Stress, Fatigue And Workload: Determining The Combined Affect On Human Performance

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STRESS, FATIGUE AND WORKLOAD: DETERMINING THE COMBINED AFFECT ON HUMAN PERFORMANCE

by

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ABSTRACT

This research generated a model that will help to predict, prevent, control and mitigate the occurrence of task related factors that negatively influence stress, fatigue, and workload; thus enhancing human performance.

Past research efforts involving stress, fatigue and workload identified factors that influence a change in performance (Lan, Ji and Looney, 2003, and Hancock & Warm, 1989). Also, while some mathematical models have been developed within each respective area, however, there is no evidence of an integrated model describing the combined affect of stress, fatigue and workload. To respond to this research gap, a quantitative model representing the state of stress, fatigue and workload experienced under task conditions was developed. This model was derived using fuzzy set theory with data inputs from both objective and subjective measures such as heart rate, NASA TLX, blood pressure and a variety of additional factors. The resultant mathematical model included both subjective and objective measures that can be collected in an occupational environment.

Control rooms at the flight centers for large space craft were utilized to validate the quantitative model developed in this research. Data was gathered during launch simulation exercises. Fuzzy Set Theory was applied to develop the mathematical model to describe the changes in stress, fatigue and workload. FST provides a means to model many real-world environments.
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LIST OF ACRONYMS/ABBREVIATIONS

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<tr>
<td>ETL</td>
<td>Engineering Test Lead</td>
</tr>
<tr>
<td>IRB</td>
<td>Intuitional Review Board</td>
</tr>
<tr>
<td>ISS</td>
<td>International Space Station</td>
</tr>
<tr>
<td>JSC</td>
<td>Johnson Space Center, Houston TX</td>
</tr>
<tr>
<td>KSC</td>
<td>Kennedy Space Center, Cape Canaveral, FL</td>
</tr>
<tr>
<td>ORMSD</td>
<td>Operational Maintenance Requirement Specifications Document</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>SE</td>
<td>System Engineer</td>
</tr>
<tr>
<td>PSE</td>
<td>Prime System Engineer</td>
</tr>
<tr>
<td>SOFI</td>
<td>Swedish Occupational Fatigue Inventory</td>
</tr>
<tr>
<td>SSE</td>
<td>Systems Specialist Engineer</td>
</tr>
<tr>
<td>UCF</td>
<td>University of Central Florida</td>
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CHAPTER ONE: INTRODUCTION

Stress, fatigue, and workload have each been demonstrated to affect worker performance. In a recent survey by the National Science Foundation (NSF), 61% of respondents claimed to have suffered from lapses in concentration at work and 19% reported having made errors as a result of being fatigued (Atkinson, 2000). Also shift work, altered work schedules, long hours of continuous wakefulness, and sleep deprivation can disrupt sleep rhythms and circadian rhythm. These disruptions adversely affect daytime functioning, causing stress and fatigue (Gawron, French, Funke, 2001).

Stress, fatigue, and workload have been studied individually in military, laboratory, and industrial settings; however, the combined effect or interaction of these three factors has not been studied, presumably because of the lack of quantifiable data available to predict human performance outcomes.

The objective of this study was to model the combined affect of stress, fatigue and workload and to determine its impacts on task related factors of human performance. Subjects participated in various simulation exercises where fatigue, stress, and workload were measured using qualitative surveys, such as NASA TLX, Swedish Occupational Fatigue Inventory (SOFI), and Yoshitake Type I and II, and quantitative measures, such as heart rate and blood pressure.

Specifically, this research generated a quantifiable model that described the combined affect of fatigue, stress, and workload under various task conditions. Analysis of the results indicates that qualitative data, such as measurements of motivation levels, and quantitative data, such as the number of problems a worker faces, is needed to accurately describe the combined affect of stress, fatigue, and workload.
The insight gained from modeling and predicting the combined effect of the factors that underlie fatigue, stress, and workload has the potential to improve safety and to increase human performance and productivity. Future program applications for this research within NASA include calculation of human performance requirements for Mars exploration controllers and crew size and capabilities limitations for the International Space Station. Other possible applications for this research include models for scheduling control teams in environments such as nuclear power stations or air traffic control centers. Additionally, this research might aid military teams in determining console rotations on carrier ships. Additional applications include use in developing underlying models and algorithms for artificial agents in training scenarios that better represent human performance changes due to fatigue, stress, workload and related adaptive behaviors (French & Morris, 2003).

