

**Enhancing Vehicle Safety Management in Training  
Deployments:  
An Application of System Dynamics**

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## **ABSTRACT**

Organization Sierra-Tango is employing a systematic and methodical safety framework to manage risks in all their operational and training activities. While this safety system has shown itself to be reasonably effective in curtailing the number of accidents within the organization, Organization Sierra-Tango is not resting on its laurels and is continuing efforts to refine and improve upon its safety management framework. One of the focus areas is that of enhancing vehicle safety management in training deployments.

This thesis fulfills Organizations Sierra-Tango's need for systematic understanding and continuous learning to enhance vehicle safety management in training deployments. This is achieved by extending the preponderant focus on the events and symptoms of accidents, which mostly ascribe human error as the primary cause of accidents, towards a more holistic perspective of accidents by also examining the often complex and dynamic contribution of organizational policies and practices towards accidents. An extensive research process was undertaken where discussions and interviews were conducted with the organization's vehicle safety Subject Matter Experts so as to develop a better understanding of the context of vehicle accidents during training deployments. Additionally, a thorough review of Organization Sierra-Tango's internal documents (accident reports, training policies, etc) and open literature on accidents and safety was performed. Two System Dynamics (SD) models were developed to synthesize the mental models from the research phase and to generate, through simulations and analysis, insights for enhancing the organization's vehicle safety framework and practices. The key insights drawn from the Work Management SD model are that, schedule pressure must be managed at all levels, driver workload should be relieved by increasing the number of drivers available rather than task reduction, and supervisor workload management has a larger bearing on a driver's accident resilience compared to driver workload management. The Near Miss Reporting SD model revealed that increasing the level of identity confidentiality of near miss reporters encourages reporting, reducing the severity of punitive measures is not recommended as a means to encourage near miss reporting, and the overall safety culture of the organization is a key driver of near miss reporting.

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# CHAPTER 1: INTRODUCTION

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## 1.1 Background and Motivation

The importance of safety in a conscript army cannot be overemphasized as it affects soldiers' morale, its reputation and image, as well as internal and public confidence. For Organization Sierra-Tango (pseudonym), these are critical factors that affect mission accomplishment and its effectiveness as a deterrent to would-be aggressors. Each accident occurring from their activities represents a "*cost*" to the organization in terms of property/ equipment repairs and downtime, loss of deployment time of affected personnel and monetary losses incurred for compensation and claims, not to mention the cost to the servicemen and their families. Organization Sierra-Tango can ill afford such "*costs*" when they can be put to better use in enhancing its operational readiness. Hence, contrary to perceptions that emphasizing safety in military activities hinders operational task/ mission accomplishment, Organization Sierra-Tango views safety as critical and relevant in supporting its inherently risky missions. The organization articulates, in no uncertain terms, its demand for safety to be integrated with all its operational, training and organized activities (Organization Sierra-Tango, 2007b).

Presently, Organization Sierra-Tango is employing a systematic and methodical safety framework to manage risks in all their operational and training activities. This safety system has shown itself to be reasonably effective in curtailing the number of accidents within the organization. However, Organization Sierra-Tango is not resting on its laurels and is continuing efforts to refine and improve upon its safety management framework. One of the focus areas is that of enhancing vehicle safety management in training deployments.

Vehicle safety exists within a complex environment involving interactions between people, equipment, policies and operating conditions. For Organization Sierra-Tango, the dynamic context surrounding vehicle safety comprises endogenous factors such as personnel competency, cautiousness and concentration, vehicle condition, operating doctrines and safety policies. Operating environments and prevailing weather conditions constitute some of the exogenous dimensions influencing vehicle safety.

As part of Organizations Sierra-Tango's endeavors to enhance vehicle safety management in training deployments, one of their goals is to identify and correct imprudent practices and inadequate policies that are raising the propensity of vehicle accidents during training deployments. One of the key strategies towards achieving this objective is to broaden the preponderant focus on the events and symptoms of accidents, which mostly ascribe human error as the primary cause of accidents, towards a more holistic perspective of accidents by also examining the often complex and dynamic contribution of organizational policies and practices towards accidents. Therefore, the motivation of this thesis is to fulfill the need for systematic understanding and continuous learning to improve Organization Sierra-Tango's vehicle safety management during training deployments. This is achieved by demonstrating the utility of System Dynamics (SD) in understanding, modeling and generating insights for enhancing the organization's vehicle safety framework and practices.

## 1.2 Thesis Objectives

The principle objective of this study is use System Dynamics (SD) to develop proof-of-concept models that will assist Organization Sierra-Tango's policy and decision makers to better appreciate and understand the role that various dynamic feedback processes and delays play in determining the consequences of vehicle accident prevention decisions in the context of training deployments. The study provides a perspective beyond the normative symptoms and conclusions of accident causality, which is typically centered on human error. By focusing on the complex and dynamic organizational factors that underpin safety, the models strives to uncover some of the high leverage areas within Organization Sierra-Tango that would enrich the knowledge database that policy and decision makers can draw upon in developing sounder decisions to reduce the rate of accident occurrences.

The secondary goal of this research is for me to gain firsthand practical experience in using the SD methodology to enhance the understanding of a complex problem and in the process appreciate its usefulness as a tool for effective decision making. This endeavor would enable me to develop a fair degree of competency to extend the application of the SD technique in understanding future complex problems in other contexts that I may encounter on both my personal and professional fronts.

## 1.3 Research Methodology

The overall research strategy for this thesis was as follows:

(1) Review of Historical Accident Statistics in both the US Military and Organization Sierra-Tango

My research began by reviewing historical accident statistics in both the US military and Organization Sierra-Tango so as to obtain a better appreciation of gravity of the challenge that accidents present to policy makers in ensuring personnel safety.

(2) Extensive Study of Organization Sierra-Tango's Accident Reports

Over 60 accident reports (during both administrative and training deployments) which are considered to be a representative sample of the vehicle accidents encountered by Organization Sierra-Tango were studied to gain a better appreciation of the context behind vehicle accidents and to distill out the typical vehicle accident causal factors encountered by Organization Sierra-Tango.

(3) Review of Organization Sierra-Tango's Training Policies and Practices Documents, and Discussions with Subject Matter Experts (SMEs)

The next step of the research was to review Organization Sierra-Tango's documents to gain a better understanding of the organization's training policies and practices and in the process develop mental models of the role that the policies and practices play in influencing vehicle safety. Face-to-face discussions and videoconferences were also conducted with SMEs from Organization Sierra-Tango so as to draw upon their personal knowledge and experiences on the probable factors behind vehicle accidents during training deployments.

(4) Literature Review of the Physiology of Individual Accident Proclivity and the Psychology of Individual Risk-taking Behavior

Human error was found to be often cited as the most common cause of vehicle accidents. A literature review on the physiology of individual accident proclivity was conducted to understand the underlying factors that affect human competency and concentration which in turn influence the likelihood of accidents. The psychology of individual risk taking behavior was also researched in order to understand how cognitive, emotive and social forces affect an individual's propensity to engage in risky behaviors (cautiousness) which often lead to accidents. This knowledge enabled the development, understanding and analysis of the SD models.

(5) Literature Review of the Influence of Organizational Policies and Practices on Safety

Organizational factors were found to be often overlooked in accident investigations. The research endeavors to adopt a more holistic perspective in understanding accidents by reviewing contemporary literature on organizational factors and safety practices affecting accidents. The review was performed to leverage upon the collective knowledge on the subject so as to deepen the understanding of the often complex and dynamic contribution of organizational policies and practices towards safety. This knowledge further enriched the development, understanding and analysis of the SD models.

(6) Development of System Dynamics (SD) models

The key causalities elicited from Organization Sierra-Tango's accident reports and discussions with SMEs, understanding of the organization's training policies and practices, and the knowledge developed from the literature review served as the premise to create high-level Causal Loop Diagrams (CLD) for vehicle safety. The high-level CLDs served as platforms to synthesize the mental models formed from the accident investigations performed and also helped to determine areas that required further research. After the high-level CLDs were sufficiently rationalized, CLDs that were considered to be most relevant to Organization Sierra-Tango's context were short-listed for further development and low-level SD models were constructed.

(7) Simulation, Refinement and Analysis of System Dynamics model

A few simulation and refinement iterations were performed in order to ensure that the low-level SD models captured the dynamics behind vehicle accidents in Organization Sierra Tango's context. Thereafter, multiple simulations and analyses were performed to demonstrate the utility of SD in generating insights of the dynamics behind vehicle safety during training deployments so that policy recommendations could be proposed to reduce the rate of accident occurrence.

## **1.4 Organization of Thesis**

The thesis is divided into 10 chapters, each having a different focus, as described in the following paragraphs.

Chapter 2 presents a general introduction of Organization Sierra-Tango covering aspects such as its mission, personnel, driver training and categorization, and vehicle type and maintenance. The emphasis of this chapter is on a description of the organization's existing safety management system.

The historical accident statistics of both the US military and Organization Sierra-Tango are provided in Chapter 3. This is followed by the findings of the typical vehicle accident causal factors in Organization Sierra-Tango's context as derived from the review of over 60 accident reports (during both administrative and training deployments). The chapter ends by providing findings from open literature on accident investigations.

Chapter 4 begins with a general description of Organization Sierra-Tango's training activities. The chapter continues by setting the context behind the occurrence of vehicle accidents during training deployments as elicited from the review of accident reports and discussions with the Subject Matter Experts.

Chapters 5 and 6 respectively outline the literature review results of the physiology of individual accident proclivity and the psychology of individual risk-taking behavior, and the influence of organizational policies and practices on safety. These chapters provide the basis to develop and interpret the System Dynamics (SD) models.

A general description of the conceptual tools of SD such as systems thinking, causal loops, stocks and flows and system behavior is given in Chapter 7. Several examples of real world applications of SD are also provided.

Chapter 8 presents the development of first the high-level Causal Loop Diagrams (CLDs) followed by the low-level SD models. The key causal loops of the SD models are also described. The simulation and analysis results of the SD models are presented in Chapter 9.

Chapter 10 proposes policy recommendations to Organization Sierra-Tango from the insights garnered from the simulation and analyses of the SD models. The chapter also discusses further research opportunities to enrich the SD models and concludes by discussing the utility of extending the SD methodology to understand and improve similar real-world complex challenges that are faced by Organization Sierra-Tango.

## **1.5 Key Definitions**

This section serves to establish a common baseline for interpreting and understanding the key terms that are frequently used in both accident research and this thesis. The definitions are adapted from those used by Organization Sierra-Tango (Organization Sierra-Tango, 2007b) and those proposed by Nancy Leveson in her book titled "*Safeware: System Safety and Computers*" (Leveson, 1995) for the context of this research. To enhance clarity, some examples are provided in the context of Organization Sierra-Tango's training deployments.

(1) Accident:

An accident is an undesired and unplanned (but not necessary unanticipated) event that results in a specified level of loss (injury, loss of life, damage to property or the environment). An example of an accident in the context of Organization Sierra-Tango's training deployments would be a vehicle veering off the road and crashing down a hill as the driver fell asleep on the wheel, leading to injuries to the driver and his or her passengers, and damage to the vehicle.

(2) Hazard:

A hazard is a state or set of conditions of a system (or an object) that, together with other conditions in the environment of the system (or object), has the potential to cause an incident to occur. An example of a driving hazard in the context of Organization Sierra-Tango's training deployments is that of a treacherous cliff following a sharp bend in a training area.

(3) Incident:

An incident is an event that has caused or has the potential to cause an injury, illness, or damage to the property or the environment. Incidents comprise both accidents and near-misses.

(4) Near Miss:

A near miss is an occurrence with no injury to personnel or damage to equipment, but had the potential to cause damage to equipment or injury/ death to personnel. An example in the context of Organization Sierra-Tango's training deployments would be that of a reversing vehicle that was headed for a collision with another vehicle as the driver did not check for rear-side obstructions. Fortunately, an accident was averted as the driver of the other vehicle sounded its horn to warn the driver of the reversing vehicle. This incident which resulted in no injury to the drivers and their passengers or damages to equipment would be classified as a near miss.

(5) Risk:

Risk is the severity of the hazard combined with the likelihood of the hazard leading to an accident, and the duration of exposure to the hazard. An example of a risk in the context of Organization Sierra-Tango's training deployments is a situation where an inexperienced (unfamiliar with the training areas) driver is tasked to perform driving missions in the night. The severity of the hazard in this case can be measured by the extent of vehicle damage and/or personnel injury/ loss in the event of an accident. The likelihood of the hazard is raised due to the driver's inexperience and the low visibility operating conditions.

(6) Risk Assessment:

Risk assessment is the process of detecting hazards and systemically assessing their overall risk. Risk assessment encompasses the first two steps of the risk management process, i.e., hazard identification and risk assessment. A risk assessment performed on the preceding example of the inexperienced driver performing missions at night would have identified the risk level of the situation as high. Conversely, a risk assessment performed on a situation of an experienced driver executing his or her mission in broad daylight would have been appraised with a low risk level.

(7) Risk Decision:

Risk decision is the choice to accept or not accept the risks associated with a task/ activity, made by the commander, leader or individual responsible for performing that task/ activity. In the context of Organization Sierra Tango's training deployments, an example of a risk decision that a supervisor would have to make is whether to cut back on safety briefings to drivers so that he has more time for other tasks such as checking on equipment availability.

(8) Residual Risk:

Residual risk is the level of risk remaining after control measures have been identified and planned. Control measures can never fully eliminate all risks. Despite all the risk mitigation efforts of Organization Sierra-Tango, an example of a residual risk during overseas training deployments is that of landslides occurring during heavy thunderstorms in the training area thereby affecting vehicles.

(9) Risk Management:

Risk Management is the process of identifying and assessing hazards and implementing control measures to eliminate or mitigate the level of risk involved in any given tasks.

(10) Risk Management Plan:

A risk management plan is a comprehensive plan that includes all safety and control measures that are developed for the management of an activity. An example of an item in a risk management plan in the context of Organization Sierra-Tango's training deployments would be that of the affect of fatigue on a driver's concentration and hence his or her accident propensity. The control measure to mitigate this risk would be for commanders to enforce rest periods for drivers of 15 minutes for every hour on continuous driving.

(11) Safety:

Safety is the property of being free from accidents or unacceptable losses. An example of how safety is measured in the context of Organization Sierra-Tango's training deployments is the number of human losses (injury or loss of life) and extent of property damages (equipment or training facilities) at the end of each training deployment. Organization Sierra-Tango's target for each training deployment is to achieve training completion without loss of life and/ or damage to property that is beyond economic repair.

## CHAPTER 2: ORGANIZATION SIERRA-TANGO

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### 2.1 Introduction

This chapter begins by presenting a general description of Organization Sierra-Tango with a focus on the vehicle operations side of the organization. The aspects covered include the organization's mission, personnel, driver training and categorization, and vehicle type and maintenance. The emphasis of this chapter is the description of Organization Sierra-Tango's existing safety management system. The information in this chapter is derived from three sources: (1) Organization Sierra-Tango's documents (Organization Sierra Tango, 2007b), (2) discussions with the organization's Subject Matter Experts (SMEs) in May and July 2007, and from (3) my experiences of serving in Organization Sierra-Tango.

### 2.2 Overview of Organization Sierra-Tango

#### 2.2.1 Defense Policy and Mission

Organization Sierra-Tango is the pseudonym for an army of a small developed country. The country can be considered to be relatively young, having attained her independence approximately four decades ago. The twin pillars of the country's defense policy are diplomacy and deterrence. These elements serve to preserve the country's sovereignty which promotes a climate of economic, political and social stability. This favorable climate is a key enabler towards the sustained growth and development of the country.

From the outset of its independence, the country has adopted a non-aggressive posture towards other countries. The longstanding policy of the nation is the use of diplomacy to manage any disagreements that may arise from time to time with its international neighbors. The Armed Forces, of which Organization Sierra-Tango is a part of, is charged with the mission to serve as a deterrence to would-be aggressors.

The Armed Forces maintains a constant high state of operational readiness so that they can be depended upon to defeat their adversaries swiftly and decisively when provoked. The deterrence factor is bolstered through prudent investments in military technology that serve as a force multiplier. The operational edge of the Armed Forces is kept honed through regular training exercises and by participating in international humanitarian operations. Training exercises are conducted either unilaterally or bilaterally with friendly nations.

#### 2.2.2 Personnel

Organization Sierra-Tango is fundamentally a conscript army of able bodied men. As stipulated in the country's laws, it is mandatory for all male citizens to perform at least two years of military service. The manpower structure of the organization is composed of three categories:



- (1) Professional Servicemen (Regulars)
- (2) National Servicemen (Reservists)
- (3) National Service (Fulltime conscripts)

All male citizens are liable to be called up for national service upon turning the age of 16 years. The enlistment date can be deferred for a few years almost exclusively on academic grounds. The enlistment age of fulltime conscripts is between 16 and 18 years depending on their education paths.

All conscripts are put through a common Basic Military Training (BMT) phase of three months which would equip them with rudimentary military skills such as weapons handling, field craft and unarmed combat. The BMT is mainly focused on army operations training. During the BMT phase, the recruits are continuously assessed on their fitness level and leadership potential. Upon passing out from BMT, the top performers will be sent to Officer Cadet School for training to become commissioned officers. The rest of the cohort will be assigned based on their fitness level and academic qualifications. Generally, the fittest will go on to join combat units for specialist and petty officer training. Those who are less fit but possess good academic qualifications would be appointed to staff work, while the remainder would be assigned to supporting roles such as quartermasters and drivers.

The “*Operational Ready Date*” is a milestone that signifies the culmination of the two years of military service. Thereafter, the fulltime conscripts transition to become reservists. Reservists are called back to their units annually for refresher training as an effort to sustain military operations currency and fitness. The call-up period can be up to 40 days out of every calendar year for a continuous period of 10 years. The law requires that employers release their employees for reservist training. During the reservist training period, employers are compensated by the government for their staff’s wages.

The regulars or professional servicemen round up the last category of Organization Sierra-Tango’s personnel. Both male and female citizens can make their careers out of Organization Sierra-Tango. The regulars provide the organization with consistency amidst the flux of fulltime conscripts and reservists.

### 2.2.3 Vehicles

Organization Sierra-Tango operates a wide range of vehicles that serve both tactical and administrative functions. Vehicles are typically categorized according to their weight (light, medium or heavy) and application (tactical or administrative). Examples of vehicles in service include land rovers, minivans, tanks and trucks. In recent years, there has been a practice to outsource non-critical administrative tasks such as troop ferrying and transportation of stores to commercial companies so as to save on vehicle operating and maintenance costs.

The general administration of vehicle related issues is consolidated at the Headquarters for Supply and Transport with responsibilities delegated to the fleet managers and transport supervisors of the military transport lines at the various operational units.

The maintenance and annual serviceability inspection of vehicles is generally centralized at the Headquarters for Supply and Transport. However, there is a small mechanical bay within each operational unit for minor repair jobs. Organization Sierra-Tango believes in preventive maintenance over corrective maintenance. As such, the mileage and maintenance schedule for each vehicle is carefully tracked and strictly adhered to. Information Technology (IT) systems have been put in place to facilitate the tracking of vehicles utilization and maintenance schedules.

## **2.3 Driver Training and Categorization**

In Organization Sierra-Tango, the bulk of the drivers are either fulltime conscripts or reservists. The more senior or supervisory level positions are filled by regulars.

### **2.3.1 Driver Training**

Fulltime conscripts are posted to the Headquarters for Supply and Transport for six to eight weeks of basic driving training after passing out from the BMT phase. The basic driving training course includes both theoretical and practical training. In the practical segment of the training, drivers are required to clock at least 500km of accident-free confidence driving before they are certified to be ready for operational tasks. The 500km confidence driving requirement is a recent increase from the previous mark of 250km. The Headquarters for Supply and Transport has plans to increase the confidence driving requirement to 750km as they believe that the increased training imbues novice drivers with greater driving competency before actual field deployments thereby decreasing the risk of accidents due to lack of experience. Another recent policy change is that basic driving training, while conducted and supervised within the confines of the Headquarters for Supply and Transport, has been outsourced to a commercial entity. The outsourcing decision was made to control the costs of maintaining an internal group of driving instructors while increasing the quality (through commercial benchmarking and certification) of driving training available to rookie drivers.

The basic driving course is meant to equip drivers with the foundational skills in operating vehicles such as land rovers and trucks so that they can execute basic driving tasks when they are deployed to the operational units. Follow on or more specialized training on advanced classes of vehicles is typically provided to drivers by the transport supervisors at the operational units, whom are responsible for the drivers' continuous training. Based on the assessment of the unit transport supervisor, both fulltime servicemen and reservists may be required to undergo refresher training. Refresher training is especially important for reservist drivers as they are less current in operating military vehicles as compared to their fulltime servicemen counterparts.

#### **2.3.1.1 Defensive Driving**

One of the core training programs that Organization Sierra-Tango caters for their drivers is defensive driving. Defensive driving preaches the practice of safe and proactive driving to prevent accidents despite the incorrect actions of other road-users or adverse road conditions. This driving technique has been hailed by Organization Sierra-Tango as being one of the

cornerstones in reducing the number of vehicle accidents. Defensive driving comprises elements such as:

- Maintaining safety distance from the vehicle ahead
- Overtaking properly
- Planning driving routes
- Recognizing hazards (paying attention to weather conditions and the driving of other road-users so as to recognize any changes in their intentions)
- Regulating speed according to the prevailing situation (traffic density or weather)

### 2.3.1.2 Policy of Least Risk Route

In the past, mission efficiency was emphasized during training and by transport supervisors which required drivers to choose the shortest route to a destination. With the added attention on safety in recent years, the concept of route planning has changed from shortest route planning to least risk route planning. Organization Sierra-Tango's risk management process is elaborated later on in this chapter.

## 2.3.2 Driver Categorization

In Organization Sierra-Tango, drivers are categorized according to their proficiency which is assessed based on the number of accident-free kilometers driven and by passing vehicle handling proficiency tests. Drivers are categorized into Cat A, Cat B, Cat C1, Cat C2 and Cat D, with Cat A drivers being the most experienced and Cat D the least. The purpose of the categorization is to provide a check on the competency level of the driver. With this system, transport supervisors can also better match their drivers with various stages of driving experience to transport details that carry different degrees of risks. For each driver, the accident-free mileage will be reset to the former category if the driver meets with an accident for which the driver is blame-worthy. A summary of the classification system is as follows:

### (1) Cat D Driver:

This is a driver that has less than 1,000 km of driving experience and can drive only when accompanied by a vehicle commander of a higher rank. The driver must wear the "*New Driver*" badge and have a personal Driver Guide (DG) assigned to him. The DG will coach him on all driving related matters on a personal basis and assist him to be acquainted with the unit's routine functions. The Cat D driver, upon completion of his orientation driving assessment test by the transport supervisor, will be able to go on driving details. Cat D drivers are to be assigned with "*easier*" details (e.g. store run) and should not be tasked for any troop lifting details.

### (2) Cat C2 Driver:

This is a driver that has completed 1,000 km of accident-free driving as a Cat D driver and has passed the Cat C2 certification test conducted by the unit. The driver can be assigned for overseas duties. The driver is eligible for a "*Safe Driving*" bonus and the "*Safe Driving*"

badge. The driver will be required to complete at least 4,000 km of accident-free driving before he is allowed to proceed to Cat C1.

(3) Cat C1 Driver:

This is a driver that has completed 4,000 km of accident-free driving as a Cat C2 driver and has passed the Cat C1 certification test conducted by the unit. The driver is authorized to drive unaccompanied. The driver is eligible for a higher “*Safe Driving*” bonus and another “*Safe Driving*” badge. The driver can be employed as a DG to conduct orientation and familiarization driving to new drivers or be employed as an ambulance driver.

(4) Cat B Driver:

This is a driver that has completed 7,000 km of accident-free driving as a Cat C1 driver and has passed the Cat B certification test conducted by the unit. The driver is eligible to apply for a civilian driving license.

(5) Cat A Driver:

This is a driver that has completed 7,000 km of accident-free driving as a Cat C1 driver and has passed Cat A certification test conducted by the unit.

## 2.4 Safety Management System

In brief, Organization Sierra-Tango’s safety management system is predicated on a set of standard procedures that is designed to systematically and methodically manage risks in all work processes; swiftly investigate causal factors should an accident/ incident occur; and to build a safety culture through open reporting of incidents and sharing of lessons learnt. This safety system is benchmarked against safety standards and practices of other professional armies in the world, and has been certified with the internationally recognized Occupational Health and Safety Assessment Series (OHSAS) 18001 specification.

### 2.4.1 Safety Philosophy

Organization Sierra-Tango’s philosophy for safety is as follows:

- (1) Commanders are responsible to professionally conduct tough, realistic, and safe training in order to fulfill the organization's mission.
- (2) Safety is an integral requirement in operations and training.
- (3) Everyone in the organization has a part to play in safety.

### 2.4.2 Safety Objectives

The objectives of Organization Sierra-Tango’s safety system are as follows:

- (1) Mission accomplishment with no injuries or loss of lives through negligence.
- (2) Reduction in all training incidents.

### 2.4.3 The Five Elements of the Safety Management System

Organization Sierra-Tango's safety management system is anchored on five elements as briefly described below and summarized in Figure 2-1. These elements are elaborated in following sections.

(1) Authorized Operating Materials:

These are formal documentation of Organization Sierra-Tango's procedures and regulations for operation and training.

(2) Risk Management:

Risk management is a process of hazard identification and risk assessment using the 5M Factors (Man, Machine, Medium, Mission and Management).

(3) Audit and Inspection:

These provide a measure of the safety health status in Organization Sierra-Tango, through verification of compliance to authorized practices and detection of potential flaws in the system.

(4) Safety Investigation:

A comprehensive and structured framework and methodology for safety investigation that identifies the causal factors of an incident and harnesses the lessons learned, thereby preventing recurrences.

(5) Open Reporting and Safety Education:

Open reporting is a culture of openness, with sharing of lessons learnt from accidents, near misses, breaches and at-risk behaviors. Safety education is the progressive and continuous safety education of members in Organization Sierra-Tango.



Figure 2-1: The Five Elements of Organization Sierra-Tango’s Safety Management System

#### 2.4.3.1 Authorized Operating Materials

Organization Sierra-Tango has a system of documented policies, standards and procedures that governs the conduct of their operations, training, administration and organized activities. These documented policies, standards and procedures presuppose that all hazards have been adequately identified with associated risks assessed and consequent controls integrated at the highest level. These documented policies, standards and procedures, which are collectively termed as “*Authorized Operating Materials*”, set the minimum safety parameters for activities in the organization.

While Organization Sierra-Tango systematically ensures that minimum safety parameters are integrated in their activities through formal safety procedures and processes, effective risk management allows commanders to methodically explore the reduction of risks to as low as practicable without compromising mission or task. This is especially necessary for activities not covered within established procedures. The next section provides more details on risk management.

### 2.4.3.2 Risk Management

Risk Management (RM) is the application of systematic thinking to make military operations safer and more effective. RM allows Organization Sierra-Tango to weigh risks against operations and training benefits, and eliminate/ reduce unnecessary risks that can lead to accidents. The need for protection of human lives and material resources through proactive accident prevention necessitates RM to be the focus of Organization Sierra-Tango's safety efforts. The application of RM also allows commanders who have to conduct activities not covered within established procedures to mitigate risks to an acceptable level without compromising the set objective(s) of each mission or task.

#### 2.4.3.2.1 The Five-Step Risk Management Process

Organization Sierra-Tango's RM process involves the identification and assessment of hazards as well as the development, implementation, supervision and evaluation of control measures for the hazards. The RM process is not static. Rather, it is a continuous process that follows the evolving operational or training context. A "Top-Down, Bottom-Up" approach for hazard identification and risk assessment is taken to ensure comprehensiveness of the risk management process, and commitment and accountability at all levels (from commanders to soldiers) so that any safety gaps can be addressed prior to commencement of operations, training and organized activities. A diagrammatic representation of Organization Sierra-Tango's continuous five-step RM process is shown in Figure 2-2. This five-step RM process is very similar to the RM framework employed by the United States Army (United States Army, 1998) and a process for project risk management developed by de Weck and his co-authors (de Weck et al, 2006).

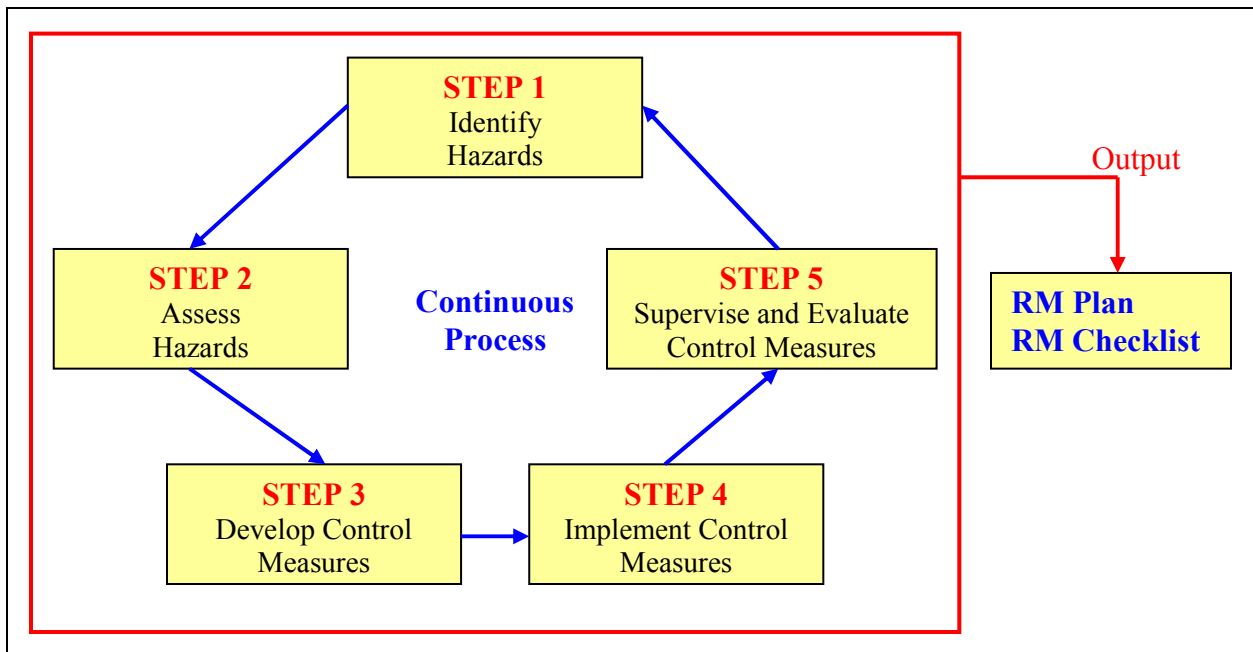


Figure 2-2: Organization Sierra-Tango's Continuous Five-Step Risk Management Process

#### 2.4.3.2.2 *The Five-M Framework*

The organization's RM process of hazard identification, risk assessment and control measure development centers on the Five-M framework of *Mission, Man, Machine, Medium* and *Management*. This Five-M framework is comprehensively structured to guide commanders through the RM process based on the various elements common across Organization Sierra-Tango's operations, training, administration and organized activities that may influence the safe conduct of these activities. The Five-M factors are elaborated below.

##### (1) Mission

The mission is essential in the analysis of risk management as it affects the success of task/mission accomplishment. The hazard identification for this factor is based on the complexity of the mission/ task and compatibility of the men/ unit deployed for the particular mission/ task. The two sub-factors are explained below:

(a) Complexity – Complexity of the mission/ task can be caused by the presence of many interdependent-tasks involving multiple services, parties and agencies each with varying degrees of performance standards and proficiency levels. As an example, battalion training is more complex as opposed to platoon training as more forces and multiple agencies within the battalion are involved in the training activity.

(b) Compatibility – Compatibility considers the "*Man*" factor matched against the assigned mission/ task. It takes into account if the unit/ men assigned for the activity or task are sufficiently trained/ prepared for the task. For example, an Armor Infantry platoon can be assigned to undertake infantry roles. However, an infantry platoon should not be assigned to undertake Armor-related missions without prior training.

##### (2) Man

Organization Sierra-Tango has found human error to be a common cause of accidents. Hence, special attention must be given by ground commanders to this factor which assesses the proficiency, physical (physiological) and mental (psychological) conditions of their subordinate commanders, instructors, men and trainees. All leaders and men participating in the activity must receive appropriate information, instruction, training and supervision to carry out their assigned tasks. In addition to the three sub-factors elaborated below, commanders should also address specific safety concerns such as progressive training and currency in training.

(a) Proficiency – Commanders are to ensure that the personnel assigned to the tasks are adequately trained, proficient and qualified. Organization Sierra-Tango believes that the risk level decreases proportionately with better-qualified and experienced staff assigned to tasks. Consideration should also be given to whether the trainees are current in handling the task that they are assigned. For instance, reservist drivers coming back for their annual training must be given revision and familiarization on military vehicles before actual field deployments.



(b) Physiology – Commanders are to judge whether servicemen/ trainees are medically and physically fit for the task, e.g., workload, fatigue and sleep deprivation. Their past medical history and/ or injuries should also be taken into consideration.

(c) Psychology – This refers to the mental condition of the servicemen/ trainees performing the task. Consideration should be given to the possibility of complacency, lack of confidence, poor work attitude or discipline, personal (family, financial, relationship) problems, workload, stress, peer pressure, etc. Servicemen with an overzealous attitude who tend to overexert themselves beyond their thresholds should be identified and managed.

### (3) Machine

This factor refers to all equipment, vehicles, weapons, ammunition and stores that are used for the organization's activities. These items pose potential hazards to users if not designed or maintained properly. Correct tools must also be used for appropriate tasks. The three sub-factors to be considered are as follows:

(a) Serviceability – There is a need to know the serviceability state, configuration and other requirements that can affect the safe operation of equipment. Serviceable equipment is usually accorded a lower risk value as compared to a damaged or defective item. Unserviceable equipment must not be used and should be marked and directed to the appropriate servicing agencies for repair before use.

(b) Maintenance – All equipment must be properly maintained. Failure to do so will result in sub-optimal performance of the equipment that may endanger the lives of soldiers operating them. In this light, weapons must be properly cleaned and oiled before and after training, vehicle servicing must be done religiously and all stores used for training must be cleaned and maintained.

(c) Ergonomics – The equipment and other items used in the activity should be properly designed to carry out the tasks. Poorly designed equipment will affect the efficiency and the safety of the user. Commanders should consider ergonomics in the assignment of personnel to handle certain equipment. For example, a small built person should not be assigned to carry heavy weapon systems during his tenure as a soldier. A soldier who is of big build can be employed to undertake such tasks instead. Moreover, soldiers should be constantly advised on proper lifting and seating postures, and the safe handling of equipment.

### (4) Medium

Medium refers to environmental factors such as climate and terrain and also the condition of facilities that necessitates control to allow training/ organized activities to be safely conducted. These can be assessed in advance, identified on-site and be directed through appropriate standing orders governing facilities like ranges, training areas, simulation centers, etc.

(5) Management

Management is responsible for the safe conduct of activities in accordance to drills and instructions laid down by Organization Sierra-Tango's authorities. It is not within any commanders' delegated authority to deviate from the organization's instructions and regulations without seeking endorsement from the Chief of Organization Sierra-Tango. Under this factor, activities are examined for its "*Planning and Preparation*", "*Control System*" and "*Support Adequacy*" for any gaps in leadership, standards/ procedures, training and support as described below:

(a) Planning/ Preparation – A planned training activity entails lesser risk as it allows sufficient time for those conducting the training/ activity to carry out the RM process and mitigate the risks. This allows for the integration of safety measures into the training/ activity during the planning stage, e.g., conduct of safety briefings/ rehearsals and verification that progressive training has been carried out. Management must allocate sufficient time to subordinate commanders to carry out their tasks.

(b) Control System – This sub-factor takes into consideration the availability of established procedures/ control structures, policies, standing operating procedures, checklists, manuals, lesson plans and administrative instructions to ensure authorized and safe conduct of the training/ activity.

(c) Support Adequacy – By adopting the "*Mission, Demand, Support*" philosophy, management has a responsibility to ensure that adequate support is provided for the training/ activity in terms of time and resources (e.g. medical, equipment, ration, transport, instructor ratio, etc) to fulfill the set objectives and achieve the standards demanded without compromising safety requirements.

2.4.3.2.3 *Subject Matter Expert (SME) Experience with the RM Process*

One of Organization Sierra-Tango's SMEs shared that when the organization's RM process was first introduced, the ground sentiment of drivers and supervisors was that the RM checklist was tedious, reduced their mission efficiency and added to their workload. Drivers appeared to comply with the new regulations as RM checklists had to be submitted to supervisors before each driving deployment was allowed to proceed. However, accident investigations revealed many cases where checklists were filled up by the drivers but the required safety tasks were actually not conducted. There were also cases where supervisors did not adequately inspect the checklists that were submitted. Fortunately, such cases of non-compliance have been decreasing. The SME believes that this is because the RM process in general has resulted in a demonstrable reduction in the overall number of accidents in the organization which feeds servicemen perceptions of the effectiveness of the RM process thereby encouraging their buy-in and adherence to the required safety processes.

#### 2.4.3.3 Audit and Inspection

Audits and inspections are enforcement strategies undertaken to complement and strengthen Organization Sierra-Tango's safety system. These processes help to verify compliance to authorized practices, regulations and instructions, as well as to detect potential flaws in the system.

Training safety inspections are aimed specifically at ensuring compliance of safety procedures and established safe practices while at the same time, providing warning to unsafe conditions and at-risk behaviors. Building on the premise that higher command have a vested responsibility for their sub-units' safe conduct of operations, training and administration, multi-tiered inspections are carried out from the units up to the formation headquarters. Units conduct weekly inspections while the battalion/ formation headquarters conduct fortnightly inspections. Such inspections serve not only to ensure compliance of safety procedures, but also to emphasize command presence on the ground to witness correct and relevant conduct of training and its implications towards safety.

#### 2.4.3.4 Safety Investigations

Safety investigations are conducted to establish causes of an incident and to determine the lessons learnt. Although safety investigations are reactive in response to incidents, it is preventive in its purpose to prevent a recurrence of a similar incident. This helps the organization learn from incidents, determine lessons learnt and review existing or implement new/ additional control measures to correct errors, failures and system inadequacies. Safety investigation differs from unit formal investigation in that it does not focus on establishing culpability nor does it recommend disciplinary actions.

Organization Sierra-Tango believes that in order to ensure that incident findings are not skewed one way or another, it is necessary to holistically examine all the underlying factors in the chain of events that result in an incident occurrence. Therefore, safety investigations in the organization are premised on a multi-causation concept that believes incidents occur through a confluence and interaction of various causal factors that can also be analyzed using the Five-M approach as described previously.

In order for safety investigations to serve their primary purpose of avoiding or preventing recurrences of a similar incident, the lessons learnt from safety investigators must be collated and disseminated to the men on the ground. Lessons learnt are typically disseminated between the different vehicle operating units of Organization Sierra-Tango through various information sharing vehicles such as emails broadcasts, unit routine orders pasted on notice boards, quarterly "*Communities of Practice*" seminars and safety newsletters. Formal documents such as training directives and training safety requirements are updated should any safety gaps be uncovered from safety investigations.

#### 2.4.3.5 Open Reporting and Safety Education:

Organization Sierra-Tango firmly believes that the strength of the organization's safety culture hinges on them internalizing an "*Open Reporting*" culture and propagating a vibrant learning and information sharing environment. It is therefore crucial for elements of open reporting and safety education to be incorporated into their safety management system.

##### 2.4.3.5.1 *Open Reporting*

Organization Sierra-Tango places a strong emphasis on nurturing a culture of openness and receptivity towards safety so as to strengthen their safety system. It is believed that only through building a culture of sharing lessons learnt from accidents, near-misses, safety breaches and at-risk behaviors that commanders at all levels can take timely and necessary preventive actions to avert recurrences of similar incidents. This also helps commanders to isolate unauthorized practices, at-risk behaviors, and take the necessary actions to arrest them before they escalate to accidents. Furthermore, an "*Open Reporting*" culture in the organization allows for transparency hence enhancing the confidence and assurance to the troops and public about the safety management of all Organization Sierra-Tango activities.

The "*Open Reporting*" initiative is fairly new, having started approximately three years ago. Servicemen are encouraged to provide feedback on safety breaches and training safety issues. Near miss reporting is also encouraged, and these are investigated seriously for useful lessons and to prevent escalation into accidents.

##### 2.4.3.5.2 *Additional Information about the Open Reporting Initiative from a SME*

One of Organization Sierra-Tango's SMEs shared that near misses are generally reported through the same channel as actual accidents, i.e., up the soldier's chain of command starting from their supervisors. The organization has also made conscientious efforts to promote convenient safety and open reporting by making available alternative channels such as a 24/7 formation safety hotline and emails to the unit's safety committee members for servicemen desiring to make reports. In order to instill accountability and deter nuisance reports, the identities of information providers are made openly available to other members of the organization. On a separate token, in order to encourage the reporting of near misses, the organization overtly and repeatedly assures that no disciplinary action will be taken against parties implicated in a near miss event.

##### 2.4.3.5.3 *Safety Education*

In safety education, Organization Sierra-Tango implements a progressive, continuous and comprehensive safety education approach to keep servicemen updated on the latest safety knowledge and skills relevant to their respective professional areas. Hence, safety education can

be considered to start on the first day of a recruit's life and spans across his tenure as a soldier, until he "*stands-down*" from military service.

To support the cultivation and promotion of a strong safety culture, both the enhancement of safety knowledge and enforcement of safety application tools are essential to create a positive reinforcing loop that will achieve lasting effect. Safety education is further supported by archiving and proliferating safety information through the organization's Information Technology (IT) system. This IT system provides servicemen with easy access to references on safety related subjects.

Training schools, units, etc, maintain an information flow to their division/ formation headquarters through the submission of monthly reports covering safety inspection findings, case studies/ lessons learnt from accidents/ near misses and their safety efforts. The division/ formation, after collating and deliberating on these reports, will in turn submit quarterly reports to Organization Sierra-Tango Headquarters. Case studies of incidents and hazards with organization-wide implications are proliferated through the organization's email system to commanders and leadership at all levels in order to ensure timely dissemination of safety information.

#### 2.4.4 Command Responsibility and System Discipline

While Organization Sierra-Tango adopts a systems approach in ensuring that safety is taken into consideration in all aspects of its activities, command responsibility and system discipline are other cornerstones to ensure the effectiveness of the system.

##### 2.4.4.1 Command Responsibility

The military is a unique profession primarily because of its command structure. Commanders are responsible for all soldiers under their command, and this includes equipping, training, morale, discipline and the very lives of their soldiers. Therefore, Organization Sierra-Tango impresses upon its commanders to possess genuine care and concern for the wellbeing of soldiers. For training to be effective and meaningful, it has to be tough and realistic, so that soldiers can be well prepared to fulfill their missions in battle. Contemporaneously, it is a command responsibility to train and operate safely and professionally. The organization strongly believes that these conditions are not contradictory; for safety is an integral part of planning and execution of operations, and risk management must be applied in order to survive and succeed in battle.

##### 2.4.4.2 System Discipline

Accident investigations have indicated that a large proportion of accidents in the organization occur as a result of human negligence and a lack of individual discipline to comply with authorized regulations, instructions, lesson plans and established safe practices. The

organization's safety chain is only as strong as its weakest link, and there is a need to adopt a strict approach of "*Zero Tolerance to Negligence*" so as to instill system discipline. Organization Sierra-Tango requires commanders to be intolerable towards any blatant non-compliance of authorized operating materials and take immediate corrective actions to deal with individual(s) who do so. Actions should not cease at meting out punishments. Commanders should take appropriate actions to continually emphasize, educate and communicate to their soldiers the importance of compliance to safety regulations, so as to prevent accidents from reoccurring.

#### 2.4.5 Concluding Remarks

Organization Sierra-Tango's safety management system incorporates operational safety and risk management as part of the processes of operations planning as well as execution. It also ensures that all training is conducted progressively, safely and professionally, with all trainers undergoing the required preparatory programs before they assume their roles. Benchmarking with services, other armies and international safety specifications like Occupational Health and Safety Assessment Series (OHSAS) 18001, where applicable, makes the organization's safety management system more robust. The organization believes that with the professional application of their safety system, there is stronger assurance that missions can be achieved without unnecessary loss of equipment and lives or injuries.

## **CHAPTER 3: ACCIDENTS STATISTICS AND FINDINGS FROM REVIEW OF ACCIDENT REPORTS**

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### **3.1 Introduction**

This chapter begins by reviewing historical accident statistics in both the US military and Organization Sierra-Tango so as to obtain a better appreciation of the gravity of the challenge that accidents present to policy and decision makers in ensuring personnel safety. Thereafter, accident reports from Organization Sierra-Tango are carefully reviewed to understand the typical factors that are reported to be the causes of vehicle accidents in the organization's operating and training contexts. This understanding helps in the definition of the scope of the System Dynamics models and lays the foundation for further open literature research on similar or related accident studies. The chapter ends by providing findings from open literature on accident investigations.

### **3.2 Accident Statistics and their Importance**

#### **3.2.1 United States Military**

Throughout the history of military operations, accidents have remained the dominant cause of fatalities. As seen from statistics retrieved from the United States, Defense Manpower Data Center - Statistical Information Analysis Division (US, DMPC – SIAD, 2007) and summarized in Table 3-1, the percentage of deaths attributable to accidents has reduced from an average of 62% in the 1980s to an average of 53% in the 1990s thereby suggesting some success in the United States military's accident prevention efforts. In the first half of the 2000s, the percentage of deaths attributable to accidents has declined to an average of 40%.

However, this percentage decrease is arguably not due solely to the accident mitigation efforts of the United States military. Another significant contributing factor for the percentage decrease is the higher proportion of combat fatalities as a consequence of the ongoing Operation Enduring Freedom in Afghanistan and Operation Iraqi Freedom in Iraq. Notwithstanding, the current proportion of deaths due to accidents remains considerable and the fact is that such personnel losses are avoidable. Johnson notes that questions can also be raised about the reliability of such statistics (Johnson, 2003) which are arguably released by the US military with the specific intention of reducing accident-related injuries through increased safety awareness. Nonetheless, it is important to recognize the legitimate concern of the US military that the proportion of accident related casualties might increase because of the increasing use of complex, highly integrated technological systems. In order to improve safety, it is necessary for policy and decision makers to enrich their understanding of the root causes of accidents so that they can improve upon existing accident mitigation policies or to put in force new policies.

Calendar Year	Total Deaths	Accidents	Percentage attributable to Accidents	Percentage attributable to Accidents for the Period
1980	2,392	1,556	65%	<b>62%</b>
1981	2,380	1,524	64%	
1982	2,319	1,495	64%	
1983	2,465	1,413	57%	
1984	1,999	1,293	65%	
1985	2,252	1,476	66%	
1986	1,984	1,199	60%	
1987	1,983	1,172	59%	
1988	1,819	1,080	59%	
1989	1,636	1,000	61%	
1990	1,507	880	58%	<b>53%</b>
1991	1,787	931	52%	
1992	1,293	676	52%	
1993	1,213	632	52%	
1994	1,075	544	51%	
1995	1,040	538	52%	
1996	974	527	54%	
1997	817	433	53%	
1998	827	445	54%	
1999	796	436	55%	
2000	758	398	53%	<b>40%</b>
2001	891	437	49%	
2002	999	547	55%	
2003	1,228	440	36%	
2004	1,874	604	32%	
2005	1,942	632	33%	
2006	1,858	465	25%	

Table 3-1: U.S. Active Duty Military Deaths - 1980 through 2006 (as of February 28, 2007)

### 3.2.2 Organization Sierra-Tango

For Organization Sierra-Tango, where its operations are largely centered on non-combat assignments such as training exercises, peacekeeping missions and humanitarian deployments as opposed to combat operations, accidents play an even greater role in precipitating personnel injury and loss. In addition, being largely conscript-based, substantial political pressure is exerted upon the organization to minimize all forms of harm that can possibly befall their personnel. Accordingly, accident prevention is one of the foremost initiatives within Organization Sierra-Tango. Considerable resources are being invested by the organization to



improve its understanding of accidents in the organization’s operating context so as to assist policy and decision makers in the conceptualization of effective policies to mitigate the rate of accident occurrence.

Organization Sierra-Tango is currently employing a systematic and methodical safety management framework (as described in Chapter 2) to manage risk in all their operational and training activities. The percentage and type of training accidents encountered in the organization over the past four work years is reproduced from the provided documents (Organization Sierra Tango, 2007b) as Table 3-2. The decrease in the number of accidents clearly suggests that the current safety system is reasonably effective in checking the number of accidents within the organization.

Type of Accident	WY 02/03	%	WY 03/04	%	WY 04/05	%	WY 05/06	%
Physical Training	49	37%	60	41%	39	39%	41	41%
Field Training	44	33%	45	31%	31	31%	26	26%
Vehicle	13	10%	9	6%	10	10%	18	18%
Parachuting	1	1%	5	3%	2	2%	2	2%
Sports	2	2%	3	2%	1	1%	5	5%
Weapons	2	2%	3	2%	4	4%	1	1%
Rappelling	0	0%	1	1%	0	0%	1	1%
Stings & Bites	2	2%	2	1%	2	2%	4	4%
Equipment	5	4%	7	5%	9	9%	0	0%
Parade	0	0%	0	0%	0	0%	2	2%
Explosives/Ammunition	10	8%	7	5%	1	1%	0	0%
Boat/Watercraft	0	0%	2	1%	0	0%	1	1%
Others	4	3%	3	2%	2	2%	0	0%
<b>Total</b>	<b>132</b>	<b>100%</b>	<b>147</b>	<b>100%</b>	<b>101</b>	<b>100%</b>	<b>101</b>	<b>100%</b>

Table 3-2: Organization Sierra-Tango Training Accidents – Past Four Work Years

Also from Table 3-2, it is evident that over the past few years “*Vehicle*” accident has been consistently the third highest category of training accidents in Organization Sierra-Tango, behind only “*Physical Training*” and “*Field Training*”. Accordingly, one of imperatives of the organization’s continuing efforts to refine and improve upon its safety framework is that of enhancing vehicle safety management in training deployments.

### 3.3 Typical Attributors of Vehicle Accidents in Organization Sierra-Tango’s Context

#### 3.3.1 Findings from Organization Sierra-Tango Accident Reports

A careful review of over 60 Organization Sierra-Tango vehicle accident reports from Work Year 2006/07 (Organization Sierra Tango, 2007a and 2007b) was performed. These accident reports,

while not exhaustive, are considered to be a representative sample of vehicle accidents encountered by the organization in their activities. The review was performed with the intent of distilling out the typical vehicle accident causal factors uncovered by Organization Sierra-Tango and was not meant in any way to critique the organization's accident investigation process. The salient findings from the vehicle accident reports are discussed in the following sections.

### 3.3.1.1 Number of Accidents Vs Accident Category

In Organization Sierra-Tango's context, vehicle accidents can be broadly classified into three categories:

- (1) Domestic (Admin): These are accidents that occur during administrative tasks such as troop ferrying and stores transportation.
- (2) Domestic (Training): These are accidents that occur during training deployments within the organization's locale.
- (3) Overseas (Training): These are accidents that occur during training deployments outside of the organization's locale.

For Work Year 2006/07, the percentage of vehicle accidents for each of the three categories is shown in Figure 3-1.

