and simulation using the model.  Based on these results, we recommend the following.

### 5.1  High-Level Policy Findings.

• <u>Understanding Delays</u>.  Some of the greatest potential for improving safety can be found by understanding the dynamic effect of various delays in the system.  In this model, these delays include the Time to Process Lessons, Lessons Implementation Time and Time to Implement Immediate Safety Effort.  These are critical because they speed up the Long Term Safety Efforts Loop which would therefore facilitate a decrease in the Short Term Safety Efforts Loop.  This would lead to a reduction in unintended side effects such as Complacency and erosion of the Effective Rest Time.

- Balancing Short Term and Long Term Safety Efforts is crucial: Too much focus on short term efforts can actually be detrimental to safety over the long term, but some short term efforts are needed to reduce vehicle accidents because of the time delay involved with institutional learning and doctrine/training change. While a tradeoff analysis of these two loops was not discussed explicitly in the analysis section of this study, it is clear from the conceptual model that a deeper study in this area may lead to improvements in safety.

- Balancing the Mission Rate/OPTEMPO with Availability of Troops is paramount to accident reduction. This must occur not only at lower-unit level (e.g. Battalion and Company levels), but also by war planners and decision makers at the highest levels of the military. This has a direct, but potentially unnoticed, impact on fatigue, complacency and stress which are major contributors to accidents

- Troop Exposure to the Enemy Threat. Operating Environments with a fluctuating/oscillating enemy threat will produce fewer vehicle accidents than those with a constant (and proportional) enemy threat. This also suggests the benefit of rotating Soldiers out more frequently "off the line" or on "R&R". In addition, shorter deployment times with more time off will have a critical impact on reducing complacency and fatigue which will lead to fewer accidents. Therefore, while we may not be able to control the enemy threat, we can often control the exposure of our Soldiers to the enemy threat, specifically the work-rest cycle.

- Conduct of Accident Investigations. The Army has an outstanding After Action Review process that is first rate and encourages continuous double loop learning throughout the organization (See Figure 5-1 below). This process is made possible by open feedback of both positive and negative aspects of mission planning and execution by subordinates and superiors alike. While this process works well for learning from operations and training exercises where retribution is rarely taken for mistakes made, it is not the case with accident investigations. Since most accident investigations involve a 15-6 inquiry which is normally focused on assigning blame, or at least give the perception that the focus is on assigning blame, many of the Soldiers and leaders involved in accident investigations are likely to remain silent. This is specifically the case with those most directly involved in the accident who have the most important information to share. Therefore, the Army should consider adopting a new approach to accident investigations that focuses on organizational learning in lieu of assigning blame. While in some cases individuals do need to be held accountable for gross negligence, in other cases it may be more important to focus on learning from the incident in lieu of concentrating on who to blame for the accident. This shift in focus will encourage double loop learning in the safety domain, which will lead to greater reductions in accidents.
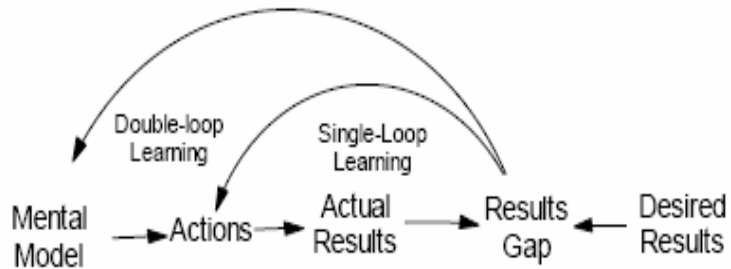
Figure 5-1 Single and Double-Loop Learning[22]

## 5.2 Low Level Policy Implications

- Complacency is the number one immediate cause of accidents and is the most important variable in the model. This does not mean it is the root cause of accidents. Actions must be taken at all levels to reduce complacency, this includes the highest levels of command, by ensuring lower units have the right amount of troops, with the rights skill sets and equipment to accomplish the mission requirements.

- Training Level is another key variable, Soldiers must be properly trained to perform tasks and leaders properly trained to supervise Soldier actions and assess/mitigate risks. It is impossible to eliminate complacency altogether, and one of the biggest safeguards to the effects of complacency is to ensure that units are highly trained at all times.