1.1 Research Objectives

The aim of this research was to determine how the combined affect of stress, fatigue, and workload influences changes in human performance. Specifically, this research generated a quantifiable model to describe the changes in human performance associated with fatigue, stress, and workload. Knowledge of how these factors impact human performance will help investigators to predict, prevent, control, and mitigate the occurrence of factors that negatively influence human performance.

It is imperative that valid and reliable models are developed to measure human performance in control room settings. Valid models will enable applications that are useful for management to determine shifting performance requirements and that will foster further understanding of the combined affects of stress, fatigue, and workload. This research will add to
the current body of knowledge and provide researchers with a tool to aid in predicting human performance of operators based on stress, fatigue, and workload factors.

1.2 Research Scope

The research activities to accomplish the aforementioned aims were conducted to fulfill dissertation requirements. The development of the fuzzy mathematical model was used to represent the combined affect of fatigue, stress and workload. The resulting values obtained from the aforementioned models were used to describe the associated levels of human performance that corresponded to specific values.

1.3 Fatigue

Fatigue is defined as a feeling of weariness, tiredness, or lack of energy by the National Institute of Health. It is important to understand the issue of fatigue in an integrated manner because of the tendency for individuals to accept increasingly greater risk in spite of reduced cognitive and physical abilities to deal with a problem (French and Morris, 2003). Additionally, fatigue is a total body measurement comprised of both mental and physical aspects. Employees can suffer from mental and physical fatigue depending on the cognitive and physical demands of their jobs. Total body fatigue investigations have studied nurses during shift work (Soh, et al., 1996). Levels of fatigue have also been a concern for medical professionals, in addition to military and nuclear power managers (Ahsberg, 1998). Work conditions, work environment, time of day, rest breaks, job control, job performance, and job challenges were considered as fatigue variables to study. Physical measurements of fatigue, as seen in changes of heart rate,
were objectively measured. Fatigue questionnaires (Yoshitake Type I and II fatigue) and level of tiredness surveys (SOFI) were given to participants to obtain subjective measures of fatigue.

1.4 Stress

Stress has three typical manifestations: a phenomenological experience, change in physiology, and altered characteristics of information processing (Hart and Hauser, 1987). These manifestations have either external or internal influences on human performance that can be seen in the quality of information received by the sensory receptors or the precision of response. Factors that have been studied in the past that affect stress level include ambient temperature, noise, sleep loss, fatigue, arousal, job demands, personality factors, job satisfaction, job workload, work roles, job characteristics, bureaucracy, job satisfaction, job strain, and time pressure (Hockey, 1986).

When under stress, people usually persist in trying the same unsuccessful solution to a problem, which then becomes the cause of increasing stress (Wickens & Holland, 2000). Thus factors this research focused on would be occupationally controlled. Ambient temperature, noise, job satisfaction, job workload, work role, job characteristics, job satisfaction, job strain, and time pressure were factors under consideration. Ambient temperature and noise levels could be changed until they interfered with computer work stations. Time pressure and management evaluation were studied because of the Columbia Accident Investigation (CAIB) finding that pointed to time as a critical concern in making decisions in a bureaucratic environment. Also of concern were levels of work, job strain, work roles, and job satisfaction, because of the demonstrated effect on performance. These factors were measured in previous studies by analyzing changes in heart rate, recruitment of additional resources, participant’s willingness to
change the stated goals or a participant’s lack of decision making (Driskell, 1991, Wickens and Holland, 2000, and Alkov, Borowsky, Gaynor, 1982).

**1.5 Workload**

Fundamentally, workload the amount of work assigned to or expected from a worker in a specified time period. To assess workload performance changes, Tsang and Wilson suggest using heart-rate variability, pupil diameter, and visual scanning to detect physiological changes. Also, NASA TLX, a subjective measurement assessment technique, has proven successful in determining workload and contains formal prescriptions for how the multi scales can be combined to obtain a single measure. It is understood that increases in workload do not necessarily have negative consequences; rather, it is the lack of ability to adapt to the increase that impedes human performance (Wickens and Holland, 2000).