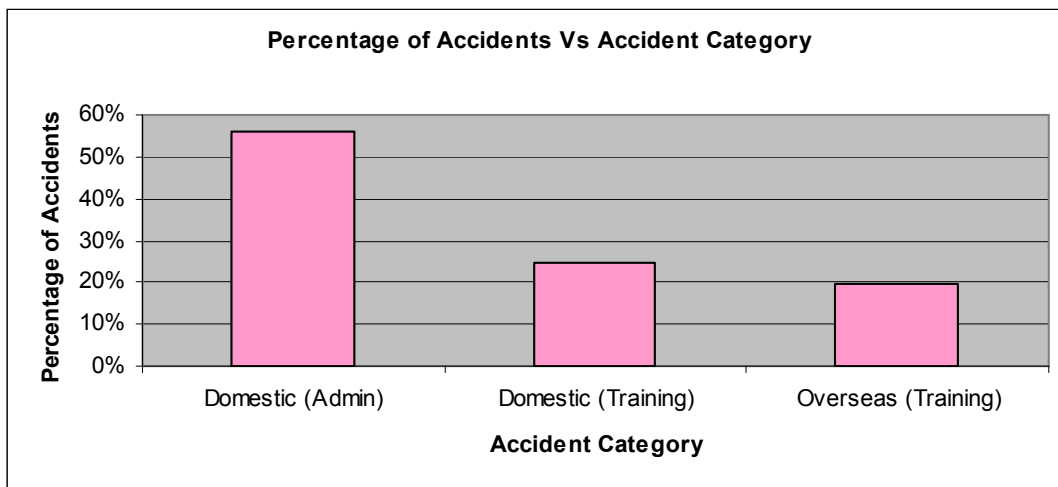


Figure 3-1: Percentage of Vehicle Accidents for the Three Accident Categories – Work Year 2006/07

From Figure 3-1, it can be seen that the percentage of accidents encountered during administrative deployments is higher than those of training deployments. However, on closer inspection of the accident reports, it was noticed that some of the accidents were blameworthy of parties outside of Organization Sierra-Tango. Figure 3-2 magnifies the data presented in Figure 3-1 by providing information on the accident initiators as concluded in the accident reports.

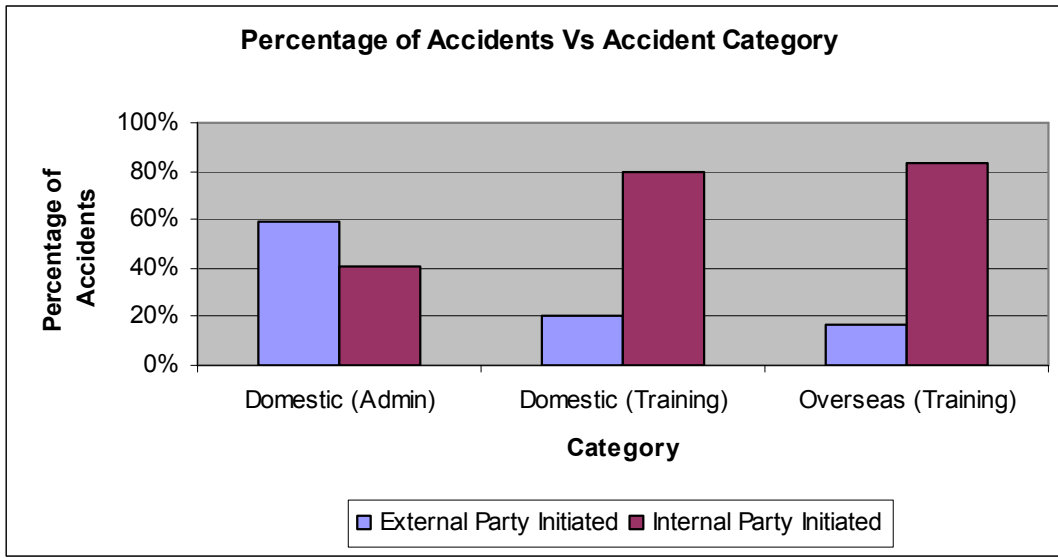


Figure 3-2: Number of Vehicle Accidents for the Three Accident Categories showing the Accident Initiators – Work Year 2006/07

For domestic deployments, about 60% of the accidents were initiated by external parties whereas 80% of the accidents during training deployments were initiated by parties internal to Organization Sierra Tango. As described in Chapter 2, defensive driving is an integral portion of the organization’s driver training curriculum. This driving skill is about as much as Organization Sierra-Tango can reasonably do to prevent and reduce the number of accidents attributable to external parties. Consequently, the primary focus of this thesis is to assist Organization Sierra-Tango in reducing the number of accidents during training deployments which can be considered to be an area that is both endogenous to the organization and of higher leverage in reducing the overall number of vehicle accidents.

### 3.3.1.2 Accident Causalities Vs Number of Occurrences

In order to appreciate the general types and number of accident causalities during Work Year 2006/07, all accident reports were review regardless of the primary party responsible for causing the accidents. The vehicle accident causal factors found can be grouped into the following seven categories:

- (1) Driver Error
- (2) Driver Fatigue
- (3) Driver Inexperience
- (4) Harsh Road Conditions
- (5) Inclement Weather
- (6) Supervisory Lapse
- (7) Vehicular Defect

The vehicle accident causalities and their number of occurrences are shown in Figure 3-3.

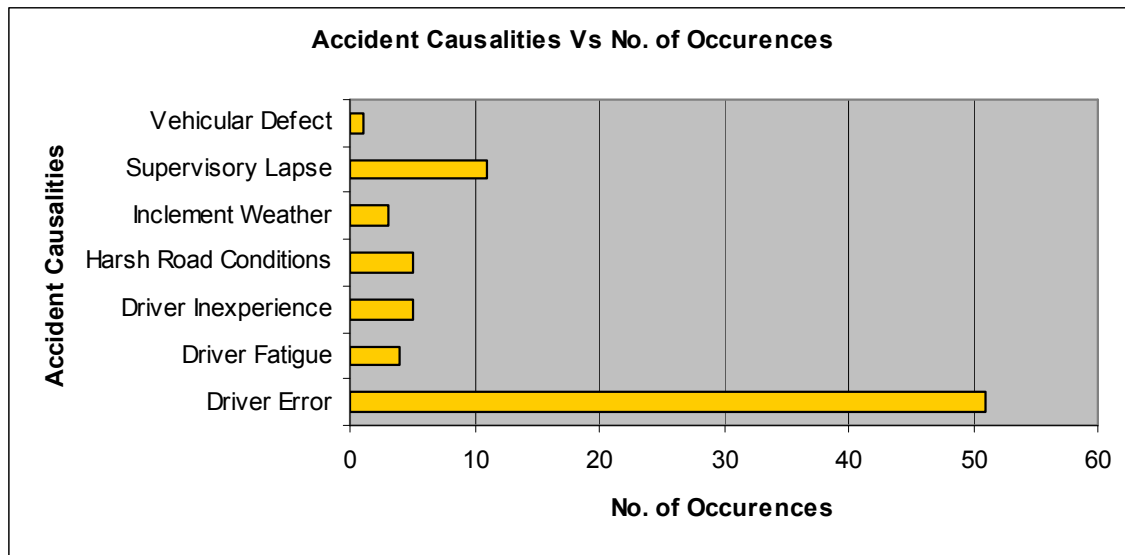


Figure 3-3: Vehicle Accident Causalities and Number of Occurrences – Work Year 2006/07

The accident reports showed that for most accidents, a combination of factors rather than a single factor was found to have caused the accident. As can be seen from Figure 3-3, a staggering 51 out of the 61 accident reports (84%) cited “*Driver Error*” as one of the prime causes of accidents followed by “*Supervisory Lapse*” at a distant 11 out of the 61 reports (18%). The next section zooms in on the typical forms of driver errors and supervisory lapses that were uncovered from the accident reports.

### 3.3.1.3 Typical Forms of Driver Errors and Supervisory Lapses

In Organization Sierra-Tango’s context, the typical forms of “*Driver Error*” found are:

- (1) Complacency: Failure to clarify doubts about driving route before setting off or making unsound assumptions
- (2) Judgment errors: Distracted/ inattentive driving or failure to abide by defensive driving doctrines
- (3) Negligence: Failure to abide by safety procedures and practices by speeding or overtaking recklessly

Figure 3-4 summarizes the contribution of each of the three forms of “*Driver Error*” in precipitating vehicle accidents. These forms of behavior are not mutually exclusive and drivers were often reported to have exhibited a combination of these errors. The data shows negligence (speeding, etc) as the primary form of driver error followed closely by judgmental errors (distracted, etc) and then complacency at a distant third.

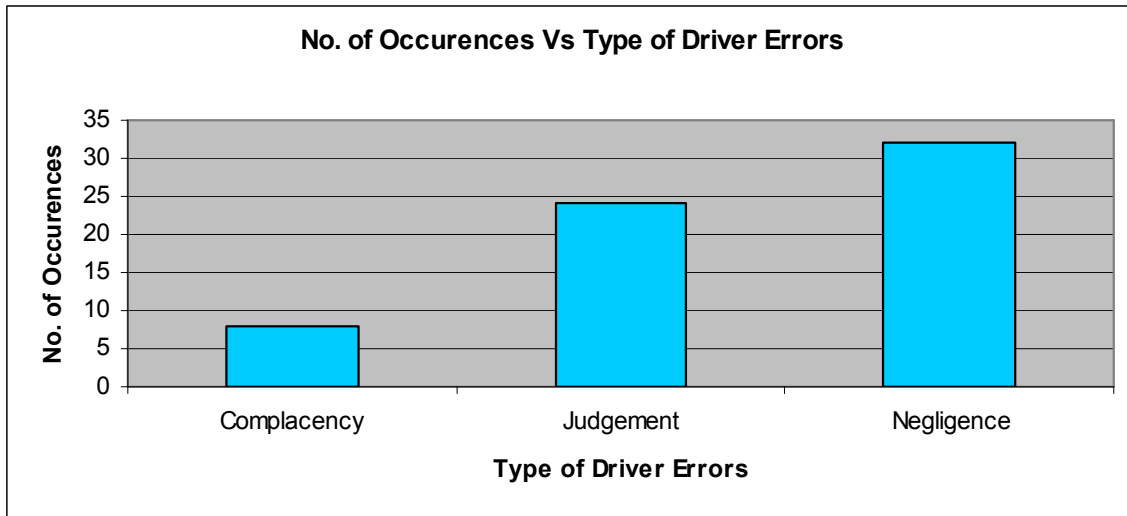
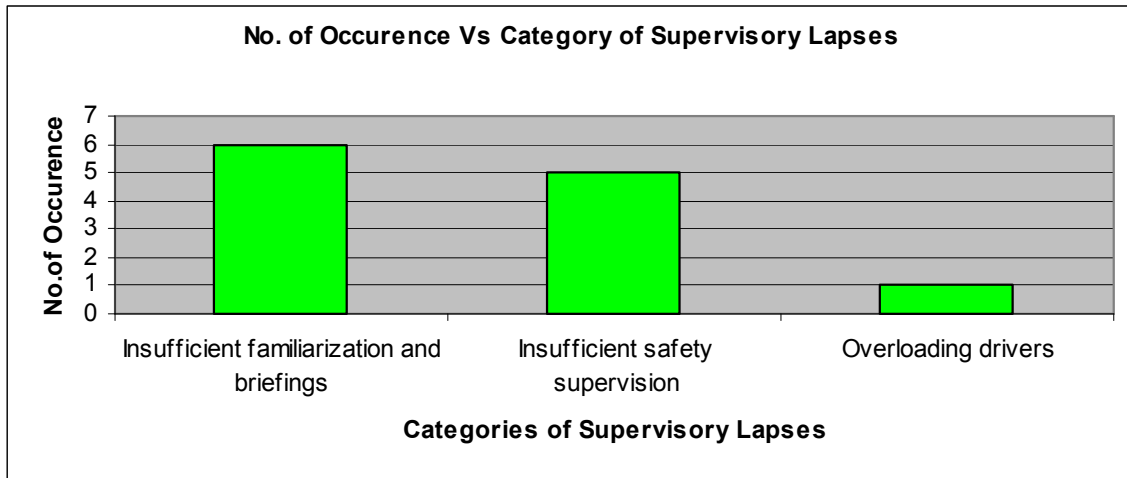


Figure 3-4: Number of Occurrences for the Three Types of Driver Errors – Work Year 2006/07

In Organization Sierra-Tango’s context, the typical forms of “*Supervisory Lapse*” found are:

- (1) Inadequate familiarization and briefings: Inadequate driver orientation on the driving hazards in the operating environment or failure to plan or provide driving instructions and routes to drivers
- (2) Inadequate safety supervision: Failure in providing sufficient safety inspections or making unsafe deployment decisions
- (3) Overloading drivers: Placing excessive number of tasks on drivers

Figure 3-5 summarizes the contribution of each of the three forms of “*Supervisory Lapse*” in precipitating vehicle accidents. These forms of behavior are also not mutually exclusive and supervisors were often reported to have exhibited a combination of these errors. The data shows that inadequate familiarization and briefings is the leading form of supervisory lapse, followed closely by inadequate safety supervision. Overloading of driving tasks is not found to be a significant manifestation of supervisory lapse.



**Figure 3-5:** Number of Occurrences for the Three Types of Supervisory Lapses – Work Year 2006/07

### 3.3.2 Comparison with Organization Sierra-Tango’s Internal Findings

The results of the accident report review were compared against a document provided by Organization Sierra-Tango (Organization Sierra Tango, 2007b), which summarized the organization’s internal findings on typical accident causalities. The document showed that the conclusions of most investigations also cited human error as the primary cause of an accident. The range of erroneous human behaviors was expanded to include physiological factors such as fatigue, inattentive/ distracted driving and competence, and psychological factors such as reckless driving typically manifested as speeding, improper overtaking and tailgating. Inadequate supervision and operating conditions are found to be the secondary causes of vehicle accidents. As the document only contained aggregate data, further analysis was not possible. Nonetheless, the document corroborated the findings from the accident report review that human error is often found to be the most common cause of vehicle accidents followed by supervisory lapses.

## 3.4 Findings from Open Literature on Accident Investigations

### 3.4.1 Existence of a Common View of Human Error as the Cause of Accidents

Madnick and Minami found in a review of US Army vehicle accident reports that 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 (Madnick and Minami, 2007). The authors continued their study by focusing on organizational level factors that influence the balance between a soldier’s accident resilience and his or her accident propensity. From the vehicle accident reports of Organization Sierra-Tango and the work of Madnick and Minami, it is evident that there is a general tendency for military

organizations to stop investigation efforts at the level of the events and symptoms of an accident as well as the operating conditions and other surface indicators, which often end up blaming human error as the cause of the accidents. Rarely are accidents subjected to greater inspections by delving deeper to include organizational level factors which may turn out to be the “*root cause*” of accidents.

Their finding is corroborated by the research of Leveson who found that the typical accident investigation boundary of most organizations (Leveson, 1995) is as shown in Figure 3-6.

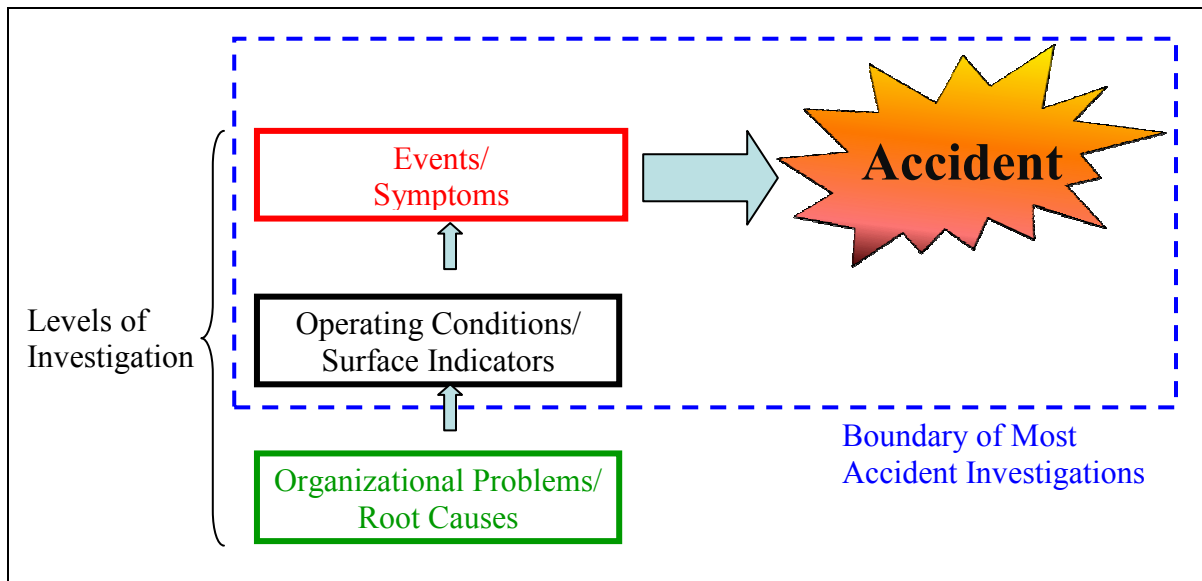


Figure 3-6: Typical Accident Investigation Boundary of Most Organizations

Most organizations fail to extend the boundary of their accident investigations to include organizational policy or structural elements that greatly influence human behavior that determine their accident propensity. This parochial mindset is captured in an example given by Leveson (Leveson, 2000) where most incidents and accidents of a new highly automated aircraft were initially blamed on human error. Upon further investigation, difficulties in the collateral design of the aircraft, the avionics systems, the cockpit displays and controls, and the demands placed on the pilots were uncovered to be the fundamental factors underpinning the aircraft accidents. Human error was merely an artifact of the root causes of the aircraft accidents.

### 3.4.2 Academic Opinions on Why Human Error is often blamed for Accidents

In his study on human error and accident causality, Rasmussen noted that in a traditional work setting, the slow pace of change led to the evolution of fairly stable work procedures and it was easy to define human error with reference to normal practice (Rasmussen, 1990). However, he opines that the traditional concept of human error in accidents is being challenged by rapid technological evolution and the transfer of people from manual manufacturing tasks to

supervision and intervention during disturbances in automated systems. Other academics provide additional insights into why human error continues to be often blamed for accidents:

(a) Hindsight Bias

Cook and O'Connor (Cook and O'Connor, 2005), and Johnson (Johnson, 2003) suggest that one reason is that our own hindsight bias makes the accident seem likely and we believe that this likelihood could have and should have been anticipated by the people involved in the accident. "*Hindsight bias*" is the effect of knowing that an outcome has occurred on another's estimate of how likely that outcome was. The fact that an outcome has occurred biases a person's judgment.

(b) Familiarity of the Human Element to Accident Investigators

Rasmussen adds that in a typical analysis to understand an accident, the backtracking would be continued until a cause is found that is familiar to the analysts (Rasmussen, 1990). As the adage goes, "*To err is human*". Accident investigations often cease at the operator level because human error – easily observed as any deviation from normal behavior or practice – continues to be particularly familiar to analysts amidst a host of other factors, many of which may be unfamiliar to the investigators.

(c) Focus on the "Apparently" Controllable Elements of the System

Cook and O'Connor suggest that another reason is that the human operator aspects of the accident seem to be the variable (and therefore, correctable) element of the system while other elements appear to be relatively fixed (Cook and O'Connor, 2005). The human element appears to be the point in the system where there was some opportunity to intervene in the accident sequence. By contrast, other aspects of the system appear to be fixed. Hence, because the operator seems to be a leverage point for change, most accident analyses stop when they encounter a human with presumed freedom of action.

(d) Substantial Amount of Effort Required for a Systems Perspective

Another opinion of why deep "*systems views*" of accidents are the exception rather than the norm is because they are inherently difficult, time consuming, expensive, and organizationally "*dangerous*" to undertake (Cook and O'Connor, 2005). Cook and O'Connor view that the independence and insight needed to produce these systems views are usually beyond the capacity of those with the responsibility for the investigation and analysis.

### 3.4.3 A Paradigm Shift in the Conduct of Accident Investigations

In his study of high-hazard industries (nuclear power plants and chemical process plants) in the private sector, Carroll found that most accident investigations produce problem diagnoses that are overly worker centric while ignoring organizational factors (Carroll, 1998). This resulted in extensive written detailed procedures and discipline imposed on the workers. Such actions increased job complexity and reduced trust between workers and management, leading to decrease productivity, alienation of workers, and a reduced flow of information between supervisors and their subordinates. This caused more problems and created a cycle of accumulating problems, accidents, and worker resentment. Clearly, there is a need to extend the



boundary of accident investigations and remedies beyond the human element to prevent such undesirable outcomes.

Johnson also cautions that if accident investigations myopically focus on the individual operator, the wider systemic factors that influenced their behavior may be missed (Johnson, 2003). Equally, the focus on management responsibility often makes unrealistic assumptions about military organizations' ability to ensure personnel follow "*safe operating procedures*" in the face of dynamic demands and complex problem solving situations. Accident investigations must therefore adopt a measured multi-dimensional approach that balances systemic factors and individual responsibility.

Rasmussen agrees by noting that in recent times some large-scale accidents point to the need for an explanation of accidents in terms of structural properties of integrated, large-scale systems rather than as isolated links or conditions in a linear causal chain of events (Rasmussen, 1990). Some of the deficiencies presently attributed to operator or management deficiencies may very well be structural problems which have to be considered at a much more fundamental level than mere efforts to improve human reliability. Rasmussen also warns that traditional causal attributions may turn out to be fighting symptoms rather than the structural origin of the breakdown of safety within an organization. It is important to question whether the system break-down is related to higher level functional structures and feed-back mechanisms rather than to the local conditions of events.

To remove hindsight bias so as to fully understand why accidents occur, Leveson and Cuther-Gershenfled recommend that it is necessary to evaluate decisions in the context in which they are made, with respect to the information available at the time the decision is made, along with the organizational factors influencing the interpretation of the data and information available (Leveson and Cuther-Gershenfled, 2004).

Cook and O'Connor add that the fact that multiple system flaws are necessary to create a disaster has the paradoxical effect of making each individual flaw seem insignificant when viewed in isolation. As a result, many such flaws may accumulate within a system to create conditions to cause an accident without raising alarm (Cook and O'Connor, 2005). Cook and O'Connor argue that in an attempt to obtain a "*systems view*" of accidents, a paradigm shift in accident investigations may be warranted. Various authorities have traditionally stressed the importance of going beyond the superficial by repeatedly asking "*why*" the event happened. Cook and Connor suggest that it may be more useful for us to ask "*how*" the event happened. Some examples are given below:

- (1) How did the conditions that permitted the accident arise?
- (2) How did the people involved with the accident recognize the potential for it?
- (3) How did they react to it once it began to evolve?
- (4) How did incentives in the world lead the system to march towards – rather than away from – the accident?
- (5) How did the workers recognize that disaster was brewing and how did they know what actions needed to be taken to avert it?

### **3.5 Conclusion of Accident Research:**

Accidents are rarely accidental. They do not just happen but are caused. Accidents are avoidable. As such, both Organization Sierra-Tango and their military counterparts such as the United States military share a common goal in implementing policy improvements to achieve a reduction in accidents. The existing safety system employed by Organization Sierra-Tango has shown itself to be reasonably effective in checking the number of accidents within the organization. However, the organization is not resting on its laurels and is continuing efforts to refine and improve upon its safety management framework. The review of accident reports from Organization Sierra-Tango and a similar study of accident reports from the US Army clearly present a need to shift the predominant focus on discrete cause or causes of accidents, which mostly ascribe human error as the primary cause of accidents, towards a more holistic perspective of accidents by also examining the often complex and dynamic contribution of organizational policies and practices towards accidents.

Accidents are not anomalies that arise from isolated human error. Instead, accidents are “*normal*” events that arise from deeply embedded features of the systems of work (Perrow, 1999). Open literature also reinforces the need to expand the scope of accident investigations to include organizational policy and structural factors. As put succinctly by Cook and O’Connor, accidents are powerful reminders of the vulnerability of systems in which they occur. Rather than being simple events in complex systems, accidents are themselves complicated events with multiple connected elements of a greater system of people, goals, technology, incentives, rules, knowledge and expertise (Cook and O’Connor, 2005).

## CHAPTER 4: TRAINING DEPLOYMENTS IN ORGANIZATION SIERRA-TANGO

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### 4.1 Introduction

This chapter begins by presenting a general overview of Organization Sierra-Tango's training activities. The remainder of the chapter focuses on overseas training deployments as it represents a richer context where vehicle accidents exist in the organization. The general safety policies and practices pertaining to driving operations in overseas training deployments are described, followed by opinions on driving operations in overseas training deployments as gathered from interviews and discussions with the Subject Matter Experts (SMEs). The information in this chapter is derived from three sources: (1) Organization Sierra-Tango's documents (Organization Sierra Tango, 2007b), (2) discussions with the organization's SMEs in May and July 2007, and from (3) my personal experiences of serving in Organization Sierra-Tango.

### 4.2 Overview of Training Deployments

The country of which Organization Sierra-Tango belongs to has been blessed by the absence of military conflicts. The organization's operational readiness is developed and sustained through regular training exercises and by participating in international humanitarian operations. Training exercises are conducted either unilaterally or bilaterally with friendly nations.

For training to be effective and meaningful, it has to be tough and realistic, so that soldiers can be well prepared to fulfill their missions in battle. Contemporaneously, it is a command responsibility to train and operate safely and professionally. As described in Chapter 2, Organization Sierra Tango strongly believes that these conditions are not contradictory; for safety is an integral part of planning and execution of operations, and risk management must be applied in order to survive and succeed in battle. Therefore, for any training area environment that is desirable for exercise realism, proper control measures will be implemented. The benefits of residual risk must always outweigh the potential cost.

In recent years, the operational tempo in Organization Sierra-Tango has increased substantially with high-end training for conventional warfare, sustained vigilance of asymmetric threats and "*Operations Other Than War*" missions. This climate has increased the challenge for commanders to strike a balance between mission results and its risk level.

#### 4.2.1 Domestic Training Deployments

Land area in the country is extremely scarce. After the available space has been divided out for businesses, housing and recreational purposes, there remains limited space for Organization Sierra-Tango to conduct its training exercises. Nevertheless, the organization makes the best use of whatever land area that has been delineated for its operations. Domestic training operations

are conducted in specially designated areas that are detached from densely populated areas for safety and citizenry inconvenience (noise, etc) considerations. Organization Sierra-Tango conducts its training exercises both during the day and also at night.

## 4.2.2 Overseas Training Deployments

### 4.2.2.1 Rationale for Training Overseas

Due to space constraints, there is impossible for Organization Sierra-Tango to expand the scope and duration of its training exercises within her country's soil. Overseas training areas offer the organization the opportunity to exercise their troops in a demanding environment and over a large expanse of terrain. This allows the organization to stretch themselves operationally in ways that they cannot do locally. Therefore, overseas training areas are crucial in allowing the Organization Sierra-Tango to develop itself as an operationally ready force. Training areas are available in several countries in which Organization Sierra-Tango has friendly relations with. Defense accords are established which allow the organization access to their training facilities during certain periods of each year. Such overseas exercises can be either unilateral or joint exercises with the host country.

### 4.2.2.2 Challenges of Overseas Training

With all the benefits of training overseas, the opportunity presents certain challenges that Organization Sierra-Tango has to manage. Training in an unfamiliar environment and executing maneuvers and activities in a combined arms framework are activities that the organization does not frequently engage in on a daily basis. This exposes servicemen to unique risks. Furthermore, as guests of the host country, Organization Sierra-Tango must ensure that their soldiers respect the rules that their hosts have laid out to protect the environment and historical sites. Therefore, training overseas means that the organization must operate on a set of rules additional to the ones it is familiar with in its domestic context.

#### 4.2.2.2.1 *Hazards in Overseas Training Areas*

This section describes some of the hazards that the organization's servicemen may face when training overseas.

##### (a) General Environment

- The climate in the overseas training area may be a stark contrast to what servicemen are typically accustomed to in domestic training areas. This weather conditions could cause heat stroke in the daytime, hypothermia at night or a general acceleration of fatigue.
- Unlike local environment where the night sky has a great amount of ambient light, a dark night (no moon) in overseas training areas may mean total darkness for operations.
- Some of the wildlife may appear friendly and harmless but may harbor pest and other diseases that may be harmful to humans. Others may turn aggressive when threatened or harassed.

- Some of the plant species can potentially cause respiratory problems, gastrointestinal problems, skin problems or even death. However, most are unlikely to cause problems unless ingested.
- Trees and bushes also present themselves as hazards. Deadfalls, overhanging branches, thick undergrowth, etc, often mask unapparent dangers.

(b) Expanse of Training Area

- Overseas training areas are often several orders of magnitude larger than domestic training areas. Drivers are generally not used to driving over extended periods of time, over extended ranges in distance. Fatigue and boredom set in that may reduce the alertness of the drivers.
- Cross-country movement especially through close terrain will have a significant impact on servicemen. The need for extra alertness and vigilance will quickly drain vehicle commanders and drivers. Crew fatigue will cause poor judgment and careless maneuver of vehicles which can be potentially hazardous. This effect will be significantly increased during night movement.
- Training areas are large and isolated areas with no "*obvious*" traffic regulations or restrictions. Ill disciplined and irresponsible drivers may take such opportunities to become "*Speed Demons*" by speeding and driving inconsiderately. Such dangerous behaviors become a hazard, not only to themselves, but to others.

(c) Road Conditions

- The layer of loose small rounded gravel often found in overseas training areas reduces the surface contact between a vehicle and the ground. Drivers could feel that their vehicles are "*floating*" on the layer of gravel which could easily cause their vehicles to skid and slide. This will be more apparent in the case of wheeled vehicles where the surface contact is even less. Traveling at excess speed, over steering and enthusiastic application of brakes to slow or stop the vehicle will cause severe skidding, which will likely result in the vehicle tipping over or overturning.
- During dry weather conditions, thick dust clouds will be churned up by moving vehicles, which can effectively obscure visibility. Unpleasant "*surprises*" often await vehicles that attempt to drive into or through such dust clouds.
- There are many deep depressions preceded or followed by sharp bends in the training area. Failure to control the speed especially at blind corners will result in serious consequences.

(d) Floods

- In overseas training areas, even in the dry season, flash floods with swift currents may occur in the creeks if there is prolonged rain. The water level can rise rapidly within a short period. This will pose a hazard to both troops and vehicles attempting to cross creeks, or who are present within the vicinity of the potential flood zone.
- Steep embankments may be softened by the rain and weakened by swift currents. The embankment may not be able to support the weight of a vehicle that is parked close to it, causing the ground to give way and the vehicle tumbling into the creek.

### 4.3 General Safety Policies and Practices in Overseas Training Deployments

Organization Sierra-Tango's general safety policies and practices for their drivers are described in this section. The emphasis of these safety measures are elaborated in the context of overseas training deployments as it is opined by the organization's Subject Matter Experts (SMEs) to represent a richer context where vehicle accidents exist in the organization.

#### 4.3.1 Driver Competency Management

It is the organization's policy to set pre-requisites for drivers to be considered for overseas training deployments. The rationale for this policy is to raise the overall experience level of servicemen that are tasked for overseas training deployments as the organization's accident statistics show that drivers with less than six months of driving experience – a demographic that most Cat D (see explanation of driver categorization in Chapter 2) belong to – are most accident prone. The minimum requirements for overseas deployment are:

- (1) The driver must possess at least a Cat C2 qualification.
- (2) The driver must not have been suspended for investigation for involvement in a traffic accident.
- (3) The driver must fulfill the orientation and familiarization training on the type of vehicle and environment that they will be driving in the host country.

#### 4.3.2 Driver Familiarization Management

As the terrain in overseas training areas can be very different from the terrain of domestic training areas, and the distances to be traverse much greater than driving in their home country, there will be higher risks involved in transport operations during overseas training exercises. With transport safety as a key concern, Organization Sierra-Tango requires all drivers and transport supervisors who will be deployed for overseas training to be properly orientated on the terrain they will be driving in. The key features of the organization's overseas orientation driving program are described below.

(a) Preliminary Briefing for All Drivers:

A person who is conversant with the traffic system of the host country will conduct a preliminary briefing to all drivers who are to be deployed for an overseas exercise. The purpose of the briefing is to psychologically prepare drivers on the conditions they are about to encounter throughout the overseas training phase.

(b) Preparation Training (in Organization Sierra-Tango's Locale):

Drivers are to complete a preparatory orientation phase before departing for overseas. The drivers are trained in a driving circuit that is set-up to simulate the traffic situations and road conditions likely to be encountered in the host country. The orientation driving is conducted on the class of vehicle that the driver is expected to perform his or her tasks in during the exercise.

(c) Preparation Training (in Host Country):

Prior to the commencement of the exercise, drivers are grouped according to their driving assignments during the exercise e.g., communications shelter drivers, commanders' drivers, scout drivers etc, and orientated on the respective routes that they are likely to traverse. Orientation drives are conducted on the vehicle that the driver is most often to operate during the exercise and supervised by orientation instructors whom are both competent and conversant with the training environment. Instructors must themselves have undergone the orientation training to keep them current before conducting the orientation driving for other drivers. Preferably, the host country's transport personnel should train the orientation instructors. The minimum number of hours to be clocked by each driver on the type of vehicle that he/ she will be driving is four hours in the day and two hours in the night.

(d) Departure Schedule:

In order to provide sufficient time and space for the conduct of orientation driving, early departure for both drivers and instructors may be necessary and have to be carefully scheduled as part of the exercise planning sequence.

### 4.3.3 Driver Fatigue Management

Driver fatigue causes poor judgment and loss of control of vehicles which can be potentially hazardous. Accordingly, Organization Sierra-Tango has several rest norms in force to prevent drivers from being unduly overworked to the extent of being a risk to himself, to his passengers and to other road users. Commanders and driving supervisors are charged with the responsibility to ensure that drivers abide by the following rules and regulations:

(a) Driving Hours:

The total number of driving hours for a driver in a normal working day should not exceed six hours. However during training/ exercises, commanders may exceed this limit. This is to ensure that training objectives are not unduly compromised while taking into consideration each driver's experience, fatigue level, weather condition and terrain.

(b) Continuous Driving:

For every 60 minutes of continuous driving, a driver should be given 15 minutes of rest.

(c) Mandatory Rest:

A driver should have six hours of sleep prior to his or her driving detail. If the duration of an exercise exceeds 24 hours, the driver should have a minimum of four hours of mandatory sleep in each subsequent 24 hour cycles.

(d) Working Norms for Duty Driver:

The working norms for a duty driver should not deviate from the sleeping hours stated in Organization Sierra-Tango's Training Directive. A duty driver shall be given a minimum of four hours of rest on the day immediately following his or her duty deployment before the driver can be assigned for his or her next driving detail.

#### 4.3.4 Driver Safety Supervision Management

Organization Sierra-Tango's safety supervision management system for their drivers exists on three levels:

- (1) Immediate superior (Transport Supervisor, Platoon Commander, etc)
- (2) Unit conducting the exercise (Officer Commanding, Battalion Commander, etc)
- (3) External safety team (Safety Inspectors from the organization's Headquarters)

Transport supervisors are responsible for the general safety supervision of the drivers such as conducting safety briefings and ensuring that drivers have completed their required safety checks. Safety briefings are carried out before the training commences and addresses hazards, their control measures, weather conditions, terrain, persons responsible for implementing/ supervising them and other relevant details for the safe conduct of the training. The officers conducting the exercise are responsible for the overall safety supervision of all servicemen involved in the training exercise.

The external safety teams are typically made up of members from the organization's headquarters and are often referred to as Safety Organization Teams (SOTs). These teams serve as a third layer of safety defense during training exercises by observing for safety breaches or risky behavior. SOTs can propose to the officers conducting the exercise for the mission to be postponed or abandoned if they discover serious breaches of safety regulations. However, the ultimate decision remains with the most senior officer conducting the exercise.

#### 4.4 Subject Matter Expert (SME) Comments on Overseas Training Deployments:

Discussions were conducted with several Organization Sierra-Tango SMEs in order to learn from their personal experience in overseas training deployments. These discussions served to further enrich my understanding on the context of vehicle accidents during training deployments. The key insights gleaned from the discussion are described below:

(a) Driver Age:

One of the SMEs initially opined that one of the key attributors of vehicle accidents is the age of the drivers. He added that the drivers are typically fulltime conscripts who are generally young (18 – 20 years old) which makes them more inclined to risky driving habits that culminate in accidents. However, he had no concrete evidence to substantiate the correlation between a driver's age and his or her risk-taking behavior. Ultimately, it was agreed that driver inexperience as opposed to age is probably one of the underlying explanations for younger people to be involved in more vehicle accidents.

(b) Flight Scheduling Woes:

One of the SMEs shared that overseas training deployments are often plagued by flight scheduling woes. Flight scheduling issues have resulted in divers arriving at their overseas destinations with little time remaining for rest and acclimatization to work fatigue and jetlag out of their system before the commencement of the training exercise.



(c) High Operations Tempo:

Training operations are of a higher tempo than what servicemen are accustomed to during routine activities. Therefore, proper time management and exercise planning is required to allow adequate rest for drivers to reduce fatigue and thereby prevent potential vehicle accidents. Each overseas training deployment is an enormous capital expenditure for Organization Sierra-Tango and there is a desire for commanders to maximize training opportunities for their soldiers. Additionally, the post 9-11 security climate has also fuelled the need to increase training so as to raise the operational readiness of the organization. Concomitantly, Organization Sierra-Tango has put in place more safety tasks and requirements for each driving task in a bid to promote vehicle safety. This has increased the overall amount of time that drivers and supervisors have to invest on each of their tasks which translates into an overall increase in the operations tempo.

(d) Mental and Physical Conditioning and its affect on Drive Fatigue:

The nature of overseas exercises which stretches from a week or more places heavy demands on both physical and mental endurance. The driving hours during a training mission is typically longer than what a driver is accustomed to back at home. Therefore, the organizations does it best to ensure that servicemen are progressively prepared/ geared up to go through such demanding training. Reservists present a challenge to progressive training as the duration that they can be called up for annual training is limited. The SMEs further commented that although driver rest hours are enforced, drivers may be required to assist in fatigue duties such as moving stores and sentry duty during their rest periods.

(e) Performance Evaluation of Commander:

It was also found that although safety is a key consideration in mission planning and execution, it is not an explicit criterion in a commander's performance evaluation. Commanders are mainly evaluated upon their ability to execute a training exercise fast and efficiently. Arguably, the performance evaluation system creates a desire within commanders to complete their mission faster which translates into a form of schedule pressure on their soldiers and drivers.

(f) "Post-Mission" Syndrome:

Another syndrome that Organization Sierra-Tango has to manage is the "*Post-Mission*" syndrome. After a training exercise has been completed, soldiers are tired but they are often in a big hurry to return to the comforts of the base camp after a long period in the field. During this phase, drivers and soldiers also tend to behave more relaxed and complacently after the high stress training period. In the past, accident reports have shown this "*Post-Mission*" syndrome to be the culprit of many vehicle accidents. Therefore, Organization Sierra-Tango recommends for its commanders to impose a mandatory rest period to calm the troops down before moving them back to base camp.

(g) "Speed Demon" Syndrome:

Overseas training areas are large and isolated areas with no "*obvious*" traffic regulations or restrictions. In the past, there have been several cases of ill disciplined and irresponsible drivers taking such opportunities to speed and drive recklessly, only to result in serious accidents. The SMEs believe that the increased driver supervision as a result of the presence

of the SOTs has dramatically deterred drivers with the propensity to succumb to the “*Speed Demon*” syndrome.

(h) Unfamiliar Terrain:

Of the pool of drivers selected for an overseas training deployment, most of them are fulltime conscripts on their maiden trip to the training areas. One of the SMEs opined that the lack of knowledge/ awareness of the road conditions and regulations in overseas training areas cause drivers to have a tendency to overlook the actual ground conditions they are traveling on. Their ignorance to potential hazards such as porous soils, gravels on road surface which causes skidding, steep slopes, sharp bends has contributed to past accidents. Organization Sierra-Tango attempts to mitigate driver familiarity with a comprehensive driver familiarization program as described in a previous section. However, the proportion of orientation instructors to rookie drivers is typically low. Therefore, the adequacy of the orientation driving training can be questionable if the instructors are overstretched.

#### **4.5 Concluding Remarks of Accidents during Training Deployments**

Chapters 2 to 4 have set the context for vehicle accidents during Organization Sierra-Tango’s training deployments. The organization’s safety management system, accident statistics and experiences in training deployments broadly defines the scope of the System Dynamics models that I have developed to assist the organization’s policy and decision makers to deepen their understanding of the hidden dynamics in managing vehicle accidents during training deployments.

Moving forward, the next two chapters present my key literature review findings on two (Man and Management) of the five “M” elements of Organization Sierra-Tango’s risk management framework as described in Chapter 2. The other “M” elements, namely Machine, Medium and Mission, are largely considered to be exogenous to the scope of this study.

# CHAPTER 5: MAN – PHYSIOLOGY OF INDIVIDUAL ACCIDENT PROCLIVITY AND THE PSYCHOLOGY OF INDIVIDUAL RISK-TAKING BEHAVIOR

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## 5.1 Introduction

The planning of safety can be central, but the execution of it has to be decentralized. Decentralization requires the responsibility of every individual to know and play their part well (Organization Sierra-Tango, 2007b). Accordingly, the role of the individual in contributing to accidents must be understood. Chapter 5 summarizes the literature review findings pertaining to two main factors: (1) the physiology of individual accident proclivity and (2) the psychology of individual risk-taking behavior. This research enriched the body of knowledge for developing and interpreting the System Dynamics models.

## 5.2 Physiology of Individual Accident Proclivity

The physiological factors influencing an individual's accident proclivity can be generally grouped under two categories – those affecting an individual's competency and those affecting an individual's concentration. These categories are elaborated below.

### 5.2.1 Competency

An individual's competency or proficiency determines not just how fast he or she is able to complete the task at hand; it also entails whether the task is completed without compromising safety or of sufficient quality so that it does not require rework. Competency can be thought to comprise three elements such as:

- (1) The individual's experience in doing the task.
- (2) The individual's skill to execute the task.
- (3) The individual's familiarity with the conditions under which the tasks is to be performed.

#### 5.2.1.1 Experience

Based on studies undertaken by Organization Sierra-Tango, one likely reason why young drivers have a higher accident frequency than drivers in other age groups is their relative lack of driving experience (Organization Sierra-Tango, 2007b). This experience shortfall could manifest itself as a lack of practical knowledge regarding driving judgments such as braking distances, manoeuvrability of the vehicle on the road under various weather conditions and other general characteristics of driving. Furthermore, it is conceivable that younger drivers have a marked lack of knowledge regarding the behaviour patterns of other road users, which in some cases could cause them to take unnecessary risks or fail to anticipate the driving actions of the other road users. Organization Sierra-Tango also found from their accident investigations that there was a negative correlation between the accident risk (accidents/ km) of a driver and the number of

cumulative kilometres driven by the driver. As discussed in Chapter 2, the organization has increased in recent years the minimum cumulative kilometres to be driven by a trainee driver before he or she is qualified for basic driving tasks. Additionally, each driver is also categorized according to their accident-free cumulative number of driving hours and tasked for missions based on their experience levels.

#### 5.2.1.2 Skill

An individual's competency also depends on the skill that he or she possesses in performing the task at hand. Skill is acquired through training and aggrandized over time with experience. However, a person's skill can also be eroded over time due to lack of practice or obsolescence of the skill in the face of new operating conditions. This suggests the need to maintain skill levels through constant practice and refresher training. Accordingly, as discussed in Chapter 2, Organization Sierra-Tango provides annual training to keep their drivers' skill current and added emphasis is placed upon ensuring that reservist drivers undergo a stint of driving refresher training before they are deployed in the fields.

A person's competency to execute a task also depends on the extent by which the skill that he or she possesses is compatible with the task to be performed. For example, it is impracticable and definitely unsafe to task a jeep driver to operate a tank. Therefore as discussed in Chapter 2, mission compatibility as defined as the individual's skill to perform the required task, is an important determinant of task safety.

#### 5.2.1.3 Familiarity with Operating Conditions

Even if an individual possesses the necessary skill and is sufficiently experienced to perform a task, his or her familiarity with the operating conditions also affects his or her competency. In the context of driving, unfamiliar terrain discounts a person's skill in executing the task due to insufficient knowledge to recognize inconspicuous hazards or negotiate sharp bends. Therefore, familiarity with operating conditions that can be honed through driving orientations is another element that must be addressed in order to raise an individual's competency and in the process raise his or her accident resilience.

### 5.2.2 Concentration

An individual's accident proclivity also depends on his or her concentration when perform the task. Distractions and fatigue are two factors affecting concentration as explicated below.

#### 5.2.2.1 The Effect of Interruptions/ Distractions on Concentration

A significant insight emerging from academic research is that major disasters often do not have proportionately large causes. Organizational theorists increasingly recognize that small events

can link together in unexpected ways to create disproportionate and disastrous effects (Weick, 1993; Perrow, 1994; Vaughan, 1997; Reason, 1997). In their study of disaster dynamics, Rudolph and Repenning suggest that in many cases both the novelty and the quantity of interruptions to established routines and expectations play a significant role in precipitating disasters (Rudolph and Repenning, 2002). They define an interruption as any unanticipated event, external to the individual that temporarily or permanently prevents completion of some organized action, thought sequence, or plan. Rudolph and Repenning distinguish between non-novel interruptions (interruptions for which the organization has an appropriate response within its existing repertoire) and novel interruptions (interruptions for which responses in the existing repertoire are inappropriate). Errors are also different from interruptions in the sense that errors are endogenous whereas interruptions are considered to be exogenous to the individual or the organization. However, errors do contribute to the increase in the overall number of pending interruptions that are imposed on individuals.

Invoking George Mandler's interruption theory of stress (Mandler, 1982), Weick suggests that stress as manifested by an accumulation of unresolved interruptions has a negative impact of human cognitive performance (Weick, 1993). In Weick's study of the Tenerife air disaster, he found that non novel interruptions increased the level of automatic arousal in the KLM crew, absorbing information processing capacity, decreasing cognitive efficiency, and reducing the number of cues the crew were able to notice and process. As the situation progressed and the number of interruptions accumulated, the crew's ability to manage the increasingly complex system they were facing declined resulting in their decision to takeoff the plane without receiving authorization from the control tower and colliding with another plane that was approaching the runway.

Agreeing, Rudolph and Repenning found that cognitive theory supports the notion that a growing stock of pending interruptions impairs the execution of all the cognitive processes necessary for resolving them, because it simultaneously compromises attention management (mental bookkeeping overload which decreases awareness of the bigger situational picture), knowledge activation (decrease the time available to process available stimuli and extract the patterns necessary to trigger inert knowledge), and the ability to trade off competing goals (conflicts among operational goals such as safety and productivity) (Rudolph and Repenning, 2002). There exists a critical threshold or a tipping point which once exceeded would cause a fundamental change in system behavior from one that is inherently stable to interruptions to one that spins out of control and descends into a crisis.

Relating these studies on the impact of interruptions on an individual's concentration, unfamiliar operating environments present a host of cognitive interruptions to drivers in forms such as feral animals and rough driving terrains. If drivers are constantly "*interrupted*" from their principle tasks because of their lack of familiarity with the operating environment, the probability of descending into an accident is increased. Management can help alleviate such interruptions by ensuring that supervisors conduct proper driving orientation and give sufficient safety briefings to drivers so as to lower the overall number of distractions encountered by a driver when they are performing their driving tasks.

### 5.2.2.2 The Effect of Fatigue on Concentration

Driver fatigue is a major cause of road accidents and has implications for road safety. Driver sleepiness is a causative factor in 1 – 3% of all US motor vehicle crashes. Surveys of the prevalence of sleepy behavior in drivers suggest that sleepiness may be a more common cause of highway crashes that is actually reflected in these estimates (Lyznicki et al, 1998). About 96% of sleep-related crashes involve passenger vehicle drivers and 3% involve drivers of large trucks (Lyznicki et al, 1998). Studies of employee overtime have also pointed to fatigue as a potential factor producing, for example, a three-fold increase in accident rate after 16 hours of work, increases in back injuries, hospital outbreaks of bacterial infection, or nuclear-power plant safety compromises (Rosa, 1995). Clearly, an individual's fatigue level must be managed in order to lower the risks of accidents.

#### 5.2.2.2.1 *Definitions*

Sleepiness and fatigue are often used interchangeably. However, these terms are not synonymous. Fatigue is a more complex phenomenon that may be defined as a subjectively experienced disinclination to continue performing the task at hand (Brown, 1994). Fatigue generally impairs human efficiency when individuals continue working even after they have become aware of their fatigue. It does not depend on energy expenditure and cannot be measured simply in terms of performance impairment. Fatigue also relates to a person's motivation, capability of performing a task, and past cumulative day-by-day patterns and durations of sleep and work. Fatigue causation is described as a joint function of time on task, circadian factors and inadequate sleep (Brown, 1993).

Sleepiness has a more specific meaning than fatigue, relating to reduced alertness as a result of increased pressure to fall asleep. Sleepiness is a normal manifestation of the biological need for sleep, just as hunger signals the need to eat and thirst to drink (Expert Panel on Driver Fatigue and Sleepiness, National Center of Sleep Disorders/ National Highway Traffic Safety Administration, 1997). It is characterized by a tendency to fall asleep and is the unavoidable consequence of the unsatisfied need to sleep. Increasing sleepiness is associated with decrements in vigilance, reaction time, memory, psychomotor coordination, information processing, and decision making (Dinges, 1995, Rosekind et al, 1996). Individuals may not, however, always recognize the onset of sleep or the deleterious effects of sleepiness. That is, the perception of the onset of sleep may lag behind the physiological and behavioral indications that the sleep process already had occurred (Rosekind et al, 1996).

The distinction between fatigue and sleepiness, while important from a scientific standpoint, is considered to be fungible for the purposes of this thesis.

#### 5.2.2.2.2 *Causes of Fatigue*

The results of the Wylie et al. research on driver fatigue and alertness indicated that the most important factor affecting fatigue was time-of-day due to circadian rhythm effects (Wylie et al,

1996). Fatigue was found to be most prevalent during late evening and at night (midnight to dawn). Time-on-task or driving duration and sleep debt was found to be secondary important factors as compared to time-of-day. In trucking, fatigue is also associated with rotating schedules, team sleeper operations, monotonous driving environments, driving in darkness, adverse weather, alcohol and drugs, physical work, noise, vibration, and heat (Wylie et al, 1996). Similarly, Brown's study shows that fatigue is insufficiently recognized and reported as a cause of road accidents and that its effects stem largely from prolonged and irregular working hours, rather than simply from time spent at the wheel (Brown, 1994).

#### *5.2.2.2.3 Effects of Fatigue on Driving Performance*

In a technical report for the Federal Highway Administration, Wylie et al provided an overview of the conclusions that have been drawn from available literature regarding fatigue on driving performance (Wylie et al, 1996). These conclusions are summarized as follows:

(1) Driver fatigue is believed to lead to increases in:

- Lapses of attention,
- Information processing and decision making time,
- Reaction time to critical events,
- Subjective feelings of fatigue.

(2) Driver fatigue is believed to lead to decreases in:

- Motivation to sustain performance,
- Psychophysical arousal,
- Vigilance,
- Alertness.

(3) Driver fatigue is also believed to lead to more variable and less effective control responses.

#### *5.2.2.2.4 Possible Countermeasures against Fatigue*

Feyer et al found in their studies examining driver fatigue in the Australian long distance road transport industry that the use of overnight rest, in combination with two-up driving, appeared to be a successful strategy for managing fatigue across the trip (Feyer et al, 1997). Other than such fatigue management strategies, technology advancements are enabling the development of countermeasures against fatigue. A series of driving simulation pilot studies on various technologies for alertness monitoring (head position sensor, eye-gaze system), fitness-for-duty testing (two pupil-based systems), and alertness promotion (in-seat vibration system) has been conducted in Circadian Technologies' Alertness Testbed (Heitmann et al, 2001). Test results of these technologies indicate promise for monitoring/ testing or preventing driver fatigue.