- Risk Assessments are critical at all levels, but most critical are actual patrol leaders (usually platoon leaders) going through the Risk Assessment process themselves; identifying risks, and developing mitigation measures. This includes briefing all members of the unit on the risks and mitigation measures and soliciting two way communication during the briefing (i.e. asking Soldiers/non-Commissioned Officers for feedback/ anything not covered in the brief or better yet, involving them in the process at the beginning). Finally, NCOs must enforce the mitigation measures and ensure all members of the unit are following the mitigation measures. This final step is of paramount importance to the risk assessment and mitigation process. As seen in myriad accident reports, too often risk assessments are completed and formally signed to "check the block," with the assessments never being briefed to Soldiers and enforced by junior leaders. (NOTE: Patrol Leaders must be trained on the Risk Assessment process in detail, this is usually not emphasized sufficiently at Training and Doctrine Command schools (i.e. Officer Basic Courses, etc.)

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[22] Carroll, John S., J. Rudolph & S Hatakenaka. "Learning From Experience in High-Hazard Organizations. Submitted to Research in Organizational Behavior. p. 79.

## 5.3 Conclusions on Research.

- System Dynamics modeling can produce insights that will help to reduce Army combat vehicle and motor vehicle accidents by providing policy makers with an improved understanding of what indicators to look for and what levers to manipulate.

- While this preliminary analysis sheds some light on the problem, further research and modeling is needed to draw deeper insights into the "root causes" of accidents. Some of the specific opportunities for further research in this area are listed in section 5.4.

- With further research and modeling, it may be possible in some cases to actually predict accident rates based on factors such as mission rate, enemy threat, OPTEMPO, training budget, number of soldiers deployed, etc. At a minimum, further research will help more clearly identify which high-level variables play the most critical role in accident mitigation, as well as clarifying the dynamic relationship between multiple variables.

- Once complete, it is possible that the model could then be expanded to accurately predict accident rates from other causes such as negligent discharges of small arms. This would require the development of more generalizable concepts that have a more universal application to various safety challenges.

- Most importantly, an enhanced model will help decision makers to better understand system behavior, and therefore make sound policy interventions at all of levels to reduce vehicle accidents, and possibly all types of accidents. To gain precision in this endeavor, accident data regarding all types of accidents are needed, and the model would need to be re-calibrated. It is possible that a few new causal loops will be needed, but the basic model structure would be similar.

## 5.4 Plans for Phase II Research.

The following ideas are mainly focused on integration of new research studies and literature into the research project and offer potential areas for extending the model. Most important in this endeavor is concentrating on further development of endogenous variables within the model to better understand the dynamic complexities of the system.

- Potentially differentiating concepts that are currently aggregated under "Enemy Threat." This could include new variables/causal loops including Task Complexity, Pressure to Perform, Perceived Need to Avoid Regulations, etc.

- Integration of Judgment Bias and Optimism Bias concepts into the model. Depressive Realism is another complimentary concept. Future research will focus on how depression from losses coupled with natural human tendencies to discount risk to ourselves might be integrated into the model and help us to better understand why accidents occur.

- Considerable research exists indicating that a deliberate driver selection program that identifies individuals that are most suited to serve as safe drivers is one of the best measures for reducing accidents. Thus, further exploration is needed to see how this could be modeled and if a driver selection program, and what type, is feasible for the Army.

- Conduct a further examination of Exogenous variables and determine improved ways to measure them, examples are Enemy Threat (Probability of contact, casualty rate, etc) and Mission Rate (Missions/ Month, Miles Driver/Month, etc). Improved quantification of these variables will help leaders to better calibrate and improve predictive capability.

- Examination of monthly data, not just annual data, for accident rate and all other variables. This will help to better calibrate the model and to discover trends or patterns in the data.

- Incorporation of concepts from Jack Homer's Worker Burnout Model. Currently these ideas are modeled as Stress and Fatigue in the model, but closer examination of Homer's model could lead to improved formulations of these concepts.

- Improved study of Behavior Modes, Partial Model Testing and Extreme Conditions. Extreme Condition testing ensures that the model is plausible under all possible values for various model parameters, and therefore improves the validity of the model. Further examination of behavior modes and partial model testing will lead to improved calibration of table functions and other equations within the model.