Workload factors of concern to console operators include task complexity, job demand, completion time, number of problems, and job type. Quantifying task complexity is problematic and has been addressed by measuring the levels of certification a console operation must obtain. The higher the level of certification an operator receives, the greater the responsibility. However, once an operator has been fully certified, a proficiency certification is required on a per mission basis. Each decision made by the console operation is critical because rework cannot be performed in time-sensitive activities, such as rendezvous with the International Space Station (ISS) or during an Extravehicular Activity (EVA) testing.

To determine which sub-components of fatigue, stress, and workload impact human performance, a control room environment was studied. Operators performed control room simulation exercises. Simulation exercises occurred on a regular interval, and were designed to
provide an environment highly representative of the task performed on actual launch and mission
days.
CHAPTER TWO: LITERATURE REVIEW

2.1 Fatigue

This study focused on total body fatigue caused by the work a control room operator is required to complete.

In the simplest situations, a diagnostic fatigue test must distinguish between two states: fatigued and not fatigued, and safe and unsafe. The ultimate application of any fatigue model is to diagnose if an individual is sufficiently rested to perform a tour of duty safely and efficiently (Raslear, et al, 2004). The ability of a model to detect fatigue may also depend on the subject population and work history. Additionally, these factors may limit the generalization of the results from one application to another.

The effects of fatigue are multifaceted and complex, overlapping the areas of performance, physiology, cognition, and emotion (Gawron, French, Funke, 2001). Human fatigue has two main components: mental and physical. Mental fatigue is defined as decrements in performance on tasks requiring mental alertness and the manipulation and retrieval of information stored in memory (Stern, Boyer, Schroeder, 1994). Physical fatigue has been defined as the point at which a person who is exerting him or herself can no longer put forth the required effort to complete a task (Caldwell and Lyddan, 1971).

Yoshitake, 1978, described fatigue using three dimensions: drowsiness and dullness, inability to concentrate, and enhanced awareness of physical discomfort. Smets developed a five-dimensional inventory to describe fatigue: general fatigue, physical fatigue, mental fatigue, reduced motivation, and reduced ability (Smets et al, 1995). Other perceived fatigue conditions
studied include sleepiness (Akerstedt, 1987), physical exertion (Borg, et al, 1987), and discomfort (Cameron, 1996). In addition to physical and mental workload, there are other conditions that affect the general state of an individual which include sensory load (Grandjean, 1988), time of day (Folkard, 1983), psychological and physical environment (Gamberale & Holmer, 1976), as well as personal-related characteristics (Wendt and Palmerton, 1976).

Fatigue can be either physical or mental depending on the cognitive and physical demands of an operator’s job. Subjective and physiological techniques can be used to assess and quantify the aspects of fatigue experienced by a person while performing a job. The physiological measurements most commonly used include cardiovascular response, energy expenditure, reaction and response time, skin temperature, and blink rate. Subjective measurements have included SOFI, Subjective Assessment Model (SAM) and the Profile Mood States survey (POM). Usually, fatigue surveys are divided into two parts, with the first section focused on systems associated with mental fatigue (type 1 fatigue) and the second focused on systems associated with physical fatigue (type 2 fatigue) (Smith, B. et al 1998).

Fatigue can also be described in terms of loss of efficiency and a general disinclination to work. Employees may suffer mental fatigue in addition to the physical fatigue they might be subject to for the requirements of a particular task. However, there was no one measure capable of assessing total body fatigue until research was conducted by Babski, Crumpton, and Harden (1999) to develop a total body fatigue indicator. The total body fatigue model they developed evaluated fatigue using subjective measures, Yoshitake Type I and II fatigue, and perceived level of tiredness surveys, in addition to objective measures, change in heart rate, percentage maximum heart rate, and performance in a tone identification task. The model was developed
using inputs from nurses, data entry operators and manufacturing personnel, and the resulting estimator described fatigue as:

\[ F_{ijk} = W_1 HR_{ijk} + W_2 TT_{ijk} + W_3 LT_{ijk} + W_4 MFS_{ijk} + W_5 PFS_{ijk} \]