Brown offers three reasons for giving serious consideration to technological countermeasures against driver fatigue (Brown, 1997):

(1) Fatigue is a persistent occupational hazard for professional drivers.

(2) Some professional drivers are under considerable pressure to reach their scheduled destination, in spite of feeling drowsy.

(3) Fatigue adversely affects an individual's ability to assess their own fitness to continue driving.

However, Brown also cautions that there are two reasons for exercising caution in implementing technological countermeasures (Brown, 1997):

- (1) Their reliability under real traffic conditions is largely unproven.
- (2) They could be used by unscrupulous drivers to support the continuation of journeys that should have been terminated because of human impairment.

#### *5.2.2.2.5 Wrap-up of Findings on Driver Fatigue*

From the literature review, it is evident that fatigue has major implications for transportation system safety. Therefore, investigating the psycho-physiological links to fatigue could enhance the understanding and management of fatigue in the driving industry. While there are possible technological countermeasures on the horizon against driving fatigue, the safest bet at present is for managers to focus on prudent driving deployment strategies to mitigate the risk of vehicle accidents due to fatigue.

### **5.3 Psychology of Individual Risk-Taking Behavior (Cautiousness)**

This section presents the results of the literature review on the psychology of an individual's risk-taking behavior (cautiousness) and its influence on accidents. The findings are inspired by the work of Chua on understanding the psychological dimensions of an individual's risk assessment and their impact on military training safety (Chua, 2004).

Research has consistently shown that an individual's perception of risk is instrumental to the individual's potential involvement in an accident (O'Hare, 1990). Solvic adds that people respond to hazards that they perceive and if their perceptions are faulty, efforts at personal, public and environmental protection are likely to be misdirected (Solvic et al, 1981). Despite this body of knowledge, errors in individual risk assessment are rarely considered as one of the root causes of training accidents, let alone recognized as a fatal flaw. Chua asserts that when confronted with a hazardous scenario, an individual's risk assessment is defined by subjective psychological responses that emanate from cognitive, social and emotive forces. These phenomena possess the capacity to distort or influence risk assessment to the extent where the perceived risk of a situation is deemed to be acceptable. Solvic agrees, stating that risk assessment is inherently subjective and prone to distortion due to judgmental limitations, and that understanding perceptions is crucial to effective decision making (Solvic et al, 1981).

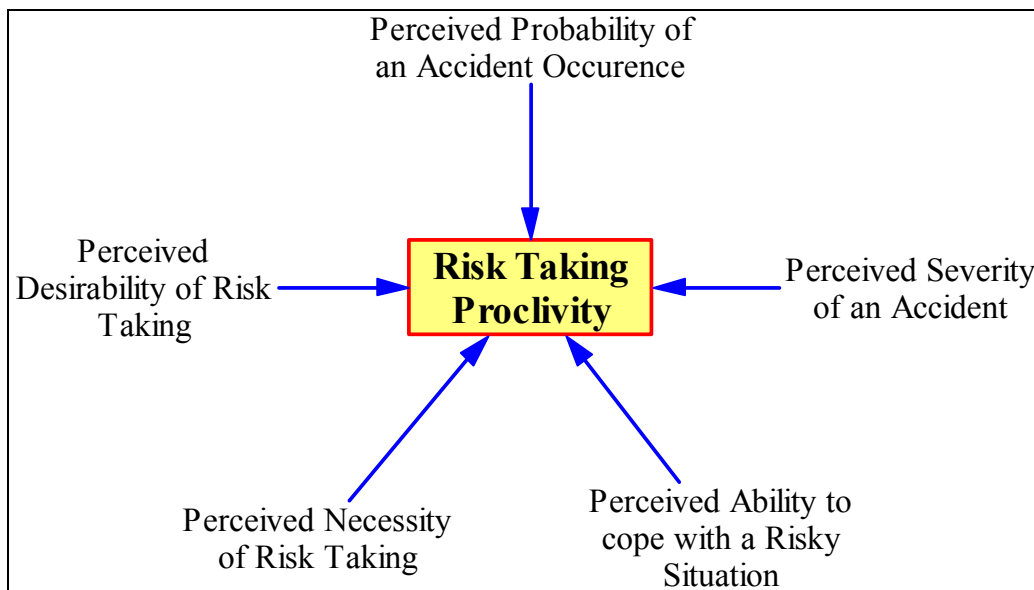
Chua challenges the assumption of human rationality in risk assessment and argues that decisions about taking risks are commonly irrational, citing psychological research (Hardman and Harris, 2002) which has persistently shown that people do not always think and therefore act in accordance with rational principles. Rasmussen adds that the definition of error, as seen from the situation of a decision maker, is very arbitrary. Acts that are quite rational and important to the decision maker at the point of action may appear to be unacceptable mistakes in hindsight, without access to the details of the situation (Rasmussen, 1990).



As defined in Chapter 1, risk is typically quantified as a compound concept of the severity of a hazard and the probability of its occurrence. Chua states that probability and severity, while important, are not the sole considerations when risks are appraised in the minds of people. Rather, individual risk assessment is premised on multiple dimensions. To illustrate his point, Chua provides the example of reckless driving, a behavior in which people often engage in despite a high probability of accident occurrence and strong likelihood of serious consequences. Therefore, Chua asserts that traditional risk assessment approaches premised solely on probability and severity considerations, are both inaccurate and insufficient. A complete and accurate understanding of risk assessment requires the expansion of the traditional two-dimensional (severity and probability) conceptualization of risk by including the impact of irrational psychological forces on an individual's risk assessment process. He proposes that an individual's decision to take risk is the culmination of collective perceptions on the following measures:

- (1) Perceived Probability of an Accident Occurrence
- (2) Perceived Severity of an Accident
- (3) Perceived Ability to Cope with a Risky Situation
- (4) Perceived Necessity of Risk-taking
- (5) Perceived Desirability of Risk-taking.

The psychological forces influencing risk assessment reside at both the strategic and operational levels of decision making (Furnham, 1997). Strategic decisions are formulated at the stage of planning when time is available for deliberation and include examples such as decisions about resource allocations, approved methods of training and standard operating procedures. Operational decisions refer to those that are framed at the stage of execution, which usually entail snap decisions made under strictly limited time periods in uncertain environments, such as whether or not to overtake a vehicle ahead, fly an aircraft into deteriorating weather or lead a platoon into dangerous terrain. The five dimensions as proposed by Chua are summarized in Figure 5-1. These measures are elaborated in the following sections.



**Figure 5-1:** The Five Psychological Forces on an Individual's Risk Assessment

### 5.3.1 Perceived Probability of an Accident Occurrence

When people are asked to evaluate risks they seldom have statistical evidence at hand to support their decisions (Slovic et al, 1981). The probability estimates of individuals are therefore determined primarily by cognitive forces and they are often computed based on mental strategies and rules-of-thumb, known as heuristics, which assist people in overcoming their limited mental capacities in complex decision making (Kahneman et al, 1982). While these inferential rules can be valid and are especially useful in some circumstances where detailed analysis is either unwarranted or unfeasible, they can also be inaccurate, skewing estimates of probability outcomes and distorting risk assessment with serious implications.

The “*Availability*” heuristic (Tversky and Kahneman, 1973) is the most commonly used heuristic in the derivation of probability judgments. The basis of this heuristic is that the easier an event can be imagined or recalled by the decision maker, the higher is the perceived probability of the event’s occurrence. Chua argues, however, that the ease with which events can be recollected is influenced by several factors that are unrelated to its probability of occurrence as explained below:

#### (a) Overestimation of Recent Events and Underestimation of Old Events

Events that have recently occurred tend to be overestimated, while those in the distant past tend to be underestimated. This is because the experience of seeing or hearing about an event makes it more available to memory and imagination, hence seemingly more probable. As such, decisions based on the probability of an impending risk may be biased.

#### (b) Publicity of an Event

The ease of recalling an event is often a function of its publicity. The more an event is sensationalized and/ or dramatized, the higher is the estimate of its likelihood, regardless of what the evidence indicates. Therefore, there exists a danger that resource allocation to promote safety may overlook hazardous scenarios that are likely but are not easily recallable as they are less spectacular.

#### (c) Personal Affiliation with an Event

The probability of events that are personally experienced is often exaggerated, while those that occur outside of one’s immediate dealings tend to be underestimated. This means that the objectives behind information-sharing systems and open dissemination of lessons learnt to improve safety may be undermined if people’s reliance on the availability heuristic is not regulated.

### 5.3.2 Perceived Severity of an Accident

Individuals tend to avoid decisions that they believe could result to disastrous consequences on mortality, morbidity and property damage. However, severity judgments may sometimes be inaccurate due to outright ignorance about the potential ramifications of an action and/ or judgmental distortions by cognitive and emotive forces elicited in response to dreaded, unfamiliar and latent risks. Focusing on the psychological aspects, Chua asserts that the

perceived severity of an accident may either be exaggerated by the effects of dreaded and unfamiliar risks, or understated by the effects of latent risks as elaborated below:

(a) Dreaded and Unfamiliar Risks

Risks that are dreaded are characterized by their apparent impact on mortality or morbidity. In Slovic's analysis of the public's perception of risks (Slovic et al, 1980), nuclear power was viewed to present the most severe risk of death, compared to motor accidents and cigarette smoking. Clearly, the perceived morbidity of nuclear accidents caused the public to fail to recognize that both motor accidents and cigarette smoking in fact account for a far higher mortality rate compared to nuclear accidents. Unfamiliar risks refer to phenomena for which the hazardous consequences are poorly understood, such as biological and chemical hazards. Slovic also found that in general, people tend to exaggerate the severity of unfamiliar risks while common risks were underestimated (Slovic, 1987).

Both dreaded and unfamiliar risks magnify the perceived severity of an accident, thereby dissuading risk-taking behavior at the operational level. However, Chua found that at the strategic level, the exaggeration of dreaded and unfamiliar risks can create situations where scarce resources are committed to protect people against the unlikely perils instead of likely hazards. Both Everitt (Everitt, 2002) and Slovic (Slovic et al, 1981) also found in their separate researches that the greater a risk was dreaded, the more people wanted to see stricter mitigation regulations, even if they acknowledged the presence of other hazards that were more likely to occur.

(b) Latent Risks

Latent risks describe hazards with consequences that are not immediately harmful, such as radiation hazards. The cognitive and emotive forces triggered by latent risks lead to underestimations in severity judgments causing people to be less averse to impending dangers. Therefore, the psychological effects of latent risks may result in compromises to safety decisions by playing down the perceived severity of the encountered hazards.

### 5.3.3 Perceived Ability to Cope with a Risky Situation

While judgments about the probability and severity of an accident are based on the characteristics of a risky situation, the perceived ability of oneself to cope with the situation is concerned with an internal assessment of one's personal ability. This dimension is pertinent in view that people sometimes take risks because of their predilection to view themselves as being able to avert the hazardous consequences of their decisions. The danger arises when an individual's perceived self-ability to handle the risky situation has been subconsciously exaggerated.

Studies have shown that human beings, particularly those who lack experience in an activity, are susceptible to the phenomenon of "*Control Illusion*" in the face of risks. For example, while novice drivers sometimes take risks because they are incapable of detecting potential hazards (Brown and Groeger, 1988), risks are also frequently taken despite an awareness of the impending danger (Lawrence, 1998). This can be partly attributable to "*Control Illusion*" which

affords novices with an optimism bias that enhances their sense of being in control and leads them to discount the real risks that they are facing. Chua provides an example of control illusion in that each time a driver speeds and remains unscathed; he or she acquires increased self-assurance and therefore speeds more regularly, even though he or she is conscious of the deadly consequences of his or her reckless behavior. On this account, novices may overestimate their own abilities to cope with risky situations and justified in continuing with their unsafe actions.

Veterans are also fallible to the “*Control Illusion*” as having extensive experience may also distort perceived self-ability, which results in the higher propensity of veterans to take risks. For example, studies in the military context have found that soldiers who believe that they have received thorough training feel more confident of their military skills, which counteracts their sense of risk (Kellet, 1987). In addition, experience may also breed complacency, which fosters the belief that control measures are unnecessary. This is evident from the fact that from time to time, accidents occur as a result of veterans disregarding the need for safety measures, such as safety briefings and the use of checklists. Moreover, experience may lead to desensitization – a psychological phenomenon in which one becomes insensitive to the tenuousness of the assumptions upon which judgments are based (Solvic et al, 1981). In time, this will be dangerous, as the mindless application of past decisions will be inappropriate for the ever-evolving challenges characteristic of military operations (Furnham, 1997). Therefore, left unchecked, experience has the counterintuitive effect of distorting an individual’s perceived ability to cope with situations, which consequently promotes risk-taking behaviors that are deleterious to safety.

Johnson adds that a person’s perceived ability to cope with a risky situation can be thought of as a form of risk homeostasis (Johnson, 2003). He gives an example where the over-engineering of vehicles such as the M1A1 and the M551A1 provides soldiers with an impression of safety that they then trade against performance. The vehicle operators will perform more dangerous maneuvers and expose themselves to greater risk because they are overconfident that the vehicle will protect them against the adverse consequences of any hazard. Therefore, the engineering of any instrument that is to be operated by a human must be guarded against eliciting this potential form of psychological behavior.

#### 5.3.4 Perceived Necessity of Risk-Taking

The psychological dimensions of risk assessment discussed thus far are based on the tacit assumption that risks are unnecessary and should be reduced. However, risk-taking may be desirable in certain situations, and even necessary. Johnson states that this is especially applicable in the military training context where the objective is to prepare and train soldiers in risky environments that sufficiently replicate the dangerous scenarios of war (Johnson, 2003). Therefore, one of the greatest dilemmas for soldiers and their commanders when deciding whether or not to take risks is the need to strike a balance between realistic training and the need for safety. In addition, individuals may also be torn between the need to conform to military values such as fighting spirit and endurance, as opposed to values related to safety. Chua examines how the perceived necessity of risk-taking may distort the risk assessment at hand and consequently inflict serious repercussions on training safety as elaborated below:

(a) Unavoidable Presence of Risks

Military training and operations necessarily entail risks. Individuals are therefore confronted by the tension of training safely and exposing themselves to risks so as to equip themselves with vital operational skills. Consequently, from the perspective of achieving training objectives, commanders may opt for a risky decision to be taken for otherwise the aim of the exercise may be eroded or even lost. The perception of the necessity to take risks can also be reinforced during peacetime missions, such as peacekeeping operations. In such cases, soldiers may be faced with situations in which mission accomplishment will be compromised if safety considerations are allowed to take precedence.

(b) Military Culture and Values

The tension between training realism and safety is exacerbated by the existing organizational culture and values. Research into high-risk occupations has demonstrated that organizational culture can convince people to perform risky activities far beyond what they would normally do (Tuler et al, 2004). The explanation is that the values, beliefs, symbols, norms, myths, rules and practices of an organization establish perceived responsibilities and exert subtle but pervasive influences on an individual's thinking and behavior. In the military context, the propagation and internalization by soldiers of organizational aspirations such as "*Willingness-to-Fight*", core values such as "*Fighting Spirit*", as well as the traditional military ethos related to courage, endurance, "*Never-Say-Die*" and a "*Can-Do*" mentality, may worsen the quandary on whether safety should be discounted in favor of risks. For individuals in combat vocations and units that place immense emphasis on these military attributes, they may perceive further reasons for risk-taking both in peacetime as well as in operational environments.

(c) Ambiguity on Acceptable Risks

While some degree of risk-taking is fundamental to military training, the adverse impact to safety arises when individuals are unclear about the extent where risks are deemed to be acceptable. In terms of training realism, soldiers may be unable to appreciate the measure at which the training risks involved become no longer acceptable in a peacetime context. In the endeavor to accomplish a mission, soldiers may be unable to appreciate the confines to which risks are more tolerable in an operational context. In extreme cases, soldiers may even end up subscribing to the over-zealous approach described by the "*Missionitis*" syndrome – the tendency to accomplish the mission no matter the costs.

### 5.3.5 Perceived Desirability of Risk-Taking

The fifth and final dimension of risk assessment suggested by Chua is the "*Perceived Desirability of Risk-Taking*". An individual may assess certain risks to be socially desirable due to his or her perceived potential "*benefits*" to be gained by taking the risks. Often, the perceived rewards tip the balance between safety considerations and competing priorities, to the extent that the former is accorded secondary importance.

Lawrence's psychological research on driving behavior has produced extensive evidence that safety is only one of the many considerations that confront an individual when making a risk

decision (Lawrence, 1998). Chua adds that while the extent of the willingness to compromise safety varies from person to person, the decision to take a risk will inevitably feature social considerations, namely, the impact on self-esteem, convenience and efficiency as discussed below:

(a) Impact on Self-Esteem

Pertaining to self-esteem, if risk-taking is perceived favorably as a display of courage, ability or strength, while risk-aversion is regarded as a sign of fear or weakness, the anticipated “*social costs*” can convince a person that the risk ought to be taken. The fear of losing self-esteem is supported by research showing that there is a common tendency for new drivers to take risks while driving in a brazen display to their friends of their newfound capability (Bobson and Keegan, 1999).

(b) Personal Convenience

The desirability of taking a risk may be encouraged if the risky approach serves to minimize the effort required to complete the task at hand. Chua provides an example in the military context where despite the existence of safety regulations, driver guides often fail to perform their required duties of disembarking from the vehicle to guide a reversing vehicle in hazardous terrain which frequently results in unnecessary incidents.

(c) Task Efficiency

Related to convenience, the risky approach will be especially attractive if it increases mission efficiency. For instance, research in the commercial aviation domain found that pilots took more risks when they hoped to return home earlier for the Christmas holidays (Driskill et al, 1998). This is also evidence in the everyday context where taxi drivers the world over choose to drive more quickly and dangerously so that they can arrive at their destination faster and take on new passengers.

Chua supplements the discussion by adding that the perceived desirability of risk-taking as influenced by the range of perceived rewards described above may provide the impetus for individuals to engage in risk-taking behavior which has indirect consequences on safety. The effects of these existing social forces suggests that safety initiatives that require considerable time and effort are likely to be futile as they fall victim to the very reasons why risk-taking is deemed to be desirable. To make his point, Chua provides an example where water sources, if set up at inaccessible locations during training, are unlikely to be effective in preventing heat injuries, since soldiers may not be willing to invest the extra effort to replenish their water supplies. In contrast, measures that are built into systems and equipment, which as a result require no time and effort on the part of the human agents, tend to be more effective as a means to reduce training risks. A prime illustration provided by Chua is the installation of speed warning devices on vehicles which is seen to be a key reason for fewer military vehicle accidents due to speeding. In the same vein, safety measures perceived to result in the loss of self-esteem are unlikely to be complied. Shaw provides evidence that that soldiers are willing to take risks in order to avoid what may be regarded as by their peers as exhibiting “*Unsoldierly*” behavior (Shaw, 1987). Therefore, the derivation of a complete understanding of training safety requires a clear recognition that the forces of perceived desirability possess the capacity to negate the effectiveness of safety measures.

## **5.4 Conclusion**

Human's play a key role in the chain of events leading to an accident. Open literature has also provided fresh insights and perspectives about the physiological (competency and concentration) and psychological (cautiousness) dimensions of an individual's risk-taking proclivity. This enriched the body of knowledge available for me to draw upon when conceptualizing my System Dynamics (SD) models. Most of the areas discussed above have been directly applied in my SD models. For those areas that are not utilized, these areas serve as good starting points for future research, either for me or anyone else interested in similar research.

## CHAPTER 6: MANAGEMENT – THE INFLUENCE OF ORGANIZATIONAL POLICIES AND PRACTICES ON SAFETY

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### 6.1 Introduction

There is an increasing awareness amongst the military, industry and academia on the vital role that organizational policies and practices play in influencing safety. Chapter 6 summarizes the literature review findings pertaining to both public and private sectors along two main tracks: (1) broad survey of organizational factors affecting safety and (2) how management can put in place safeguards against the factors that influence an individual's risk-taking behavior that were discussed in Chapter 5. This research further enriched the body of knowledge for developing and interpreting the System Dynamics models.

### 6.2 Academic Views on the Importance of Organizational and Management Factors in Accident Analysis

The significance of organizational factors in influencing accidents started to gain acceptance in the Seventies (Powell et al, 1971). Perrow has argued that accidents cannot be extirpated because of the human desire to introduce increasingly complex and tightly coupled technologies (Perrow, 1999). On the other hand, Johnson notes that not all accidents stem from the economic pressures for technological innovation. For example, the stubborn nature of heat-related military injuries points to a less sophisticated form of “*normal accidents*”. These accidents stem from pressures within the organization that cause individuals to escape the lessons of the past (Johnson, 2003). Díaz and Cabrera found from their literature review that there are indications that low-accident companies were eminently better than high-accident companies in terms of the management's commitment to safety, in employee training, standard of selection procedures, absenteeism and turnover (Díaz and Cabrera, 1997).

Rasmussen notes that the behavior of employees is conditioned by the conscious decisions made by work planners or managers. Managers are often in positions of more “*in power of control*” than an operator in the dynamic flow of events. However, their decisions may not be considered during a causal analysis after an accident because they are “*normal events*” which are not usually represented in an accident analysis. Furthermore, the role of management can be missed in analysis because they are to be found in a conditioning side branch of the causal tree, not in the path involved in the dynamic flow (Rasmussen, 1990). Therefore, the present concept of “*power of control*” should be reconsidered with a clear recognition of management involvement in the dynamic chain of events.

In Reason's model of accidents (Reason, 1993), he noted that organizational factors that weaken an organization's defenses against accidents by creating “*latent pathways*” to accidents can be proactively identified and corrected. The following sections are an attempt to leverage the vast amount of research that has been performed over the years on identifying organizational factors that influence safety.



## 6.3 Organizational Factors Affecting Accidents

### 6.3.1 Workload Management

For any process improvement program (e.g., quality or safety enhancement), workload management is an important area for managers to focus on in order to derive the program's desired benefits, if at all. This is because process improvement programs invariably involve a significant investment of time for employees to be trained or become accustomed to the new work processes. During this learning phase, employees' productivity would inevitably suffer a temporarily decline as they have less time to focus on their tasks proper. The following sections elaborate the importance of workload management in any process improvement program.

#### 6.3.1.1 Study of Quality Improvement Programs

In their study of the dynamics of quality improvement programs in organizations, Repenning and Sterman found that when such programs are introduced, workers experience increased schedule pressure due to two reasons (Repenning and Sterman, 1997). The first reason for schedule pressure is that employees' workload is often not reduced proportionately with the time that they have to spend learning the new tools or processes of the improvement program. Secondly, managers, not recognizing this trend as a case of a worse-before-better phenomenon, tend to view the decline in employee productivity as counterintuitive to the improvement program, thereby concluding that the decline is due to their workers slacking off. Managers respond by exerting even greater schedule pressure on their employees through actions such as calling in more often to check on progress, demanding more often work progress updates, etc. Repenning and Sterman found that while increasing production pressure has the desired effect of increasing productivity in the short run, it also yields a long run side effect. Workers under great scrutiny from management and greater pressure to make production goals have less time to attend improvement team meetings and are less willing to undertake experiments that require temporary reductions in throughput. The reduction in effort dedicated to process improvement means that fewer process problems are corrected, and the work defect introduction rate rises. Process throughput falls and managers respond more drastically by increasing surveillance, adding more detailed reporting requirements and increasingly bureaucratic procedures thereby exacerbating the problem. As production pressure and management controls increase, they may also begin to conflict. Workers are caught between ever higher throughput goals and the need to comply with stricter control measures. Under time pressure and faced with multiple, incompatible objectives, Repenning and Sterman found that employees typically respond by eroding standards, cutting corners, taking risks, failing to follow up and resolve problems, and failing to document their work. They will keep these workarounds secret from management and manipulate metrics to appear to be meeting both throughout objectives and satisfying the control structure when they in fact are not. These actions undermine the objectives of the initial process improvement programs often leading to their premature and unhappy abandonment.

### 6.3.1.2 Study of Quality Erosion in the Service Industry

Oliva and Sterman found in their study of quality erosion in the service industry that employees respond to work pressure by adjusting their behavior to meet throughput expectations (Oliva and Sterman, 2001). These behavioral adjustments can be manifested in two ways. First, workers regulate service or quality levels according to the prevailing throughput requirements. For instance, employees tend to cut service or quality levels in order to increase throughput. Secondly, another way that employees attempt to deal with high work pressure is to increase their work intensity by taking shorter breaks or working overtime. Increasing their work intensity produces short term benefits of increased productivity. However, these actions are not sustainable in the long run as fatigue and motivational issues will set in and if left unchecked will exacerbate the situation.

### 6.3.1.3 Other Literature Findings on Schedule Pressure

Rasmussen notes that the behavior in work of individuals and consequently also of organizations is by definition oriented towards the requirements of the work environment as perceived by the individual (Rasmussen, 1990). He adds that humans typically seek the way of least effort to complete their tasks.

Abdel-Hamid and Madnick found that productivity is also influenced by how tight or slack a project schedule is (Abdel-Hamid and Madnick, 1989). If a project falls behind under a tight schedule, workers often decide to work harder in an attempt to compensate for the perceived shortage and bring the project back on schedule. Conversely, man-day excesses could arise if project management initially overestimates a project; as a result, the project would be perceived ahead of schedule. Boehm notes that when such a situation occurs, "*Parkinson's law indicates that people will use the extra time for... personal activities, catching up on the mail, etc.*", which means that they become less productive (Boehm, 1981).

Leveson and Cuther-Gershenfeld also found that schedule pressure was one of the key contributors that compounded the system safety oversights of National Aeronautics and Space Administration (NASA) that unfortunately culminated in the Columbia space shuttle accident (Leveson and Cuther-Gershenfeld, 2004). The schedule pressure faced by the space shuttle project team created a mindset that dismissed all warning signals and safety concerns. This type of culture is often called a "*culture of denial*" where risk assessment is unrealistic and credible risks and warnings are dismissed without appropriate investigation.

Lyneis et al observed that what is measured and rewarded in an organization drives behavior (Lyneis et al, 2001). If adherence to schedule is all that is monitored, then people are likely to focus their energies to meet the schedule regardless of its impact on quality, cost and safety. However, they caution against the other extreme where too many conflicting factors are monitored (e.g., cost, schedule, and quality), then either staff become demoralized and ignore them all or they shift emphasis from one to another in response to the current crisis. Therefore, designing a reward system in advance can help assure achievement of an organization's strategic objectives.

#### 6.3.1.4 Summary of Key Learning Points

DeMarco sums it up succinctly when he said that, “*People under time pressure don’t work better, they just work faster and a casualty of this behavior is reduced quality*” (DeMarco, 1982). From the case studies and literature review, it is evident that regulating the effect of schedule pressure on employees is a crucial aspect of organizational management. All process (safety, quality, etc) improvement programs necessarily involve substantial time investment on the part of their staff during the introduction and ramp up phases. Most improvement programs are characterized by a worse-before-better phenomenon in work output. Managers must recognize that a decline in work productivity is unavoidable and provide for its occurrence. Otherwise, not only would the initial objectives of the improvement program be undermined, the situation could also become worse than what it originally was before the introduction of the program.

### 6.3.2 Safety Culture

#### 6.3.2.1 Definitions

Harrison defines organizational culture in terms of the beliefs and values of the organization, which act as prescriptions for the way in which organizational members should work (Harrison, 1972). Similarly, Zohar defines organizational climate as a set of molar perceptions, shared by individuals with their work environment, which are valid as reference for guiding behavior in the execution of tasks during day-to-day eventualities (Zohar, 1980).

Clarke notes that “*Safety Culture*” may be perceived as a subset of organizational culture, where the beliefs and values refer specifically to matters of health, safety and risk management (Clarke, 1999). Schein (1992) suggests that the way in which senior managers instruct, reward, allocate their attention and behave under pressure, will be particularly salient in shaping organizational culture. Employees’ perceptions of senior managers’ attitudes and behaviors in relation to the safety and wellbeing of the workforce, therefore, will form the basis for the safety behavior of workers, and therefore, the safety performance of the company.

#### 6.3.2.2 Nurturing of Safety Culture within an Organization

The Canadian Department of National Defense recognizes the importance of safety culture in strengthening an organization’s resilience to accidents by noting that “*unless management creates a safety culture based on risk management and unless supervisors instill this workplace ethos in their workers... and then enforces this view consistently, we will never break the chain and accidents will continue to occur*” (Canadian Department of National Defense, 1999). Supporting this recognition is a study by Díaz and Cabrera on safety climate as an evaluation measure of organizational safety. They found results consistent with those of Zohar (Zohar, 1980) in which safety climate appears to be related to the general safety level in the organizations studied (Díaz and Cabrera, 1997).

Reason suggests that safety culture can be “*socially engineered*” by way of reporting systems and management practices that encourage documentation of near misses (Reason, 1998). However, others have argued that the implementation of a culture of safety is not such an easy task as discussed below.

Linking anthropological and organizational perspectives on culture, Schein (Schein, 1992) presents a three-tiered model consisting of cultural artifacts that are visible on the surface; a middle level of stated rules, values, and practices; and an often invisible, but pervasive, underlying level of deep cultural assumptions. Culture change is difficult, Schein notes, because it requires change at all three levels and each is progressively harder to address.

A great body of research also indicates that, once formed, people’s beliefs change very slowly, and are extraordinarily persistent in the face of contrary evidence (Nisbett and Ross, 1980). Initial impressions tend to structure the way that subsequent evidence is interpreted. New evidence appears reliable and information if it is consistent with one’s initial beliefs, whereas contrary evidence is easily dismissed as unreliable, erroneous or unrepresentative (Solvic et al, 1981). Leveson and Cuther-Gershenfeld agree by warning that trying to change culture without changing the environment in which it is embedded is doomed to failure. Superficial fixes that do not address the set of shared values and social norms, as well as deeper underlying assumptions, are likely to be undone over time (Leveson and Cuther-Gershenfeld, 2004).

### 6.3.2.3 Management Commitment to Safety

Díaz and Cabrera found that one of the most crucial elements of an organization’s safety climate is the company’s policies towards safety (Díaz and Cabrera, 1997). These policies include features such as an emphasis on compliance with safety standards, feedback on performance, assignation of funds and resources to safety areas, the importance of safety training, management commitment to safety, etc. Management commitment to safety has been cited by various authors as the most critical element in a successful safety program (Cohen, 1977; Zohar, 1980). The findings of Díaz and Cabrera also stressed the importance of management commitment to safety. However, their other key finding was that in most organizations, the organizational philosophy is biased either towards productivity or safety. Only in rare organizations does this dichotomy not exist and both productivity and safety are considered to be compatible. Díaz and Cabrera acknowledge balancing productivity and safety is inherently difficult. Nevertheless, it is important for management to present a consistent message about safety to their employees and also to strive for a balance in their push for both productivity and safety.

Clark also found that a key feature of a company’s safety culture is the shared perceptions amongst managers and staff concerning the importance of safety (Clarke, 1999). She argues that accurate intergroup perceptions are essential to the development of mutual trust and understanding between levels, which forms the basis for a positive safety culture. However, the development of a shared perception of the importance of safety between different echelons of an organization is not trivial. This is because employees are likely to have little direct evidence of managerial attitudes. Rather, first-line supervisors will provide the staff’s primary point of contact with the management structure, and therefore, supervisors’ behavior and expression of

views will influence the development of staff's opinions about management and their policies (Clark, 1999). Staff will interpret their supervisors' behavior to represent what the organization "really wants" from its employees. Agreeing, Leather notes that intentions communicated in this way are not always consistent with those projected in official company safety documents (Leather, 1987). Therefore, as Waring states, although positive safety attitudes at senior management level are essential in developing a positive safety culture, it cannot be assumed that such attitudes will cascade through the organization. The development of safety culture should not be viewed as a separate issue, but one that forms and integrative part of the wider organizational culture (Waring, 1996).

### 6.3.3 Incident Reporting Systems

The desire for early warnings that our systems are becoming dangerous has led to interest in incident and near miss reporting systems. Incident reporting systems also provide an important means of learning from failure across a spectrum of safety-critical applications. For example, British Airways operate their confidential British Airways Safety Information System (BASIS) reporting system. The NASA safety reporting system gathers mishap information from across their diverse operations. In the medical domain, the Australian Patient Safety Foundation, the US National Patient Safety Foundation and the UK National Patient Safety Agency all either operate or are establishing national incident reporting systems.

#### 6.3.3.1 Benefits of Incident Reporting Systems in Risk Management

Incident reporting helps all of the activities in the risk management framework described in Chapter 2. For example:

- (1) Accounts of previous adverse events or near miss incidents can directly inform the identification of potential hazards.
- (2) Incident reporting also serves to provide feedback on existing control measures as accounts of previous mishaps often describe ways in which existing barriers failed. This enables safety officers to refine existing measures that are intended to prevent the causes or mitigate the consequences of adverse events.

#### 6.3.3.2 Implementation Challenges of Incident Reporting Systems

Johnson found from his evaluation of existing information systems (such as those mentioned above) that these systems share many common challenges (Johnson, 2003). For instance, it can be difficult to elicit information about near miss events when individuals are concerned that their actions might invoke disciplinary actions either on themselves or others. Similarly, once mishaps have been reported, there are few guarantees that different investigators will identify similar causal factors for similar incidents. This is because outcome measures cannot be directly used to assess the criticality and lessons to be learned of near-miss incidents. The fact that an adverse event was avoided forces investigators to make crude estimates of the "*worst plausible outcome*".

Johnson also noted that military incident reporting systems face a number of additional problems. For instance, the military command structure can make it difficult to sustain promises of confidential, blame-free reporting. This breeds an aversion in servicemen to report near misses which is a significant barrier because other civilian incident reporting systems have identified such assurances as a prerequisite for the development of trust in any reporting application (Johnson, 2002). Agreeing, Madnick and Minami found that in the US Army, most soldiers believe that the purpose of an accident investigation is to assign blame and are thus likely to remain silent (Madnick and Minami, 2007). These perceptions and resulting actions discount the effectiveness of the organization's learning process especially when people most directly involved in the accident that have the most important information to share are not stepping forward. Therefore, Madnick and Minami suggest that the US Army should consider adopting a new approach to accident investigations that focuses on organizational learning in lieu of assigning blame.

Cook and O'Connor cautions that the value of incident reporting systems in providing lead indicators for impending accident remains speculative (Cook and O'Connor, 2005). History has shown that even relatively strong danger signals such as the partial collapse of the Texas A&M University bonfire structure in 1994 or the partially burned O-rings from shuttle boosters before the Challenger space shuttle mission can be misinterpreted (Vaughn, 1997). Equally strong counterbalancing forces usually exist to attenuate the strength of the warning signals, most notably the pressure to make systems economically efficient. Cook and O'Connor note that before an accident, proponents of safety measures find themselves in a difficult position. The various warning signals usually do not herald a specific failure and as a result, their efforts to improve safety appear diffuse and general in character.

### 6.3.3.3 Success Factors of Incident Reporting Systems

As discussed in the earlier section on the perceived management commitment to safety, Clarke demonstrates in her research (Clarke, 1996) that perceived managerial commitment to safety is predictive of incident reporting by staff, with those who perceived their managers as not being committed to safety, less likely to make reports. This observation is corroborated by Leveson and Cuther-Gershenfeld in their research on the Columbia space shuttle disaster. They found that for effective communication of safety information, there must be a culture of openness and honesty where everyone's voice is valued. Employees need to feel they will be supported by management if they raise safety concerns; managers need to display leadership on safety issues and eliminate barriers to dissenting opinions (Leveson and Cuther-Gershenfeld, 2004).

### 6.3.4 Organizational Learning

The importance of organizational learning from incidents and accidents was mentioned in the previous section. To reiterate, incidents and accidents serve to reduce the likelihood and mitigate the consequences of future accidents by providing the feedback that is necessary to avoid recurrences of adverse events. This section summarizes some of the other research findings on the role of organizational learning in enhancing safety.

In his studies of lessons to be learnt from seven space shuttle incidents, Goodman noted that unless lessons from other shuttle programs are studied and heeded, risks to technology integration, resources and schedule may not be effectively mitigated (Goodman, 2007). Goodman argues that the technical and organizational causes of problems encountered tend to be common across a wide range of disciplines in the aerospace industry. Therefore, the acquisition and dissemination of well-written lessons learned and formal accident investigation reports can assist technical and management personnel to identify opportunities for improvement at both the technical and management levels. Leveson agrees by adding that many serious accidents and losses can be traced to the fact that a system did not operate as intended because of changes that were not fully documented, coordinated or fully analyzed to determine their effects. Therefore, it is important for organizations to maintain a record of intent so that the entire organization can understand the rationale behind important decisions, without which there is a chance that key safety decisions can be unwittingly undone (Leveson, 1995).

When organizations are confronted with novelty, the common strategy often entails enlarging the repertoire of organizational responses, building resilience and its ability to cope with “*surprises of the moment*” (Weick, Sutcliffe and Obstfeld, 1999). Other organizational theorists on the other hand argue that people must step back from the situation at hand, revisit their core assumptions, reframe the situation, recombine existing procedures and routines into alternative responses (e.g., improvisation), and engage in some type of higher-order evaluation, such as double-loop learning (Argyris and Schön, 1974). In their analysis of disaster dynamics, Rudolph and Repenning suggest that the ability to cultivate both sets of skills (double-loop learning and unquestioned adherence to preexisting routines) and recognize the conditions under which each is appropriate is unlikely to improve with experience solely in non-crisis situations. The irony is that the lessons people learn before they cross the tipping point of a disaster are likely to misguide them once a crisis is underway. This is because experience uninformed by a thorough understanding of how a nonlinear system behaves under different conditions is unlikely to prepare people for the increased pace, discontinuous changes, and tighter coupling that characterizes a system beyond its tipping point (Rudolph and Repenning, 2002). This suggests that the process of learning from past incidents and accidents to build up accident resilience is not a means to an end. Rather, it is part of a larger continuous process where evolving conditions will introduce new accidents and new lessons will emerge.

In the same vein as Rudolph and Repenning, Cook and O’Connor opine that predicting the next accident is difficult and in some sense impossible (Cook and O’Connor, 2005). They argue that the reason is because the specific accidents we foresee clearly are prevented but it is the ones we cannot foresee that occur. As such, the next accident will more often than not be different than the last one. However, this does not suggest that organizations should do away with learning from past accidents. Even if we are unable to predict the next accident, we may still be able to anticipate some characteristics of future accidents to reduce their probability of occurrence or attenuate their effects. Therefore, organizations must persevere with their accident investigation and learning initiatives.

### 6.3.5 The Fallacy of Training

Increasing training to raise the competency level of individuals is one common course of action that an organization can undertake to increase the accident resilience of its people. However, Johnson highlights an important fallacy that training can have on individuals.

In the context of military training, exercises are often carefully designed so that any exposure of servicemen to risks occurs under controlled circumstances. These simulated operations are choreographed; the position of every participant and every system is often predetermined down to the last second (Johnson, 2003). Unfortunately, training mishaps can still occur even under such carefully controlled conditions. This is because soldiers are often pre-trained by undergoing several “*dry runs*” or simulations before the conduct of the actual training exercise. Johnson notes that while such “*dry runs*” are necessary to lower the execution risk of the actual exercise especially when dealing with explosives or ordnances, being subjected to excessive simulations can also render soldiers to become overly mechanical when executing their missions so much so that they lose the ability to deal with exceptions that may occur during the actual training exercise. In addition, as discussed in Chapter 5, training under conditions that are overly rigid may impart an optimism bias to soldiers due to the “*Control Illusion*” which exaggerates their perceived ability to cope with risks.

Johnson also notes that excessive repetitious training can also induce fatigue, boredom and inattention that undermine the good intentions of training. Therefore, while training simulations can be exploited to better predispose soldiers to perform successfully their tasks under combat conditions, such exercises cannot provide guarantees that future mishaps will not occur.

### 6.3.6 System Safety Teams

Leveson offers some basic principles that are important in ensuring the effectiveness of a system safety organizational structure (Leveson, 1995). These principles are:

- (1) System safety needs a direct link to decision-makers and influence on decision-making (influence and prestige);
- (2) System safety needs independence from project management (but not engineering);
- (3) System safety needs direct communication channels to most parts of the organization (oversight and communication).

In their study of the Columbia space shuttle accident, Leveson and Cuther-Gershenfeld note that the system safety team within an organization must not only be given responsibility and accountability for safety. The team must also be given the authority necessary to execute that responsibility effectively by serving as sources of questions and challenges (Leveson and Cuther-Gernshenfeld, 2004). Additionally, proper recognition must be accorded to safety teams. Management must avoid cases where safety engineers are stigmatized, ignored and ostracized by the rest of their colleagues.



## 6.4 Management Actions to Curb an Individual's Risk-Taking Propensity

This section is a follow-up to the individual risk-taking psychology section in Chapter 5. Based on the findings from Chua (Chua, 2004), this section suggests possible management actions to rein in an individual's risk-taking propensity in the context of military operations.

### 6.4.1 Correcting Erroneous Perceived Probabilities of an Accident Occurrence

Chua argues that in relation to cognitive distortions, the channels of prevention are necessarily through education, as opposed to regulations or enforcement. The most direct measure is to educate soldiers by increasing their awareness of their natural tendency to rely on the “*Availability*” heuristic when making risk assessments which may lead to flawed perceptions on the likelihood of an accident occurrence. In doing so, soldiers will be better predisposed to recognize their potential for perception errors and challenge their underlying assumptions when faced with risky situations (Redmill, 2002). Chua adds that this is pertinent in the military context because of two reasons. Firstly, people often rely on such heuristics without conscious awareness. Secondly, soldiers tend to be “*action-oriented*”, preferring doing from thinking, which renders them particularly vulnerable to using heuristics as a timesaver.

Beyond efforts to generate awareness about the “*Availability*” heuristic, military personnel may also be taught techniques for rational probability risk assessments. This involves educating them to rely on statistical information, which albeit abstract, is more accurate than availability judgments (Heuer, 1999). Chua notes that at the organizational level, the compilation and dissemination of accident statistics, including causes and frequency of occurrences, will be invaluable for soldiers' risk assessments by minimizing their reliance on the “*Availability*” heuristic.

### 6.4.2 Preventing Accident Severity Misjudgments

In view of how misperceptions of severity emanate predominantly from unconscious cognitive and emotive forces, an awareness of their presence and influence is probably the best defense. At the operational level, educating personnel about their cognitive fallacies may again be the most effective way to alleviate their cognitive distortions. At the strategic level, enforcement strategies can be undertaken to complement educational measures.

Independent third parties can be appointed to audit decisions on risk assessments, with the objective of detecting risk assessments that are made under the influence of distorted severity judgments. This is based on the belief that independent parties, who are detached from the activity being appraised, will be less influenced by the effects of dreaded, unfamiliar and latent risks. Therefore, their assessments will be less emotive and more objective. Furthermore, unlike the primary assessor who is disposed to assimilate information from the other dimensions of risk assessment, a third party can focus his/ her appraisal solely on the dimension of perceived severity to ascertain the validity of the rationalization process. Therefore, together with the measures aimed at generating awareness amongst personnel, having an additional and

independent layer of verification will safeguard against distortions in perceived severity and facilitate management of safety at the strategic level.

### 6.4.3 Reducing Overconfidence in Being Able to Cope with a Risky Situation

Strategies conceived to improve training safety must be cognizant that risk-taking decisions may emanate from an over-rated self-ability to cope with a risky situation. Chua proposes the institution of several measures to reduce accidents that arise as a result of distortions to perceived self-ability. Firstly, as with the other dimensions of risk assessment, education is one of the key measures in teaching soldiers to estimate their coping and response abilities more accurately, by recognizing the potential fallacies associated with the “*Control Illusion*” and experience. Secondly, as a complement to educational measures, complacency and desensitization can be minimized by enforcement measures, such as supervisory mechanisms or surprise checks and inspections, geared towards the identification of risk assessment that may have been distorted by misperceptions of self-ability. Finally, to overcome the effects of control illusion, individuals should be primed to the common scenarios under which feelings of invulnerability may arise, before the commencement of an activity. For example, prior to vehicular movement, drivers ought to be reminded that actions such as speeding, tail-gating, and lane-changing or overtaking under heavy traffic conditions, are all manifestations of the “*Control Illusion*” to varying extents.

### 6.4.4 Regulating the Perceived Necessity of Risk-Taking Behavior

Johnson notes that many military operations carry an intrinsically high level of risk. Even if hazards are identified, in many cases it is impossible to entirely eliminate the potential hazard from occurring without also sacrificing military objectives (Johnson, 2002). Therefore, in consideration that risk-taking must continue to be a necessary feature of training and operations, measures will have to be put in place to ensure that the emphasis does not lead to undue compromises to training safety.

As part of safety educational measures, soldiers may be coached on how to sensibly discern the impact of risk-aversion on the achievement of training objectives and mission accomplishment. This requires an explication of the different sets of considerations that will pertain during actual combat operations as opposed to training, as well as the boundaries for risk-taking behavior during operations. These efforts should be supported by legislative measures that stipulate clear guidelines and criteria for calling a halt to training or the withdrawal of a mission so there be a breach of regulations. Contemporaneously, in order to forestall situations in which the pursuit of training realism may lead to unacceptable safety compromises, particular attention should be paid to activities that are intrinsically prone to over-zealousness by soldiers. These include the various forms of endurance training that soldiers have to undergo, as well as two-sided exercises that pit opposing forces against each other. Finally, potential benefits can be gleaned from moderating the spirit of “*gung-hoism*”, especially if it is blindly pursued, though this must be achieved without diluting the operational mentality of soldiers. As stated by the US Army, leaders must reemphasize to soldiers that when encountering an unsafe situation, the mission must now become safety (US Army Safety Center, 2001).

#### 6.4.5 Moderating the Perceived Desirability of Risk-Taking

Chua states that to derive a complete understanding of training safety, the forces of perceived desirability must be recognized to possess the capacity to negate the effectiveness of safety measures. The fact that the perceived desirability of risk-taking may translate into actual risk-taking behavior indicates that the regulations in force may not be sufficient, or enforcement of these regulations may be ineffective.

As a pre-requisite, regulations must be stated clearly to provide an unambiguous reference to what constitutes acceptable or unacceptable risks. In turn, given that people take risks when the anticipated benefits are perceived to outweigh the costs involved, the enforcement aspect can be strengthened either by increasing the potential costs associated with risk-taking, or by increasing the expected benefits for risk-aversion. Specifically, this can be achieved by introducing disincentives for risk-taking (e.g., meting out of disciplinary punishment) and introducing incentives for risk-aversion (e.g., rewarding the preservation of an accident-free record). Additionally, concurrent measures in the areas of policing and supervision will have to be strengthened. Otherwise, punitive measures will have negligible effects on behavior if the possibility of detecting violations is remote. Finally, by keeping a personal accident record for every soldier and maintaining it throughout his career, “*high-risk*” personnel who frequently take risks as a result of the social rewards may be identified for extra attention. Such measures will go a long way in ensuring that the social forces involved in the perceived desirability of risk-taking will be prevented from exerting any serious consequences on training safety.

### 6.5 Conclusion

The literature review on organizational factors or issues pertaining to safety enriched the body of knowledge for me to draw upon when conceptualizing my System Dynamics models. As with Chapter 5, most of the areas discussed above have been directly applied in my SD models. For those areas that are not utilized, these areas serve as good starting points for future research, either for me or anyone else interested in this research.

## CHAPTER 7: INTRODUCTION TO SYSTEM DYNAMICS

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### 7.1 Introduction

Accelerating economic, technological, social, and environmental change challenges managers to learn at ever increasing rates. More so than ever, managers must learn how to design and manage complex systems embodying multiple feedback effects, long time delays and nonlinear responses to their decisions. Yet learning in such environments is difficult because managers never confront many of the consequences of their most important decisions (Morrison, 2007). Additionally, humans suffer from “*Bounded Rationality*” (Simon, 1981) where our cognitive capacity (memory and ability to process information) is unreliable in handling complexity and dynamic changes that characterize real world problems. Therefore, a systematic process is necessary to assist us to understand the complex relationships that drive complex system behavior. System Dynamics (SD) was developed for this need.

The field of System Dynamics was founded during the 1950s by Professor Jay W. Forrester at the MIT Sloan School of Business and was introduced to the mainstream academic literature in the book “*Industrial Dynamics*” in 1961. SD uses computer simulation models to understand the structure and dynamics of real world complex systems. This allows people to learn more about the often ambiguous causalities of policy resistances and conceive more effective decisions.

System Dynamics is fundamentally interdisciplinary. While it is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics and engineering, SD also recognizes that other fields such as psychology and organizational behavior are as important as the hard sciences in learning about real world complex systems. Therefore, SD combines mathematical analytic rigor with the nuances of social organization artifacts such as ambiguity, time pressure, personalities and politics (Sterman, 2000).

### 7.2 Mental Models

Models are physical (hardware or software) or mental (perceptions conditioned through cultural norms, past experiences, etc) abstractions of reality conceived by the modeler’s existing mental models. Forrester believes that mental models are the basis of all human decision making (Forrester, 1961). Accordingly, the concept of mental models has been central to System Dynamics from the beginning of the field. In SD, the term “*mental model*” embodies the modeler’s beliefs, biases and assumptions about the network of causes and effects that determine a system’s behavior, along with the boundary of the model and the time horizon that the modeler considers relevant.

Despite many of people’s best intentions, flawed mental models created through biases and/ or incomplete knowledge cause them to make decisions that result in failure even when they perceive themselves to be making the right decisions. George Box once said, “*All models are wrong but some models are useful*” (Box, 1979). The principle reason is that no model can completely replicate the events in the real world. Nonetheless, a model structure that is

developed based on real world data enhances its utility in the understanding of real world problems. SD provides a framework for improving mental models about complex systems thereby facilitating people to make better decisions to enact change that will improve the behavior of the system.

### 7.3 Systems Thinking and Double-loop Learning

“*Systems thinking*” is a fundamental mental model used in System Dynamics theory for understanding complex problems. “*Systems thinking*”, as defined by Peter Senge in his book “*The Fifth Discipline: The Art and Science of the Learning Organization*” is a framework for understanding, through a body of knowledge and tools, that the behavior of a system is driven by the relationships and interactions of all parts of a system, not any individual part of the system (Senge, 1990). “*Systems thinking*” enables the identification of individual components of a system and the understanding of how they interact to create causal and often non-linear feedback loops that are often the reasons of counter-intuitive outcomes.

The process of learning is essentially a feedback process. Most people learn through a process of “*Single-loop Learning*” (Argyris and Schön, 1974) where they achieve their current goals in the context of existing decision rules, biases, culture, etc, grounded upon their mental models. The “*Single-loop Learning*” process is illustrated in Figure 7-1 (Sterman, 2000).