- Lessons Learned Delay Times study (should have more impact on system); focus on improved calibration of Effectiveness of Changes to Training and Doctrine. Also look at limits to learning, and nonlinearities involved regarding the effect of Lessons Ratio on the system.

- Conduct a tradeoff analysis between the Long Term and Short Term Safety Efforts loops. As discussed in the recommendations, it is clear that some balance between these two loops is critical to reduction of Accidents. Phase II of this study will include a much deeper analysis of the tradeoffs between these two feedback loops, including how to harness the benefits of both while avoiding unintended side effects.

## Acknowledgements

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# Appendix 1 (Key Parameters & Equations)

Accident Propensity
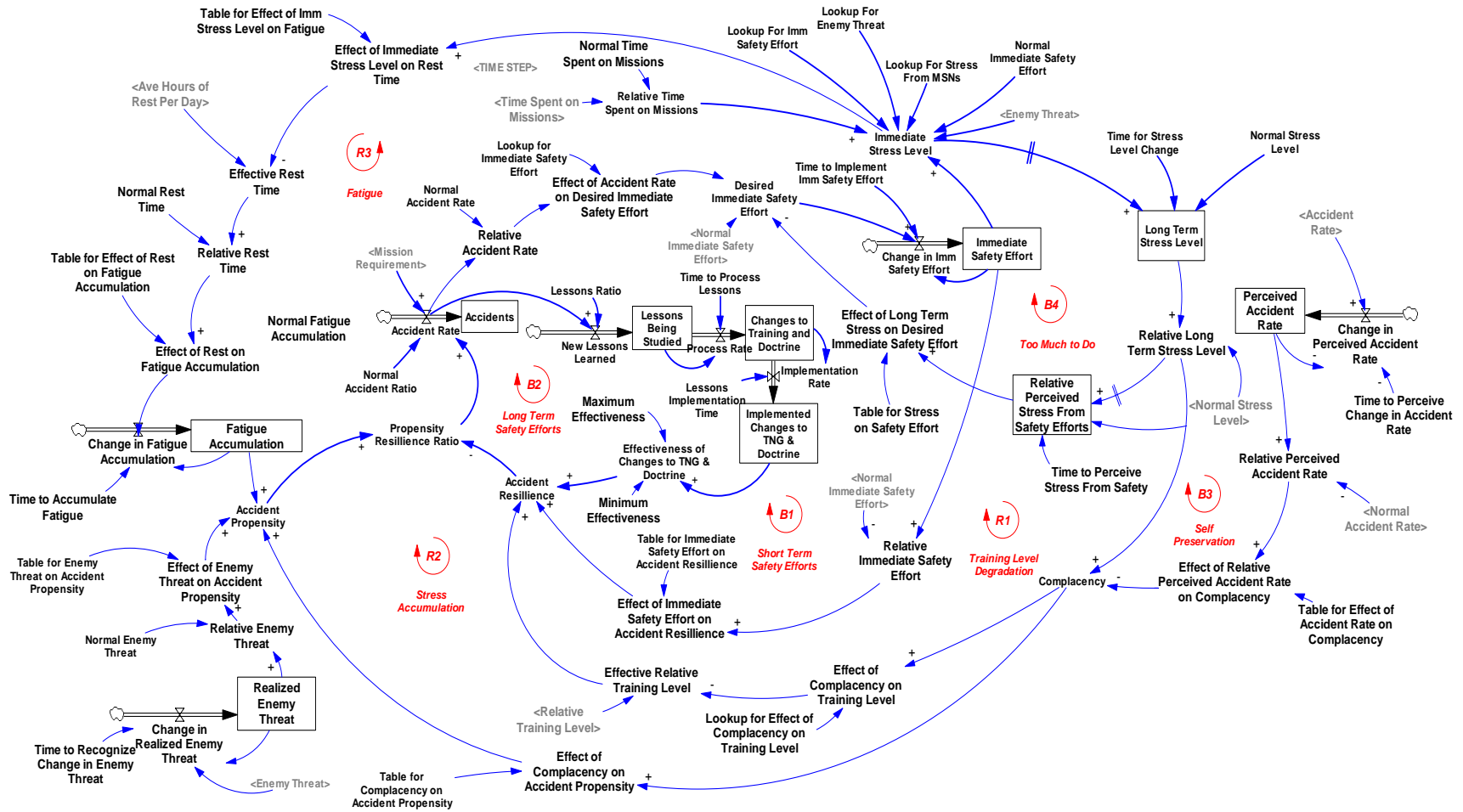
| Parameter | Name | Value | | Parameter | Name | Value |
|---|---|---|---|---|---|---|
| NAR | Normal Accident Ratio | 2.92e-005 | | TSLC | Time for Stress Level Change | 6 |
| MR | Mission Requirement | 100,000 | | NSL | Normal Stress Level | 1 |
| NAR | Normal Accident Rate | 2.92 | | TPSFS | Time to Perceive Stress From Safety | 3 |
| TIISE | Time to Implement Immediate Safety Effort | 1 | | TRCET | Time to Recognize Change in Enemy Threat | 1 |
| LR | Lessons Ratio | .1 | | TPCAR | Time to Perceive Change in Accident Rate | 3 |
| TPL | Time to Process Lessons | 6 | | NET | Normal Enemy Threat | .05 |
| LIT | Lessons Implementation Time | 6 | | NRT | Normal Rest Time | 12 |
| ME | Maximum Effectiveness | 4 | | TAF | Time to Accumulate Fatigue | 1 |
| MEF | Minimum Effectiveness | 1 | | NFA | Normal Fatigue Accumulation | 1 |