Where:
- \( F_{ijk} \) = Overall fatigue level
- \( W_{1-5} \) = Relative weighed value of each fatigue indicator
- \( HR_{ijk} \) = Change in heart rate membership value
- \( TT_{ijk} \) = Tone task reaction time membership value
- \( LT_{ijk} \) = Level of tiredness membership value
- \( MFS_{ijk} \) = Number of mental fatigue symptoms reported membership value
- \( PFS_{ijk} \) = Number of physical fatigue symptoms reported membership value

And:
- \( i \) = participant number
- \( j \) = testing time
- \( k \) = testing session number

The relative weights (\( W_{1-5} \)) for the equation were determined using the Analytic Hierarchy Process (AHP). AHP involved making pair-wise comparisons for each utilized fatigue assessment indicator in order to estimate the overall fatigue level. The relative weights for each variable were determined to be: \( W_1 = 0.15, W_2 = 0.15, W_3 = 0.2, W_4 = 0.25, \) and \( W_5 = 0.25 \).

The model correctly predicted the fatigue levels of assessed nurses 52.5% of the time (Babski and Crumpton-Young, 2000), and can therefore be applied to determining modifications in job tasks, work-rest schedules, and workloads that maximize worker daily productivity while helping to ensure safety (Soh, Crumpton, McCauley-Bell, 1996).

Typical factors that induce fatigue include sleep quality, time of day, and level of physical fitness. Lan, Ji, and Looney identified the significant factors that cause human fatigue and captured these factors in a static Bayesian Network (Figure 1). Lan argues that, for fatigue to be detected, there must be a persistent presence of certain behaviors over time instead of the presence of the behavior at one particular instance. His research found that a dynamic model of
fatigue is more tolerant to external signal disturbances and changes are seen only after persistent and continuous observation of certain behaviors.

According to Gawron, French, and Funke, age, work-rest schedule, sleep deprivation, motivational factors, coping strategies, total time spent working, and circadian disruptions affect fatigue. Supporting evidence has been gathered from the transportation industry (long duration hauls), airline pilots, and sleep deprivation studies. Gawron noted that studies of military personnel showed that fatigue in highly-motivated individuals is difficult to predict because of coping strategies they use, such as lowering of risk thresholds or increasing effort. Additionally, research has shown that the total amount of time working is more important than the total time spent on a particular task because of the affects of fatigue (McDonald, Fuller, and White, 1991). The effects of sleep deprivation on reaction time and accuracy on physiological functions (including sleep inertia, neuroendocrine level, and level of immune response) and cognitive abilities, such as reaction time and logical reasoning are well established.
There is only limited epidemiological evidence for the precise impact that rest break schedules have on levels of risk. Several studies have shown that, when rest breaks are taken at the onset of fatigue, they are an affective tool for restoring performance; however, recent studies have shown no direct epidemiological evidence for the impact of breaks upon risk as a function of time-on-task (Brown, 1994, Tucker, 2003, and Lilley, Feyer, Kirk, and Gander, 2002). Pre-planned rest breaks might not coincide with an individual’s experience of heightened fatigue. Alternatively, an individual might not be able to judge when a break is needed.

Rest breaks every two hours are common in many industrial settings. Research has shown that interval breaks are an effective means of controlling the accumulation of fatigue as a function of time-on-duty. When practical, it is desirable to combine pre-planned rest breaks with an option for workers to take short breaks when heightened fatigue is experienced (Wagner, 1988, and Frank, 2000).

Rest breaks are a potential fatigue counter-measure that can help to control the risks associated with fatigue. The effects of fatigue can be assessed by the reduction in the biological stress response (including lower levels of catecholamine and cortisol and lower blood pressure). Additionally, rest breaks can have beneficial psychosocial effects, such as facilitating social relations and enhancing worker satisfaction (Tucker, 2003). The space industry workers on console do not have scheduled rest breaks but are encouraged to take a break when their respective system is quiet.