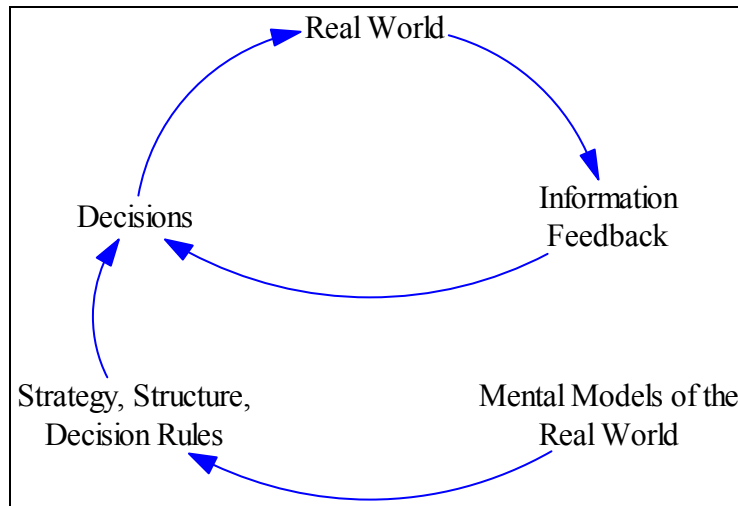


Figure 7-1: Single-loop Learning Process

Argyris argues that individuals and organizations alike should progress from “*Single-loop Learning*” towards “*Double-loop Learning*”. In “*Double-loop Learning*”, feedback from the real world can also elicit changes in existing mindsets. “*Double-loop Learning*” involves the fresh understanding or reframing of a situation resulting in new goals and decision rules, not just new decisions. The essence of the “*Double-loop Learning*” process is captured in Figure 7-2 (Sterman, 2000). The development of “*Systems thinking*” is a “*Double-loop Learning*” process where individuals replace their reductionist, parochial, short-run and static view of the world

with a holistic, board, long term, and dynamic view, and thereafter redesign our policies and organizations based on this enlightenment.

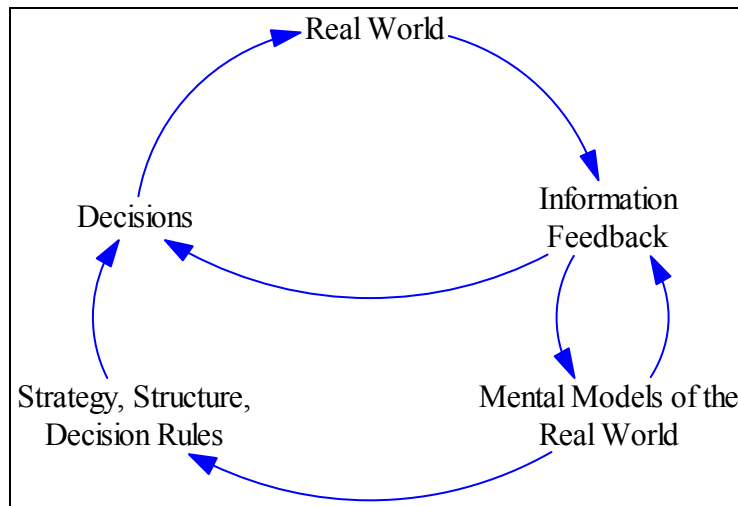


Figure 7-2: Double-loop Learning Process

## 7.4 Tools for Systems Thinking

This section introduces the basic tools of “*Systems thinking*” and System Dynamics.

### 7.4.1 Causal Loop Diagrams

A central concept of System Dynamics theory is that of feedback relationships. Causal Loop Diagrams (CLDs) are used in SD to trace feedback relationships between individual variables within a system that interact to determine system behavior. In most real world systems, its components are in and of themselves not complex. Rather, it is the existence of dynamic interactions and interdependencies between the components that make the system complex. The significance and applicability of the feedback systems concept to managerial systems has been substantiated by a large number of studies (Roberts, 1981). For example, Weick observes that “*the cause-effect relationships that exist in organizations are dense and often circular. Sometimes these causal circuits cancel the influences of one variable on another, and sometimes they amplify the effects of one variable on another. It is the network of causal relationships that impose many of the controls in organizations and that stabilizes or disrupts the organization. It is the patterns of these causal links that account for much of what happens in organizations. Though not directly visible, these causal patterns account for more of what happens in organizations than do some of the more visible elements such as machinery, time clocks*” (Weick, 1979). Rasmussen also comments that the behavior of the complex, real world is a continuous, dynamic flow, which can only be explained in causal terms after its decomposition into discrete events (Rasmussen, 1990). He added that in causal explanations, the level of decomposition

needed to make it understood and accepted depends entirely on the intuitive background of the intended audience.

In System Dynamics models, system variables are linked together by unidirectional arrows with assigned polarities. An arrow with a “+” sign indicates a positive causal relationship between two variables while an arrow with a “-” sign indicates a negative causal relationship between variables. A positive causal relationship exists when, *ceteris paribus*, a change in the first variable of a system causes a change in the second variable in the same direction. Conversely, when a change in the first variable of a system causes, *ceteris paribus*, a change in the second variable in the opposite direction, a negative causal relationship exists. Double slash marks are used on arrows to indicate the existence of time delays for those causal relationships. Loop indicators such as “B1” and “R1” indicate respectively whether the loop is a Balancing (B)/ negative feedback loop or a Reinforcing (R)/ positive feedback loop. In addition, loop identifier numbers (1, 2, 3...) are used to distinguish between loops. Therefore, Loop B1 would be read as “*Balancing Loop 1*”.

#### 7.4.2 Stock and Flows

Another central concept to System Dynamics theory is the representation of system structure in terms of stocks and flows. Stocks capture the accumulation and dissipation of physical (tangible) or informational (intangible) quantities in a system over a period of time. Stocks give systems inertia and provide them with memory. Stocks create delays by accumulating the difference between the inflow to a process and its outflow. By decoupling rates of flow, stocks are the source of disequilibrium dynamics in systems (Sterman, 2000).

The diagramming notion used in SD modeling for stocks and flows is illustrated in Figure 7-3.

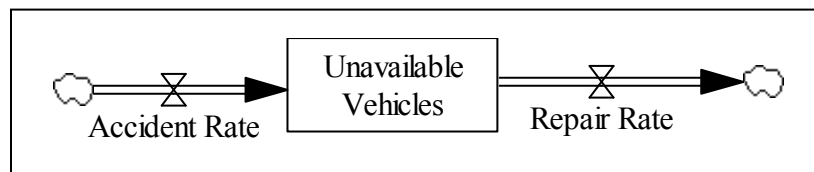


Figure 7-3: Stock and Flow Example

In this example, “*Accident Rate*” serves as the inflow that increases the stock of “*Unavailable Vehicles*” while the “*Repair Rate*” serves as the outflow that depletes the stock of “*Unavailable Vehicles*”. Therefore, if the “*Accident Rate*” is greater than the “*Repair Rate*”, the stock of “*Unavailable Vehicles*” will continue to increase until effort is put in to either decrease the “*Accident Rate*” or to increase the “*Repair Rate*”.

## 7.5 Fundamental Modes of Dynamic Behavior

A system's structure as defined by causal relationships, stocks and flows, delays and their nonlinear interactions between the system's variables determines all observed modes of the system's behavior. It should be emphasized that correlations do not represent the structure of a system. A common misconception is that where a correlation exists between two variables, causality is also present. An example is that of the positive correlation between ice-cream sales and the number of murders. Both ice-cream sales and the number of murders increase in summer and fall in winter. Clearly, increased ice-cream consumption does not cause more murders and vice versa. Rather, one of the causes affecting ice-cream sales and the number of murders is the average temperature. Therefore, confusing correlation with causality can lead to gross misjudgments and policy errors.

A cardinal principle of System Dynamics states that the structure of a system gives rise to its behaviors (Sterman, 2000). This section uses causal loop diagrams to represent system structures that describe some of the fundamental modes of system behavior such as Exponential Growth, Goal Seeking, Oscillation and S-shaped Growth.

### 7.5.1 Exponential

Reinforcing loops react to an initial external stimulus placed on the system by generating growth, amplifying deviations and reinforcing change (Sterman, 2000). An example of a reinforcing/positive feedback loop is shown in Figure 7-4.

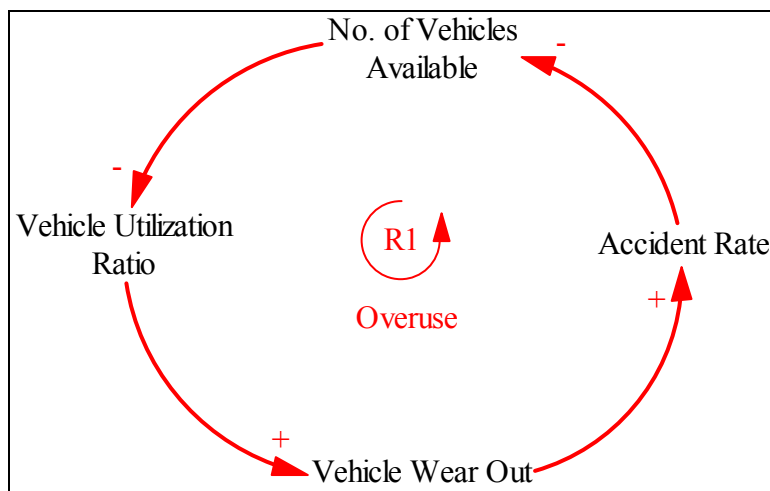


Figure 7-4: Overuse Reinforcing Loop

The **Overuse Reinforcing Loop (R1)** shows that as the “*Accident Rate*” increases, the “*Number of Vehicles Available*” decreases, assuming a fixed repair rate. Over time, this decrease in the “*Number of Vehicles Available*” increases the overall “*Vehicle Utilization Ratio*” assuming that there is no reduction in the number of missions to be executed and that no spare vehicles are



available. The increased “*Vehicle Utilization Ratio*” will, without a concomitant increase in vehicle maintenance, increase “*Vehicle Wear Out*” which in turn will lead to an even higher “*Accident Rate*” due to vehicle malfunctions. In this example, the “*Accident Rate*” increases exponentially over time as shown in Figure 7-5.

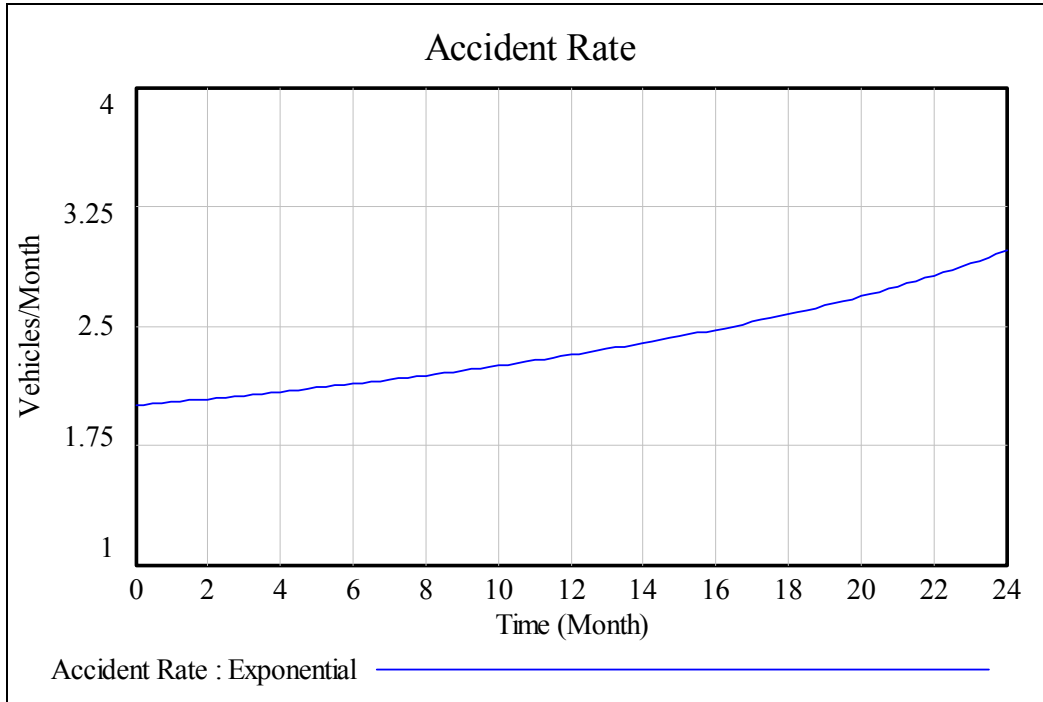


Figure 7-5: Overuse Reinforcing Loop – Exponential Growth System Behavior

It is also important to note that the exponential behavior exhibited by reinforcing feedback loops can be either an increase or a decrease. In System Dynamics parlance, this means that reinforcing loops can be either “*virtuous*” or “*vicious*”. The preceding example describes a case where the Overuse Reinforcing Loop is “*vicious*”, i.e., an increase in the “*Accident Rate*” leads to a further increase in the “*Accident Rate*”. However, consider the case where the “*Accident Rate*” decreases. The “*Number of Vehicles Available*” will correspondingly increase, assuming a fixed repair rate, leading to a decrease in the overall “*Vehicle Utilization Ratio*” assuming that there is no change in the number of missions to be executed. The lower “*Vehicle Utilization Ratio*” will, without a change in the vehicle maintenance rate, decrease “*Vehicle Wear Out*” which in turn will lead to an even lower “*Accident Rate*” as a result of lower vehicular malfunctions. In this case, the Overuse Reinforcing Loop is seen to be “*virtuous*”.

### 7.5.2 Goal-seeking

Balancing loops seek balance, equilibrium and stasis by counteracting the effect of an initial external stimulus placed on the system thereby bringing the system in line with a goal or desired

state (Sterman, 2000). An example of a balancing/ negative feedback loop is shown in Figure 7-6.

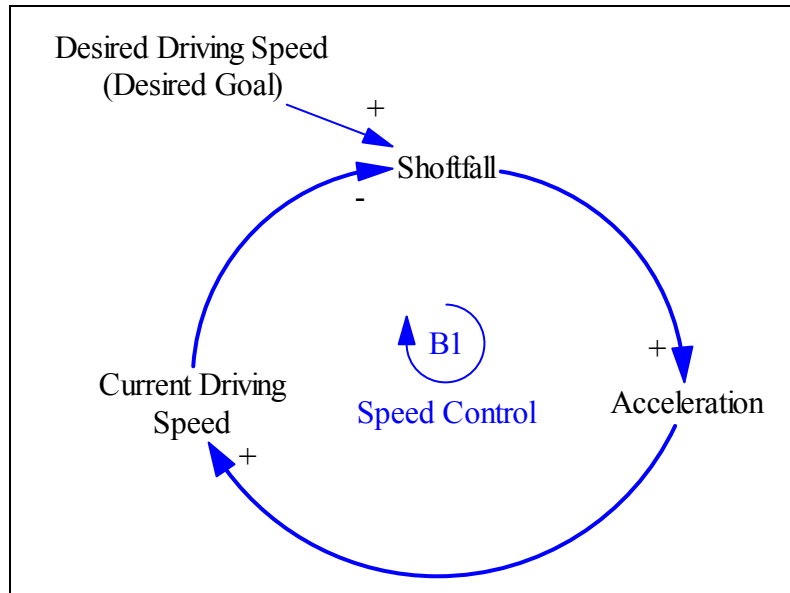


Figure 7-6: Speed Control Balancing Loop

The **Speed Control Balancing Loop (B1)** shows that when the “*Current Driving Speed*” (e.g., 50mph) of a driver is lower than his or her “*Desired Driving Speed*” (e.g., 80mph), the “*Shortfall*” increases. Therefore, the driver reacts by increasing vehicular “*Acceleration*” which increases the “*Current Driving Speed*”. The “*Shortfall*” begins to decrease and the driver reacts by easing his or her foot off the pedal thereby decreasing “*Acceleration*”. When the “*Desired Driving Speed*” is attained, the “*Shortfall*” is reduced to zero and similarly the “*Acceleration*” ceases. This behavior of the “*Current Driving Speed*” over time in such a scenario is shown in Figure 7-7.

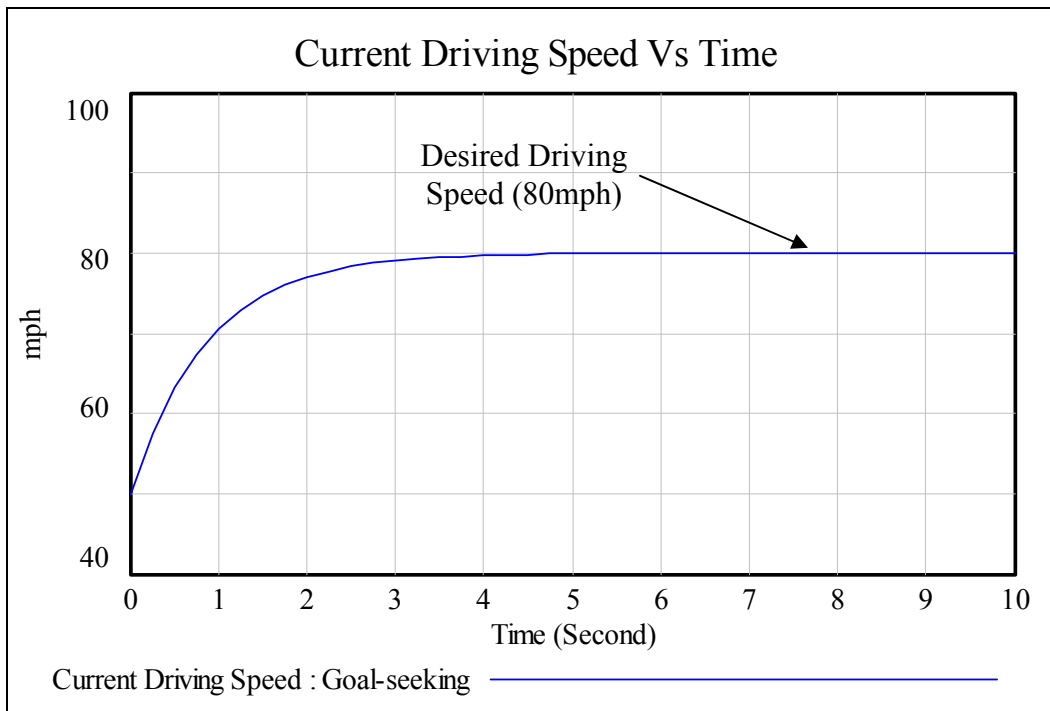


Figure 7-7: Speed Control Balancing Loop – Goal Seeking System Behavior

### 7.5.3 Oscillation

Oscillation is another fundamental mode of behavior observed in dynamic systems. In an oscillatory system, the state of the system constantly overshoots its goal or equilibrium state, reverses, undershoots and so on. Overshooting and undershooting arises from the presence of significant time delays in a negative feedback loop (Sterman, 2000). Figure 7-8 is an example of an oscillating system.

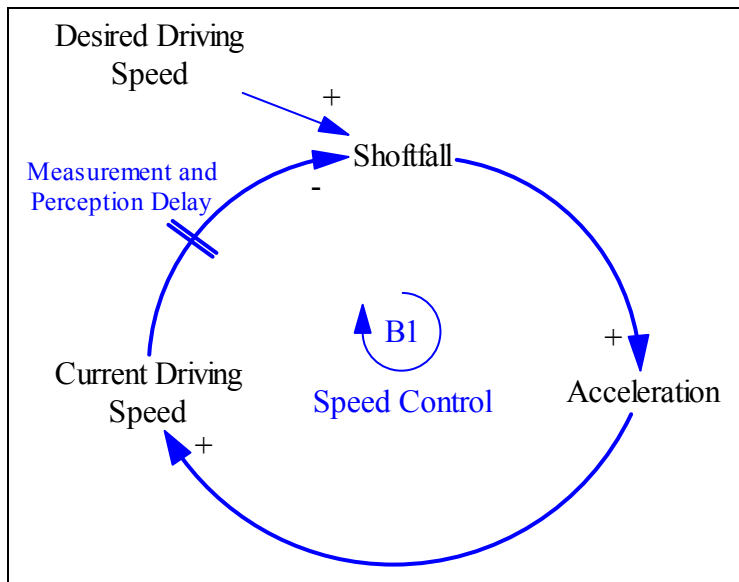


Figure 7-8: Speed Control Balancing Loop with Measurement and Perception Delays

The **Speed Control Balancing Loop (B1)** has been modified to incorporate a perception delay. This delay characterizes the delay for the driver to measure or perceive changes in the “*Current Driving Speed*” from the vehicle’s speedometer. This delay affects the “*Shortfall*” and the vehicular “*Acceleration*” applied, resulting in the “*Current Driving Speed*” actually undershooting slightly, briefly oscillating before arriving at the “*Desired Driving Speed*” as shown in Figure 7-9.

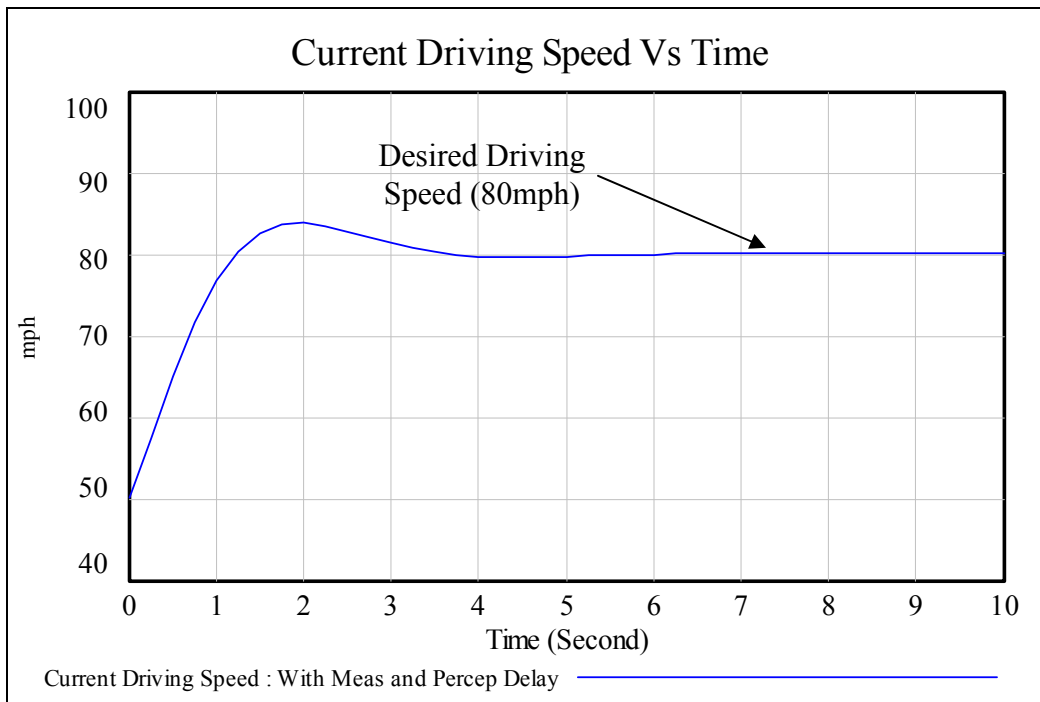


Figure 7-9: Speed Control Balancing Loop with Delay – Oscillating System Behavior

#### 7.5.4 S-shaped

A commonly observed mode of behavior in dynamic systems is S-shaped growth – growth that is exponential at first, but then gradually slows until the state of the system reached an equilibrium level. A system generates pure S-shaped growth only if two critical conditions are met. Firstly, the negative feedback loops must not include any significant time delays (Sterman, 2000). Secondly, a fixed carrying capacity exists. In a system exhibiting S-shaped behavior, there is a shift in loop dominance between the reinforcing and balancing loops in the system. An example of a system exhibiting S-shaped growth is that of the diffusion of a new product to the pool of potential adopters as shown in Figure 7-10.

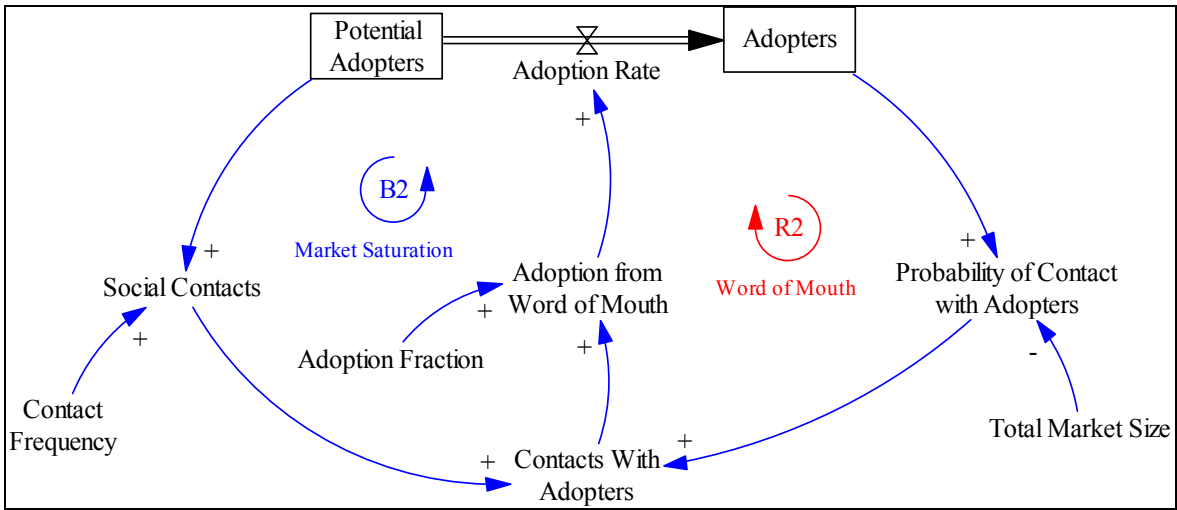


Figure 7-10: Market Saturation Balancing Loop and Word of Mouth Reinforcing Loop

The behavior of the number of “*Adopters*” is S-shaped as shown in Figure 7-11. Initially, the Word of Mouth Reinforcing Loop (R2) dominates and the number of “*Adopters*” sees exponential growth. As time proceeds, a tipping point is crossed where the Market Saturation Balancing Loop (B2) dominates. Therefore, the exponential growth tapers off until all the “*Potential Adopters*” have been converted to “*Adopters*”.

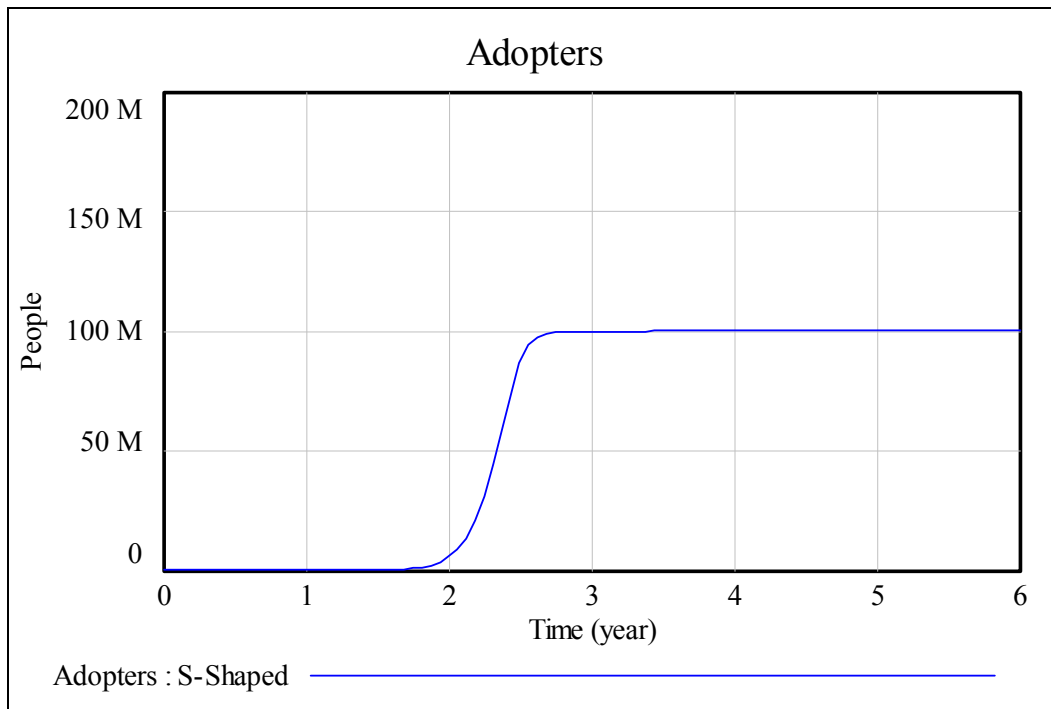


Figure 7-11: Market Saturation Balancing Loop and Word of Mouth Reinforcing Loop – S-shaped System Behavior

## 7.6 Unique Capabilities of System Dynamics Modeling

The unique capabilities of System Dynamics are elaborated in Table 7-1 below (Madnick, 2007; Sterman, 2000):

Capability	Description
<b>Objective Input</b>	Utilizes data to determine parameters affecting the causality of individual cause-and-effect relationships.
<b>Subjective (Expert) Judgment</b>	Represents and models cause-and-effect relationships based on expert judgment.
<b>Intentions Analysis</b>	Identifies the long-term unintended consequences of policy choices or actions taken in the short term.
<b>Tipping point analysis</b>	Identifies and analyzes “tipping points” – where incremental changes lead to significant impacts.
<b>Transparency</b>	Explains the reasoning behind predictions and outputs of the SD model.
<b>Modularity</b>	SD models can be organized into collections of communicating sub-models.
<b>Scalability</b>	Uses its modularity to increase complexity without becoming unmanageable.
<b>Portability</b>	Utilizes the same basic SD modeling structures in different regions of the world without requiring re-formulation.
<b>Focusability</b>	Increases definition in specific areas of the SD model to address specific and possibly new issues.

Table 7-1: Unique Capabilities of System Dynamics Modeling

## 7.7 System Dynamics Modeling Process

The System Dynamics modeling process is an iterative method comprising the following five general steps:

- (1) Problem Articulation: Clarifying and understanding the context of the problem
- (2) Dynamic Hypothesis: Developing mental models to explain the problem
- (3) Model Construction: Synthesizing mental models by constructing a high-level CLD for the problem; continue by developing a low-level model comprising feedback loops, stocks and flows

- (4) Model Testing: Testing the low-level model for errors by running simulations and analyzing the results
- (5) Policy Analysis: Using the model to conduct simulations of several different policies so as to gain insights into their effects

## 7.8 The Importance of Simulation in Modeling

Simulation is substituting for, or imitating, reality (Rechtin, 1991). The complexity of models developed for real world problems dwarfs the average human cognitive capacity to simulate mentally and understand their implications. Hence, computer simulation is the only practical way to test these models; speeding up and strengthening learning feedbacks. Without simulation, even the best conceptual models can only be tested and improved by relying on the learning feedback through the real world, a process that is slow and often rendered ineffective by dynamic complexity, time delays, inadequate and ambiguous feedback, poor reasoning skills, defensive reactions, and the costs of experimentation. The discipline and constraint imposed by the rigorous testing enabled by simulation becomes the only reliable way to test hypotheses and evaluate the likely effects of policies. Otherwise, it is easy for mental models to be driven by ideology or unconscious biases (Sterman, 2000).

## 7.9 System Dynamics Modeling Software

A number of different software applications exist for System Dynamics modeling work. Several commercially available packages for SD simulation include:

- (1) “**MapSys**”, from Simtegra
- (2) “**Powersim Studio**”, from Powersim Corporation
- (3) “**STELLA**” and “**iThink**” from iSee Systems (formerly High Performance Systems)
- (4) “**Vensim**”, from Ventana Systems, Inc

This research used Vensim to create the SD models and to perform simulations.

## 7.10 Applications of System Dynamics Modeling

System Dynamics has been used extensively to model a diverse range of real world systems. Some examples of the use of SD modeling include:

- The study of why software systems development is often plagued with cost overruns, late deliveries, poor reliability and user dissatisfaction that is grounded in the feedback systems principles of System Dynamics (Abdel-Hamid and Madnick, 1989).
- The use of System Dynamics to resolve the apparent paradox of declining measures of cocaine use and rising consumption, crime, arrests and deaths (Homer, 1993).



- An explanation of the dynamics of quality improvement programs in organizations using System Dynamics as a platform to marry the physical and behavioral dimensions that influence the success or failures of these improvement initiatives (Repenning and Sterman, 1997).
- The use of System Dynamics to model how the indiscriminate use of antibiotics increases the ability of bacteria to develop antibiotic resistances (Homer et al, 2000).
- The use of System Dynamics to draw strategic management insights when managing complex projects such as the Peace Shield Air Defense System (Lyneis et al, 2001).
- The application of System Dynamics to show how an accumulation of non-novel interruptions can shift an organizational system from a resilient, self-regulating regime, which offsets the effects of this accumulation, to a fragile, self-escalating regime that amplifies them, which increases the organization's susceptibility to disasters (Rudolph and Repenning, 2002).
- An explanation based on System Dynamics of how schedule and budget pressures lead to the erosion of safety mechanisms and increase in complacency within NASA which ultimately precipitated in the Columbia Space Shuttle disaster (Leveson and Cuther-Gershenfled, 2004).

## CHAPTER 8: DESCRIPTION OF SYSTEM DYNAMICS MODELS

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### 8.1 Introduction

This chapter describes the development of the proof-of-concept System Dynamics (SD) models to demonstrate the methodology's utility is drawing insights into the underlying dynamics behind Organization Sierra-Tango's vehicle accidents during training deployments. The chapter begins with a discussion on some of the typical managerial responses to an increase in accident rate, followed by a general description of the key modeling steps employed. The heart of the chapter is the description of the principle high-level Causal Loop Diagrams (CLDs) that I have developed and found to be most relevant to Organization Sierra-Tango's training context. This is followed by the detailed construction of the CLDs into two SD models. The chapter ends by presenting some of the other high-level CLDs that I have conceived but were not chosen for further detailed development. These CLDs can serve as starting points for further research and modeling.

### 8.2 Typical Managerial Reactions to an Increase in Accident Rate

From Chapter 6, it is evident that organizational culture, policies and structures play a pivotal role in shaping the safety climate and behavior of members within the organization. These organizational factors are shaped by the perceptions and mental models of managers and other decision makers. Therefore, it is important to appreciate the typical managerial reactions to increases in accident rates so as to set the foundation to understand their effects on vehicle safety. From the discussions with Organization Sierra-Tango SMEs and research of other related literature (See Chapter 6), it was found that some of the typical managerial reactions to an increase in accident rate are to:

- (1) Improve Mission Compatibility
- (2) Reduce Mission Complexity
- (3) Reduce Mission Intensity
- (4) Increase Safety Requirements
- (5) Increase Safety Awareness and Education Programs
- (6) Increase Severity of Punitive Measures
- (7) Increase Training Intensity

In relation to Organization Sierra-Tango's training context, mission compatibility can be ensured by only deploying drivers who possess the level of competence and experience that match the demands of the training exercise. Mission planners can reduce mission complexity through measures such as reducing task sequences and interdependencies, or by raising driver competency by providing adequate training and driving familiarizations. Mission intensity can be abated by decreasing the overall number of operational tasks that are assigned to drivers, increasing the time available for drivers to perform their tasks or increasing the number of drivers available.

Increasing the number of safety requirements in Organization Sierra-Tango's context can be manifested in two ways. The first managerial response is to increase the number of safety tasks that a driver has to perform before, during and after each mission. The other response is to raise the number of supervisory tasks for driving supervisors such as checking safety checklists more thoroughly and providing more safety updates to their commanders. Safety awareness and education programs can be increased through measures such as raising the number of safety briefings and reminders. Increasing the severity of punitive measures such as raising fines, increasing the length of confinement or even detention are other realizations of this managerial reaction in the organization's context.

In Organization Sierra-Tango, decision makers can also interpret an increase in accident rate as a signal of insufficient training and thereby decide to raise the driver training intensity by increasing training duration and frequency, or to increase training rigidity.

This knowledge of typical managerial responses to an increase in accident rate set the premise for the vehicle safety Causal Loop Diagrams that are described in the rest of the chapter.

### **8.3 Description of Key Modeling Steps**

The key steps that were employed for the System Dynamics modeling process are described below.

- (1) Time was invested in the problem articulation phase so as to clarify and understand the context of the "*problem*". Reference modes, modeling objectives, model boundaries and the time horizon to be considered were developed to guide the SD modeling process.
- (2) Several dynamic hypotheses – skeletal Causal Loop Diagrams – pertaining to vehicle safety and accidents were formulated based on the information collated from Organization Sierra-Tango through the documents provided and interviews with the organization's Subject Matter Experts (SMEs). The knowledge was complemented with my own experience of having served in Organization Sierra-Tango.
- (3) The third step was to conduct an extensive review of available literature on topics related to accidents and safety. The skeletal CLDs served as a useful reference to guide the literature review process. After the literature exercise was completed, many knowledge gaps were filled and key variables were identified, giving rise to a second much more detailed version of the CLDs from which preliminary SD models were constructed.
- (4) Finally, the CLDs and preliminary SD models were exposed to criticism by representatives of Organization Sierra-Tango, members of a research community and other SD modeling peers. Several rounds of feedback, revision and exposure to criticism were performed. This iterative process was critical not only in improving the fidelity of the SD models but also enriched the understanding of the problem for all who participated in the process.

## 8.4 Problem Articulation

### 8.4.1 Reference Modes

Based on hypothetical data provided by Organization Sierra-Tango (Organization Sierra-Tango, 2007a and 2007b), the conjectural trend of vehicle accidents during training deployments is shown in Figure 8-1. During the interpretation of the data, it was also assumed that the overall number of training deployments conducted over the past few years is constant so that the accident trend is considered as normalized. It must be emphasized that while the trend depicted does not reflect the true accident trend that is experienced by Organization Sierra-Tango, it nonetheless serves as a reasonable basis for conceiving the reference modes used for the development of the proof-of-concept System Dynamics models.

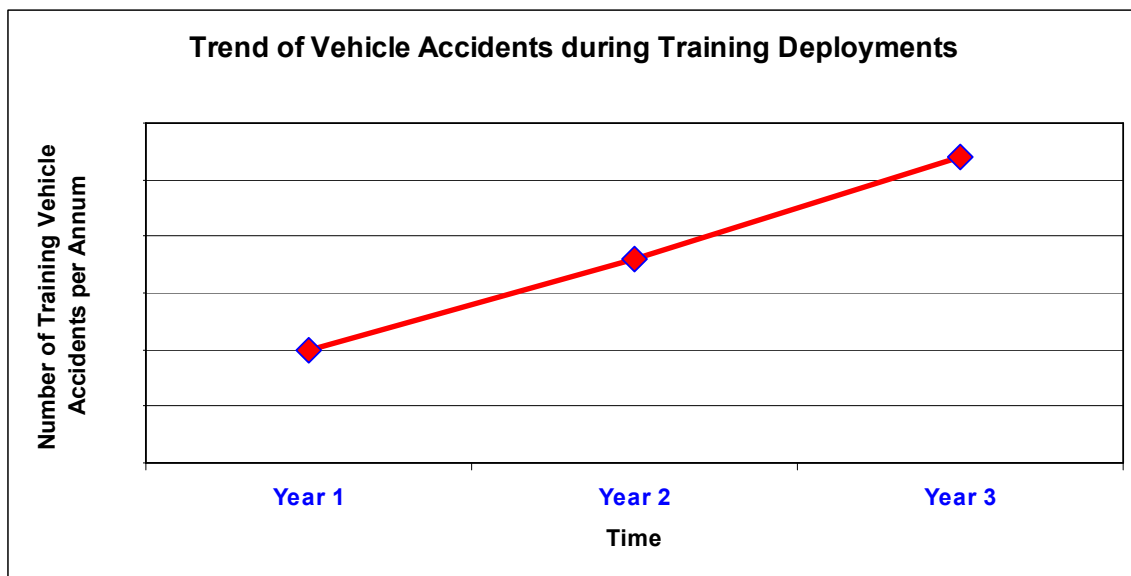


Figure 8-1: Hypothetical Trend of Vehicle Accidents during Training Deployments

Based on the hypothetical accident trend, three reference modes were developed. Figure 8-2 shows the first reference mode where management measures failed to elicit any improvement in the safety situation and the accident rate increases before arriving at a plateau. Figure 8-3 shows another reference mode where management actions have limited success but manage to contain the prevailing accident rate. The final reference mode shown as Figure 8-4 is one where management actions not only succeed in containing the prevailing accident rate but also in abating it such that it attains a lower level.

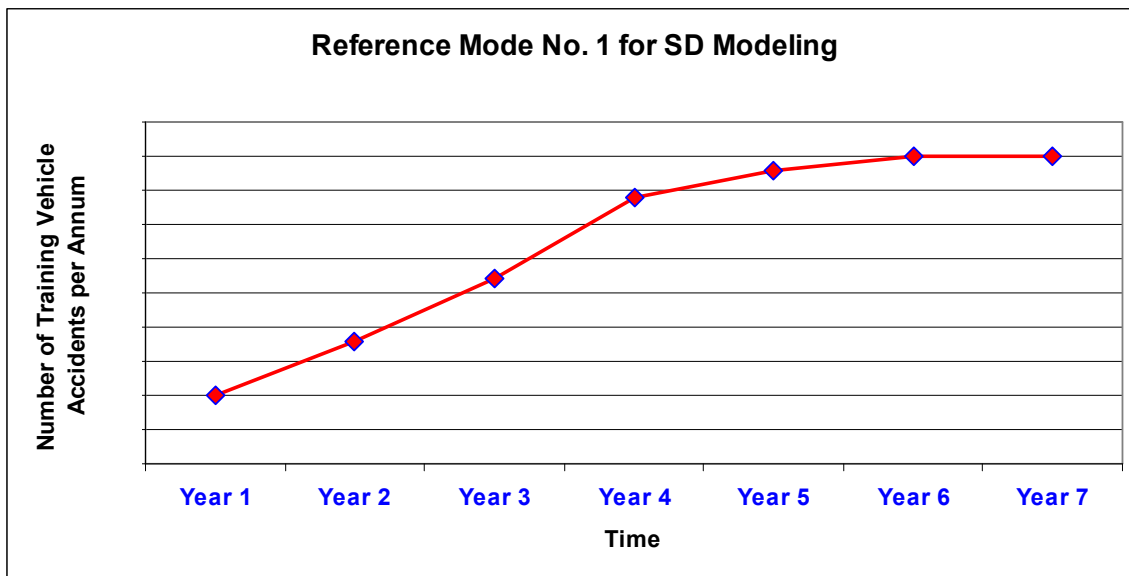


Figure 8-2: Reference Mode Number 1 for System Dynamics Modeling

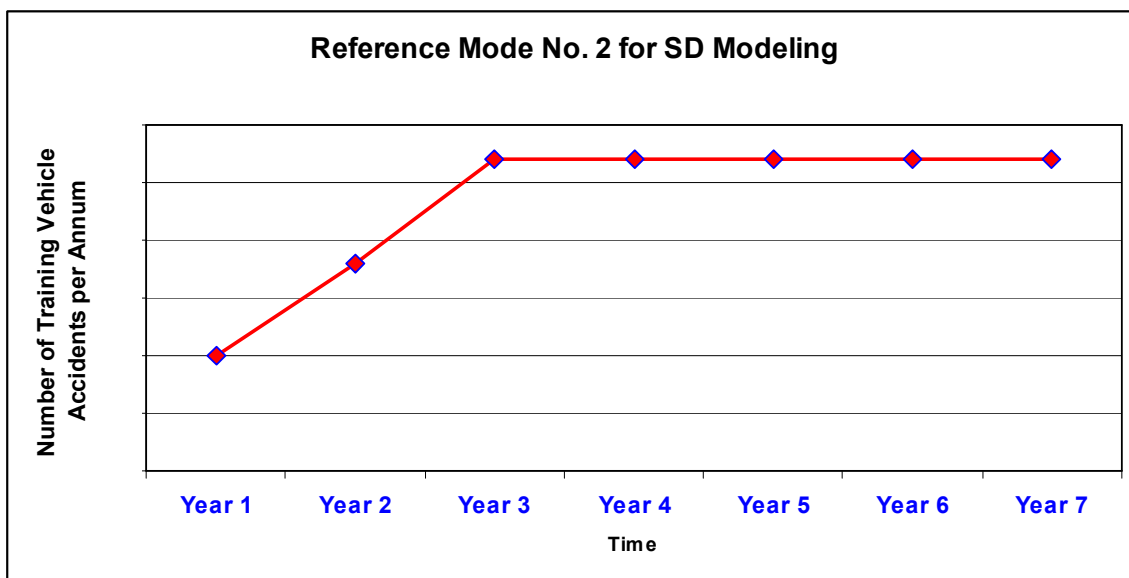


Figure 8-3: Reference Mode Number 2 for System Dynamics Modeling

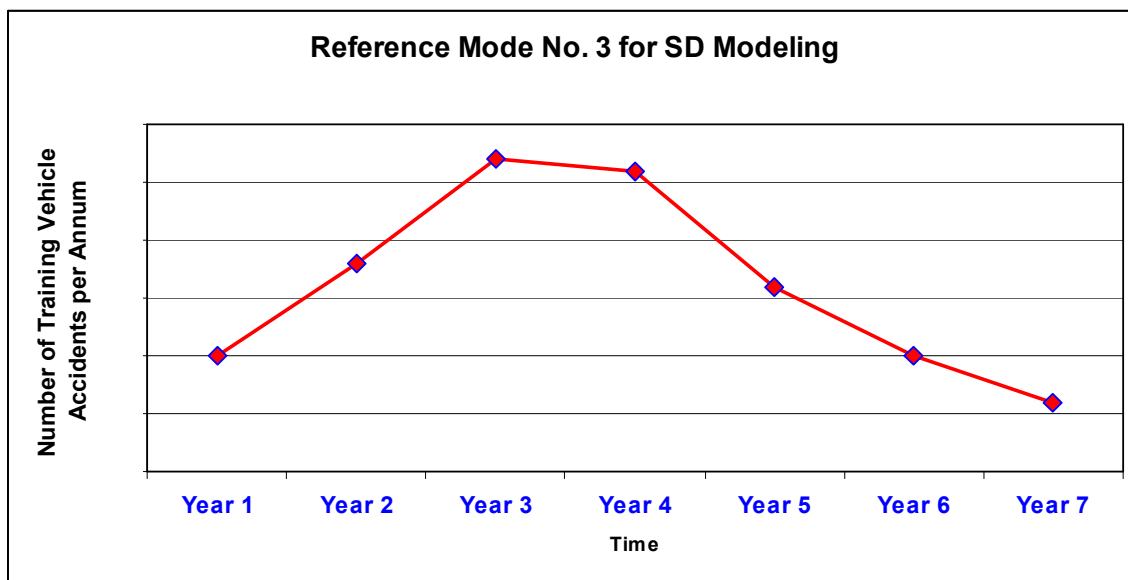


Figure 8-4: Reference Mode Number 3 for System Dynamics Modeling

#### 8.4.2 Time Horizon

The current time is regarded to be the end of Year 3. The time horizon considered for SD modeling is three years before and another four years into the future.

#### 8.4.3 Model Purpose

The purpose of the SD models is to assist Organization Sierra-Tango's policy and decision makers to better appreciate and understand the role that various dynamic feedback processes and delays play in determining the consequences of their accident prevention decisions. The models strive to uncover some of the high leverage areas within Organization Sierra-Tango that would enrich the knowledge database that policy and decision makers can draw upon in developing sounder decisions to reduce the rate of accident occurrences.

#### 8.4.4 Model Boundary

As coined elegantly by Organization Sierra-Tango, safety can be thought to be influenced by five overarching M (Machine, Man, Management, Medium and Mission) factors. The primary focus of my study is on factors endogenous to the organization such as decision makers, supervisors and drivers, and how their policies, decisions and actions affect the vehicle accident propensity during training deployments. Accordingly, the SD modeling effort focuses on two of the five M factors, namely Man and Management, as they are also identified from internal (material and

SMEs from Organization Sierra-Tango) and external (material from open literature) research as the key and most relevant factors impacting vehicle accidents in the organization's context.

#### 8.4.5 Clients

The clients for the SD models are not confined to the policy and decision makers of Organization Sierra-Tango. Commanders, supervisors and drivers of the organization are also part of the larger clientele whom behaviors must change in order improve the vehicle safety state within the organization.

### 8.5 Dynamic Hypothesizes

This section presents a detailed description of the two high-level Causal Loop Diagrams that have I have developed and found to be most relevant in Organization Sierra-Tango's context. The first CLD on Work Management contains the main dynamic hypothesizes that attempt to explain the hypothetical accident trend and reference modes described above. The Near Miss Reporting CLD is the second set of dynamic hypothesizes that is aimed at drawing some insights into the organization's new open reporting initiative. The two CLD are elaborated in the following sections.

#### 8.5.1 Work Management Causal Loop Diagram

The Work Management CLD contains some of the key dynamic feedback loops that offer some insights into the high number of occurrences of driver errors (mainly negligence and judgmental errors) and supervisory lapses (primarily insufficient supervision and briefings, and inadequate driving orientations) uncovered from the review of the accident reports (Chapter 3), and their impact on the overall vehicle accident rate. The mental models behind the various feedback loops are premised upon knowledge that had been gain through the thorough review of both internal and external literature as described in Chapters 2, 4 – 6. The main knowledge constituents are listed below:

(1) From Chapter 2:

- SME Experience with the Risk Management (RM) Process

(2) From Chapter 4:

- General Safety Policies and Practices in Overseas Training Deployments
- SME Comments on Overseas Training Deployments

(3) From Chapter 5:

- Physiology of Individual Accident Proclivity (Competency and Concentration)
- Psychology of Individual Risk-Taking Behavior (Cautiousness)

(4) From Chapter 6:

- Organizational Factors Affecting Accidents (Workload Management)
- Organizational Factors Affecting Accidents (System Safety Teams)

The Work Management CLD is shown as Figure 8-5. The various feedback loops and key variables of the CLD are described in the following sections.

#### 8.5.1.1 Central Model Construct – Accident Resilience

Before elaborating on the various feedback loops in the Work Management CLD, it is important to introduce the central model construct that is “*Accident Resilience*”. The accident rate is modeled as a balance between a driver’s accident resilience and his/ her accident propensity. This means that if circumstances cause a driver’s accident resilience to decrease the prevailing accident rate will increase and vice versa. The attributes of a driver’s accident resilience can be represented by three C factors which are:

- (1) Cautiousness
- (2) Competency
- (3) Concentration

#### 8.5.1.2 B1 – Driver Adherence Improvement on Cautiousness Balancing Loop

One of the typical managerial responses to curb an increase in the number of accidents is to introduce more safety tasks for each driving task. The increase in the number of safety tasks can be manifested in ways such as requiring drivers to perform more thorough safety checks on the condition of the vehicle, double-checking of the driving routes or to fill-up more tedious RM checklists and forms before and after each driving mission. The “*B1 – Driver Adherence Improvement on Cautiousness*” balancing loop captures the dynamics of the desired outcome of such a program. Should the driver adhere by increasing his or her safety time spent per task under the new safety process, the driver’s overall cautiousness will improve thereby raising his/ her accident resilience which reduces the accident rate.

#### 8.5.1.3 B2 – Driver Cutting Corners on Driving Tasks Balancing Loop

The increase in the number of safety tasks for each driving task under the new safety program effectively increases the required safety time spent per task and therefore the total driver time spent per task even though the number of driving tasks remains the same. Assuming that there was no slack time available before the introduction of the new safety program, the required driver work rate remains constant and the overall number of drivers remains the same, this reduces the normal driver work rate and creates schedule pressure. The “*B2 – Driver Cutting Corners on Driving Tasks*” balancing loop captures the dynamics that due to schedule pressure, the driver’s perceived desirability to take risks increases (see Chapter 5) and he/ she responds by decreasing the driving time spent per task by speeding in a bid to raise his or her work efficiency. Speeding decreases the driving time spent per task thereby reducing the total time spend per task. This has the effect of increasing the driver work rate and in the process relieves schedule pressure and therefore less reason to speed. Consequently, the driver’s accident resilience improves and the accident rate decreases.