Accident Propensity: AP=ECAP*EETAP*FA

Accident Rate: AR=NAR*MR*PRR

Accident Resilience: AIR=ECTD*EISEAR*ERTL

Accidents: $A = \int_0^t AR\,dt$

Change in Enemy Threat: CET= (ET-RET)/TRCET

Change in Fatigue Accumulation: CFA= (ERFA-FA)/TAF

Change in Imm Safety Effort: CISE=(DISE-ISE)/TIISE

Change in Perceived Accident Rate: CPAR= (AR-PAR)/TPCAR

Changes to Training and Doctrine: $CTD = \int_0^t (PR - IR)\,dt$

Complacency: C= ERPARC*RLTSL

Desired Immediate Safety Effort: DISE= EARDISE*ELTSDIS*NISE

Effect of Accident Rate on Desired Immediate Safety Effort: EARDISE = f(RAR)

Effect of Complacency on Accident Propensity: ECAP= f(C)

Effect of Complacency on Training Level: ECTL= f(C)

Effect of Enemy Threat on Accident Propensity: EETAP= f(RENT)

Effect of Immediate Safety Effort on Accident Resilience: EISEAR= f(RISE)

Effect of Immediate Stress Level on Rest Time: EISLRT = f(ISL)

Effect of Relative Perceived Accident Rate on Complacency: ERPARC= f(RPAR)

Effect of Rest on Fatigue Accumulation: ERFA=f(RRT)

Effect of Long Term Stress on Desired Immediate Safety Effort: ELTSDISE= f(RPSFSE)

Effective Relative Training Level: ERTL= RTL*ECTL

Effective Rest Time: ERT= AHRPD*EISLRT

Effectiveness of Changes to Training and Doctrine:

$$ECTD = MIN(MAXE, MINE + (.05 * \sqrt{ICTD})$$

Fatigue Accumulation: $FA = \int_0^t CFA\,dt + NFA$

Immediate Safety Effort: $ISE = \int_0^t CISE\,dt$

Immediate Stress Level: ISL = ET*(ISE/NISE)*RTSM

Implementation Rate: IR= CTD/LIT

Implemented Changes to TNG & Doctrine: $ICTD = \int_0^t IR\,dt$

Lessons Being Studied: $LBS = \int_0^t (NLL - PR)\,dt$

Long Term Stress Level : $LTSL = \int_0^t \left(\frac{ISL}{TSLC}\right) + NSL$

New Lessons Learned: NLL=AR*LR

Perceived Accident Rate: $PAR = \int_0^t CPAR\,dt + NAR$

Process Rate: PR=LBS/TPL

Realized Enemy Threat: $RET = \int_0^t CRET\,dt + NET$

Relative Accident Rate: RAA=AR/NAR

Relative Enemy Threat: RENT=RET/NET

Relative Long Term Stress Level: RLTSL = LTSL/NSL

Relative Perceived Accident Rate: RPAR = PAR/NAR

Relative Perceived Stress From Safety Efforts:

$RPSFSE = \int_0^t (RLTSL/TPSFS)\,dt + NSL$

Relative Rest Time: RRT=ERT/NRT

# Appendix 2 (Model Documentation)

The purpose of this Appendix is to document the causality between variables in this model.  This Appendix contains non-military sources only, and shows that research in both the public and private sector supports all of the critical links in this model.  The "yellow oval" indicates which link the associated citations support.