Non-challenging jobs, poor-quality supervision, a feeling of minimal control over a job, poor job performance, and low pay rates were associated with employees experiencing job fatigue, according to Finkelman. Fatigue might also result from processing too much or too little information. Finkelman found that positions that were not physically demanding or that did not
involve processing of detailed information were also associated with increased fatigue risk because of low levels of arousal and rapid onset of boredom. According to Finkelman, the information processing demands of a job assignment have the highest correlation with reported job fatigue. In contrast, sleep deprivation was minimally associated with the reporting of job fatigue (Finkelman, 1994). However, tiredness and exhaustion as motivational variables were factors that affected fatigue levels according to a 1996 study by Salmon, et al.

Sensory load refers to conditions in which work demands require a rapid and precise eye movement, which, in turn, places demands on the visual system (Ahsberg, 1989 and Grandjean, E., 1988). Eye strain has been recognized as a specific problem among visual display terminal (VDT) operators (Dainoff, 1982).

Reaction time has been associated with irregular working hours, and increasing response irregularity in complex reaction time tests in laboratory settings has been interpreted as a sign of mental fatigue (Bills, A. 1931).

It is important to approach the issue of fatigue in an integrated manner (Mital and Kumar, 1994). Past research has shown that fatigue is linked with pain, tiredness (Reiger, 1984), central and peripheral nervous system mechanisms (Merton, 1954), environmental stimulus (Putt, 1977), lack of motivation (Mital and Kumar, 1994), and other factors.

In 1987, Piper et al. produced a fatigue framework circle that identified causative factors for fatigue (Figure 2). These are the same factors that were identified by Jan, Li, and Looney in 2003 as factors that influence fatigue levels. Subsequently, work environmental factors were included to Piper’s framework of contributing factors to fatigue. This led to fatigue being described using five possible dimensions: subjective, physiologic, biochemical, behavioral and environmental.
2.1.1 Objective Measures of Fatigue

Methods for measuring fatigue include measuring changes in heart rate, blood glucose level, body temperature, communication, attitude, and activity level. Levels of fatigue can also be measured using behavioral checklists, task performance indicators, and assessing environmental factors such as lighting, room temperature, and noise level (Piper, 1987, Jin, Li, and Looney, 2004). Subjective data collection must include information on type (muscular, mental or both), intensity, duration, alleviating or aggravating factors, and associated patterns. Physical measurement, levels of tiredness surveys, and fatigue questionnaires can be used to gather subjective measures of fatigue. Changes in heart rate, respiratory rate, skin temperature, and percent of maximum heart rate are objective measurements. Environmental factors that should be considered include weather, heat, noise, and vibration.

Blink rate has been found to be closely related to mental tension (Ponder and Kennedy, 1927). The average blink rate under standard conditions is three to seven blinks per minute. The blink rate is affected by time on task, fatigue level, and how visually demanding the task is. The
degree of reduction in blink rate is roughly proportional to task difficulty. As a task becomes more difficult, the ability to blink becomes inhibited (Stern, J., et al, 1994).

Fatigue has also been shown to have an effect on blood pressure. Significant increase in systolic and diastolic blood pressure during static work can trigger a reflex that slows the heart rate through the carotid baroreceptor mechanism (Piper, B., 1989). Heart rate changes are minimal to modest with predominately static work, varying between 82 and 110 beats per minute.

Changes in respiratory rate are a more significant physiological variable than heart rate for detecting fatigue (Philips and Repperger, 2003). Respiratory rate changes appear more quickly and provide better indicators of change in stress in static work than changes in heart rate (Phillips, 2003).

2.1.2 Current Studies of Fatigue

In 1996, Soh, Crumpton, and McCaulley-Bell completed work on the use of fuzzy logic to develop a mathematical model to quantify nurses’ fatigue. Physiological measures (heart rate, reaction time, and skin temperature) and subjective measures (fatigue-related symptoms) were taken from six nurses at the beginning and end of each shift. Data was also collected on the tasks performed by each nurse and their job characteristics. Linguistic risk levels for each input variables were established. Through the use of pair-wise comparisons, significant factors within each physiological and subjective measure category were determined. For example, nurses were asked to rank their perceived inability to concentrate, feelings of stress, and perceived tiredness. Additionally, a matrix of pair-wise comparisons was used to determine the weights of each variable with the help of Expert Choice Decision Support Software. The results of the study
found that the original total body fatigue model overestimated fatigue in 51.7% of the cases, accurately predicted fatigue levels in 36.7% of the total cases, and underestimated fatigue levels in 11.6% of the total cases. Of the overestimated cases, 81.3% were overestimated by one level and 18.7% were overestimated by two levels. Of the underestimated cases, 33.33% were underestimated by one level, 33.33% by two levels, and 33.33% by three levels. The model was found to assess effects besides the fatigue resulting from the work performed by the nurses. Back pain, arthritis, and housework were some of the other factors found to affect the initial state of fatigue. The addition of personal factors and relative weights were identified as further research areas to address.