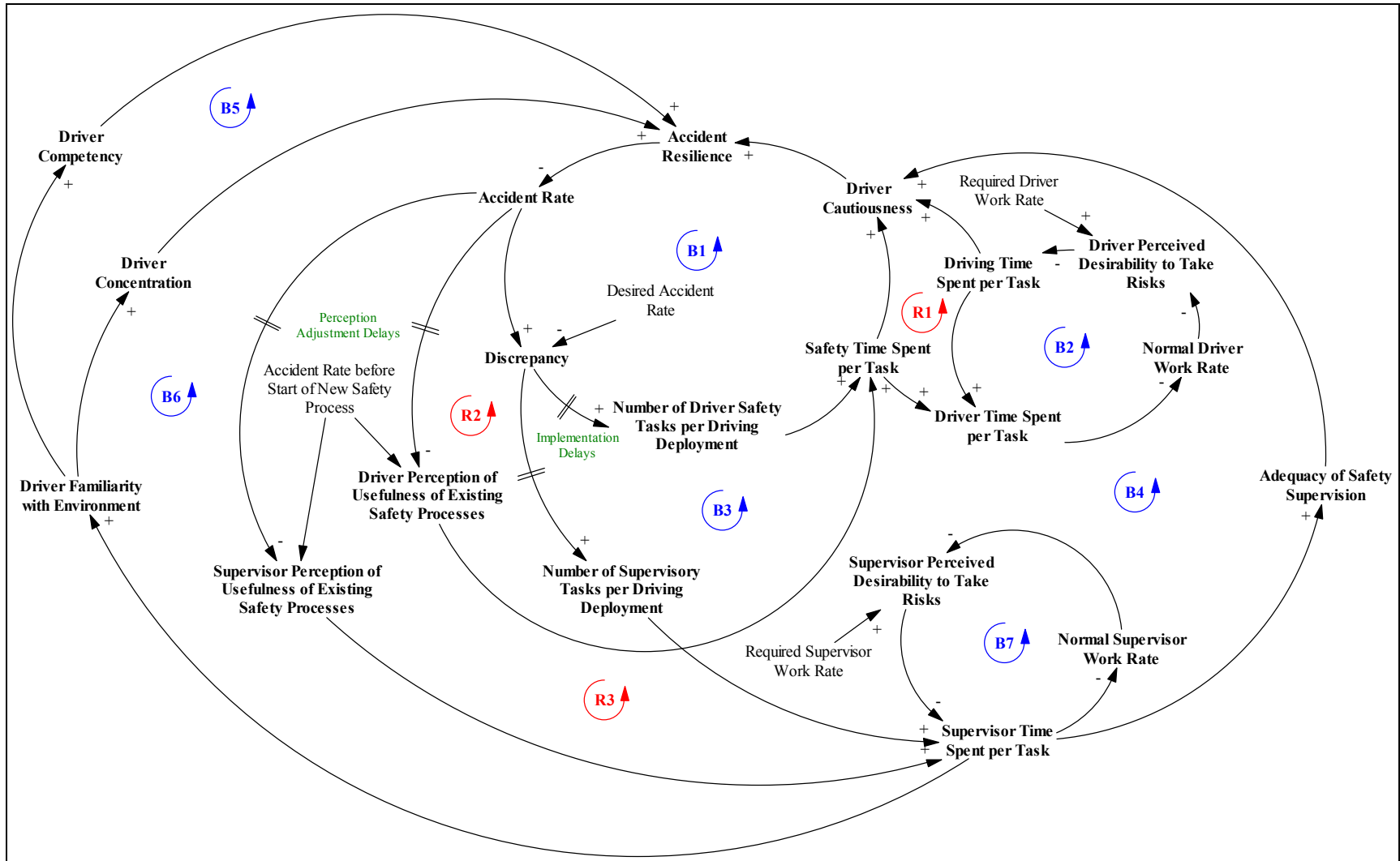


Figure 8-5: Work Management Causal Loop Diagram

#### 8.5.1.4 R1 – Driver Speeding Reinforcing Loop

The “*R1 – Driver Speeding*” reinforcing loop captures another set of dynamics that occurs when the driver speeds due to schedule pressure. As a result of speeding, the driver’s cautiousness is reduced thereby lowering his or her accident resilience and the accident rate increases.

#### 8.5.1.5 R2 – Driver Perception of Safety Program – Adherence Reinforcing Loop

The “*R2 – Driver Perception of Safety Program – Adherence*” reinforcing loop is an important feedback loop that captures the driver’s perception of the effectiveness and hence usefulness of existing safety initiatives. As discussed in Chapter 7, reinforcing loops can be virtuous or vicious. The vicious nature of the loop would be exhibited should the safety initiatives fail to demonstrate any success in reducing or even worsening the accident rate as a possible consequence of other dynamic effects. After a perception adjustment delay, drivers will lose confidence in the safety initiatives and therefore reduce their adherence to the required safety tasks by spending less time on them which has the net effect of lowering the driver’s cautiousness. Consequently, accident resilience is lowered and the accident rate is increased.

#### 8.5.1.6 B3 – Driver Cutting Corners on Safety Tasks Balancing Loop

Drivers’ perception of the usefulness of safety initiatives also has a balancing effect. The “*B3 – Driver Cutting Corners on Safety Tasks*” balancing loop shows that should drivers lose confidence in the safety initiatives and therefore reduce their adherence to the required safety tasks by spending less time on them, the total driver time spent per task is reduced. This has the effect of increasing the normal driver work rate which relieves schedule pressure and therefore less reason to speed. Consequently, the driver’s accident resilience improves and the accident rate decreases.

#### 8.5.1.7 B4 – Supervisor Adherence Improvement on Cautiousness Balancing Loop

Similar to the case for drivers, one of the typical managerial responses to curb an increase in the number of accidents is to also increase the extent of supervision on the drivers. It is not reasonable for all driving risks to be eliminated. Proper risk management calls for the supervisors to communicate the residual operational risks to the drivers, hence the need for proper safety briefing and driving orientations. Safety supervision is also critical as without which, there is a higher chance for drivers to lose control of themselves to the feeling of “*no government*” and drive more recklessly. However, the increase in the extent of supervision can be manifested in ways such as requiring supervisors to inspect driver RM forms more meticulously, fill up more detailed supervisory documentation or to increase the frequency of making reports to commanders for each driving deployment. This increases the overall amount of supervisory time required per task and eats into the time required for safety briefings and inspections, and driving orientations. The “*B4 – Supervisor Adherence Improvement on Cautiousness*” balancing loop captures the dynamics of one desired outcome of such a

managerial initiative. Should the supervisor adhere by increasing his or her time spent on safety briefings and inspections required under the new safety process, the overall adequacy of safety supervision is enhanced. As a result, the driver's overall cautiousness will improve thereby raising his/ her accident resilience which reduces the accident rate.

The availability of third party safety supervision teams is another element that helps to raise the overall safety supervision level of a training deployment. Safety supervision teams are available during Organization Sierra-Tango's training deployments (see Chapter 2) and are hence considered to be a constant and excluded from the Work Management CLD.

#### 8.5.1.8 B5 – Supervisor Adherence Improvement on Competency Balancing Loop

The “*B5 – Supervisor Adherence Improvement on Competency*” balancing loop captures the dynamics of another desired outcome of the managerial response to increase the number of supervisory tasks. Should the supervisor adhere by increasing his or her time spent on driving orientations as required under the new safety process, the overall driver familiarity with the operating environment is enhanced and therefore the driver's competency is raised. As a result, the driver's accident resilience is increased which reduces the accident rate.

The driver familiarity with the operating environment can also be enhanced through training in similar environments. This is already done in Organization Sierra-Tango through simulated training courses as described in Chapter 2. Therefore, this element is considered as a constant and excluded from the Work Management CLD. As discussed in Chapter 5, a driver's competency also depends on his or her skill and experience levels. Chapter 2 describes Organization Sierra-Tango's strict policy through certification of deploying only drivers that possess the skill and experience level required for the task at hand. Hence, these elements are considered as constants and also excluded from the Work Management CLD.

#### 8.5.1.9 B6 – Supervisor Adherence Improvement on Concentration Balancing Loop

The “*B6 – Supervisor Adherence Improvement on Concentration*” balancing loop captures the dynamics of third desired outcome of the managerial response to increase the number of supervisory tasks. Should the supervisor adhere by increasing his or her time spent on driving orientations as required under the new safety process, the driver's concentration is raised as the operating environment will present less novelties and hence less distractions and other cognitive interruptions (Chapter 6) to the driver. As a result, the driver's accident resilience is increased which reduces the accident rate.

#### 8.5.1.10 B7 – Supervisor Cutting Corners on Supervisory Tasks Balancing Loop

The increase in the extent of supervision under the new safety program effectively increases the required supervisory time spent per task. Assuming that there was no slack time available before the introduction of the new safety program, the required supervisor work rate remains constant

and the overall number of supervisors remains the same, this reduces the normal supervisor work rate and creates schedule pressure. The “*B7 – Supervisor Cutting Corners on Supervisory Tasks*” balancing loop captures the dynamics that due to schedule pressure, the supervisor’s perceived desirability to take risks increases (see Chapter 5) and he/ she responds by decreasing the supervisory time spent per task in ways such as reducing time spent or going through the motions on driving orientations, glossing over details in safety briefings or taking shortcuts on safety inspections in a bid to raise his or her work efficiency. Corner cutting decreases the supervisory time spent per task thereby increasing the supervisor work rate and in the process relieves schedule pressure and therefore less reason to cut corners. However, the dynamics of such actions are that either or both of the adequacy of safety supervision and driver familiarity with environment will decrease, which has the net effect of lowering the driver’s cautiousness, competency and concentration. Consequently, accident resilience is lowered and the accident rate is raised.

#### 8.5.1.11 R3 – Supervisor Perception of Safety Program – Adherence Reinforcing Loop

The “*R3 – Supervisor Perception of Safety Program – Adherence*” reinforcing loop is an important feedback loop that captures the supervisor’s perception of the effectiveness and hence usefulness of existing safety initiatives. As discussed in Chapter 7, reinforcing loops can be virtuous or vicious. The vicious nature of the loop would be exhibited should the safety initiatives fail to exhibit any success in reducing or even worsening the accident rate as a possible consequence of other dynamic effects. After a perception adjustment delay, supervisors will lose confidence in the safety initiatives and therefore reduce their adherence to the required supervisory tasks by spending less time on them which has the net effect of lowering the driver’s cautiousness, competency and concentration. Consequently, accident resilience is lowered and the accident rate is increased.

### 8.5.2 Near Miss Reporting Causal Loop Diagram

As discussed in Chapter 6, incident reports can improve the overall accident rate through various avenues such as learning from accidents and near misses, identifying potential hazards and providing feedback on existing safety measures so that they can be improved upon. The Near Miss Reporting CLD focuses on the reporting and learning aspects of near misses on improving training effectiveness.

The Near Miss Reporting CLD contains some of feedback loops that offer some dynamic insights into the Organization Sierra-Tango’s nascent open reporting initiative (Chapter 2), and its impact on the overall vehicle accident rate. The mental models behind the various feedback loops are premised upon knowledge that had been gained through the thorough review of both internal and external literature as described in Chapters 2, 5 and 6. The main knowledge constituents are listed below:

- (1) From Chapter 2:
  - Additional Information about the Open Reporting Initiative from a SME
- (2) From Chapter 5:
  - Psychology of Individual Risk-Taking Behavior (Cautiousness)
- (3) From Chapter 6:
  - Organizational Factors Affecting Accidents (Safety Culture)
  - Organizational Factors Affecting Accidents (Incident Reporting Systems)

The Open Reporting CLD is shown as Figure 8-6. The various feedback loops and key variables of the CLD are described in the following sections.

#### 8.5.2.1 B1 – Fear of Punishment on Self Balancing Loop

Another typical managerial response to counter an increase in the number of accidents is to increase the severity of punitive measures. The “*B1 – Fear of Punishment on Self*” balancing loop captures the dynamics of the desired outcome of such a program. The increased in the severity of punitive measures feeds the driver’s fear of punishment on self after a delay. This fear of punishment increases the driver’s cautiousness and therefore accident resilience, leading to a decrease in the accident rate. However, it should be realized that using “*the stick*” method to control behavior, while arguably effective and efficient, is useful only to a certain extent. The severity of punitive measures on negligent drivers is already fairly high in Organization Sierra-Tango and therefore this loop, while important, is assessed to not have too large an impact on the overall accident resilience.

#### 8.5.2.2 R1 – Fear of Punishment on Comrades Reinforcing Loop

The managerial decision to increase the severity of punitive measures breeds another form of fear which has a negative influence on the overall accident rate. The “*R1 - Fear of Punishment on Comrades*” balancing loop shows that the increase in the severity of punitive measures also feeds the driver’s perceived fear of punishment on comrades after a delay. This is because; despite reassurances that no punishment would be meted on individuals that are implicated in a near miss incident, the increase in severity of punishment raises the fear in potential reporters that such their reports may cause their comrades to be punished – an outcome that goes against the military code of camaraderie (see Chapter 6). Additionally, even if the “*No Punishment*” policy is enforced in the near term, there are lingering fears for longer term repercussions such as lower performance rating, career limitations, etc. Consequently, reporting of near misses is discouraged which has the effect of decreasing learning from near misses which reduces training effectiveness from what it would otherwise have been. As training effectiveness declines, so too does the skill of the driver and hence his or her competency. This discounts the driver’s accident resilience which increases the accident rate. This loop is assessed to have a strong influence on near miss reporting in Organization Sierra-Tango’s context.

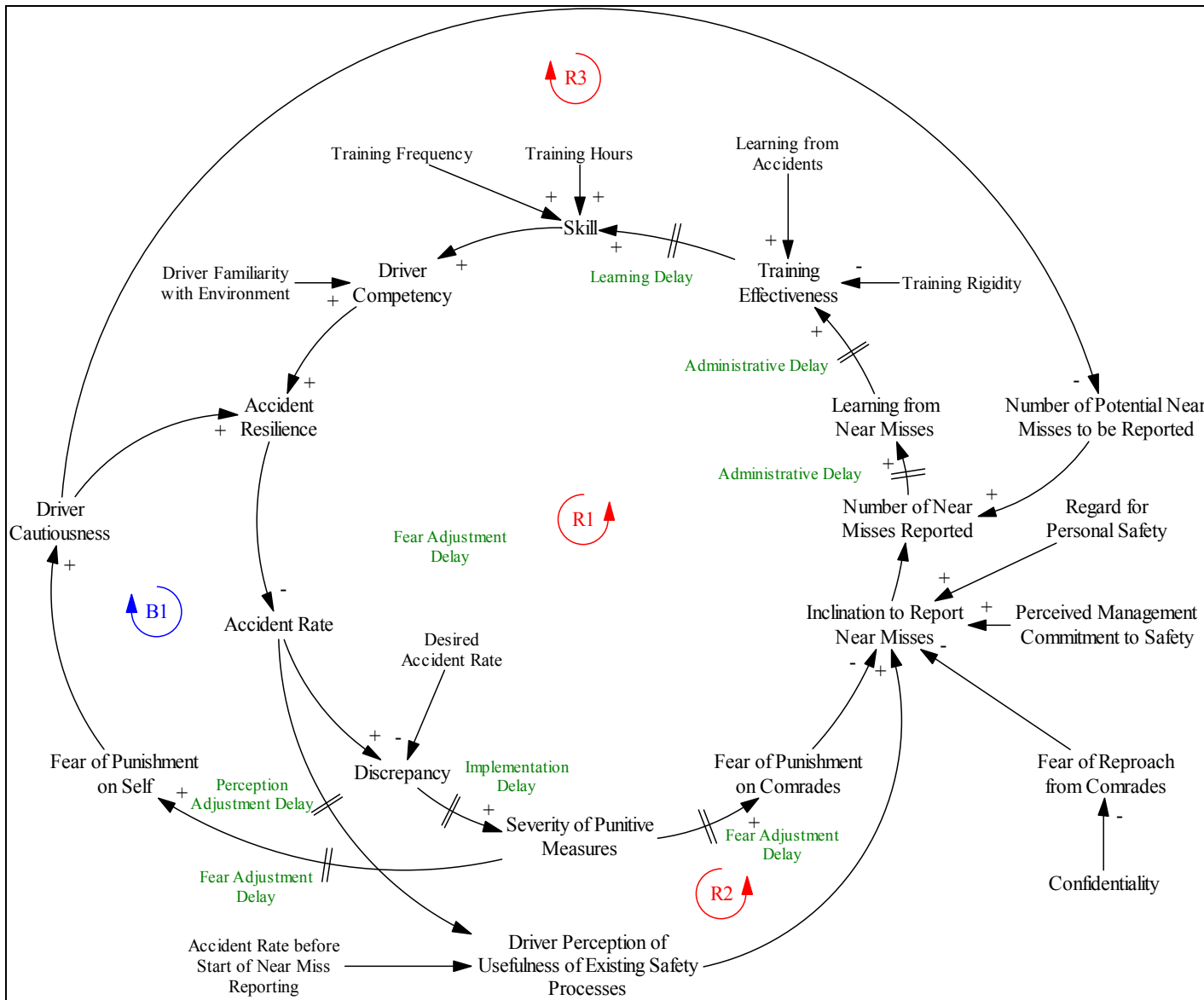


Figure 8-6: Near Miss Reporting Causal Loop Diagram

It should be highlighted that training effectiveness is also determined by learning from accidents and the overall rigidity of the training. These two factors are considered to be constants in Near Miss Reporting CLD. Also, a driver's skill is not only influenced by training effectiveness, but also the training frequency and duration. As training frequency and duration are assessed to be already optimized in Organization Sierra-Tango's, these two factors are also considered to be constants in the Near Miss Reporting CLD. Finally, a driver's competency is determined not only by his or her skill but also by his or her familiarity with the operating environment as discussed earlier in this chapter and in Chapter 5. As such, if supervisors spend less time on driving familiarizations for example as a result of the effects discussed in the Work Management CLD, the driver's familiarity with the operating environment will decline which further reduces his or her accident resilience and therefore the accident rate increases.

#### 8.5.2.3 R2 – Driver Perception of Safety Program – Near Miss Reporting Reinforcing Loop

The “*R2 – Driver Perception of Safety Program – Near Miss Reporting*” Reinforcing loop is an important feedback loop that captures a driver's perception of the effectiveness and hence usefulness of the near miss reporting initiative. As discussed in Chapter 7, reinforcing loops can be either virtuous or vicious. The vicious nature of the loop would be exhibited should the near miss reporting initiative fail to demonstrate any success in reducing or even worsening the accident rate as a possible consequence of other dynamic effects. After a perception adjustment delay, drivers will lose confidence in the safety initiatives and become more disinclined to report near misses. Learning from near misses diminishes which reduces training effectiveness from what it would otherwise have been. As training effectiveness declines, so too does the skill of the driver and hence his or her competency. This discounts the driver's accident resilience which increases the accident rate. This loop is assessed to have a strong influence on near miss reporting in Organization Sierra-Tango's context.

#### 8.5.2.4 R3 – Punishment Effect on Number of Potential Near Misses to be Reported Reinforcing Loop

The “*R3 – Punishment Effect on Number of Potential Near Misses to be Reported*” Reinforcing loop is a feedback loop that captures the effect that punitive measures have on the number of potential near misses to be reported. As the severity of punitive measures increase, the fear of punishment on self increases and drivers perform their duties more cautiously. As a result of driving more carefully, the pool of potential near misses decreases and there is less learning from near misses which reduce training effectiveness from what it would otherwise have been. As training effectiveness declines, so too does the skill of the driver and hence his or her competency. This discounts the driver's accident resilience which increases the accident rate. Consequently, managers may react to the increased accident rate by raising the severity of punitive measures even further. The effect of this reinforcing loop is assessed to be small impact on the overall

accident rate as learning from near misses is a small contributor to training effectiveness. Furthermore, there are other factors that would impact the accident rate and managers cannot raise the severity of punitive measures indefinitely.

#### 8.5.2.5 The Effect of Near Miss Reporters' Confidentiality on Near Miss Reporting

An important variable in the Near Miss Reporting CLD that affects near miss reporting is “*Confidentiality*”. As described in Chapter 2, Organization Sierra-Tango’s current policy is not to withhold the whistleblower's identity from anyone so as to foster a culture of openness. However, as research in Chapter 6 shows, this lack of identify confidentiality discourages near misses from being reported due to the serviceman’s fear of reproach from comrades from being perceived to be one who takes delight in another person’s misery. A slight policy adjustment such as a selective access to the whistleblower's identity would potentially encourage reporting of near misses.

#### 8.5.2.6 Other Factors affecting Near Miss Reporting

The “*Perceived Management Commitment to Safety*” and “*Regard for Personal Safety*” are another two variables in the Near Miss Reporting CLD that affect near miss reporting.

As discussed in Chapter 6, the perceived management commitment to safety is an important factor that determines the safety behavior of members within an organization. The challenge is that often the safety message from management does not permeate down to the ground levels especially if the intermediate levels do not abide or do not appear to abide to the same safety philosophy as management. In the context of vehicle safety and near miss reporting, this means that if drivers perceive their supervisors to be not adhering to safety practices by not making near miss reports perhaps due to the effects of schedule pressure as discussed in the Work Management CLD, drivers will also be less inclined to make their own near miss reports.

The regard for personal safety is another important driver for near miss reporting. Should the near miss that the serviceman had just witnessed have potential consequences that are severely dreaded, he or she would be more inclined to report the near miss in order to promote the wellbeing of themselves and their comrades. The effect of the regard for personal safety is considered to be a constant in the Near Miss Reporting CLD as highly dreaded incidents have been rather few and far in between in Organization Sierra-Tango’s context.

## 8.6 Detailed Construction of System Dynamics Models

From the high-level conceptual mental models that are captured in the Work Management and Near Miss Reporting Causal Loop Diagrams, and explicated in the previous sections, preliminary System Dynamics models were constructed. This process



transformed the high-level conceptual models into low-level and more detailed models where parameter values are used for exogenous variables and equations for endogenous variables so as to create a mathematical model of the system that can be simulated by modifying the values of the model variables.

As mentioned previously, the CLDs and preliminary SD models were exposed to criticism by representatives of Organization Sierra-Tango, members of a research community and other SD modeling peers. Several rounds of feedback, revision and exposure to criticism were performed and this iterative process was critical not only in improving the fidelity of the SD models but also enriched the understanding of the problem for all who participated in the process. The SD models were also subjected to sensitivity and extreme values testing to ensure that they do not break down and exhibit anomalous behaviors. Sensitivity testing was conducted by examining how sensitive the model reacted to small changes in various model parameters. One example of an extreme values test for the Work Management SD model would be to check that extreme values for “*Driver Task Completion Rate*” do not cause the “*Driver Task Outstanding*” stock to become negative.

The next two sections contain diagrams that depict the detailed structures of the Work Management SD model and the Near Miss Reporting SD model. The SD models are premised upon their respective CLDs described previously and are constructed using the Vensim software program. It should be noted that some of the model segments contain purely modeling tools/ mechanisms and hence do not exhibit any feedback loops. Variables with a parenthesis around them are called “*Shadow*” variables and are merely a duplicate of an existing variable within the model. The complete equation listing of the SD models are provided in Appendices B and C of this thesis.

### 8.6.1 Work Management System Dynamic Model

The complete Work Management SD model is divided into seven segments for modeling manageability. The seven segments are shown in Figures 8-7 to 8 -13.

### 8.6.2 Near Miss Reporting System Dynamic Model

The complete Near Miss Reporting SD model is divided into three segments for modeling manageability. The three segments are shown in Figures 8-14 to 8-16.

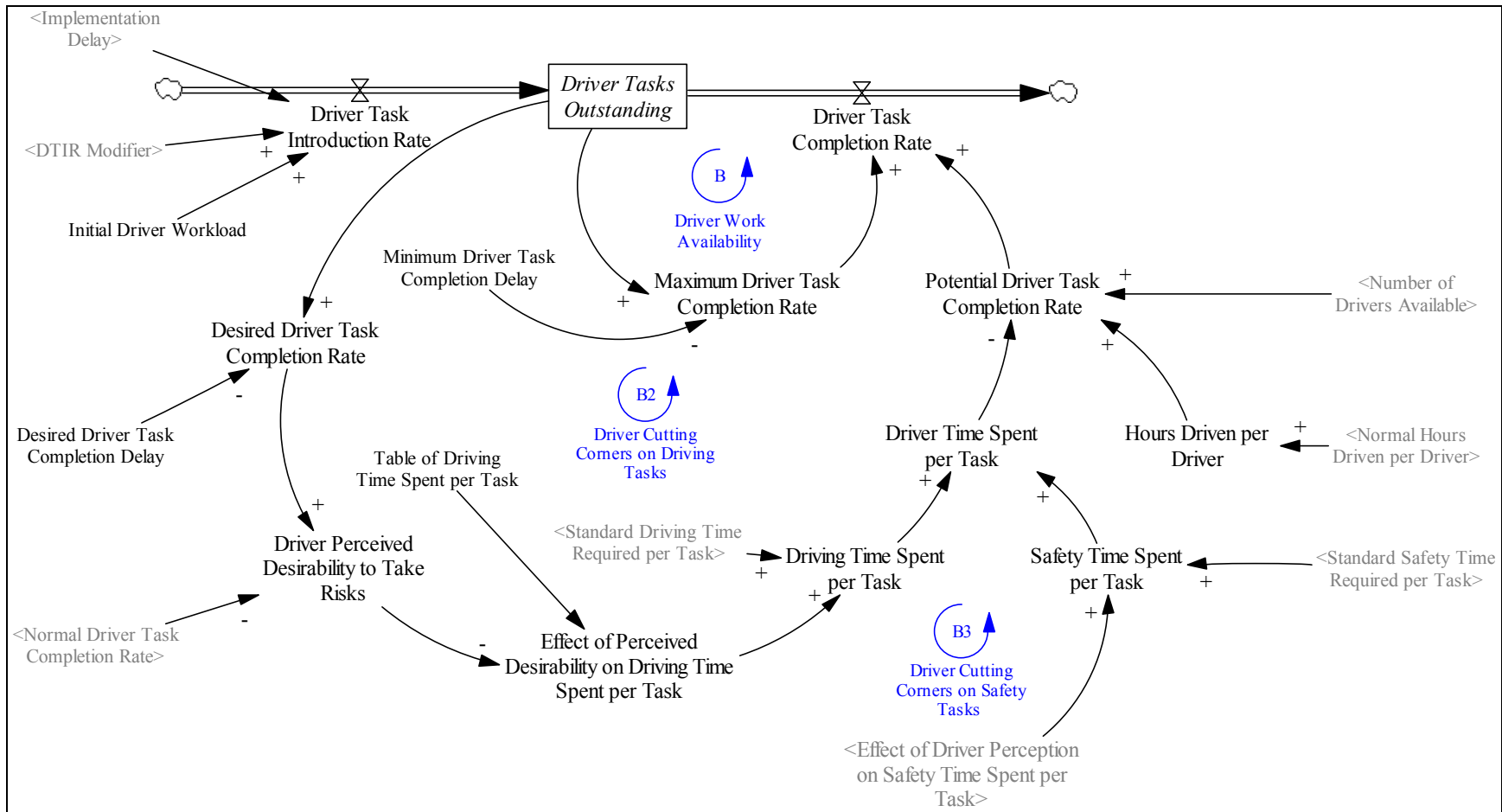


Figure 8-7: Work Management System Dynamics Model – Driver Task Management Segment

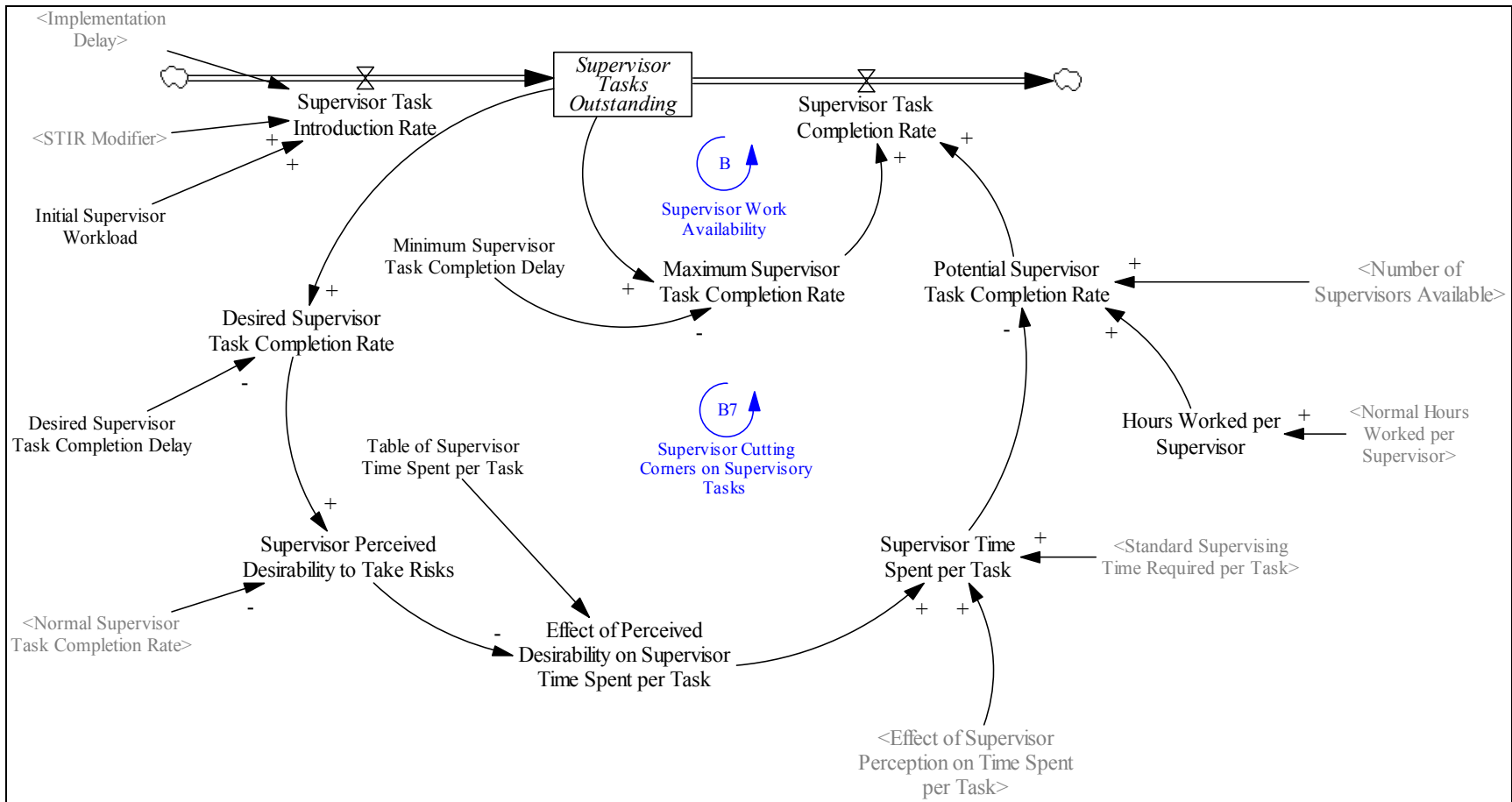


Figure 8-8: Work Management System Dynamics Model – Supervisor Task Management Segment

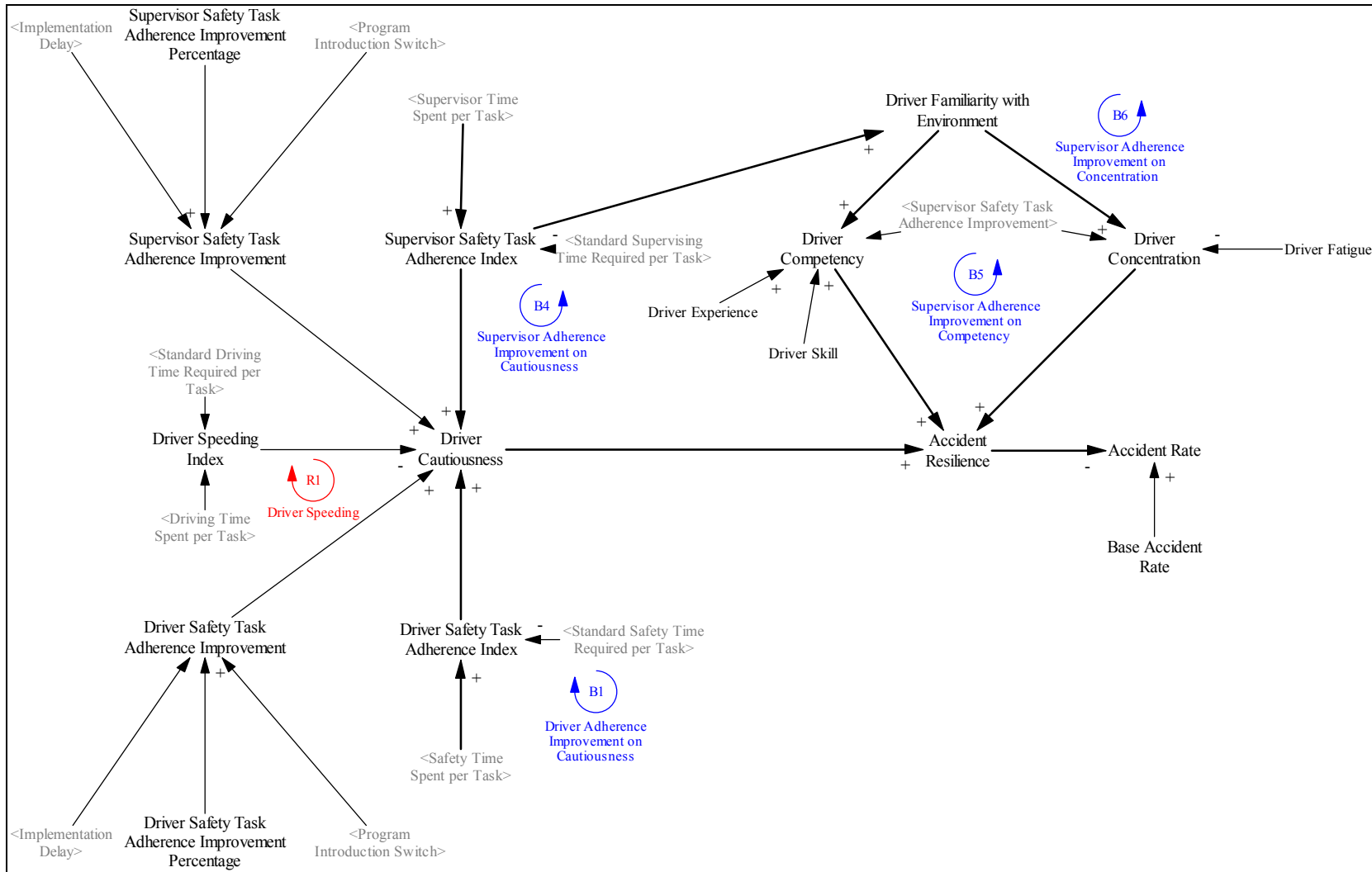


Figure 8-9: Work Management System Dynamics Model – Driver Accident Resilience

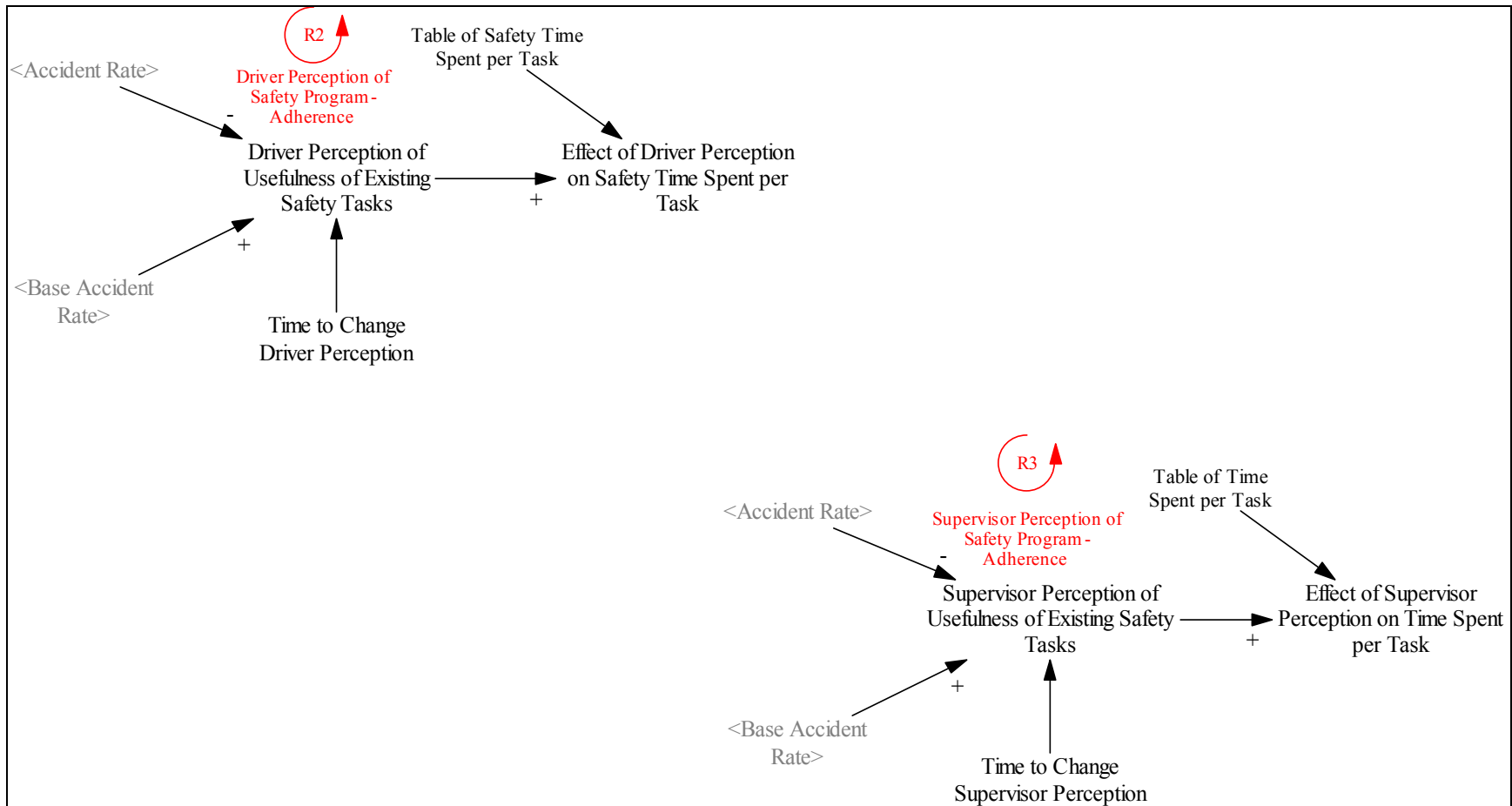


Figure 8-10: Work Management System Dynamics Model – Perceptions of Usefulness of New Process

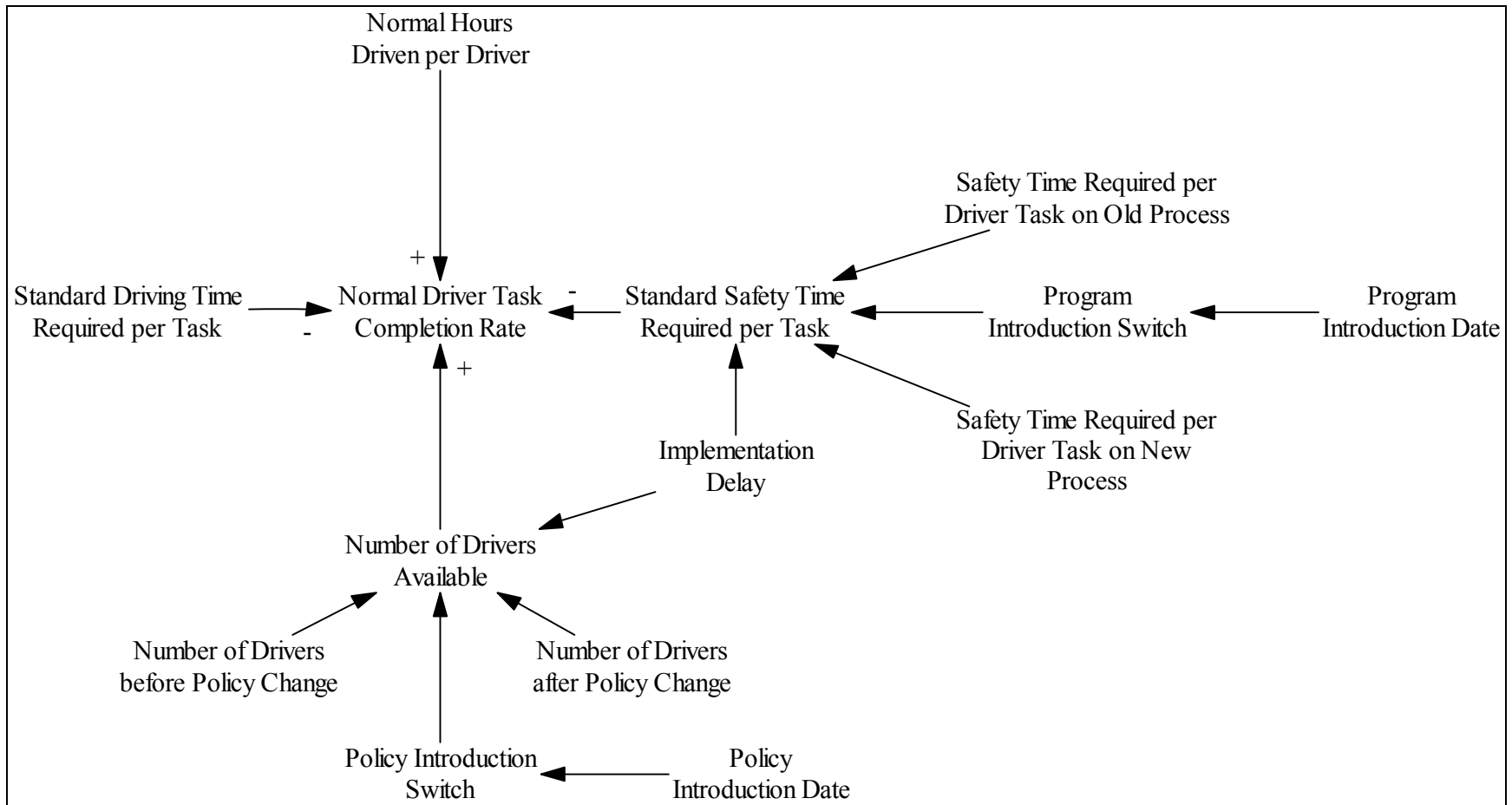


Figure 8-11: Work Management System Dynamics Model – Normal Driver Task Completion Rate

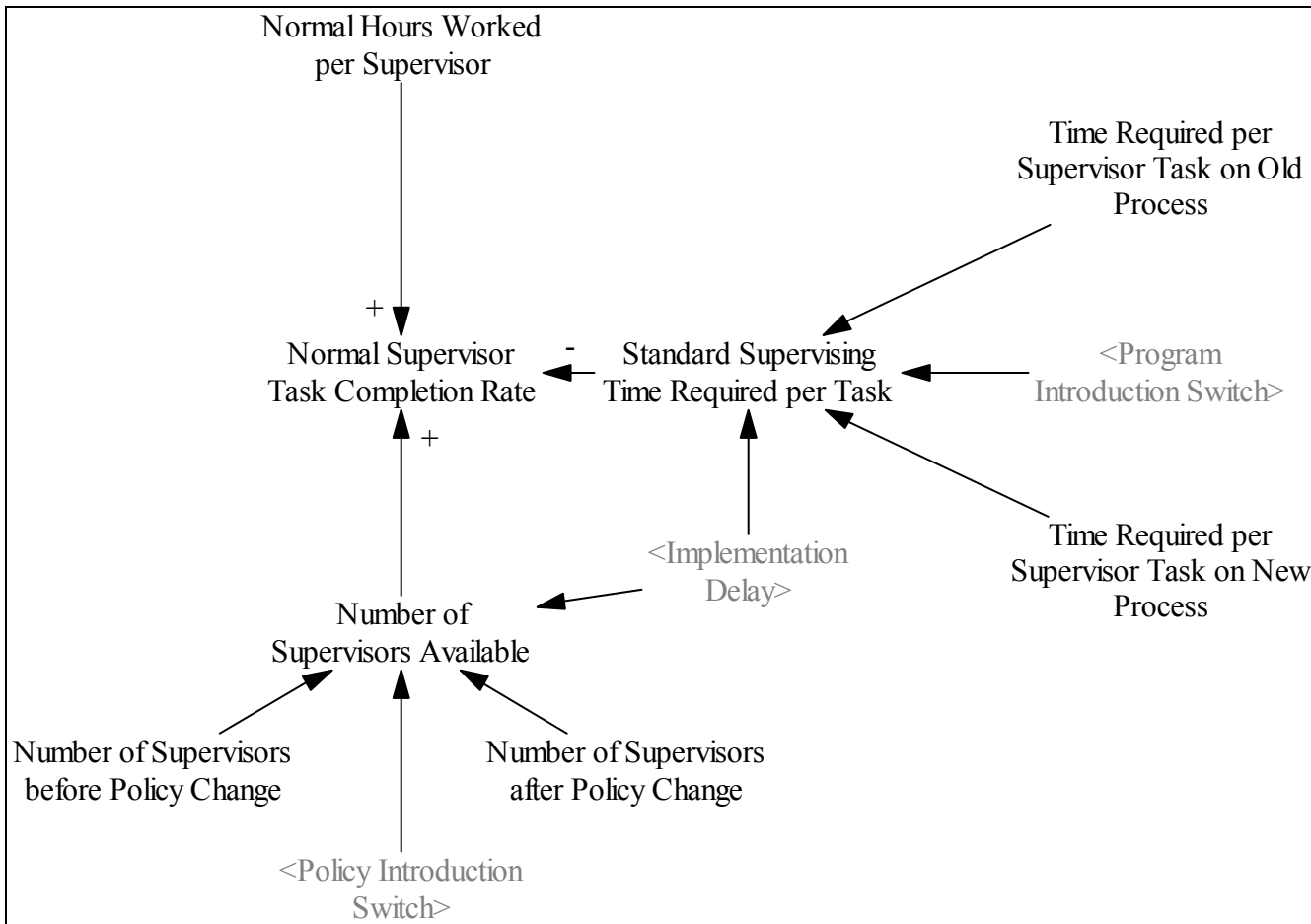


Figure 8-12: Work Management System Dynamics Model – Normal Supervisor Task Completion Rate

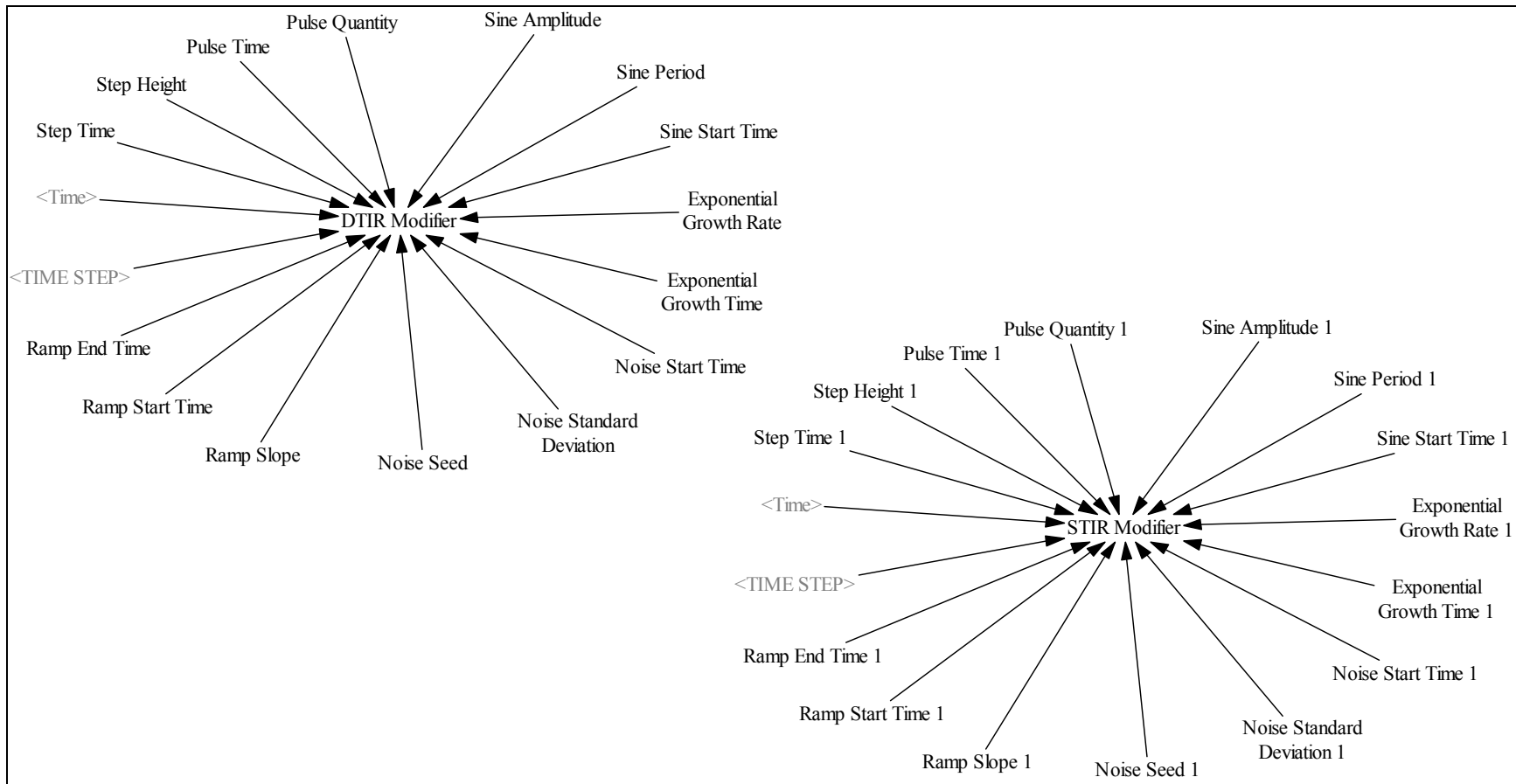


Figure 8-13: Work Management System Dynamics Model –Task Input Rate Modifiers



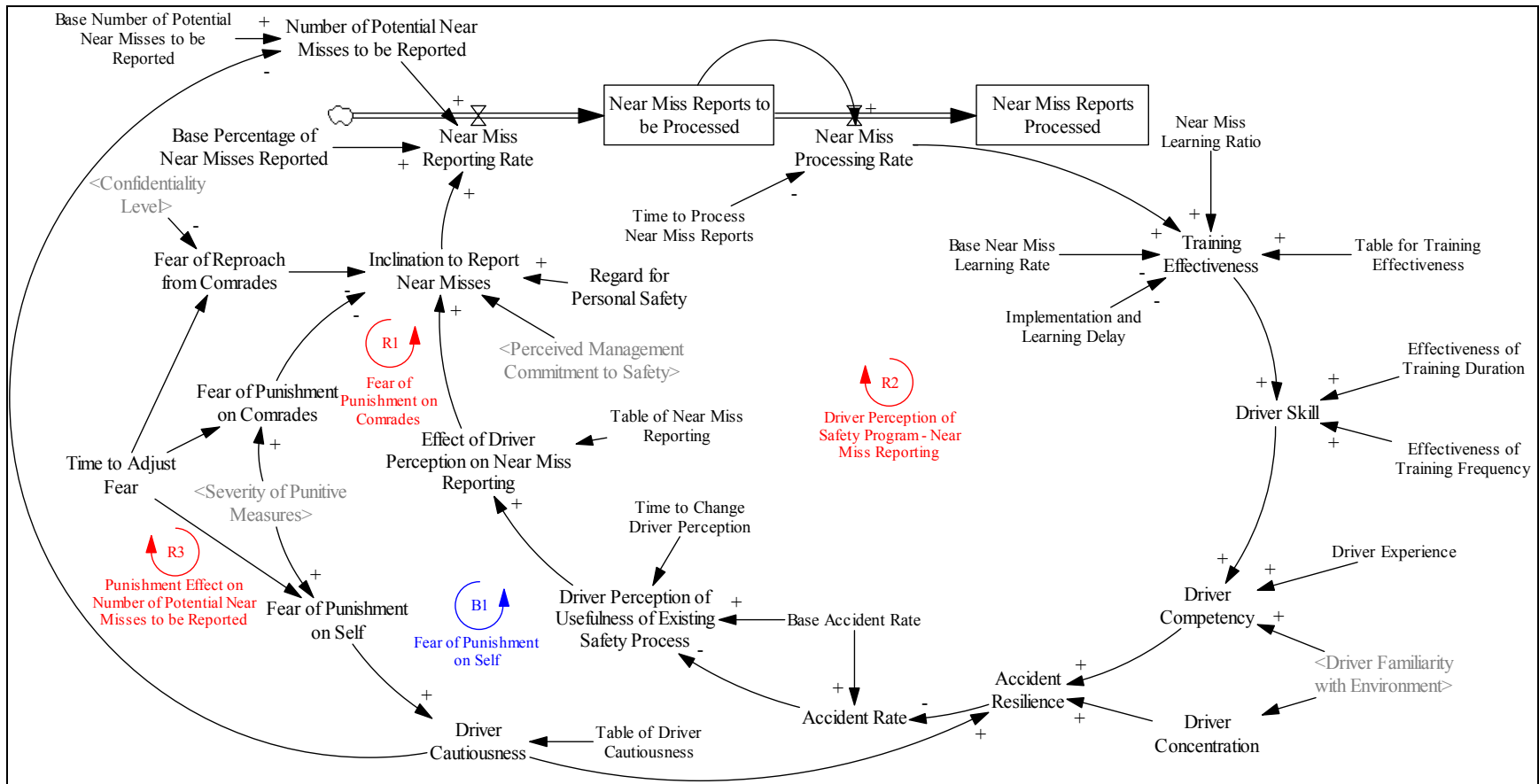


Figure 8-14: Near Miss Reporting System Dynamics Model – Open Reporting Subsystem