## Accident Rate Effects Lessons Learned

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- Garvin, David. A.  "Building a Learning Organization."  Harvard Business Review. Jul/Aug 93, Vol. 71  Issue 4, p 78-91.

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- Kock Jr., McQueen, & Baker.  "learning and Process Improvement in Knowledge Organizations: A Critical Analysis of Four Contemporary Myths." The Learning Organization.  1996.  Vol. 3, Iss. P. 31.

Immediate Stress Level
Long Term Stress Level
B4
Too Much to Do
Average Hours of Rest per Day
Immediate Safety Effort
Perceived Stress From Safety
Effective Rest Time
B1
Short Term Safety Efforts
R1
Training Level Degradation
Complacency
Lessons Learned
R3
Fatigue
B2
Long Term Safety Efforts
Changes to Doctrine and Training
Accident Rate
Effective Training Level
Fatigue
Accident Resilience
Accident Propensity
R2
Stress Accumulation
Initial Training Level
B3
Self Preservation
Enemy Threat

# Lessons Learned Impacts Changes to Doctrine and Training

- Carroll, John S., J. Rudolph & S. Hatakenaka. "Learning From Experience in High-Hazard Organizations."

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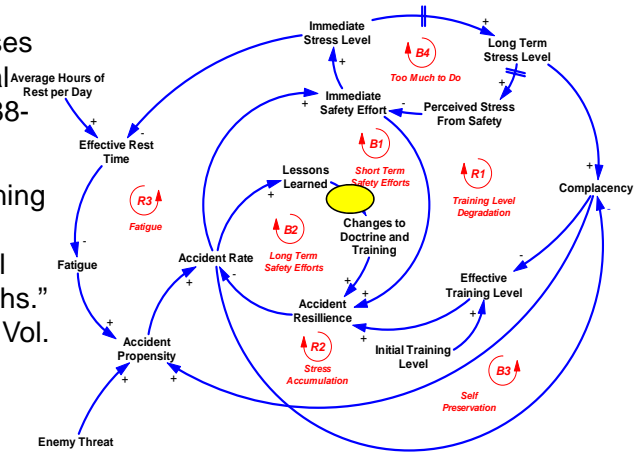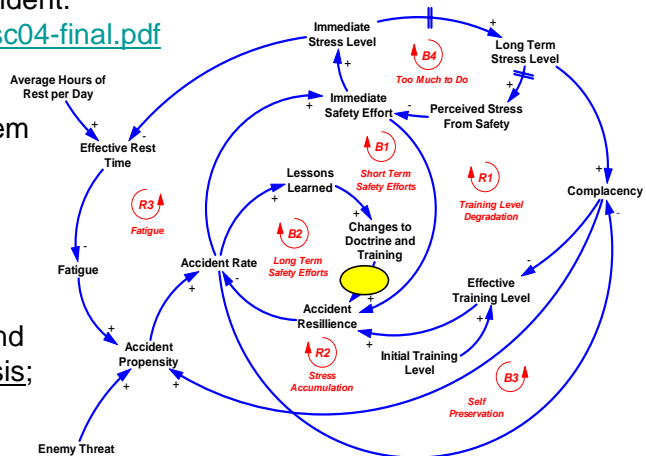
# Improved Changes to Training and Doctrine Increases Accident Resillience

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- Carroll, John S., J. Rudolph & S. Hatakenaka. "Learning From Experience in High-Hazard Organizations."