Researchers have found that it is difficult to determine a person’s fatigue level based on appearance. However, in a study conducted by Kashiwagi, twenty factors were used to evaluate fatigue. Using a fatigue scale, Kashiwagi assumed that human fatigue has three dimensions, which can be defined as weakened activation, weakened motivation, and physical disintegration (Kashiwagi, 1973). Weakened activation and motivation have been found to be applicable to most jobs.

The purpose of Kashiwagi’s study was to construct a new fatigue rating scale. The items selected to indicate weakened activation included: being too sluggish to walk, unsteady voice, absentmindedness, a hollow-cheeked appearance, avoidance of conversation, a sulky appearance, spiritless eyes, signs of irritability, and a dull and listless facial appearance.

The ten items selected to indicate weakened motivation included making verbal misstatements, avoiding the eyes of other people, finding speech difficult, feeling sluggish, restless, or anxious, having a pale face, muscular stiffness in the face, trembling fingers, or being unable to concentrate and listen (Kashiwagi, 1971). The Japanese National Railway validated
the fatigue scale using engine drivers. The results showed that a person’s appearance was associated with fatigue judgments.

De Vries showed that personality and temperament dimensions (emotional stability, extraversion, and strength of excitation) account for a significant proportion of variance in fatigue (De Vries, 2002). Using the Five Factor personality model and Pavlovian temperament variables, DeVries attempted to predict levels of fatigue. He determined that high personality scores for autonomy and low scores for extraversion, conscientiousness, emotional stability, and strength of excitation were predictors of fatigue. His results also showed that agreeableness, strength of inhibition, and mobility did not play a role in the prediction of fatigue.

Caffeine is a stimulant drug often used to offset the effects of fatigue. In 1991, Frewer performed a study to determine if caffeine minimized the decrement in information processing skills and vigilance performance associated with fatigue. The effects of caffeine on attention were determined by examining physiological, subjective, and cognitive variables (Frewer, 1991).

Using a letter cancellation task, significant changes between processing time and dose interaction were observed. With higher levels of caffeine, reaction times were significantly faster. In the continuous attention task, interval time and dose affect were found to be significant (Frewer, 1991). The results concluded that caffeine did alter information processing and vigilance performance. Frewer found that caffeine levels also affected diastolic blood pressure. These results are significant because food and drinks are not permitted in the control room during the last hour of countdown through the first hour of on-orbit operations.

Michielsen, 2004, conducted a study to determine the factors that predicted general fatigue and emotional exhaustion. A model of mediators and moderators of the stress-health
relationship was used to select variables. Emotion exhaustion was described as a feeling of being worn out and empty due to a work situation (Lee and Ashforth, 1993 and Leiter, 1993). Past studies have shown that exhaustion is strongly influenced by temporary work situations and can last up to eight years (Toppinen-Tanner, 2002). A questionnaire on the Assessment and Experience of Work was used to measure psychosocial job demands and job stress. The Trier Inventory for the Assessment of Chronic Stress was used to help predict stress based on workloads.

The study found that extraversion, workload, and perceived stress were the strongest predictors of general fatigue. Additionally, it was found that a combination of personality factors and situational variables played a substantial role in the explanation of fatigue levels. Burisch found that disposition and environmental factors could be used to predict fatigue. In his study, it was found that the environmental factor workload was superior for predicting emotional exhaustion. This is because workload is changeable, whereas personality is assumed to be a stable characteristic (Burisch, 2002).