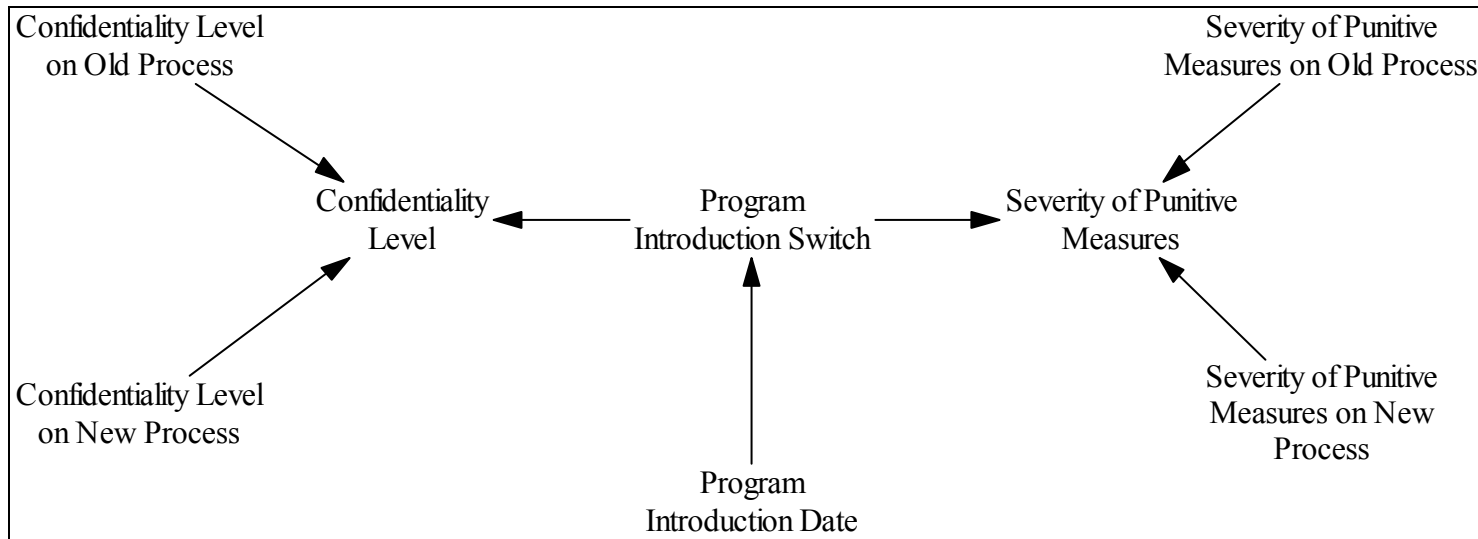


Figure 8-15: Near Miss Reporting System Dynamics Model – Confidentiality and Severity of Punitive Measures

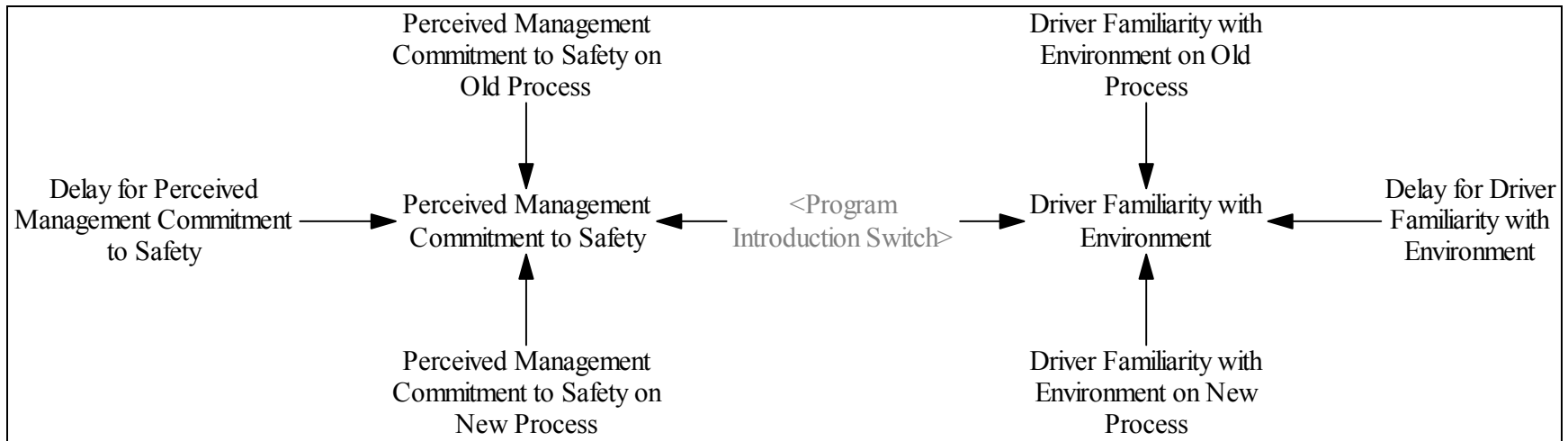


Figure 8-16: Near Miss Reporting System Dynamics Model – Perceived Management Commitment to Safety and Driver Familiarity

## 8.7 Other High-Level Causal Loop Diagrams for Vehicle Safety

This section presents the other high-level CLDs that were conceived but were not chosen for further detailed development. The dynamics captured in the various feedback loops are self-explanatory and hence detailed explanations are not provided. These CLDs can serve as starting points for further research and modeling.

### 8.7.1 Machine Causal Loop Diagram

The Machine CLD is shown as Figure 8-17. The CLD has three reinforcing loops that capture the dynamics between maintenance and vehicle operability that impacts the accident rate. The three reinforcing loops are:

- (1) Budget for Mechanics
- (2) Budget for Spares
- (3) Preventive Maintenance

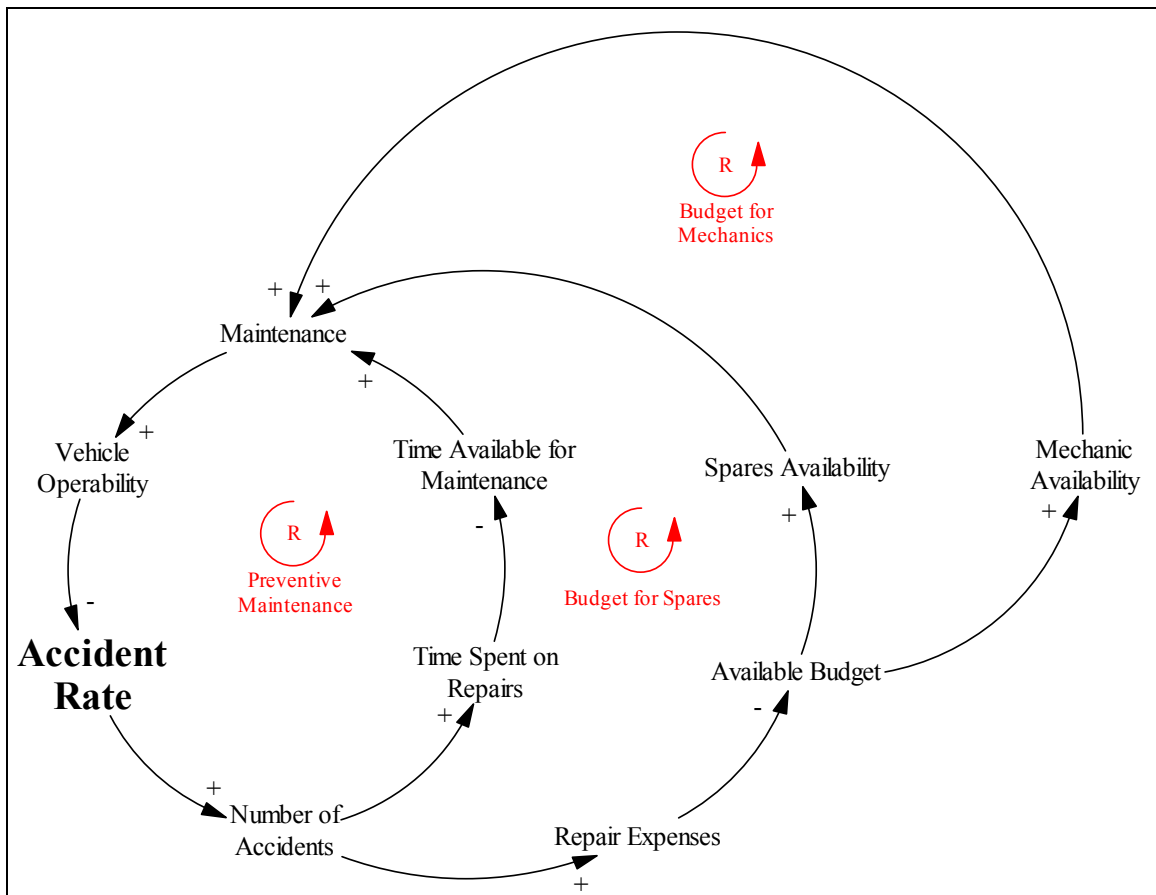


Figure 8-17: Machine Causal Loop Diagram

### 8.7.2 Mission Causal Loop Diagram

The Mission CLD is shown as Figure 8-18. The CLD has three balancing loops that capture the typical managerial mission adjustment responses to changes in the prevailing accident rate. The three balancing loops are:

- (1) Mission Compatibility
- (2) Mission Complexity
- (3) Mission Intensity

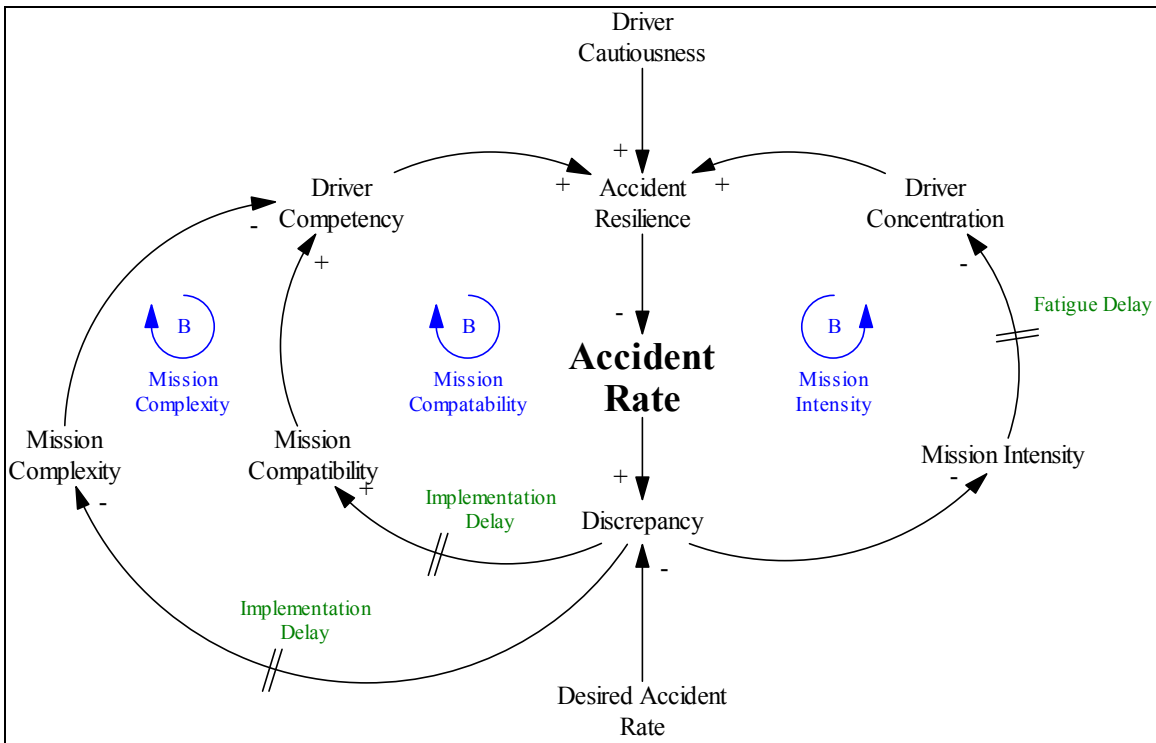


Figure 8-18: Mission Causal Loop Diagram

### 8.7.3 Training Causal Loop Diagram

The Training CLD is shown as Figure 8-19. The CLD captures the typical managerial training adjustment responses to changes in the accident rate. The main feedback loops of the CLD are:

- (1) Learning from Accidents Balancing Loop
- (2) Rigidity Erosion of Ability to Deal with Exceptions Reinforcing Loop
- (3) Training Longer Balancing Loop
- (4) Training More Often Balancing Loop

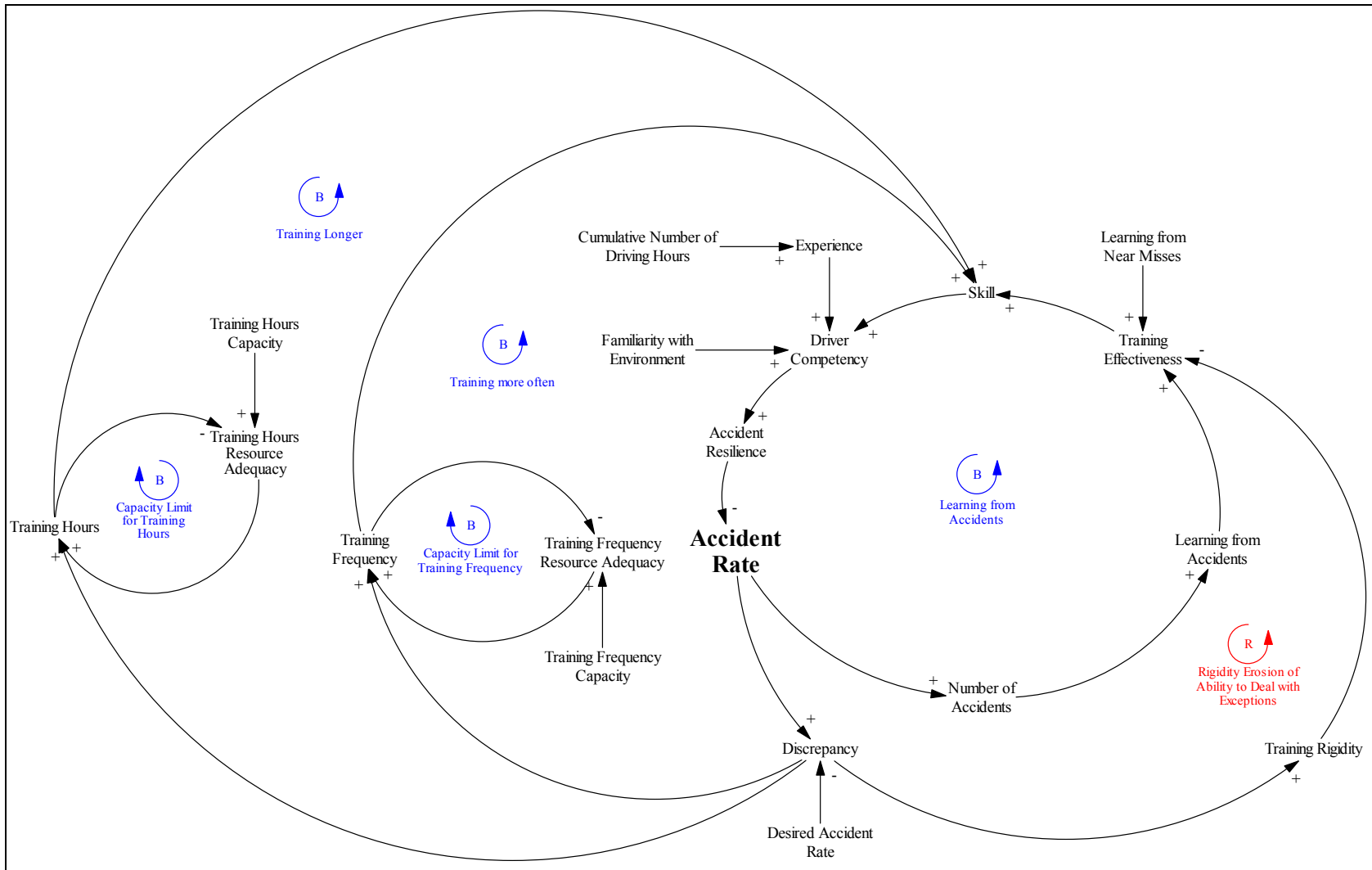


Figure 8-19: Training Causal Loop Diagram

### 8.7.4 Work Management Causal Loop Diagram – Commander Extension

Currently, the Work Management CLD only considers the influence of driver and supervisor behavior on the overall accident rate. However, commanders also have a role to play in the overall accident rate. Chapter 4 describes the fact that in Organization Sierra-Tango, the bulk of a commander’s mission performance is measured based on mission efficiency. Arguably, this performance appraisal system has an influence on the overall emphasis of military values over safety that increases the perceived necessity to take risks on the part of drivers and supervisors that has an effect on the overall accident rate. Additionally, the success or failure of the new safety process also affects a commander’s perception on its usefulness which influences his or her emphasis on military values over safety. These dynamics are captured in the CLDs shown in Figure 8-21 (impact on driver behavior) and 8-22 (impact on supervisor behavior). The main feedback loops of the CLDs are:

- (1) Commander Perception of Safety Process – Effect on Driver Perception on Risk-Taking Necessity Reinforcing Loop
- (2) Commander Perception of Safety Process – Effect on Supervisor Perception on Risk-Taking Necessity Reinforcing Loop

The commander extension to the Work Management CLD is another area for future research to enrich the model.

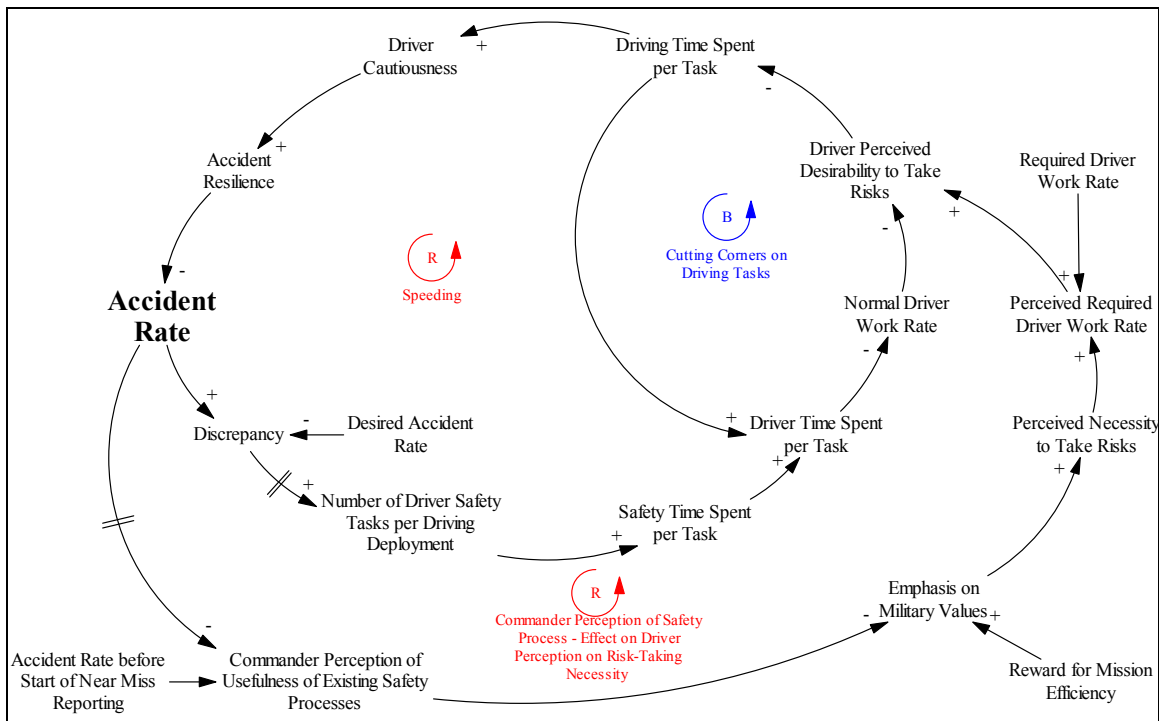


Figure 8-20: Commander Extension to Work Management Causal Loop Diagram (Impact on Driver Behavior)

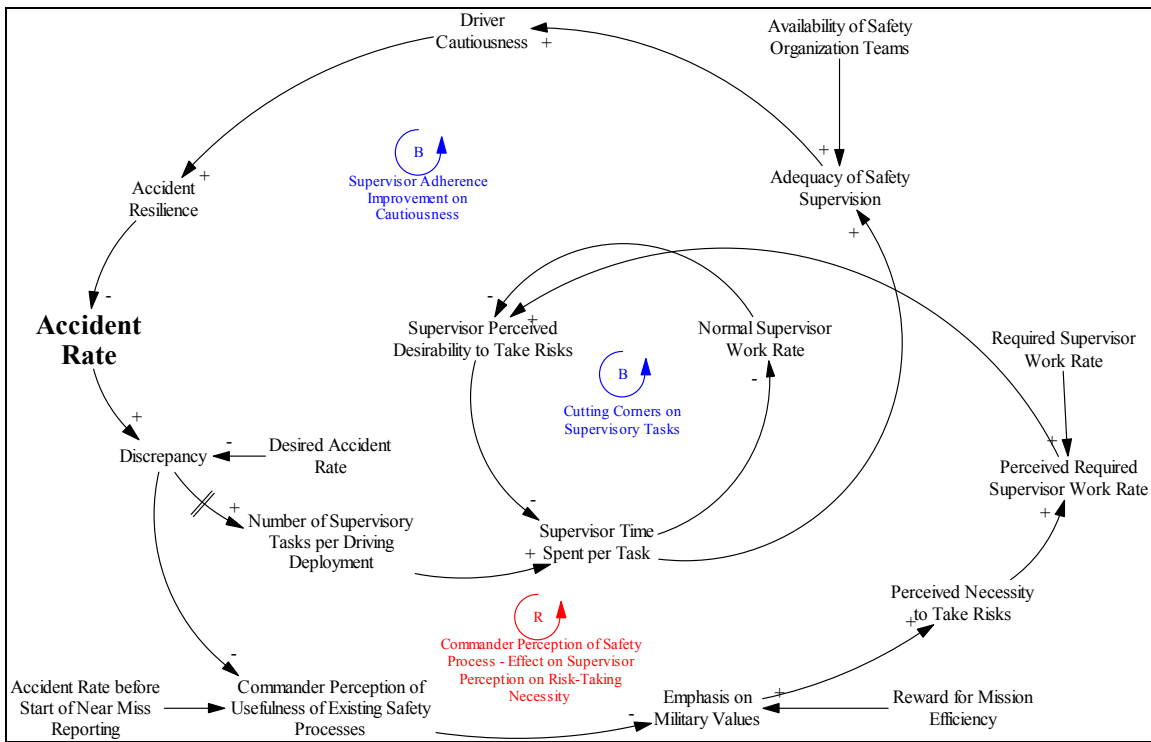


Figure 8-21: Commander Extension to Work Management Causal Loop Diagram (Impact on Supervisor Behavior)

### 8.7.5 Work Management Causal Loop Diagram – Fatigue Extension

As discussed in Chapter 6, when schedule pressure increases, other than cutting corners on tasks, workers can also respond by working longer to alleviate the schedule pressure. However, extended overtime is not sustainable as it would lead to fatigue and morale issues which would have detrimental reinforcing impacts on the work output rate and consequently on the accident rate. The effect of overtime on fatigue and motivation were not included in the Work Management CLD as cases of fatigue and motivational issues causing vehicle accidents in Organization Sierra-Tango’s context are rare as revealed from the review of the accident reports in Chapter 3. Nonetheless, the Fatigue Extension to the Work Management CLD as shown Figure 8-20 is an area for future research. The extension has two main feedback loops:

- (1) Work Harder Balancing Loop
- (2) Burnout Reinforcing Loop



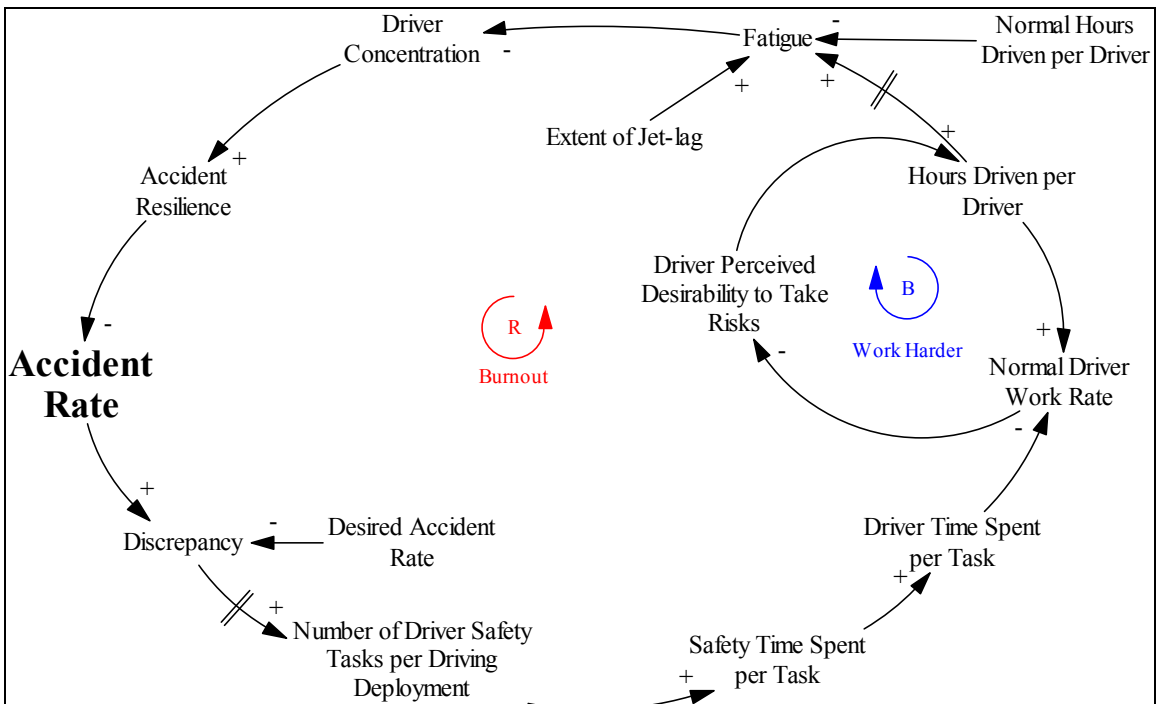


Figure 8-22: Fatigue Extension to Work Management Causal Loop Diagram

## 8.8 Conclusion

This chapter has described the development of the two SD models that I have conceptualized and constructed to assist Organization Sierra-Tango in deepening their understanding of some of the complex dynamics that underpin vehicle safety during training deployments. While the causal feedback loops that I have developed are undoubtedly far less than a complete representation of the real world, it does illustrate some of the key variables, both tangible and intangible, that impact a driver's accident propensity. Furthermore, these variables are not independent, but are related to one another in complex fashions. The Work Management and Near Miss Reporting SD models are next used for policy analysis which is the focus of the next chapter.

## **CHAPTER 9: SIMULATION AND ANALYSIS OF SYSTEM DYNAMICS MODELS**

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### **9.1 Introduction**

This chapter presents the results of several simulations and analyses that were performed using both the Work Management System Dynamics (SD) model and the Near Miss Reporting System Dynamics model that were introduced in Chapter 8. Through the analysis of the simulation results, several insights into the implementation of safety improvement programs as well as the near miss reporting aspect of incident reporting systems are gained.

### **9.2 Simulation and Analysis of Work Management System Dynamics Model**

#### **9.2.1 Scenario of the Introduction of New Safety Program – Replicating the Hypothetical Trend of Vehicle Accidents**

From Chapter 8, the hypothetical trend of vehicle accidents during training deployments is one that is monotonically rising for three years as shown in Figure 8-1. Therefore, the Work Management SD model must first generate an accident rate profile that is similar to the hypothetical trend. To achieve this, a conjectural scenario was conceived where a new safety program that increased the number of tasks for both drivers and supervisors was introduced. However, the increased in the number of tasks was not met with a concomitant reduction in the required driver and supervisor work rate, resulting in schedule pressure which feeds the perceived desirability to take risks as discussed in Chapter 8. This scenario is plausible not only because it is able to generate a close replica of the hypothetical trend, the resulting dynamics captured in the Work Management SD model also relates to the high number of occurrences of driver errors (mainly negligence and judgmental errors) and supervisory lapses (primarily insufficient supervision and briefings, and inadequate driving orientations) uncovered from the review of the accident reports (Chapter 3).

The simulation run for the scenario is shown as Figure 9-1 and it can be observed that the general accident rate profile largely matches the hypothetical trend of vehicle accidents during training deployments as shown in Figure 8-1.

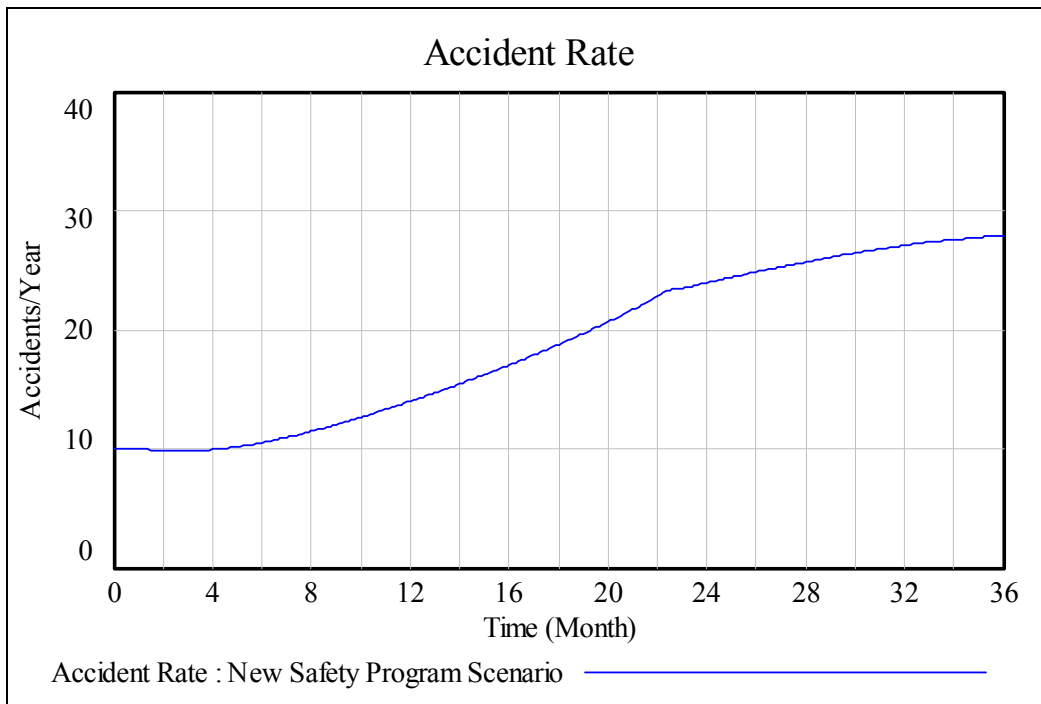


Figure 9-1: Simulation Run of the Scenario of the Introduction of New Safety Program that Matches the Hypothetical Trend of Vehicle Accidents during Training Deployments

### 9.2.2 Recreation of Reference Mode 1

“*Reference Mode No. 1*” for the Work Management SD model represents the case where management measures failed to elicit any improvement in the safety situation caused by the introduction of the new safety program and the accident rate increases before arriving at a plateau. In the context of the scenario and the Work Management SD model, this is represented by the case where no actions are taken by management to reduce the increased workload that is imposed upon both drivers and supervisors as a result of the new safety program. The simulation run for such a situation is shown as Figure 9-2. It can be observed that the general accident rate profile is largely matches that of “*Reference Mode No. 1*” as shown in Figure 8-2.

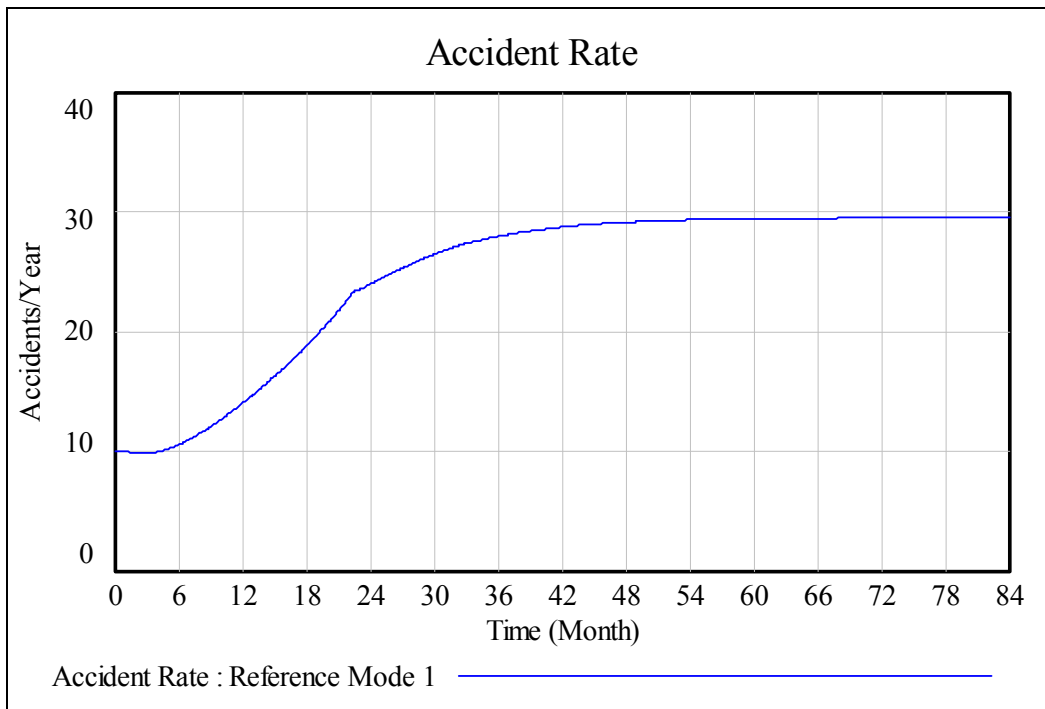


Figure 9-2: Simulation Run of Reference Mode No. 1 – No Improvement to the Safety Situation

### 9.2.2.1 Reference Mode 1 – Effects on Driver Behavior

As discussed in Chapter 8, such a situation will create schedule pressure that increases the perceived desirability to take risks on the part of drivers. Drivers respond by spending less time on their driving tasks by driving faster and cutting corners on the required safety tasks. These behaviors reduce a driver’s cautiousness and therefore suggest an explanation for the high number of occurrences of negligence as a form of driver error as found from the review of the accident reports in Chapter 3.

Figure 9-3 shows that the actual driving time spent per task is less than the standard driving time required per task, meaning that drivers are necessarily speeding which reduces their cautiousness. Figure 9-4 shows that the actual safety time spent per task is less than the standard safety time required per task which further reduces their cautiousness. As a result of these behaviors, the overall driver resilience is reduced, leading to an increase in the overall number of accidents. It should be highlighted that due to an implementation delay for the new safety program that can be reasonably expected in an entity as large as Organization Sierra-Tango; there is a gradual ramp-up in the standard safety time required per task rather than a step increase.

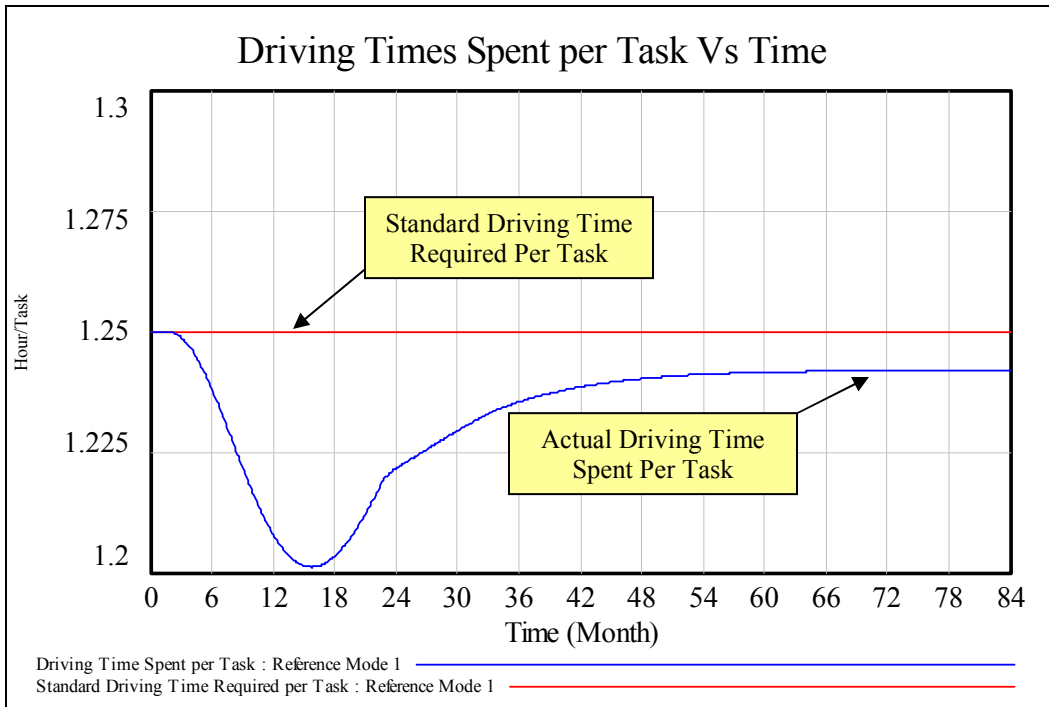


Figure 9-3: Simulation Run of Reference Mode No. 1 – Comparison of Driving Times Spent per Task

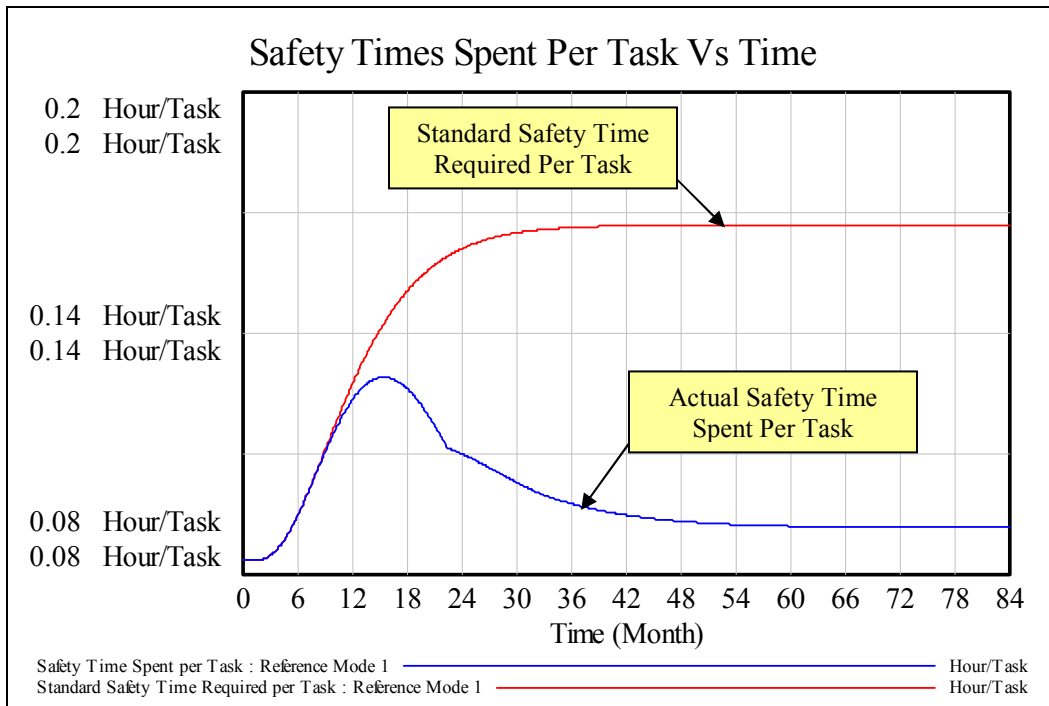


Figure 9-4: Simulation Run of Reference Mode No. 1 – Comparison of Safety Times Spent per Task

From Figure 9-4, it can be observed that there is a drop in the actual safety time spent per task from around Month 15. This happens because of the effect of the driver's perception on the usefulness of the safety tasks on his or her adherence to them. There is a delay involved for a driver to alter his or her perception of the safety tasks. As the accident rate continues to rise as can be seen from Figure 9-2, the driver's adherence to the safety tasks declines and he or she spends less time on them. As discussed in Chapter 8, this has a balancing effect as the overall time required per task decreases, thereby relieving some schedule pressure and therefore there is less impulse for drivers to speed (actual driving time per task increases) as observed in Figure 9-3. Both the actual driving time per task and the actual safety time per task are superimposed on each other as shown in Figure 9-5. Figure 9-5 also shows that that an equilibrium point is reached sometime after Month 60. Therefore, the increase in accident rate comes to a rest as shown in Figure 9-2.

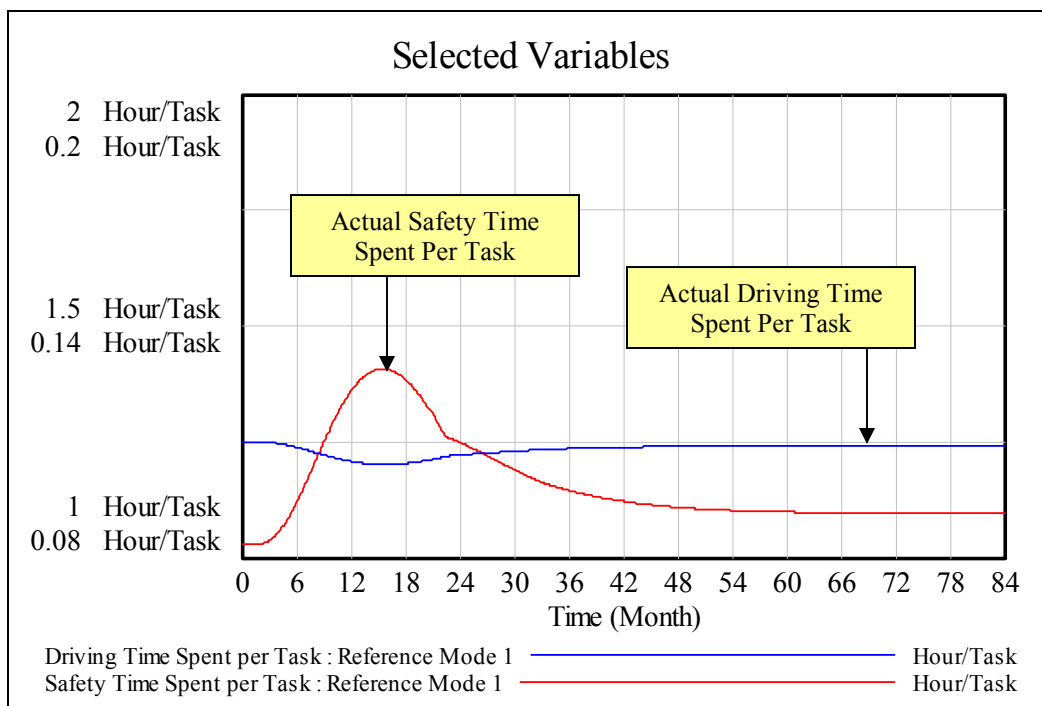


Figure 9-5: Simulation Run of Reference Mode No. 1 – Comparison of Actual Driving and Safety Times Spent per Task

### 9.2.2.2 Reference Mode 1 – Effects on Supervisor Behavior

As discussed in Chapter 8, such a situation will also create schedule pressure that increases the perceived desirability to take risks on the part of supervisors. Supervisors respond by cutting corners on their tasks and this behavior reduces a driver's cautiousness, competency and concentration as explained in Chapter 8 and therefore suggests an explanation for the high number of occurrences of insufficient safety briefings, driving orientations and inspections as forms of supervisory lapses as found from the review of the accident reports in Chapter 3.

Figure 9-6 shows that the actual supervisory time spent per task is less than the standard supervisory time required per task, meaning that supervisors are spending less time than what is required to raise the extent of supervision and therefore not deriving the new safety program's intended benefits. In order to accommodate the increased in time for each supervisory task, supervisors respond by spending less time on their supervisory tasks by going through the motions during safety inspections, by cutting down on details during safety briefings or by spending less time on driving orientations, all of which reduce a driver's cautiousness, competency and concentration. As a result of these supervisory behaviors, the overall driver resilience is reduced, thereby contributing to the increase in accident rate. As previously highlighted for the case of drivers, due to an implementation delay for the new safety program that can be reasonably expected in an entity as large as Organization Sierra-Tango; there is a gradual ramp-up in the standard supervisory time required per task rather than a step increase.

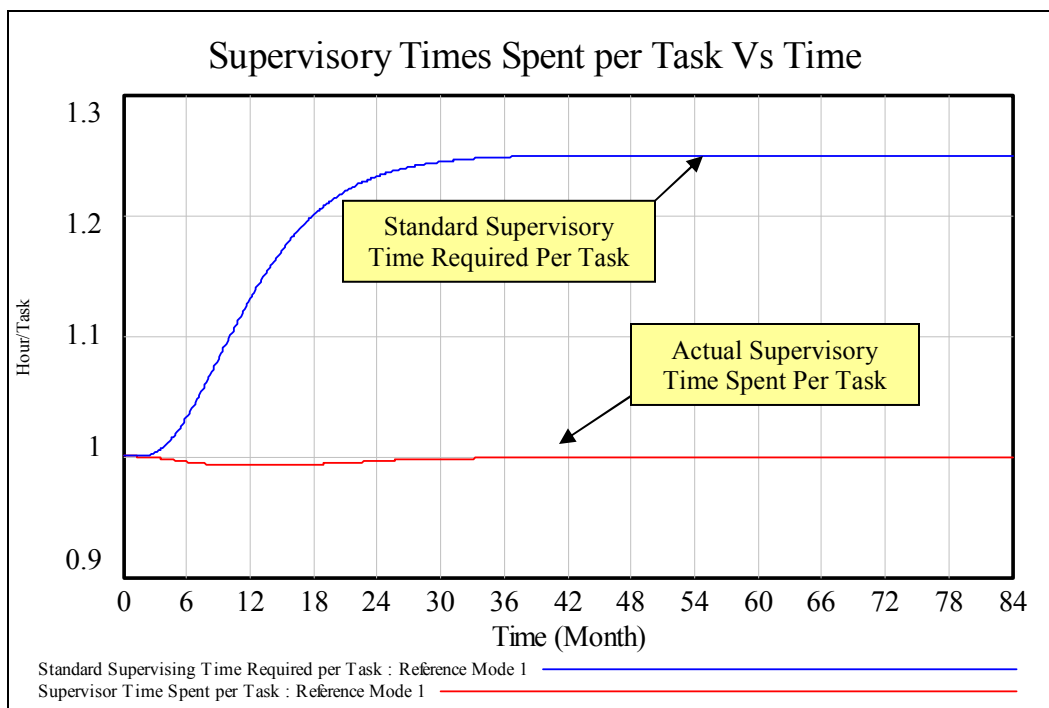


Figure 9-6: Simulation Run of Reference Mode No. 1 – Comparison of Supervisory Times Spent per Task

From Figure 9-6, it can be observed that there is a small dip in the actual supervisor time spent per task before settling at a level that is lower than the original (this is not apparent due to the scaling of the graphs). The initial decrease is because supervisors are responding to the increase in schedule pressure. There exists a delay for a supervisor to alter his or her perception of the safety tasks. As the accident rate continues to rise as can be seen from Figure 9-2, the supervisor's adherence to the new safety tasks declines and he or she spends less time on them. As discussed in Chapter 8, this has a balancing effect as the overall supervisor time required per task decreases, thereby relieving some schedule pressure as observed in Figure 9-6.

### 9.2.3 Recreation of Reference Mode 2

“*Reference Mode No. 2*” for the Work Management SD model represents the scenario where management measures have limited success but manage to contain the prevailing accident rate under the new safety program. This reference mode lies midway between reference modes No. 1 and 3 and is considered to be not as insightful in the sense that the undesirable situation of a high accident rate prevails albeit it is no longer increasing. As the main focus is to understand how the prevailing accident rate can be corrected, no dedicated simulations were performed to replicate “*Reference Mode No. 2*”. Nevertheless, “*Reference Mode No. 2*” is replicated in one of the policy analysis simulations of “*Reference Mode No. 3*” as seen in the next section.