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- Cook, Richard I. "Two Years Before the Mast: Learning How to Learn About Patient Safety." Health Care. National Patient Safety Foundation, Chicago IL, 1999.
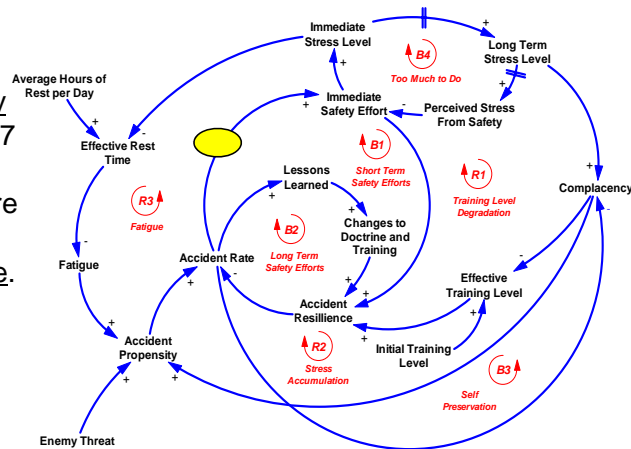
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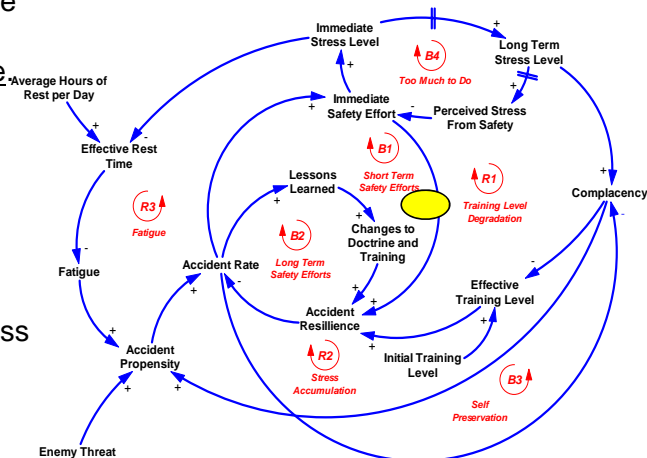
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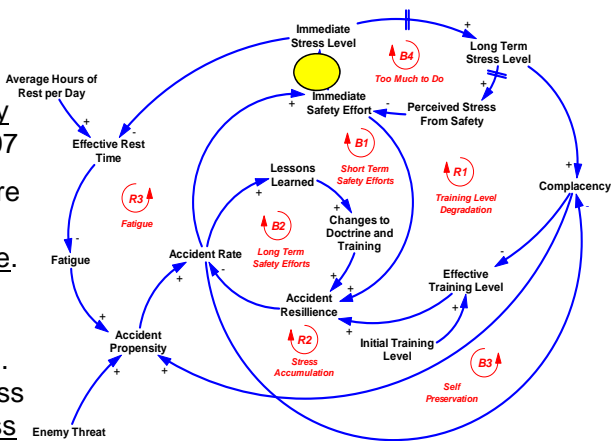
## Long Term Stress Effects the Level of Stress Perceived From Safety

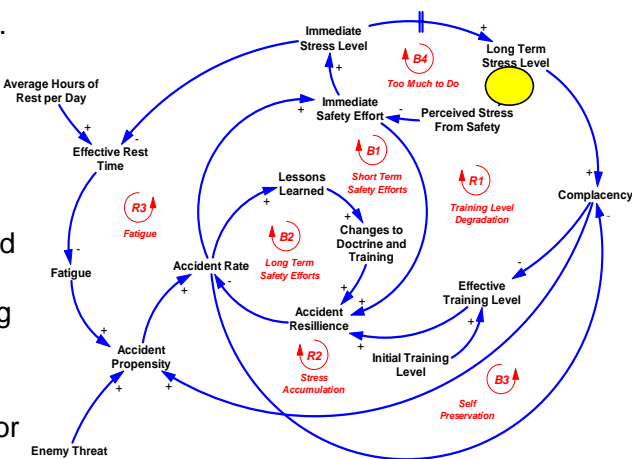- Carroll, John S., J. Rudolph & S. Hatakenaka. "Learning From Experience in High-Hazard Organizations."