### 2.1.3 Tools to Evaluate Fatigue

A quantitative model of work-related fatigue was developed by Fletcher to evaluate sleep deprivation and work scheduling. The model included hours of wakefulness, hours of work, task-related factors, such as automation and motivation, and cumulative sleep deprivation. The predictions from the model were correlated against psychomotor vigilance task lapses ($r = 0.92$) and reaction time responses (slowest 10%, $r = 0.91$). Additional correlations were performed on four measures of continuous sleep deprivation study, with factors relating to vigilance ($r = -0.75$), performance ($r = -0.75$), sleepiness ($r = 0.82$), and tiredness ($r = 0.79$).
The results indicate that the predictions from this model correlate well across a range of objective and subjective measures. This relationship also appears to hold for cumulative and continuous sleep deprivation protocols (Fletcher, 2001).

Fatigue bio-mathematical models originated from the need to determine the formal underlying relationships between sleep and circadian dynamics in the control of alertness and neurobehavioral performance capabilities. Because individuals can differ distinctly in response to sleep loss, fatigue, and their countermeasures, models must incorporate estimates of these differences between individuals. Models seek to estimate behavioral capability and/or the relative risk of adverse events in a fatigued state (Dinges, 2004).

The basis of bio-mathematical models of performance, fatigue, and sleepiness lies on the seminal two-process model of sleep regulation proposed by Borbely in 1990. The basic assumption of this model is that sleep is regulated by two independent processes: a sleep dependent homeostatic process (process S) and a sleep-independent circadian process (process C). These two processes are summed together to estimate sleep propensity and the duration of sleep (Reifman, 2004).

There are currently seven bio-mathematical models that are used to predict fatigue, with emphasis placed on sleep and circadian cycles. The seven models currently available are: two-process model, sleep/wake predictor model, SAFE model, Interaction Neurobehavioral model, SAFTE Model, FAID Model, and CAS Model. In terms of the broad prediction goals for each model, six of the models seek to predict some aspect of subjective fatigue or sleepiness (the SAFTE model is the exception); four examine physiological alertness (with SAFTE, FAID and CAS being the exceptions); and five examine the impact of countermeasures, such as caffeine and naps (the SAFE and FAID models are the exceptions in this case). Few of the models are
concerned with predicting accident risk (only the sleep-wake predictor and CAS models examine this factor); work rest schedule (the sleep-wake predictor, SAFTE and CAD models); circadian phase (the sleep-wake predictor, interactive neurobehavioral and SAFTE models); and specific task parameters (the sleep-wake predictor and SAFTE models). The sleep/wake predictor model is the only model that captures all the above-mentioned factors associated with fatigue.

Each of the models provides estimates of the recovery potential of sleep, and all but the FAID model provide estimates of change as a function of time awake. One of the models, the two-process model, examines a space mission scheduling, and the CAS model investigates the affects of irregular work schedules as an input variable. With the exception of the SAFTE model, all provide primary output information on subjective alertness and/or subjective fatigue levels.

The majority of the models seek validation through laboratory experiments or field operations on patterns of alertness at work and rest. The only input or output parameter that is common to all seven models is output estimate for recovery potential of sleep. Other than assuming more sleep is better than less sleep, it is not clear how accurate any of the model estimates are, relative to recovery potential. The effects of pharmacological agents, such as alcohol and caffeine, are not included in any of the models.

The sleep/wake predictor, FAID, and SAFTE models attempt to estimate individual variability. The SAFE and CAS models also estimate the effects of environmental variability. These two factors are what most workers feel are the most salient in determining responses to fatiguing work schedules. However; they are not frequently studied parameters (Mallis, et al, 2004).
Most fatigue models share a common feature in that the models require an input of actual or estimated sleep times. A reliance on actual sleep times for model inputs is problematic because it is difficult, costly, and time consuming to collect objective measures of sleeping and waking hours for every possible duty schedule, and even then, the fatigue levels associated with a given schedule can only be estimated after the schedule has been introduced (Roach, et al, 2004).

All the bio-mathematical models reviewed provide estimates of recovery for sleep (that is, sleep timing and duration) and most provide estimates of change in the function of time awake, with the exception of the SAFE model. However, the SAFE model has the most comprehensive input information of all the models: aviation-specific variables, environmental variables (such as light level and location), sleep variables, and work variables. The sleep/wake predictor only used sleep variables as input information. The FAID and CAS models only used work hours as inputs into the model.