### 9.2.4 Recreation of Reference Mode 3

“*Reference Mode No. 3*” for the Work Management SD model represents the case where management measures not only succeed in containing the prevailing accident rate but also in abating it such that the accident rate attains a lower level. In the context of the scenario and the Work Management SD model, this is represented by the case where actions are taken by management to effectuate a concomitant reduction in workload that is imposed upon both drivers and supervisors as a result of the new safety program. Two policies are explored. The first policy is one where the reduction in workload is brought about by a proportionate reduction in the number of tasks required of both drivers and supervisors from Month 36. The other policy is one where the reduction in workload is achieved by an increase in the number of drivers and supervisors available from Month 36. The simulation runs for the first and second policies are shown in Figure 9-7. It can be observed that the general accident rate profile of both simulations largely match that of “*Reference Mode No. 3*” as shown in Figure 8-4. It should be mentioned that the difference between the two simulation runs is not significant as the workload and manpower adjustments used are estimates rather than the exact values to mitigate the schedule pressure that is created under the new safety program. The simulation run for “*Reference Mode No. 1*”, i.e., “*Policy 0: No Action*” is superimposed onto Figure 9-7 so as to provide a general appreciation of the improvement that can be achieved with proper work management.

From Figure 9-7, it is apparent that the system has not attained an equilibrium condition. Another simulation run was conducted for “*Policy 2: Increase Manpower from Month 36*” where the time horizon is extended by another three years till Year 10. The simulation is shown as Figure 9-8 and the simulation run for “*Policy 0: No Action*” is again superimposed for the purpose of comparison.



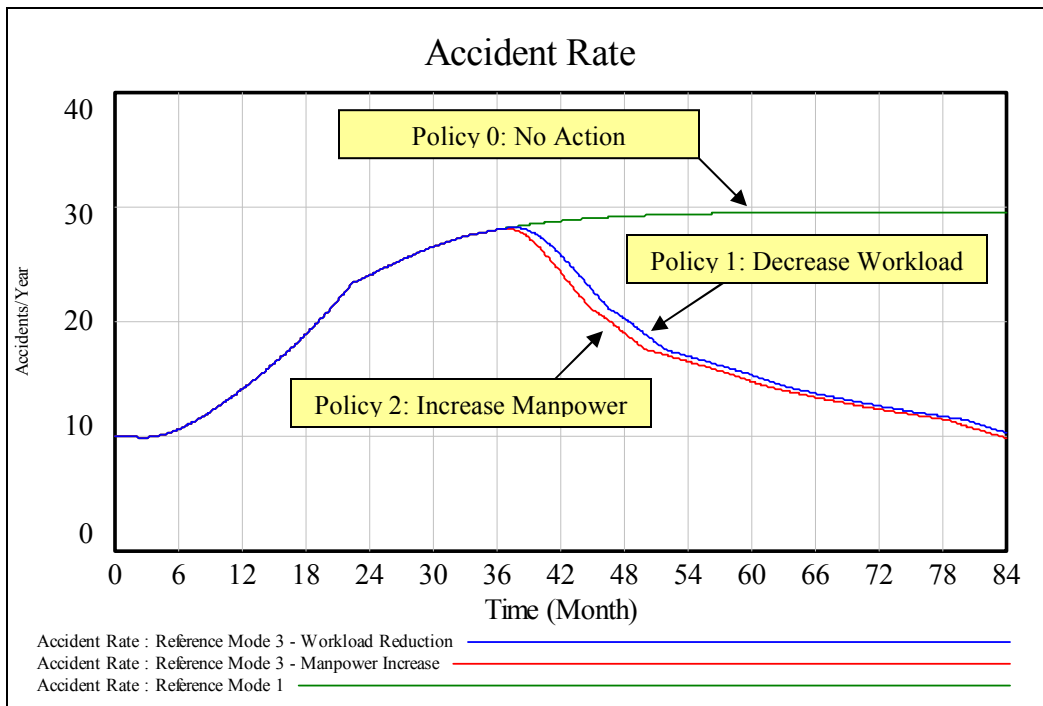


Figure 9-7: Simulation Runs of Reference Mode No. 3 – Improvement to the Safety Situation

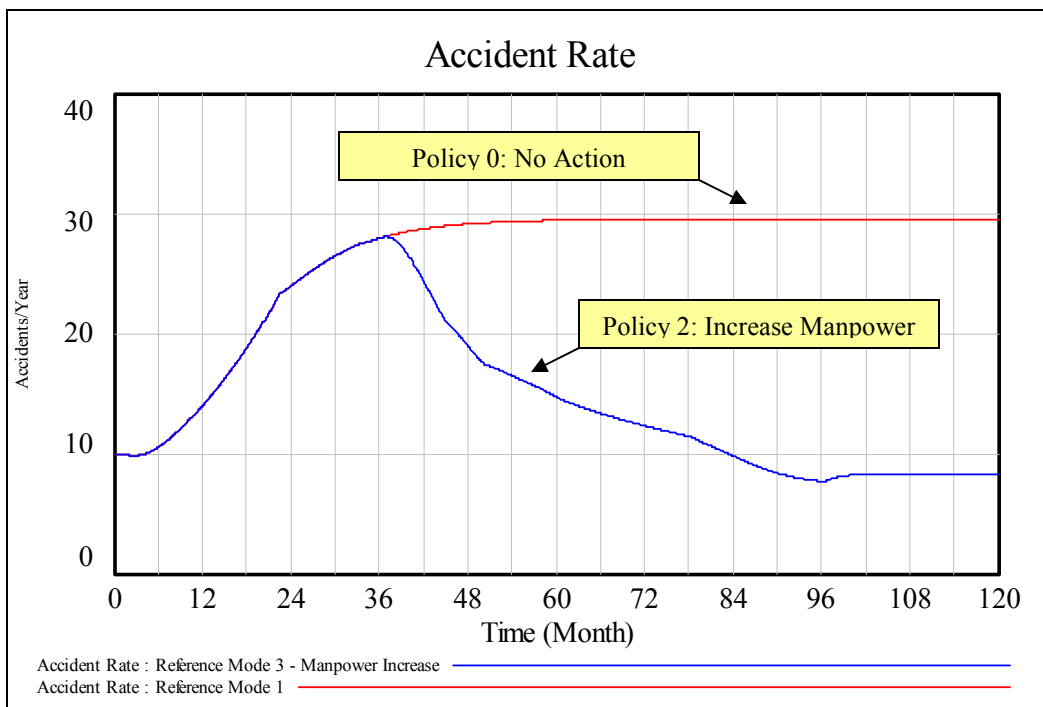
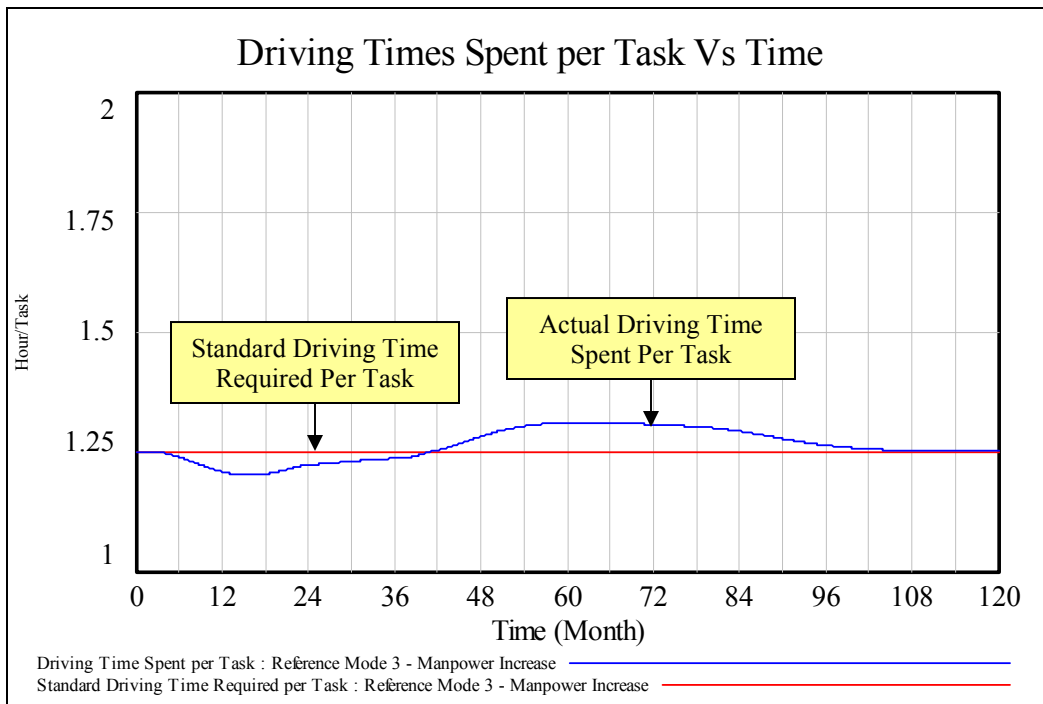


Figure 9-8: Simulation Run of Reference Mode No. 3 (Policy 2: Increase Manpower, Time Horizon Extended to Year 10)

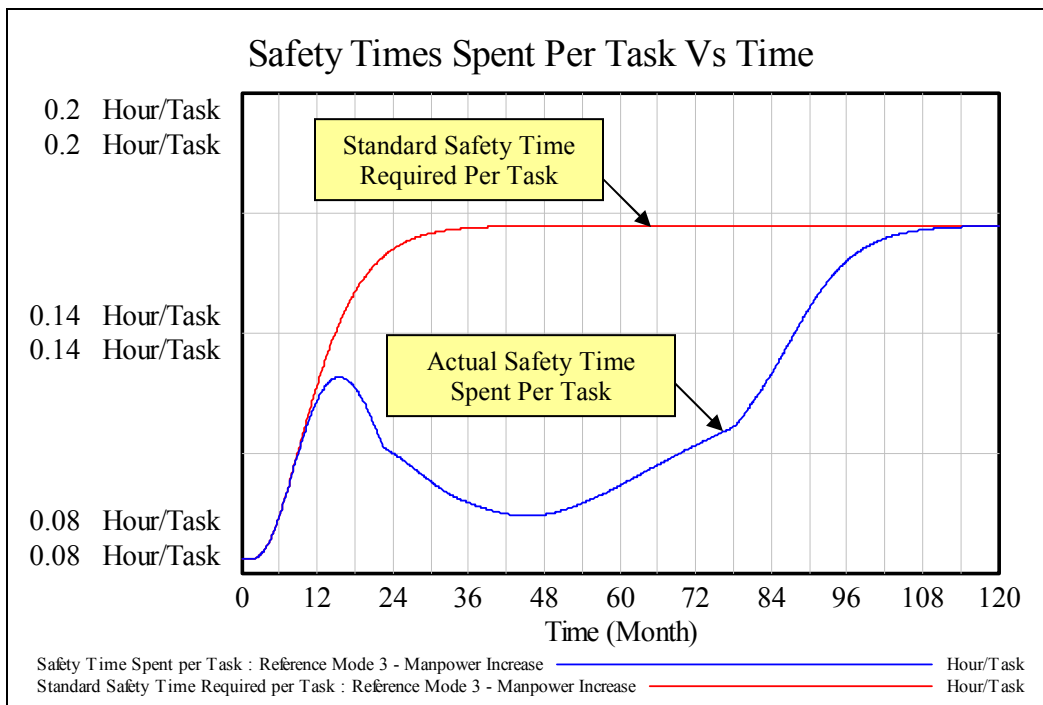
#### 9.2.4.1 Reference Mode 3 – Effects on Driver Behavior

Figure 9-9 compares the driving times spent per task under “*Policy 2: Increase Manpower from Month 36*” where the time horizon is extended by another three years till Year 10. Figure 9-10 compares the safety times spent per task under the same policy.

As can be observed from Figure 9-9, the actual driving time spent per task begins to increase from Month 36 as schedule pressure is relieved as more and more drivers become available. There is a gradual increase in the number of drivers as there is an implementation delay due to time required to effect resource reallocation. Somewhere around Month 42, schedule pressure actually goes negative and drivers respond by spending more time driving. As drivers drive slower, their cautiousness is raised and their accident resilience increases. This contributes to the decrease in the accident rate as can be seen in Figure 9-8. The actual safety time spent per task only begins to increase from Month 48 due to the delay for a driver to change his or her perception of the usefulness of the safety tasks. The decrease in the accident rate as a result of drivers performing their tasks more cautiously fuels the reinforcing effect of a driver’s perception of the usefulness of the safety tasks. Drivers’ adherence to safety tasks increase and the actual safety time spent per task increase as seen from Figure 9-10. The adherence to safety tasks causes the driver’s cautiousness and hence accident resilience to increase even further thereby lowering the accident rate. As the actual safety time spent per task increases, the schedule pressure slack diminishes and the actual driving time spent per task begins to decrease. Finally, an equilibrium condition is reached where drivers are spending the standard driving time spent per task (no speeding) and also spending the safety time required for the new safety program. Under such a condition, the full intended benefit of the safety program is realized and the driver’s cautiousness and hence accident resilience is raised. Therefore, the accident rate comes to rest at a level lower compared to the safety situation before the inception of the safety program as seen in Figure 9-8.



**Figure 9-9:** Simulation Run of Reference Mode No. 3 (Policy 2: Increase Manpower, Time Horizon Extended to Year 10) – Comparison of Driving Times Spent per Task



**Figure 9-10:** Simulation Run of Reference Mode No. 3 (Policy 2: Increase Manpower, Time Horizon Extended to Year 10) – Comparison of Safety Times Spent per Task

### 9.2.4.2 Reference Mode 3 – Effects on Supervisor Behavior

Figure 9-11 compares the supervisory times spent per task under “*Policy 2: Increase Manpower from Month 36*” where the time horizon is extended by another three years till Year 10. Similar to the case for the drivers, schedule pressure is relieved from Month 36 as more and more supervisors become available. There is a gradual increase in the number of supervisors as there is an implementation delay due to time required to effect resource reallocation. Supervisors’ perception of the usefulness of the safety program begins to increase slowly as the accident rate improves due to the delay required for perceptions to change. The reduction in schedule pressure and the change in perception that brings about adherence account for the steep rise in the actual supervisory time spent per task. As the supervisory time spent per task increases, so to does the adequacy of supervision and the time spent on driving orientations. These factors raise the driver’s cautiousness, competency and concentration thereby contributing to the decrease in the accident rate. Around Month 48, the additional number of supervisors has all been deployed. The supervisor’s perception of the usefulness of the safety program and consequent adherence to them continues to increase the supervisory time spent per task albeit at a lower rate. The actual supervisory time spent per task overshoots the standard supervisory time required per task due to the schedule pressure slack. As time progresses, the schedule pressure slack is used up as the task backlog begins to build up from the decrease in the supervisor task completion rate as a result of spending more time on supervisory tasks. Finally, the system attains equilibrium where there is no schedule pressure and supervisors spend the standard supervisory time required per task and reap the intended benefits of the safety program. This contributes to the overall improvement in the accident rate as shown in Figure 9-8.

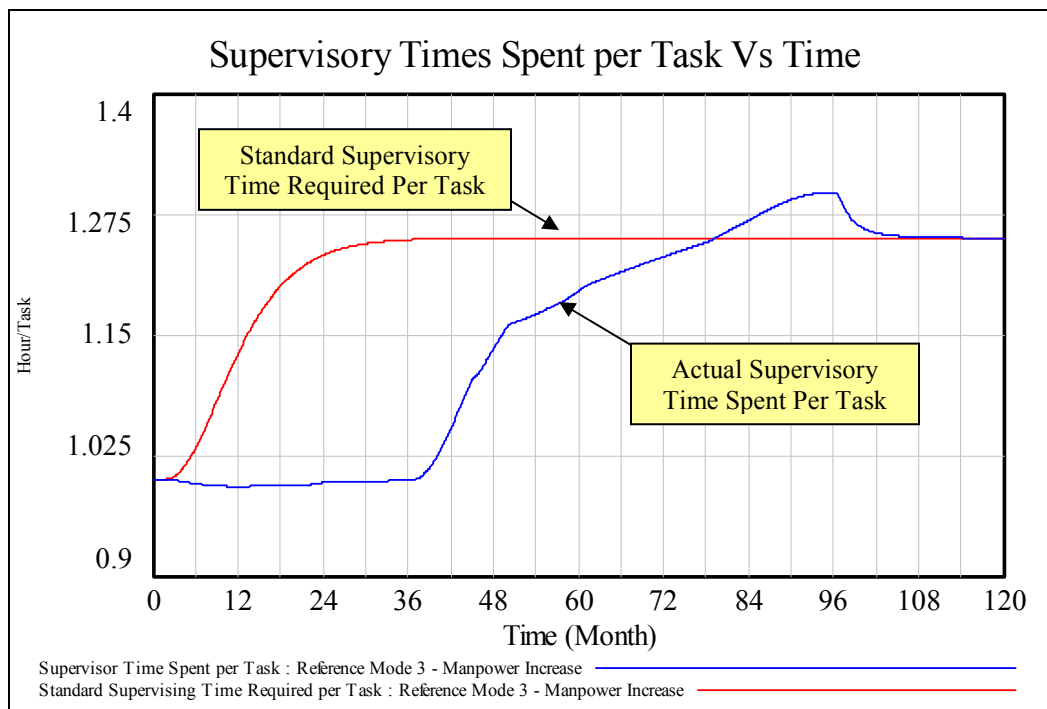


Figure 9-11: Simulation Run of Reference Mode No. 3 (Policy 2: Increase Manpower, Time Horizon Extended to Year 10) – Comparison of Supervisory Times Spent per Task

### 9.2.4.3 Policy Analysis – Determining Relative Leverages of Managing Driver Workload versus Supervisor Workload

Another set of simulations were performed in order to appreciate the relative levers of management strategies to reduce workload under two different policies. “Policy 2-1” is the case where only driver workload is managed from Month 36 under the new safety program. “Policy 2-2” is the case where only supervisor workload is managed from Month 36 under the new safety program. Both of these simulations are based on “Policy 2: Increase Manpower from Month 36” where the time horizon is extended by another three years till Year 10. The results of the two simulations are shown in Figure 9-12. The simulation runs for “Reference Mode No. 1”, i.e., “Policy 0: No Action” and “Policy 2: Increase Manpower from Month 36” are superimposed to obtain a general appreciation of the improvement that can be achieved under the two work management strategies.

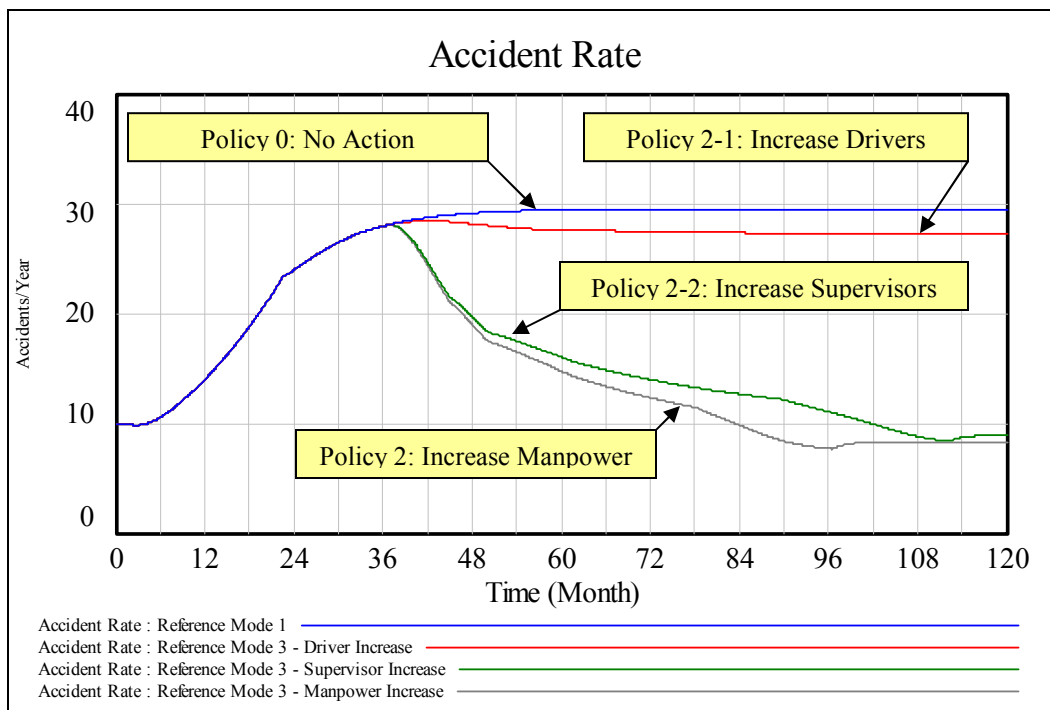


Figure 9-12: Simulation Runs of Reference Mode No. 3 (Policy 2: Increase Manpower, Time Horizon Extended to Year 10) – Comparison of Different Workload Management Strategies

From the simulation results shown in Figure 9-12, it can be observed that the strategy to only manage driver workload (Policy 2-1) manages to contain the accident rate but at a level that remains higher than before the safety program was started. This result can be considered to be a very close recreation of “Reference Mode 2” as shown in Figure 8-3. On the other hand, the strategy to only manage supervisor workload is not only effective is reversing the accident trend the accident rate is equilibrium is lower than before the safety program was started. The principle explanation for the difference between the two strategies is their relative influence on a driver’s accident resilience. Managing the workload of drivers allows them to reap the benefits

of the new safety program and improve their cautiousness. However, managing the workload of supervisors reaps the benefits of the new safety program by improving all three attributes of a driver's accident resilience which are cautiousness, competency and concentration. Therefore, the strategy to manage supervisor workload alone is found to be of higher leverage compared to the strategy to manage driver workload alone.

## 9.2 Simulation and Analysis of Near Miss Reporting System Dynamics Model

As described in Chapter 8, the Near Miss Reporting SD model was constructed to gain some insights into Organization Sierra-Tango's new initiative on open reporting of hazards and incidents. This SD model focuses on the reporting and learning aspects of near misses on improving training effectiveness.

### 9.2.1 Modeling Baseline – System in Equilibrium

As the open reporting program is still in its incipient stage, no data is available from the organization to develop reference modes on the rate of near miss reporting and its influence on the accident rate. As such, the model is calibrated such that the system begins in equilibrium under the existing conditions where both the near miss reporting rate and the accident rate are constants are shown in Figures 9-13 and 9-14 respectively. Practically, equilibrium represents a system operating as designed in steady state. In this idealized steady state, the effects of any perturbations on the system as a result of policy changes can be easily discerned.

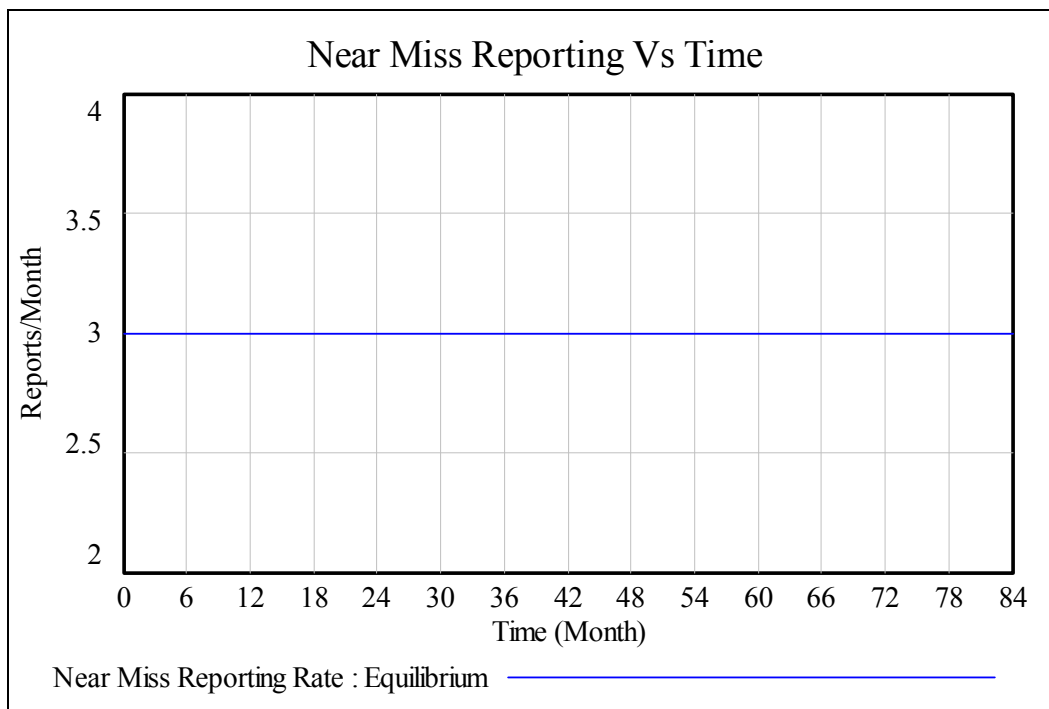


Figure 9-13: Simulation Run of Near Miss Reporting SD Model in Equilibrium – Near Miss Reporting Rate

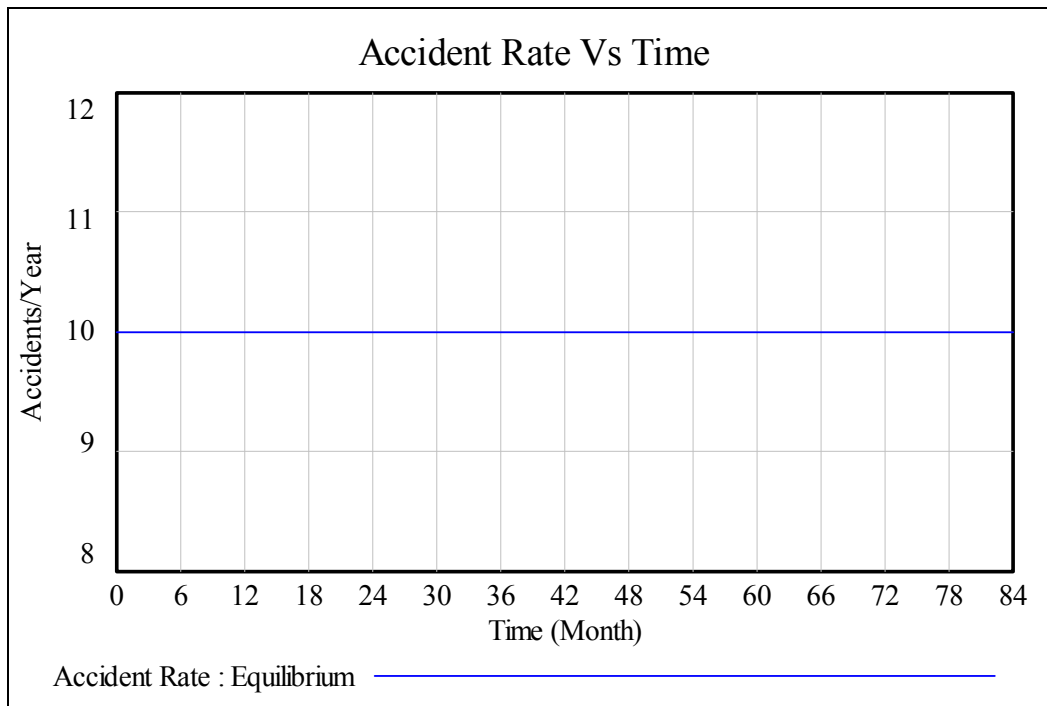
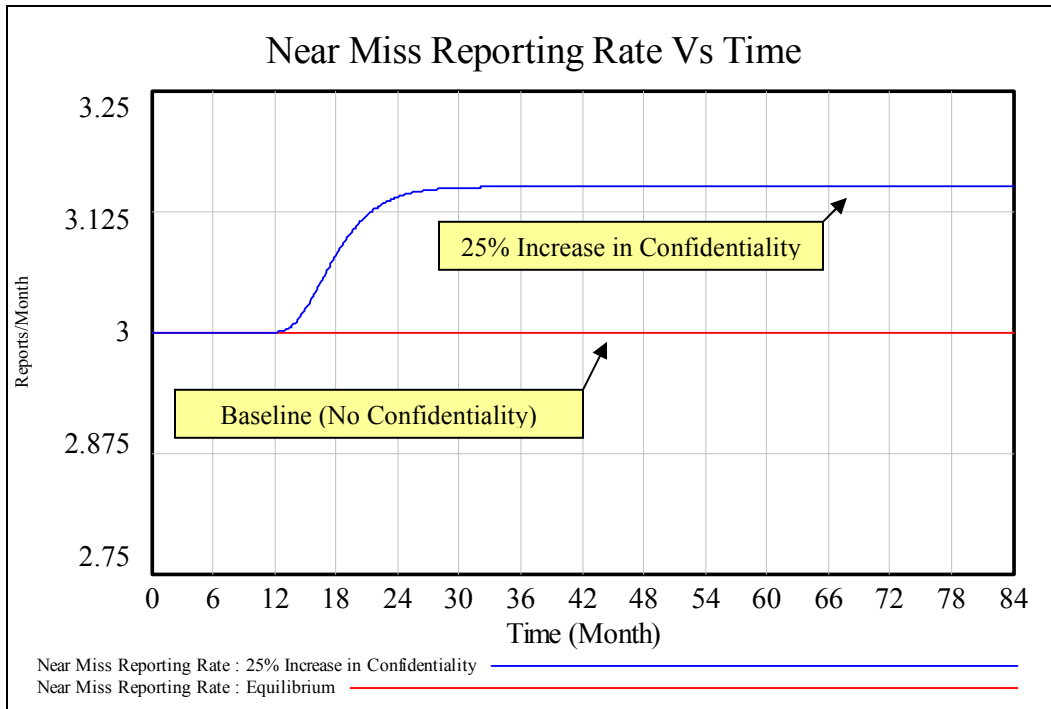


Figure 9-14: Simulation Run of Near Miss Reporting SD Model in Equilibrium – Accident Rate

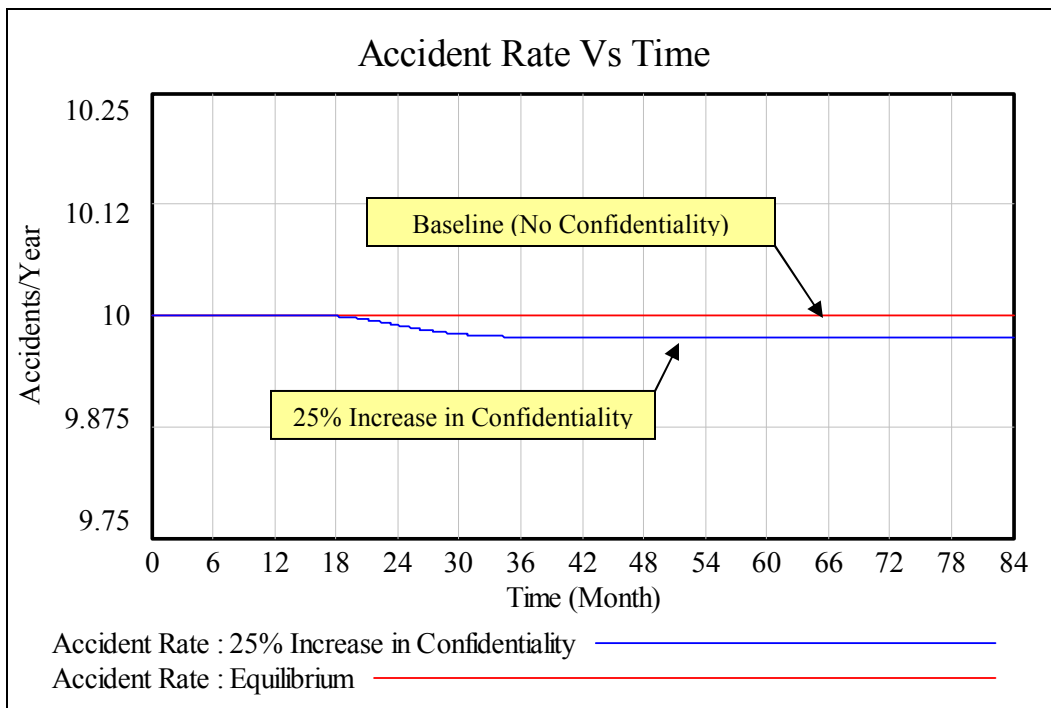
### 9.2.2 Policy Analysis – Increasing Confidentiality of Reporter’s Identity

Currently, Organization Sierra-Tango’s policy is to make readily available the identity of near miss reporters (Chapter 2). From the literature review in Chapter 6, it was found that near miss reports are encouraged when the confidentiality of near miss reporters is increased. As such, a simulation was performed to observe the effect of increasing the level of confidentiality of near miss reporters on the near miss reporting rate and the accident rate. The simulation is performed with a 25% increase in the confidentiality of near miss reporters from the confidentiality baseline which is essentially zero. The increase in confidentiality commences in Month 12. The simulation results are shown in Figures 9-15 and 9-16.

As the confidentiality of near miss reporters increases, the fear of reproach from comrades in potential near miss reporters decreases. Assuming that the number of potential near misses that can be reported remains constant, more near misses are reported as the psychological barrier is reduced. However, there is a delay for perceptions to change. Therefore, the near miss reporting rate assumes a slow ramp-up profile as shown in Figure 9-15. As more near misses are reported, learning from near misses increases and training effectiveness is raised from what it otherwise would have been. However, learning from near misses is a small subset of the greater body of knowledge that enriches training effectiveness. Therefore, the reduction in the accident rate with the increased number of near misses reported is muted as shown in Figure 9-16.



**Figure 9-15:** Simulation Run of Near Miss Reporting SD Model with Confidentiality Increased by 25% – Near Miss Reporting Rate



**Figure 9-16:** Simulation Run of Near Miss Reporting SD Model with Confidentiality Increased by 25% – Accident Rate



### 9.2.3 Policy Analysis – Varying Severity of Punitive Measures

A set of simulations was performed to learn the effect of varying severities of punitive measures on the near miss reporting rate and the accident rate. The results of both an increase and decrease of 25% in the baseline severity of punitive measures are presented in Figures 9-17 and 9-18.

Looking at simulations, it can be observed that both the near miss reporting rate and the accident rate increase by a larger amount when punishment severity is reduced whereas they decrease by a smaller amount for a proportionate increase in the punishment severity. This is because changes in punishment severity affect both the fear of punishment on comrades and the fear of punishment on self. When punishment severity is reduced, both the fear of punishment on comrades and on self are reduced. The lower fear of punishment on comrades will after a delay increase a driver's inclination to report near misses. As the baseline severity of punitive measures in the organization is assessed to be fairly high, a reduction in the severity of punitive measures and the consequent decrease of fear of punishment on self will decrease driver's cautiousness more than an increase in driver's cautiousness for a proportionate increase in punishment severity. Therefore, for the same magnitude change in punishment severity, the number of accidents and potential near misses to be reported increases more than decreases. The combined effects of near miss reporting inclination and the number of accidents and potential near misses to be reported explain the difference between the two scenarios. For both cases, the overshoot and undershoot behaviors are due to the delays in the system.

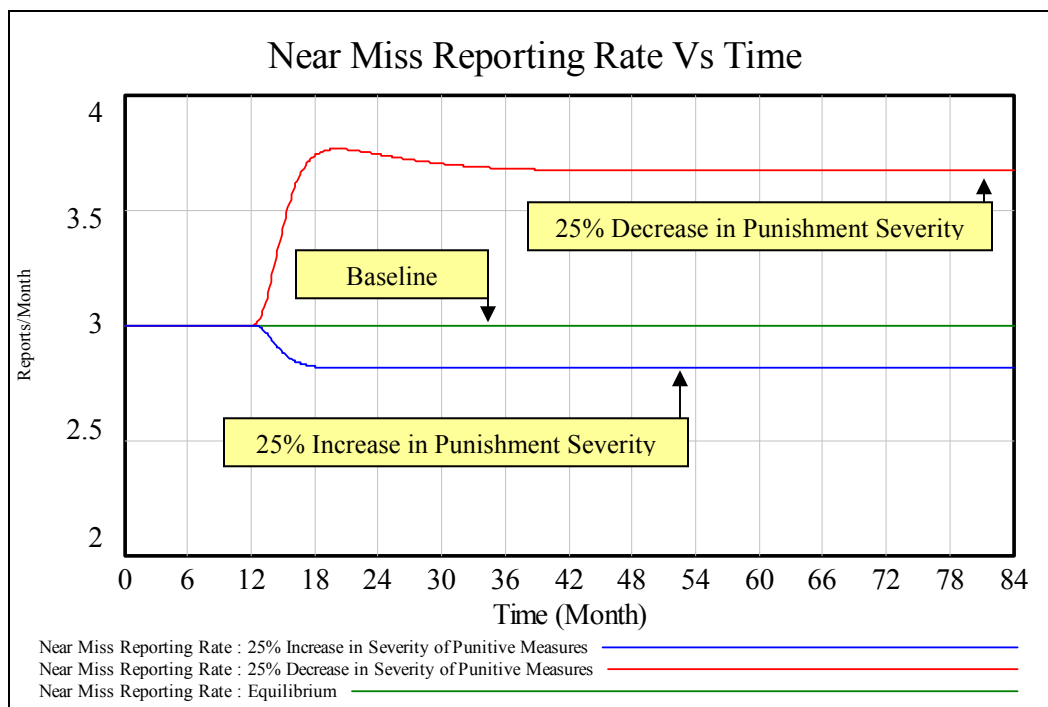
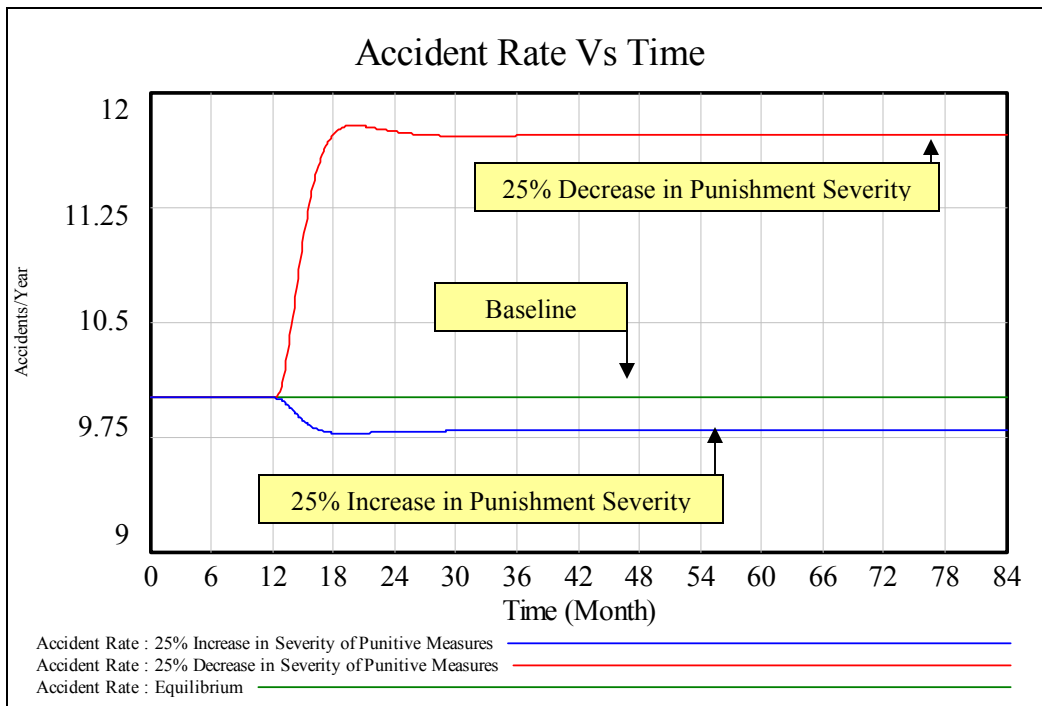


Figure 9-17: Simulation Runs of Near Miss Reporting SD Model with Severity of Punitive Measures Varied by 25% – Near Miss Reporting Rate

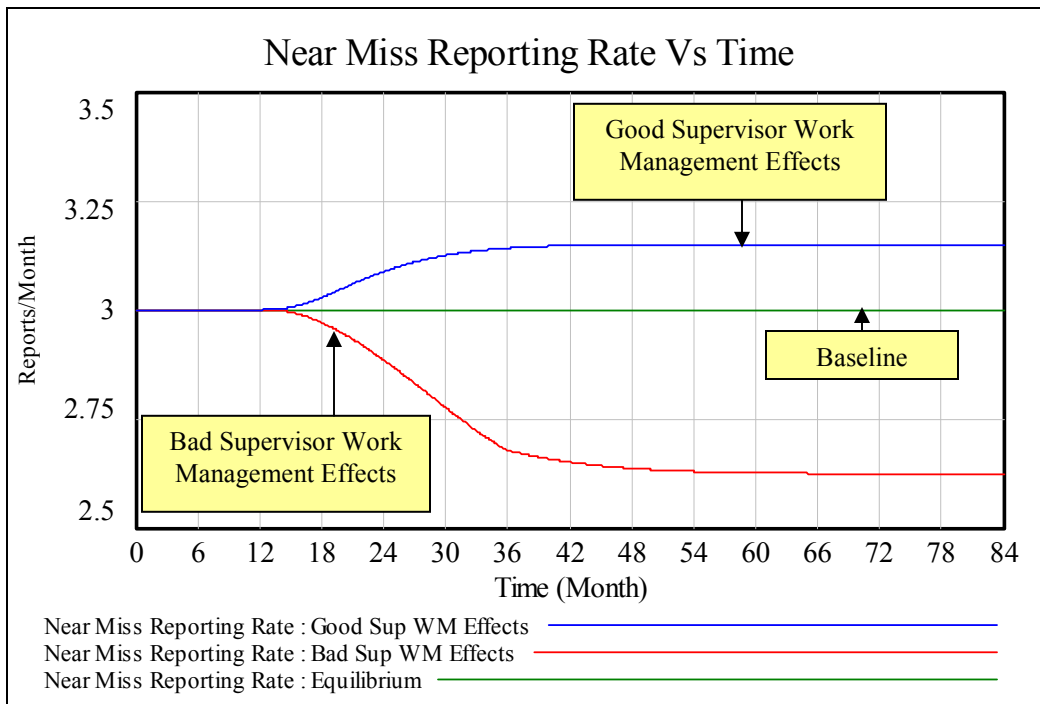


**Figure 9-18:** Simulation Runs of Near Miss Reporting SD Model with Severity of Punitive Measures Varied by 25% – Accident Rate

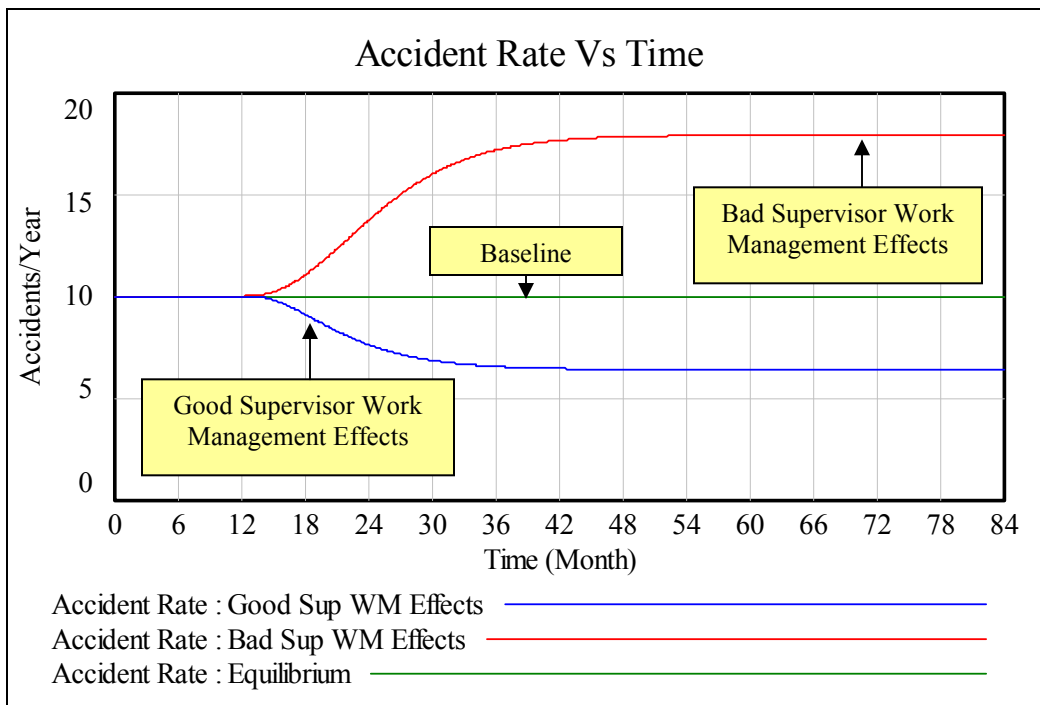
#### 9.2.4 Policy Analysis – Varying Supervisor Work Management Climates

From the simulations and analyses that were performed using the Work Management SD model as discussed in the previous section, improper work management on the part of supervisors would cause them to spend less time on their supervisory tasks which has a detrimental impact on all three attributes of a driver’s accident resilience which are cautiousness, competency and concentration. In addition, as supervisors fail to adhere to their required safety tasks, their actions will cause drivers to lower their perceived management commitment to safety which is a critical element that affects their near miss reporting inclination as discussed in Chapter 6.

This set of simulations was performed in order to gain some general insights into the effects that different supervisor work management climates can have on the near missing reporting rate. These effects of supervisor work management on driver competency and concentration, and their perceived management commitment to safety are simulated in the Near Miss Reporting SD Model. The simulation results are shown in Figures 9-19 and 9-20.



**Figure 9-19:** Simulation Runs of Near Miss Reporting SD Model with Supervisor Work Management Effects – Near Miss Reporting Rate



**Figure 9-20:** Simulation Runs of Near Miss Reporting SD Model with Supervisor Work Management Effects – Accident Rate

From the simulation results, it can be observed that in a climate of good supervisor work management, the near miss reporting rate increases and the accident rate decreases. More near misses are reported because the driver's perceived management commitment to safety is high and the improving accident rate sustains their perceived usefulness of the near miss reporting initiative. In addition to the effect of more learning from near misses on increasing training effectiveness and ultimately driver competency, the accident rate also decreases due to the raising of the driver's accident resilience as discussed previously. In a climate of bad supervisor work management, the near miss reporting rate decreases and the accident rate increases. Fewer near misses are reported because the driver's perceived management commitment to safety is low and the worsening accident rate diminishes their perceived usefulness of the near miss reporting initiative. In addition to the effect of less learning from near misses on decreasing training effectiveness and ultimately driver competency, the accident rate also increases due to the lowering of the driver's accident resilience as discussed previously. It is interesting to note that in a climate of bad supervisor work management, the impact on the near miss reporting rate and the accident rate is greater compared to a climate of good supervisor work management. The main explanation is because an improving accident rate serves to sustain the perceived usefulness of the near miss reporting initiative whereas a worsening accident rate reduces the perceived usefulness of the near miss reporting initiative.

### **9.3 Concluding Remarks**

The simulations and analyses that were performed using the two SD models (Work Management and Near Miss Reporting) presented some interesting insights into improving vehicle safety management and promoting a climate of near miss reporting. These findings are summarized in the final chapter of this thesis.

## CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS

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### 10.1 Introduction

This chapter presents conclusions and recommendations that are consistent with the findings in this thesis research as derived from three sources: (1) literature review, (2) development of the System Dynamics (SD) models, and (3) simulation and analysis performed using the SD models. The chapter closes by providing some of my thoughts on possible future research areas that can build upon the work that has begun with this thesis.

### 10.2 Work Management System Dynamics Model: Conclusions and Recommendations

#### 10.2.1 Awareness and Management of Schedule Pressure is Essential for a Safety Improvement Program to Succeed

The management of staff workload and hence schedule pressure is essential for the desired benefits of any safety improvement program to be realized. As the work presented in this thesis has shown, safety initiatives that involve increasing safety tasks without a concomitant reduction in workload creates schedule pressure on servicemen that enhances their perceived desirability to take risks. Their subsequent risk-taking actions undermine the original intentions of the safety program and a situation can be created whereby the safety state of the organization is exacerbated. However, before schedule pressure can be effectively regulated, managers must first be cognizant of its existence as a necessary consequence of any process change program. More generally, the implementation of change within an organization is often protracted, disruptive and often involves short-term costs before long-term benefits are realized. Without a sound awareness of these dynamics and prudent actions to mitigate their effects, managers can abandon change programs before they have a chance to succeed. Therefore, managers hoping to successfully implement any change initiatives within their organizations would stand to benefit by internalizing the mental model that schedule pressure is part and parcel of any change program.

#### 10.2.2 Schedule Pressure Must Be Managed at All Levels

Schedule pressure that comes hand in hand with any change program is often felt at all levels within an organization. In the context of vehicle safety improvement programs, this thesis has shown that schedule pressure can be exerted upon both drivers and supervisors and raises their perceived desirability to take risks. As the perceived desirability to take risks increases, drivers tend to drive more recklessly and cut corners on their safety tasks. Similarly, supervisors respond with workarounds by spending less time on safety briefings/ inspections and driving orientations. All of these actions lower a driver's cautiousness, competency and concentration, thereby lowering his/ her accident resilience and resulting in more accidents. Managers and policy makers are reminded that their decisions will cascade through all echelons within their

organization and it is hence imperative to manage the affects, both desired and undesired, at all levels.

### 10.2.3 Relieving Driver Workload through Increasing the Number of Drivers Available Rather Than Task Reduction

From the simulations and analyses performed using the Work Management SD model, it was shown that excessive driver workload can be alleviated by either increasing the number of drivers available or by reducing the number of tasks. In the context of Organization Sierra-Tango's military operations, the strategy of increasing the number of drivers available rather than reducing the number of tasks is recommended. This is because the main purpose of military training is to prepare servicemen for the rigors of actual combat operations. Therefore, reducing the number of training tasks just so as to regulate workload might erode or even result in the whole point of the training exercise being lost. Nevertheless, before executing this strategy, a number of factors will also have to be taken into account. Firstly, the increase in the number of drivers should not come at the expense of driver competency (skill and experience). For example, there should not be a relaxation of the CAT C2 and above rule that Organization Sierra-Tango has set for overseas training. If not, the overall competency of the pool of drivers will be diluted and so will their accident resilience. Secondly, as the pool of drivers is enlarged, communication overheads are raised and more coordination is generally required. This may increase supervisor workload and also discount driver competency when executing their military training missions. Therefore, managers must weight the relative benefits and tradeoffs before deciding on an appropriate course of action.

### 10.2.4 Supervisor Workload Management Has a Larger Bearing on Driver Accident Resilience Compared to Driver Workload Management

While both driver and supervisor work management are critical elements in deriving the benefits of a safety improvement program, the SD modeling results suggests that managing supervisor workload can be considered to be of higher leverage compared to driver workload in reducing the accident rate. This is because supervisors' adherence to their tasks (such as safety briefings, inspections and driving orientations) impacts all three attributes (cautiousness, competency and concentration) of a driver's accident resilience. This finding is insightful and can be also considered to be counterintuitive as most would expect that actions directed at human agents that are at the closest level to an accident would have the highest results. As a result, this insight reinforces contemporary academic views that safety investigators and researchers must broaden their perspectives of causal factors beyond surface elements such as the immediate human element.

### 10.2.5 Perceptions of the Usefulness of Safety Initiatives Affects People's Adherence to Them

This research shows that if the safety situation under the regime of a new safety program becomes worse than it was before, a perception can be created amongst both drivers and supervisors that the new safety initiative is futile which decreases their adherence to the very safety tasks that are necessary for the initiative to bear fruit. As a consequence, the vicious nature of the reinforcing feedback loop is manifested and the accident rate can be increased even further. In most change programs, there is a "*worse-before-better*" phenomenon which means that the initial decline in the situation that the program is meant to correct is inevitable. Therefore, in order to forestall the vicious effects of the perception-adherence reinforcing loop and to ride on the waves of its virtuous effects, it is recommended to Organization Sierra-Tango that as part of any process improvement program, measures such as educational and informational sessions should be established to communicate to servicemen the reasons behind the inconveniences or seemingly worse-off situation that they are experiencing during the early stages of the program's implementation.