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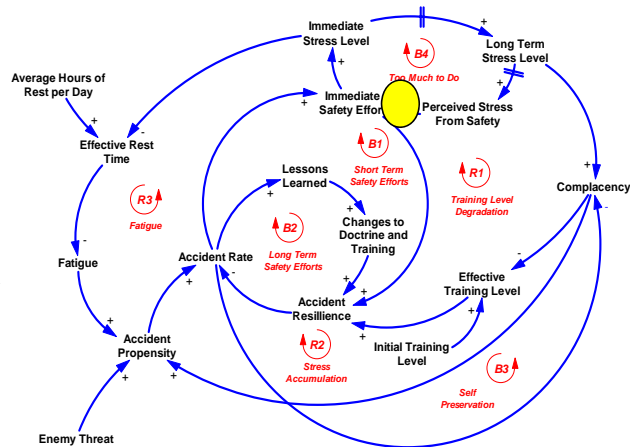
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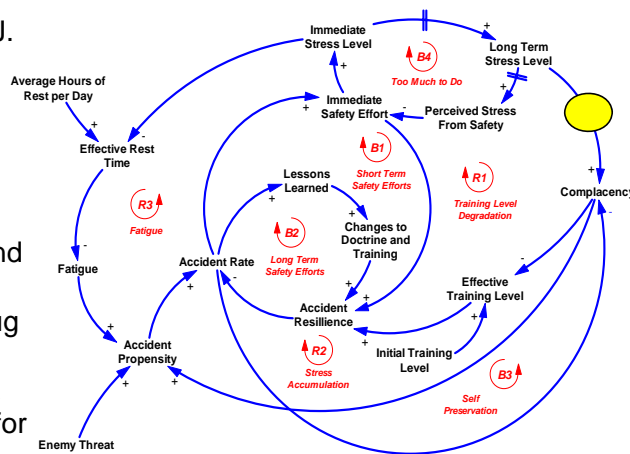
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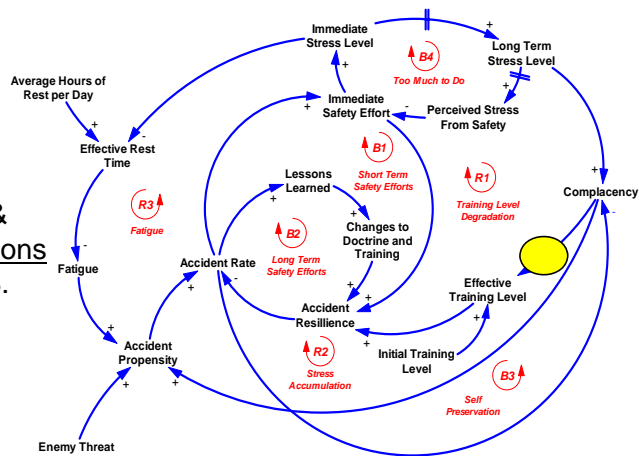
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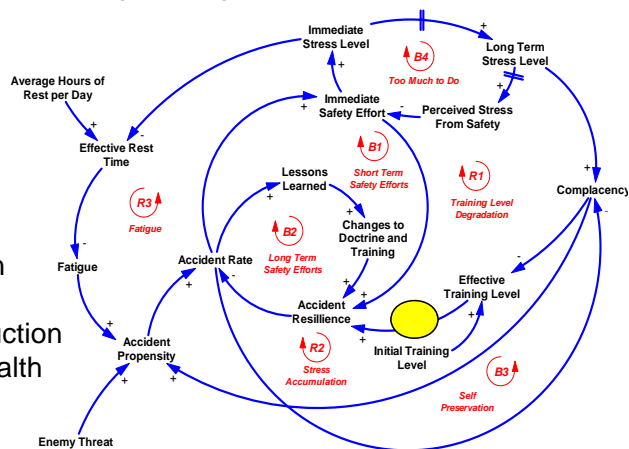
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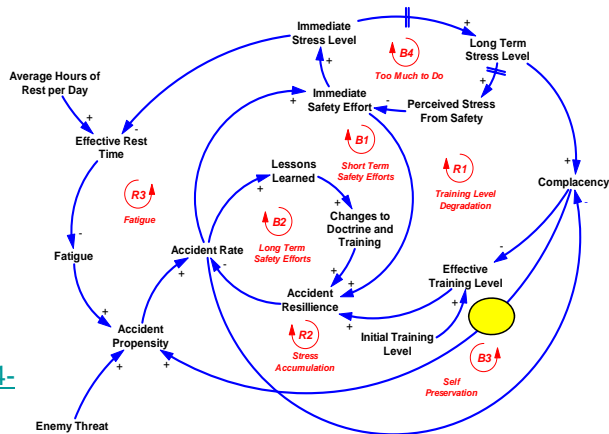


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