## 10.3 Near Miss Reporting System Dynamics Model: Conclusions and Recommendations

### 10.3.1 Increasing the Level of Identity Confidentiality of Near Miss Reporters Encourages Reporting

From the literature review, SD modeling and simulation, it has been shown that increasing the level of identity confidentiality of near miss reporters encourages reporting as this lowers their fear of reproach from their comrades. The Near Miss Reporting SD model showed that due to increased learning from near misses, training effectiveness is augmented beyond what it otherwise would have been and this has a positive effect by raising driver competency and reducing the accident rate. Therefore, the level of identify confidentiality of near miss reports is one lever where Organization Sierra-Tango can adjust to optimize the effectiveness of the open reporting initiative. One suggestion for the organization would be to make the identity of near miss reporters selectively available to individuals such as incident investigators and unit commanders. This approach will not only raise confidentiality levels and encourage more near miss reporting, it also retains a level of discipline in the system to deter nuisance or vengeful reporting.

### 10.3.2 Reducing the Severity of Punitive Measures is not recommended as a Means to Encourage Near Miss Reporting

While reducing the severity of punitive measures is also a means of encouraging more near misses to be reported, this approach is not recommended to Organization Sierra-Tango as this management lever serves as a double-edged sword. The lowering of punishment severity reduces the fear of punishment on comrades and encourages near miss reporting. However, the fear of punishment on self is also reduced and this causes drivers to be less cautious thereby

lowering their accident resilience and leading to more accidents. Additionally, the increased number of near misses reported is also an artifact of drivers driving more recklessly as the number of potential near misses to be reported is increased. The cons of reducing punishment severely outweigh the potential benefits of increased near miss reporting. Therefore, as the severity of punitive measures in the organization is already assessed to be fairly high, my recommendation would be for the organization's policy and decision makers to maintain the current level of punishment severity while manipulating other management levers to encourage near miss reporting.

### 10.3.3 The Overall Safety Culture of the Organization is a Key Driver of Near Miss Reporting

The research performed also shows that the overall safety culture in an organization plays a key role in effectuating near miss reporting. In order for near miss reporting to be sustained, reporters must perceive their efforts to have a positive influence on the accident rate or they would be discouraged from reporting. Additionally, if supervisors are seen to be cutting corners on safety tasks for instance due to improper workload management, drivers will become more disinclined to report near misses as their perceived management commitment to safety is diminished. Hence, the success of Organization Sierra-Tango's open reporting initiative hinges greatly upon the effective management of the greater safety system as a whole within the organization. All safety improvement programs are intertwined in a web of complex dynamics and this research provides more evidence for any organization desiring to achieve success in their change programs to adopt a holistic approach in the conceptualization and implementation of their improvement plans.

## 10.4 Future Research Opportunities

The SD models that have been developed and analyzed are by no way a complete representation of the safety dynamics in the real world. There are many future research opportunities remaining and ways to improve upon the SD models. The key opportunities and improvement areas are discussed below:

### (1) Increasing the Fidelity of the Work Management and Near Miss Reporting SD Models

While both the Work Management and the Near Miss Reporting SD models are undoubtedly useful in deriving insights into improving Organization Sierra-Tango's vehicle safety framework, the fact remains that both models are predicated on less than complete data. The Work Management SD Model was developed based on a set of hypothetical data from Organization Sierra-Tango and no information was available on the organization's nascent open reporting initiative. Therefore, should more data be made available at a later stage, the SD models can be modified by adding new model elements and calibrating parameter values so that the fidelity of the insights that can be drawn from both models can be enhanced. Additionally, a fully calibrated model may assist mission planners by recommending supervisor to driver ratios and suggesting workload levels that can assist training



deployments to be executed effectively – where both the training and safety objectives are fulfilled.

(2) Including Commander Behavioral Aspects into the Work Management SD Model

The Work Management SD model has focused on understanding the behaviors of drivers and supervisors and how their actions influence the accident rate within the organization. As discussed in the Chapter 8, commanders also have a distinct role to play in the overall structure of the work management framework. The current performance appraisal system employed by Organization Sierra-Tango that is heavily biased towards mission efficiency has an important bearing on the behaviors of commanders which flows down to impact those of their supervisors and drivers. More research (literature, interviews and modeling) is required to yield insights into the dynamics of commanders' involvement in the overall work management framework.

(3) Improving the Near Miss Reporting SD Model

There are several areas within the Near Miss Reporting SD model that can be improved. Firstly, the causal effect between an increased near miss reporting rate and a driver's fear of punishment is not captured. As the near miss reporting rate goes up, the perceived chance of their risky practices being reported to higher authorities is increased. Hence, the fear of being found out and possibly punished increases a driver's cautiousness and his or her accident resilience. Secondly, on a point related to the first, near misses do not only have the effect of enhancing training effectiveness; near misses also serve to flag out drivers who are prone to risky behaviors. In doing so, remedial actions such as education or more dedicated supervision can be directed at these individuals which will improve the aggregate driver cautiousness level and ultimately reduce the accident rate. Lastly, the Near Miss Reporting SD model has addressed the "*stick*" aspect of incident reporting systems. More research can enrich the model by incorporating the effect that incentives can have on an individual's inclination to report near misses. This is an area that Organization Sierra-Tango is interested in exploring as part of the efforts to improve the effectiveness of their open reporting initiative.

## 10.5 Thesis Conclusion

This thesis has met its principle objectives. The insights and lessons learned from the literature research and System Dynamics modeling process has improved the intuition of Organization Sierra-Tango's policy and decision makers and enlarged the knowledge database that they can draw upon when formulating new or improving upon existing policies. Even though these insights are drawn from the context of vehicle accidents, there are important lessons such as managing workload and schedule pressure that can be generalized to similar safety domains within or outside of the organization. In addition, the work in this thesis also demonstrates the utility of the SD methodology as a tool to enhance the understanding of the dynamics underlying a real-world complex challenge.

As with most tools, learning is easy but mastery is a lifelong process. This thesis is but a first step in my development as a System Dynamist. I intend to continue my training in the SD

methodology by taking a “*Systems thinking*” approach towards all issues that might confront me in both my professional work and my personal life, and where applicable develop SD models to synthesize mental models and draw out insights that will assist me in managing these challenges better.

## APPENDIX A: ACRONYMS

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<b>BMT:</b>	Basic Military Training
<b>CLD:</b>	Causal Loop Diagram
<b>DG:</b>	Driver Guide
<b>IT:</b>	Information Technology
<b>NASA:</b>	National Aeronautics and Space Administration
<b>OHSAS:</b>	Occupational Health and Safety Assessment Series
<b>RM:</b>	Risk Management
<b>SDM:</b>	System Design and Management
<b>SME:</b>	Subject Matter Expert
<b>SD:</b>	System Dynamics
<b>SOT:</b>	Safety Organization Team

## APPENDIX B: DOCUMENT REGISTRY OF WORK MANAGEMENT SYSTEM DYNAMICS MODEL VARIABLES

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- (001)  $\text{Accident Rate} = \text{Base Accident Rate} / \text{Accident Resilience}$   
Units: Accidents/Year  
The Accident Rate is the variable that represents the annual vehicle accident rate that is observed by the organization. The Accident Rate depends on the Base Accident Rate modified by the Accident Resilience of the drivers.
- (002)  $\text{Accident Resilience} = \text{Driver Cautiousness} * (\text{Driver Competency}) * (\text{Driver Concentration})$   
Units: Dimensionless  
Accident Resilience is a measure of a driver's resilience to driving accidents. It depends on a driver's cautiousness, competency and concentration.
- (003)  $\text{Base Accident Rate} = 10$   
Units: Accidents/Year  
The Base Accident Rate is the variable that represents the accident rate observed in the organization at the start of the simulation.
- (004)  $\text{Desired Driver Task Completion Delay} = 1$   
Units: Month  
The Desired Driver Task Completion Delay is the variable that represents the organization's goal for time required to complete all driving tasks under reasonable, normal conditions during training deployments.
- (005)  $\text{Desired Driver Task Completion Rate} = \text{Driver Tasks Outstanding} / \text{Desired Driver Task Completion Delay}$   
Units: Task/Month  
The Desired Driver Task Completion Rate is the variable that represents the organization's desired rate of completing driving tasks during training deployments.
- (006)  $\text{Desired Supervisor Task Completion Delay} = 1$   
Units: Month  
The Desired Supervisor Task Completion Delay is the variable that represents the organization's goal for time required to complete all supervisory tasks under reasonable, normal conditions during training deployments.
- (007)  $\text{Desired Supervisor Task Completion Rate} = \text{Supervisor Tasks Outstanding} / \text{Desired Supervisor Task Completion Delay}$   
Units: Task/Month  
The Desired Supervisor Task Completion Rate is the variable that represents the organization's desired rate of completing supervisory tasks during training deployments.

- (008) Driver Cautiousness =  $(1/\text{Driver Speeding Index}) * (\text{Driver Safety Task Adherence Index} * \text{Driver Safety Task Adherence Improvement}) * (\text{Supervisor Safety Task Adherence Index} * \text{Supervisor Safety Task Adherence Improvement})$   
 Units: Dimensionless  
 The Driver Cautiousness is a variable that represents a driver's level of cautiousness when performing his or her tasks.
- (009) Driver Competency =  $\text{Driver Experience} * (\text{Driver Familiarity with Environment} * \text{Supervisor Safety Task Adherence Improvement}) * \text{Driver Skill}$   
 Units: Dmnl  
 The Driver Competency is a variable that represents a driver's level of competency when performing his or her tasks.
- (010) Driver Concentration =  $\text{Driver Fatigue} * (\text{Driver Familiarity with Environment} * \text{Supervisor Safety Task Adherence Improvement})$   
 Units: Dimensionless  
 The Driver Concentration is a variable that represents a driver's level of concentration when performing his or her tasks.
- (011) Driver Experience = 1  
 Units: Dmnl  
 The Driver Experience is a variable that represents the effect that a driver's experience, as determined by his or her cumulative driving hours, has on his or her driving competency. This factor is assumed to be constant for this Work Management Model.
- (012) Driver Familiarity with Environment =  $\text{Supervisor Safety Task Adherence Index}$   
 Units: Dmnl  
 The Driver Familiarity with Environment is a variable that represents the effect that a driver's familiarity with environment, as determined by his or her familiarity training and pass experience in the environment, has on his or her driving competency.
- (013) Driver Fatigue = 1  
 Units: Dmnl  
 The Driver Fatigue is a variable that represents the effect that a driver's fatigue, as determined by his or her hours driven per day over a particular duration and effect of jet-lag, has on his or her driving concentration. This factor is assumed to be constant for this Work Management Subsystem.
- (014) Driver Perceived Desirability to Take Risks =  $\text{Desired Driver Task Completion Rate} / \text{Normal Driver Task Completion Rate}$   
 Units: Dmnl  
 The Driver Perceived Desirability to Take Risks is the variable that represents how schedule pressure shapes a driver's perceived desirability to take risks in order to increase task efficiency. The variable is defined as the ratio between the Desired Driver Task Completion Rate and the Normal Driver Task Completion Rate.

- (015) Driver Perception of Usefulness of Existing Safety Tasks =  $\text{SMOOTH3I}(\text{MIN}(\text{Base Accident Rate}/\text{Accident Rate}), 1), \text{Time to Change Driver Perception}, 1)$   
 Units: Dimensionless  
 The Driver Perception of Usefulness of Existing Safety Tasks represents the driver's perception of the usefulness of existing safety tasks.
- (016) Driver Safety Task Adherence Improvement =  $\text{SMOOTH}(1*((1-\text{Program Introduction Switch})+(\text{Driver Safety Task Adherence Improvement Percentage}*\text{Program Introduction Switch})), \text{Implementation Delay})$   
 Units: Dmnl  
 The Driver Safety Task Adherence Improvement is the variable that represents the expected improvement in a driver's cautiousness based on his adherence to safety tasks when performing his tasks during training deployments.
- (017) Driver Safety Task Adherence Improvement Percentage = 1.05  
 Units: Dmnl  
 The Driver Safety Task Adherence Improvement Percentage is the variable that represents the expected percentage improvement in a driver's cautiousness based on his adherence to safety tasks practices when performing his tasks during training deployments.
- (018) Driver Safety Task Adherence Index =  $\text{Safety Time Spent per Task}/\text{Standard Safety Time Required per Task}$   
 Units: Dimensionless  
 The Driver Safety Task Adherence Index is a measure of a driver's adherence to safe tasks performance that has been put in place by the Organization.
- (019) Driver Skill = 1  
 Units: Dmnl  
 The Driver Skill is a variable that represents a driver's skill level as a result of three factors - (1) Training Effectiveness, (2) Effectiveness of Training Duration and (3) Effectiveness of Training Frequency. This factor is assumed to be constant for this Work Management Subsystem.
- (020) Driver Speeding Index =  $\text{Standard Driving Time Required per Task}/\text{Driving Time Spent per Task}$   
 Units: Dmnl  
 The Driver Speeding Index is a measure of the extent of which the driver exceeds the organization's acceptable driving speed limit.
- (021) Driver Task Completion Rate =  $\text{MIN}(\text{Potential Driver Task Completion Rate}, \text{Maximum Driver Task Completion Rate})$   
 Units: Task/Month  
 The Driver Task Completion Rate is a flow which represents the rate at which tasks are completed by drivers during training deployments.

- (022) Driver Task Introduction Rate = Initial Driver Workload\*SMOOTH3I( DTIR Modifier , Implementation Delay , 1 )  
Units: Task/Month  
The Driver Task Introduction Rate is a flow which represents the rate at which new tasks are assigned to drivers during training deployments.
- (023) Driver Tasks Outstanding = INTEG (Driver Task Introduction Rate-Driver Task Completion Rate, Driver Task Introduction Rate\*Desired Driver Task Completion Delay)  
Units: Task  
The Driver Tasks Outstanding stock represents the task backlog for drivers during training deployments.
- (024) Driver Time Spent per Task = Driving Time Spent per Task+Safety Time Spent per Task  
Units: Hour/Task  
The Driver Time Spent per Task is the variable that represents the effort in terms of total time that a driver actually expends on a driving task during training deployments.
- (025) Driving Time Spent per Task = Standard Driving Time Required per Task\*Effect of Perceived Desirability on Driving Time Spent per Task  
Units: Hour/Task  
The Driving Time Spent per Task is the variable that represents the effort in terms of driving time that a driver actually expends on a driving task during training deployments. This variable is essentially the standard driving time required per task modified by the effect of the driver's perceived desirability to take risks.
- (026) DTIR Modifier = 1+STEP(Step Height,Step Time)+(Pulse Quantity/TIME STEP)\*PULSE(Pulse Time,TIME STEP)+RAMP(Ramp Slope,Ramp Start Time,Ramp End Time)+STEP(1,Exponential Growth Time)\*(EXP(Exponential Growth Rate\*Time)-1)+STEP(1,Sine Start Time)\*Sine Amplitude\*SIN(2\*3.14159\*Time/Sine Period)+STEP(1,Noise Start Time)\*RANDOM NORMAL( -4 , 4 , 0 , Noise Standard Deviation , Noise Seed )  
Units: Dimensionless  
The test input can be configured to generate a step, pulse, linear ramp, exponential growth, sine wave, and random variation. The initial value of the input is 1 and each test input begins at a particular start time. The magnitudes are expressed as fractions of the initial value.
- (027) Effect of Driver Perception on Safety Time Spent per Task = Table of Safety Time Spent per Task(Driver Perception of Usefulness of Existing Safety Tasks)  
Units: Dimensionless  
The Effect of Driver Perception on Safety Time Spent per Task is the variable that represents the effect of a driver's perception on the usefulness of existing safety tasks on the actual time that the driver spends on a task.

- (028) Effect of Perceived Desirability on Driving Time Spent per Task = Table of Driving Time Spent per Task(Driver Perceived Desirability to Take Risks)  
 Units: Dmnl  
 The Effect of Perceived Desirability on Driving Time Spent per Task is the variable that represents a factor that modifies the actual driving time spent per task based on the driver's perceived desirability to take risks.
- (029) Effect of Perceived Desirability on Supervisor Time Spent per Task = Table of Supervisor Time Spent per Task(Supervisor Perceived Desirability to Take Risks)  
 Units: Dmnl  
 The Effect of Perceived Desirability on Supervisor Time Spent per Task is the variable that represents a factor that modifies the actual supervising time spent per task based on the supervisor's perceived desirability to take risks.
- (030) Effect of Supervisor Perception on Time Spent per Task = Table of Time Spent per Task(Supervisor Perception of Usefulness of Existing Safety Tasks)  
 Units: Dimensionless  
 The Effect of Supervisor Perception on Safety Time Spent per Task is the variable that represents the effect of a supervisor's perception on the usefulness of existing safety tasks on the actual time that the supervisor spends on a task.
- (031) Exponential Growth Rate = 0  
 Units: 1/Month  
 The exponential growth rate in the input.
- (032) Exponential Growth Rate 0 = 0  
 Units: 1/Month  
 The exponential growth rate in the input.
- (033) Exponential Growth Rate 1= 0  
 Units: 1/Month  
 The exponential growth rate in the input.
- (034) Exponential Growth Time = 0  
 Units: Month  
 The time at which the exponential growth in the input begins.
- (035) Exponential Growth Time 0 = 0  
 Units: Month  
 The time at which the exponential growth in the input begins.
- (036) Exponential Growth Time 1 = 0  
 Units: Month  
 The time at which the exponential growth in the input begins.



- (037) FINAL TIME = 120  
Units: Month  
The final time for the simulation.
- (038) Hours Driven per Driver = Normal Hours Driven per Driver  
Units: Hour/Driver/Month  
The Daily Hours Driven per Driver is the variable that represents the actual productivity of a driver during training deployments.
- (039) Hours Worked per Supervisor = Normal Hours Worked per Supervisor  
Units: Hour/Supervisor/Month  
The Daily Hours Worked per Supervisor is the variable that represents the actual productivity of a supervisor during training deployments.
- (040) Implementation Delay = 12  
Units: Month  
The Implementation Delay is the variable that represents the time delay required in the organization to fully implement any changes in process.
- (041) Initial Driver Workload =  $(240*10)/(4/3)$   
Units: Task/Month  
The Initial Driver Workload is the variable that represents the base number of driver tasks per month during training deployments.
- (042) Initial Supervisor Workload =  $(240*5)/(1)$   
Units: Task/Month  
The Initial Supervisor Workload is the variable that represents the base number of supervisor tasks per month during training deployments.
- (043) INITIAL TIME = 0  
Units: Month  
The initial time for the simulation.
- (044) Maximum Driver Task Completion Rate = Driver Tasks Outstanding/Minimum Driver Task Completion Delay  
Units: Task/Month  
The Maximum Driver Task Completion Rate from Tasks is the variable that represents the maximum rate at which tasks can be completed by drivers during training deployments.
- (045) Maximum Supervisor Task Completion Rate = Supervisor Tasks Outstanding/Minimum Supervisor Task Completion Delay  
Units: Task/Month  
The Maximum Supervisor Task Completion Rate from Tasks is the variable that represents the maximum rate at which tasks can be completed by supervisors during training deployments.

- (046) Minimum Driver Task Completion Delay = 0.5  
Units: Month  
The Minimum Driver Task Completion Delay is the variable that represents the minimum time required to complete all driving tasks even when capacity is unlimited during training deployments.
- (047) Minimum Supervisor Task Completion Delay = 0.5  
Units: Month  
The Minimum Supervisor Task Completion Delay is the variable that represents the minimum time required to complete all supervisory tasks even when capacity is unlimited during training deployments.
- (048) Noise Seed = 1000  
Units: Dimensionless  
Varying the random number seed changes the sequence of realizations for the random variable.
- (049) Noise Seed 0 = 1000  
Units: Dimensionless  
Varying the random number seed changes the sequence of realizations for the random variable.
- (050) Noise Seed 1 = 1000  
Units: Dimensionless  
Varying the random number seed changes the sequence of realizations for the random variable.
- (051) Noise Standard Deviation = 0  
Units: Dimensionless  
The standard deviation in the random noise. The random fluctuation is drawn from a normal distribution with min and max values of +/- 4. The user can also specify the random number seed to replicate simulations. To generate a different random number sequence, change the random number seed.
- (052) Noise Standard Deviation 0 = 0  
Units: Dimensionless  
The standard deviation in the random noise. The random fluctuation is drawn from a normal distribution with min and max values of +/- 4. The user can also specify the random number seed to replicate simulations. To generate a different random number sequence, change the random number seed.

- (053) Noise Standard Deviation 1 = 0  
 Units: Dimensionless  
 The standard deviation in the random noise. The random fluctuation is drawn from a normal distribution with min and max values of +/- 4. The user can also specify the random number seed to replicate simulations. To generate a different random number sequence, change the random number seed.
- (054) Noise Start Time = 0  
 Units: Month  
 The time at which the random noise in the input begins.
- (055) Noise Start Time 0 = 0  
 Units: Month  
 The time at which the random noise in the input begins.
- (056) Noise Start Time 1 = 0  
 Units: Month  
 The time at which the random noise in the input begins.
- (057) Normal Driver Task Completion Rate =  $(\text{Number of Drivers Available} * \text{Normal Hours Driven per Driver}) / (\text{Standard Driving Time Required per Task} + \text{Standard Safety Time Required per Task})$   
 Units: Task/Month  
 The Normal Driver Task Completion Rate is the variable that represents the throughput the organization can achieve with the number of drivers available working normal hours and allocating the standard time to each driving task.
- (058) Normal Hours Driven per Driver = 240  
 Units: Hour/Driver/Month  
 The Normal Hours Driven per Driver is the variable that represents the average productivity of a driver during training deployments.
- (059) Normal Hours Worked per Supervisor = 240  
 Units: Hour/Supervisor/Month  
 The Normal Hours Worked per Supervisor is the variable that represents the average productivity of a supervisor during training deployments.
- (060) Normal Supervisor Task Completion Rate =  $(\text{Number of Supervisors Available} * \text{Normal Hours Worked per Supervisor}) / (\text{Standard Supervising Time Required per Task})$   
 Units: Task/Month  
 The Normal Supervisor Task Completion Rate is the variable that represents the throughput the organization can achieve with the number of supervisors available working normal hours and allocating the standard time to each driving task.

- (061) Number of Drivers after Policy Change = 10.625  
 Units: Driver  
 The Number of Drivers before Policy Change is the variable that represents the number of drivers available under the new policy to execute driving tasks during training deployments.
- (062) Number of Drivers Available = SMOOTH3I( (Number of Drivers before Policy Change\*(1-Policy Introduction Switch)+(Number of Drivers after Policy Change)\*Policy Introduction Switch) , Implementation Delay , Number of Drivers before Policy Change )  
 Units: Driver  
 The Number of Drivers Available is the variable that represents the number of drivers available to execute driving tasks during training deployments.
- (063) Number of Drivers before Policy Change = 10  
 Units: Driver  
 The Number of Drivers before Policy Change is the variable that represents the number of drivers available under the old policy to execute driving tasks during training deployments.
- (064) Number of Supervisors after Policy Change = 6.25  
 Units: Supervisor  
 The Number of Supervisor before Policy Change is the variable that represents the number of drivers available under the new policy to execute supervisory tasks during training deployments.
- (065) Number of Supervisors Available = SMOOTH3I( (Number of Supervisors before Policy Change\*(1-Policy Introduction Switch)+(Number of Supervisors after Policy Change)\*Policy Introduction Switch) , Implementation Delay , Number of Supervisors before Policy Change )  
 Units: Supervisor  
 The Number of Supervisors Available is the variable that represents the number of supervisors available to execute supervisory tasks during training deployments.
- (066) Number of Supervisors before Policy Change = 5  
 Units: Supervisor  
 The Number of Supervisors before Policy Change is the variable that represents the number of drivers available under the old policy to execute supervisory tasks during training deployments.
- (067) Policy Introduction Date = 36  
 Units: Month  
 The Policy Introduction Date is the variable that represents the date in which the new manpower policy is to be initiated.

- (068) Policy Introduction Switch = STEP( 1 , Policy Introduction Date )  
 Units: Dmnl  
 The Program Introduction Switch is a modeling tool used to initiate the commencement of the new manpower policy.
- (069) Potential Driver Task Completion Rate = (Hours Driven per Driver\*Number of Drivers Available)/Driver Time Spent per Task  
 Units: Task/Month  
 The Potential Driver Task Completion Rate is the variable that represents the potential rate of completing driving tasks during training deployments.
- (070) Potential Supervisor Task Completion Rate = (Hours Worked per Supervisor\*Number of Supervisors Available)/Supervisor Time Spent per Task  
 Units: Task/Month  
 The Potential Supervisor Task Completion Rate is the variable that represents the potential rate of completing supervisory tasks during training deployments.
- (071) Program Introduction Date = 1  
 Units: Month  
 The Program Introduction Date is the variable that represents the date in which the new safety process is to be initiated.
- (072) Program Introduction Switch = STEP( 1 , Program Introduction Date )  
 Units: Dmnl  
 The Program Introduction Switch is a modeling tool used to initiate the commencement of the new safety process.
- (073) Pulse Quantity = 0  
 Units: Dimensionless\*Month  
 The quantity added to the input at the pulse time.
- (074) Pulse Quantity 0 = 0  
 Units: Dimensionless\*Month  
 The quantity added to the input at the pulse time.
- (075) Pulse Quantity 1 = 0  
 Units: Dimensionless\*Month  
 The quantity added to the input at the pulse time.
- (076) Pulse Time = 0  
 Units: Month  
 The time at which the pulse increase in the input occurs.
- (077) Pulse Time 0 = 0  
 Units: Month  
 The time at which the pulse increase in the input occurs.

- (078) Pulse Time 1 = 0  
Units: Month  
The time at which the pulse increase in the input occurs.
- (079) Ramp End Time = 1e+009  
Units: Month  
The end time for the ramp input.
- (080) Ramp End Time 0 = 27  
Units: Month  
The end time for the ramp input.
- (081) Ramp End Time 1 = 1e+009  
Units: Month  
The end time for the ramp input.
- (082) Ramp Slope = 0  
Units: 1/Month  
The slope of the linear ramp in the input.
- (083) Ramp Slope 0 = 1/3  
Units: 1/Month  
The slope of the linear ramp in the input.
- (084) Ramp Slope 1 = 0  
Units: 1/Month  
The slope of the linear ramp in the input.
- (085) Ramp Start Time = 0  
Units: Month  
The time at which the ramp in the input begins.
- (086) Ramp Start Time 0 = 24  
Units: Month  
The time at which the ramp in the input begins.
- (087) Ramp Start Time 1 = 0  
Units: Month  
The time at which the ramp in the input begins.

- (088) Safety Time Required per Driver Task on New Process = 10/60  
 Units: Hour/Task  
 The Safety Time Required per Driver Task on New Process is the variable that represents the organizational norm for the effort in terms of safety time that a driver is required to spend on average on a driving task during training deployments after the new process is initiated.
- (089) Safety Time Required per Driver Task on Old Process = 5/60  
 Units: Hour/Task  
 The Safety Time Required per Driver Task on Old Process is the variable that represents the organizational norm for the effort in terms of safety time that a driver is required to spend on average on a driving task during training deployments before the new process is initiated.
- (090) Safety Time Spent per Task = Standard Safety Time Required per Task\*Effect of Driver Perception on Safety Time Spent per Task  
 Units: Hour/Task  
 The Safety Time Spent per Task is the variable that represents the effort in terms of safety time that a driver actually expends on a driving task during training deployments. This variable is essentially the standard driving time required per task modified by the effect of the driver's perception of the usefulness of existing safety tasks.
- (091) SAVEPER = TIME STEP  
 Units: Month [0,?]  
 The frequency with which output is stored.
- (092) Sine Amplitude = 0  
 Units: Dimensionless  
 The amplitude of the sine wave in the input.
- (093) Sine Amplitude 0 = 0  
 Units: Dimensionless  
 The amplitude of the sine wave in the input.
- (094) Sine Amplitude 1 = 0  
 Units: Dimensionless  
 The amplitude of the sine wave in the input.
- (095) Sine Period = 10  
 Units: Month  
 The period of the sine wave in the input.
- (096) Sine Period 0 = 10  
 Units: Month  
 The period of the sine wave in the input.

- (097) Sine Period 1 = 10  
Units: Month  
The period of the sine wave in the input.
- (098) Sine Start Time = 0  
Units: Month  
The time at which the sine wave fluctuation in the input begins.
- (099) Sine Start Time 0 = 0  
Units: Month  
The time at which the sine wave fluctuation in the input begins.
- (100) Sine Start Time 1 = 0  
Units: Month  
The time at which the sine wave fluctuation in the input begins.
- (101) Standard Driving Time Required per Task = 1.25  
Units: Hour/Task  
The Standard Driving Time Required per Task is the variable that represents the organizational norm for the effort in terms of driving time that a driver is required to spend on average on a driving task during training deployments.
- (102) Standard Safety Time Required per Task =  $\text{SMOOTH3I}(\text{Safety Time Required per Driver Task on Old Process} * (1 - \text{Program Introduction Switch}) + (\text{Safety Time Required per Driver Task on New Process}) * \text{Program Introduction Switch})$  , Implementation Delay , Safety Time Required per Driver Task on Old Process)  
Units: Hour/Task  
The Standard Safety Time Required per Task is the variable that represents the organizational norm for the effort in terms of safety time that a driver is required to spend on average on a driving task during training deployments.
- (103) Standard Supervising Time Required per Task =  $\text{SMOOTH3I}(\text{Time Required per Supervisor Task on Old Process} * (1 - \text{Program Introduction Switch}) + (\text{Time Required per Supervisor Task on New Process}) * \text{Program Introduction Switch})$  , Implementation Delay , Time Required per Supervisor Task on Old Process)  
Units: Hour/Task  
The Standard Supervising Time Required per Task is the variable that represents the organizational norm for the effort in terms of supervisory time that a supervisor is required to spend on average on a supervisory task during training deployments.
- (104) Step Height = 0  
Units: Dimensionless  
The height of the step increase in the input.



- (105) Step Height 0 = 0  
Units: Dimensionless  
The height of the step increase in the input.
- (106) Step Height 1 = 0  
Units: Dimensionless  
The height of the step increase in the input.
- (107) Step Time = 36  
Units: Month  
The time at which the step increase in the input occurs.
- (108) Step Time 0 = 24  
Units: Month  
The time at which the step increase in the input occurs.
- (109) Step Time 1 = 36  
Units: Month  
The time at which the step increase in the input occurs.
- (110) STIR Modifier =  $1 + \text{STEP}(\text{Step Height 1}, \text{Step Time 1}) + (\text{Pulse Quantity 1} / \text{TIME STEP}) * \text{PULSE}(\text{Pulse Time 1}, \text{TIME STEP}) + \text{RAMP}(\text{Ramp Slope 1}, \text{Ramp Start Time 1}, \text{Ramp End Time 1}) + \text{STEP}(1, \text{Exponential Growth Time 1}) * (\text{EXP}(\text{Exponential Growth Rate 1} * \text{Time}) - 1) + \text{STEP}(1, \text{Sine Start Time 1}) * \text{Sine Amplitude 1} * \text{SIN}(2 * 3.14159 * \text{Time} / \text{Sine Period 1}) + \text{STEP}(1, \text{Noise Start Time 1}) * \text{RANDOM NORMAL}(-4, 4, 0, \text{Noise Standard Deviation 1}, \text{Noise Seed 1})$   
Units: Dimensionless  
The test input can be configured to generate a step, pulse, linear ramp, exponential growth, sine wave, and random variation. The initial value of the input is 1 and each test input begins at a particular start time. The magnitudes are expressed as fractions of the initial value.
- (111) Supervisor Perceived Desirability to Take Risks = Desired Supervisor Task Completion Rate / Normal Supervisor Task Completion Rate  
Units: Dmnl  
The Driver Perceived Desirability to Take Risks is the variable that represents how schedule pressure shapes a driver's perceived desirability to take risks in order to increase task efficiency. The variable is defined as the ratio between the Desired Driver Task Completion Rate and the Normal Driver Task Completion Rate.
- (112) Supervisor Perception of Usefulness of Existing Safety Tasks =  $\text{SMOOTH3I}(\text{MIN}((\text{Base Accident Rate} / \text{Accident Rate}), 1), \text{Time to Change Supervisor Perception}, 1)$   
Units: Dimensionless  
The Supervisor Perception of Usefulness of Existing Safety Tasks represents the supervisor's perception of the usefulness of existing safety tasks.

- (113) Supervisor Safety Task Adherence Improvement =  $\text{SMOOTH}(1 * ((1 - \text{Program Introduction Switch}) + (\text{Supervisor Safety Task Adherence Improvement Percentage} * \text{Program Introduction Switch})), \text{Implementation Delay})$   
 Units: Dmnl  
 The Supervisor Safety Task Adherence Improvement is the variable that represents the expected improvement in a driver's cautiousness based on his adherence to safety tasks when performing his tasks during training deployments.
- (114) Supervisor Safety Task Adherence Improvement Percentage = 1.05  
 Units: Dmnl  
 The Supervisor Safety Task Adherence Improvement Percentage is the variable that represents the expected percentage improvement in a driver's cautiousness based on his adherence to safety tasks practices when performing his tasks during training deployments.
- (115) Supervisor Safety Task Adherence Index =  $(\text{Supervisor Time Spent per Task} / \text{Standard Supervising Time Required per Task})$   
 Units: Dimensionless  
 The Supervisor Safety Task Adherence Index is a measure of a driver's adherence to safe tasks performance that have been put in place by the Organization.
- (116) Supervisor Task Completion Rate =  $\text{MIN}(\text{Potential Supervisor Task Completion Rate}, \text{Maximum Supervisor Task Completion Rate})$   
 Units: Task/Month  
 The Supervisor Task Completion Rate is a flow which represents the rate at which tasks are completed by supervisors during training deployments
- (117) Supervisor Task Introduction Rate =  $\text{Initial Supervisor Workload} * \text{SMOOTH3I}(\text{STIR Modifier}, \text{Implementation Delay}, 1)$   
 Units: Task/Month  
 The Driver Task Introduction Rate is a flow which represents the rate at which new tasks are assigned to drivers during training deployments.
- (118) Supervisor Tasks Outstanding =  $\text{INTEG}(\text{Supervisor Task Introduction Rate} - \text{Supervisor Task Completion Rate}, \text{Supervisor Task Introduction Rate} * \text{Desired Supervisor Task Completion Delay})$   
 Units: Task  
 The Supervisor Tasks Outstanding stock represents the task backlog for supervisors during training deployments.

- (119) Supervisor Time Spent per Task = Standard Supervising Time Required per Task\*Effect of Supervisor Perception on Time Spent per Task\*Effect of Perceived Desirability on Supervisor Time Spent per Task  
Units: Hour/Task  
The Safety Time Spent per Task is the variable that represents the effort in terms of safety time that a driver actually expends on a driving task during training deployments. This variable is essentially the standard driving time required per task modified by the effect of driver schedule pressure.
- (120) Table of Driving Time Spent per Task([(0,0.5)-(2.5,1.2)],(0,1.1),(0.9,1.05),(1,1),(1.1,0.85),(1.3,0.7),(1.7,0.625),(2,0.6))  
Units: Dmnl  
This table function represents the tendency of drivers to alter their driving time spent per task as a function of perceived desirability to take risks.!!!
- (121) Table of Safety Time Spent per Task([(0,0)-(1,1)],(0,0.5),(0.25,0.52),(0.5,0.6),(0.75,0.7),(1,1))  
Units: Dmnl  
This table function represents the tendency of drivers to alter their safety time spent per task as a function of their perception of the usefulness of existing safety tasks.!!!
- (122) Table of Supervisor Time Spent per Task([(0,0.5)-(2.5,1.2)],(0,1.1),(0.9,1.05),(1,1),(1.1,0.85),(1.3,0.7),(1.7,0.625),(2,0.6))  
Units: Dmnl  
This table function represents the tendency of supervisor to alter their supervisor time spent per task as a function of perceived desirability to take risks.!!!
- (123) Table of Time Spent per Task([(0,0.85)-(1,1)],(0,0.869565),(0.25,0.875),(0.5,0.89),(0.75,0.93),(1,1))  
Units: Dmnl  
This table function represents the tendency of supervisors to alter their time spent per task as a function of their perception of the usefulness of existing safety tasks.!!!
- (124) Time Required per Supervisor Task on New Process = 1.25  
Units: Hour/Task  
The Time Required per Supervisor Task on New Process is the variable that represents the organizational norm for the effort in terms of time that a supervisor is required to spend on average on a supervisory task during training deployments after the new process is initiated.
- (125) Time Required per Supervisor Task on Old Process = 1  
Units: Hour/Task  
The Time Required per Supervisor Task on Old Process is the variable that represents the organizational norm for the effort in terms of time that a supervisor is required to spend on average on a supervisory task during training deployments before the new process is initiated.

- (126) TIME STEP = 0.125  
Units: Month [0,?]  
The time step for the simulation.
- (127) Time to Change Driver Perception = 12  
Units: Month  
The Time to Change Driver Perception is a variable that represents the delay that it takes for a driver to change his or her perception of the usefulness of existing safety tasks.
- (128) Time to Change Supervisor Perception = 12  
Units: Month  
The Time to Change Supervisor Perception is a variable that represents the delay that it takes for a supervisor to change his or her perception of the usefulness of existing safety tasks.

## APPENDIX C: DOCUMENT REGISTRY OF NEAR MISS REPORTING SYSTEM DYNAMICS MODEL VARIABLES

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- (01)  $\text{Accident Rate} = \text{Base Accident Rate} / \text{Accident Resilience}$   
Units: Accidents/Year  
The Accident Rate is the variable that represents the annual vehicle accident rate that is observed by the organization. The Accident Rate depends on the Base Accident Rate modified by the Accident Resilience of the drivers.
- (02)  $\text{Accident Resilience} = (\text{Driver Cautiousness}) * \text{Driver Competency} * \text{Driver Concentration}$   
Units: Dimensionless  
Accident Resilience is a measure of a driver's resilience to driving accidents. It depends on a driver's cautiousness, competency and concentration.
- (03)  $\text{Base Accident Rate} = 10$   
Units: Accidents/Year  
The Base Accident Rate is the variable that represents the accident rate observed in the organization at the start of the simulation.
- (04)  $\text{Base Near Miss Learning Rate} = 0.03$   
Units: Dmnl/Month  
The Base Near Miss Processing Rate is the flow that represents the rate at which near misses are processed by the organization under equilibrium conditions.
- (05)  $\text{Base Number of Potential Near Misses to be Reported} = 30$   
Units: Reports/Month  
The Base Number of Potential Near Misses to be Reported is the variable that represents the number of potential near misses to be reported under normal conditions.
- (06)  $\text{Base Percentage of Near Misses Reported} = 0.1$   
Units: Dmnl  
The Base Percentage of Near Misses Reported is the variable that represents the percentage of potential near misses that are actually reported under normal conditions.
- (07)  $\text{Confidentiality Level} = \text{Confidentiality Level on Old Process} * (1 - \text{Program Introduction Switch}) + \text{Confidentiality Level on New Process} * \text{Program Introduction Switch}$   
Units: Dmnl  
The Confidentiality Level is the variable that represents the existing confidentiality level accorded to near miss reporters.
- (08)  $\text{Confidentiality Level on New Process} = 1$   
Units: Dmnl  
The Confidentiality Level on Old Process is the variable that represents the confidentiality level accorded to near miss reporters after the new process is initiated.

- (09) Confidentiality Level on Old Process = 1  
 Units: Dmnl  
 The Confidentiality Level on Old Process is the variable that represents the confidentiality level accorded to near miss reporters before the new process is initiated.
- (10) Delay for Driver Familiarity with Environment = 12  
 Units: Month  
 The Delay for Driver Familiarity with Environment is the variable that represents the delay between the initiation of the new safety processes and its affect on the driver's familiarity with the operating environment. This model structure is meant to be a crude simulation of the expected affect of the Work Management Model.
- (11) Delay for Perceived Management Commitment to Safety = 12  
 Units: Month  
 The Delay for Perceived Management Commitment to Safety is the variable that represents the delay between the initiation of the new safety processes and its affect on perceived management commitment to safety. This model structure is meant to be a crude simulation of the expected affect of the Work Management Model.
- (12) Driver Cautiousness = Table of Driver Cautiousness(Fear of Punishment on Self)  
 Units: Dmnl  
 The Driver Cautiousness is a variable that represents a driver's level of cautiousness when performing his or her tasks.
- (13) Driver Competency = Driver Experience\*Driver Familiarity with Environment\*Driver Skill  
 Units: Dmnl  
 The Driver Competency is a variable that represents a driver's level of competency when performing his or her tasks. In this model, a driver's competency is determined by the driver's skill, experience and familiarity with environment.
- (14) Driver Concentration = 1\*Driver Familiarity with Environment  
 Units: Dmnl  
 The Driver Concentration is a variable that represents a driver's level of concentration when performing his or her tasks.
- (15) Driver Experience = 1  
 Units: Dmnl  
 The Driver Experience is a variable that represents the effect that a driver's experience, as determined by his or her cumulative driving hours, has on his or her driving competency. This factor is assumed to be constant for this Near Miss Reporting Subsystem.

- (16) Driver Familiarity with Environment =  $SMOOTH3I( (Driver\ Familiarity\ with\ Environment\ on\ Old\ Process*(1-Program\ Introduction\ Switch)+Driver\ Familiarity\ with\ Environment\ on\ New\ Process*Program\ Introduction\ Switch) , Delay\ for\ Driver\ Familiarity\ with\ Environment , 1 )$   
 Units: Dmnl  
 The Driver Familiarity with Environment is a variable that represents the effect that a driver's familiarity with environment, as determined by his or her familiarity training and pass experience in the environment, has on his or her driving competency.
- (17) Driver Familiarity with Environment on New Process = 1  
 Units: Dmnl  
 The Driver Familiarity with Environment on New Process is the variable that represents the driver's average familiarity with the operating environment after the new process is initiated.
- (18) Driver Familiarity with Environment on Old Process = 1  
 Units: Dmnl  
 The Driver Familiarity with Environment on Old Process is the variable that represents the driver's average familiarity with the operating environment before the new process is initiated.
- (19) Driver Perception of Usefulness of Existing Safety Process =  $SMOOTH3I( MIN( (Base\ Accident\ Rate/Accident\ Rate) , 1 ) , Time\ to\ Change\ Driver\ Perception , 1 )$   
 Units: Dimensionless  
 The Driver Perception of Usefulness of Existing Safety Process represents the driver's perception of the usefulness of existing safety processes.
- (20) Driver Skill = Effectiveness of Training Duration\*Effectiveness of Training Frequency\*Training Effectiveness  
 Units: Dmnl  
 The Driver Skill is a variable that represents a driver's skill level as a result of three factors - (1) Training Effectiveness, (2) Effectiveness of Training Duration and (3) Effectiveness of Training Frequency.
- (21) Effect of Driver Perception on Near Miss Reporting = Table of Near Miss Reporting(Driver Perception of Usefulness of Existing Safety Process)  
 Units: Dimensionless  
 The Effect of Driver Perception on Near Miss Reporting is the variable that represents the effect of a driver's perception on the usefulness of existing safety processes on his or her near miss reporting enthusiasm.
- (22) Effectiveness of Training Duration = 1  
 Units: Dmnl  
 The Effectiveness of Training Duration is a variable that represents the effect that training duration has on a driver's skill. This factor is assumed to be constant for this Near Miss Reporting Subsystem.

- (23) Effectiveness of Training Frequency = 1  
 Units: Dmnl  
 The Effectiveness of Training Frequency is a variable that represents the effect that training frequency has on a driver's skill. This factor is assumed to be constant for this Near Miss Reporting Subsystem.
- (24) Fear of Punishment on Comrades = SMOOTH3I( Severity of Punitive Measures , (Time to Adjust Fear-3) , 1 )  
 Units: Dmnl  
 The Fear of Reproach on Comrades is a variable that represents the effect that a driver's fear of causing suffering on his comrades, as determined by the existing degree of punitive measures, has on his or her near miss reporting enthusiasm.
- (25) Fear of Punishment on Self = SMOOTH3I( Severity of Punitive Measures , (Time to Adjust Fear-3) , 1 )  
 Units: Dmnl  
 The Fear of Reproach on Self is a variable that represents the effect that a driver's fear of military reproach, as determined by the existing degree of punitive measures, has on his or her driving cautiousness.
- (26) Fear of Reproach from Comrades = SMOOTH3I( 1/Confidentiality Level , Time to Adjust Fear , 1 )  
 Units: Dmnl  
 The Fear of Reproach from Comrades is a variable that represents the effect that a driver's fear of being ostracized, as determined by the degree at which his or her confidentiality is protected, has on his or her near miss reporting enthusiasm.
- (27) FINAL TIME = 84  
 Units: Month  
 The final time for the simulation.
- (28) Implementation and Learning Delay = 6  
 Units: Month  
 The Implementation Delay Factor is the variable that represents the delay between lessons learn from near misses and integration into training doctrines.
- (29) Inclination to Report Near Misses = (0.2)\*Effect of Driver Perception on Near Miss Reporting+(0.2)\*Perceived Management Commitment to Safety+(0.2)\*Regard for Personal Safety+(0.2)\*(1/Fear of Punishment on Comrades)+(0.2)\*(1/Fear of Reproach from Comrades)  
 Units: Dmnl  
 The Inclination to Report Near Misses is the variable that represents a driver's inclination to report near misses as a function of his fears and perceptions.



- (30) INITIAL TIME = 0  
Units: Month  
The initial time for the simulation.
- (31) Near Miss Learning Ratio = 0.01  
Units: Dmnl/Reports  
The Near Miss Learning Ratio is the variable that represents the proportion of near misses processed that are actually found to be useful towards improving training effectiveness.
- (32) Near Miss Processing Rate = Near Miss Reports to be Processed/Time to Process Near Miss Reports  
Units: Reports/Month  
The Near Miss Processing Rate is the flow that represents the rate at which near misses are processed by the organization.
- (33) Near Miss Reporting Rate = Number of Potential Near Misses to be Reported\*Base Percentage of Near Misses Reported\*Inclination to Report Near Misses  
Units: Reports/Month  
The Near Miss Reporting Rate is the flow that represents the rate at which near misses are reported by drivers.
- (34) Near Miss Reports Processed = INTEG (Near Miss Processing Rate,5)  
Units: Reports  
The Near Miss Reports to Processed stock represents the number of near miss reports that have been processed by the organization.
- (35) Near Miss Reports to be Processed= INTEG (Near Miss Reporting Rate-Near Miss Processing Rate, 3)  
Units: Reports  
The Near Miss Reports to be Processed stock represents the number of near miss reports that are awaiting to be processed by the organization
- (36) Number of Potential Near Misses to be Reported = Base Number of Potential Near Misses to be Reported/Driver Cautiousness  
Units: Reports/Month  
The Number of Potential Near Misses to be Reported is the variable that represents the overall number of near misses that can potentially be reported.

- (37) Perceived Management Commitment to Safety = SMOOTH3I( (Perceived Management Commitment to Safety on Old Process\*(1-Program Introduction Switch)+Perceived Management Commitment to Safety on New Process\*Program Introduction Switch) , Delay for Perceived Management Commitment to Safety , 1 )  
 Units: Dmnl  
 The Perceived Management Commitment to Safety is a variable that represents the effect that a driver's perception of management commitment to safety, as determined through his or her interactions with their immediate supervisor, has on his or her near miss reporting enthusiasm.
- (38) Perceived Management Commitment to Safety on New Process = 1  
 Units: Dmnl  
 The Perceived Management Commitment to Safety on New Process is the variable that represents the driver's perceived management commitment to safety after the new process is initiated.
- (39) Perceived Management Commitment to Safety on Old Process = 1  
 Units: Dmnl  
 The Perceived Management Commitment to Safety on Old Process is the variable that represents the driver's perceived management commitment to safety before the new process is initiated.
- (40) Program Introduction Date = 12  
 Units: Month  
 The Program Introduction Date is the variable that represents the date in which the new safety process is to be initiated.
- (41) Program Introduction Switch = STEP( 1 , Program Introduction Date )  
 Units: Dmnl  
 The Program Introduction Switch is a modeling tool used to initiate the commencement of the new safety process.
- (42) Regard for Personal Safety = 1  
 Units: Dmnl  
 The Regard for Personal Safety is a variable that represents the effect that a driver's regard for his or her own safety, as determined by his or her risk-taking propensity and the effectiveness of the organization's safety awareness and education programs, has on his or her near miss reporting enthusiasm. This factor is assumed to be constant for this Near Miss Reporting Subsystem.
- (43) SAVEPER = TIME STEP  
 Units: Month [0,?]  
 The frequency with which output is stored.

- (44) Severity of Punitive Measures = Severity of Punitive Measures on Old Process\*(1-Program Introduction Switch)+Severity of Punitive Measures on New Process\*Program Introduction Switch  
Units: Dmnl  
The Severity of Punitive Measures is the variable that represents the existing severity of punitive measures for safety transgressions by a driver.
- (45) Severity of Punitive Measures on New Process = 1  
Units: Dmnl  
The Severity of Punitive Measures on New Process is the variable that represents the severity of punitive measures for safety transgressions by a driver after the new process is initiated.
- (46) Severity of Punitive Measures on Old Process = 1  
Units: Dmnl  
The Severity of Punitive Measures on Old Process is the variable that represents the severity of punitive measures for safety transgressions by a driver before the new process is initiated.
- (47) Table for Training Effectiveness([(0,0)-(2,2)],(0,0.95),(1,1),(2,1.05))  
Units: Dmnl  
This table function represents the change in training effectiveness as a function of their perception of the usefulness of existing safety tasks.\!!\!
- (48) Table of Driver Cautiousness([(0,0)-(2,2)],(0,0.7),(0.6,0.75),(1,1),(1.4,1.04),(2,1.05))  
Units: Dmnl  
This table function represents the tendency of drivers to moderate their reckless driving tendencies as a function of their fear of punishment on self.\!!\!
- (49) Table of Near Miss Reporting([(0,0)-(1,1)],(0,0.5),(0.25,0.52),(0.5,0.6),(0.75,0.7),(1,1))  
Units: Dmnl  
This table function represents the tendency of drivers to alter their near miss reporting enthusiasm as a function of their perception of the usefulness of existing safety tasks.\!!\!
- (50) TIME STEP = 0.125  
Units: Month [0,?]  
The time step for the simulation.
- (51) Time to Adjust Fear = 6  
Units: Month  
The Time to Adjust Fear is a variable that represents the delay that it takes for a driver to change his or her fears.
- (52) Time to Change Driver Perception = 12  
Units: Month

The Time to Change Driver Perception is a variable that represents the delay that it takes for a driver to change his or her perception of the usefulness of existing safety tasks.

(53) Time to Process Near Miss Reports = 1

Units: Month

The Time to Process Near Miss Reports is the variable that represents the delay that it takes for the organization to process near miss reports.

(54) Training Effectiveness = SMOOTH3I( Table for Training Effectiveness ((Near Miss Processing Rate\*Near Miss Learning Ratio)/Base Near Miss Learning Rate) , Implementation and Learning Delay , 1 )

Units: Dmnl

The Training Effectiveness stock represents the present effectiveness level of driver training. The effectiveness is bolstered by lessons learnt from near misses. Lessons learnt from accidents are assumed to be outside of the model boundary for this Near Miss Reporting Subsystem.

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