When comparing capabilities currently implemented in the models, the SAFE, the sleep/wake predictor, and the CAS models estimate individual variability in terms of awake or sleep patterns, type of work, or endogenous circadian parameters (Mallis, et al, 2004). Mallis’ study considered the number of hours of sleep a participant had the night before the simulation and regular sleep time as variables; however, amount of sleep was not objectively measured because of the vast research completed on sleep deprivation and because sleep cannot be controlled by occupational means.

Ahsberg developed the Swedish Occupational Fatigue Inventory (SOFI) as an instrument for measuring work-related perceived fatigue. This instrument was tested with 25 expressions, evenly distributed between five latent factors. The five factors were interpreted as lack of
energy, physical exertion, physical discomfort, lack of motivation, and sleepiness. Physical exertion and physical discomfort are considered as physical factors, whereas while lack of motivation and sleepiness are considered as primarily mental factors. Lack of energy is seen as a more general factor that reflects both mental and physical fatigue.

Using five differing industries, Ahsberg found that the proposed five-factor model did not demonstrate a satisfactory fit (Figure 3). A relatively strong correlation between the specific latent factors, such as sleepiness and lack of motivation, indicated that these states of fatigue are overlapping and cannot be completely separated. Some correlations were also found between the reported intensity in overall fatigue (CR 10) and the reported qualitative dimensions of fatigue (SOFI). The results of the regression analysis showed that, depending on the occupation, different SOFI-factors contribute more to overall fatigue (Ahsberg, 2000).

![Figure 3: 25 Factors of the SOFI Model.](image)
2.1.4 Summary of Fatigue

A review of the current literature demonstrates that extraversion, workload, perceived stress, job challenges, quality of supervision, job control, job performance, pay rates, information processing demands, blink rate, respiratory rate, monitored heart rate, weakened activation, and weakened motivation have been considered for fatigue variable quantification.

This variable list was paired down to include only those factors that could be controlled occupationally and that contribute significantly to the combined overall affect of fatigue as it relates to performance.

2.2 Stress

Stress is a dynamic phenomenon, associated with the quality of transactions between a person and environmental demands (Lazarus & Folkman, 1984, Hancock & Warm, 1989). Stress at work is usually referred to as a psychological injury or illness (Kumar, 1994, McDonald, W., 2003). Work stress has been described as an incompatibility between the individual and his or her work environment (Humphrey, 1998).

Salas, Driskell, and Hughes further refined the definition of stress as a process by which environmental demands “evoke an appraisal process, in which perceived demands exceed resources and which results in undesirable physiological, psychological, behavioral, and/or social outcomes”.

A third recognized definition of stress is the interaction between events and interpretation. Stressors are defined as the precipitating event or agents that potentially threaten an organism’s well-being (Baum, Singer, and Baum, 1981).
Control of human performance is expressed in terms of physiological responses, subjective experiences, cognition of the performed tasks, and in objective behavior and performance (Hockey, 1997). Stressors create demands that exceed resource capabilities, and can be divided into two types: ambient and performance-contingent. Ambient stressors are factors that are part of the environment. Performance-contingent stressors are directly tied to task performance (Driskell & Salas, 1996).

Research has suggested that there is a distinction between team and individual stressors (Salas, Dickinson, Converse, & Tannenbaum, 1992). These variables are time, workload, team size, and team pressure. Research conducted in military, medical and university settings find that ambiguity, uncertainty, time pressure, level and locus of control, and task complexity all affect performance (Xiao, et al, 1996, Kanki, 1996, Urban et al, 1995, and Serfaty et al, 1993).

Evidence from space research and related environments have shown that negative responses to stress largely depend on how each individual evaluates their capacity to manage the threat imposed by the stressor (Kanki, 1996; Orasanu & Backer, 1996). One of the most common indexes used to measure individual differences in response to stressors is the EPI, or Heron inventory. Extroversion is perceived to be a temperament factor that correlates with the degree of performance change, although the direction of the effect is not always the same for the different stressors or task conditions. Also of interest is the measurement of morning versus evening personality types (Folkard et al, 1981). The differences in performance rhythms are marked by changes in diurnal habits, fluctuation of body temperature, and circadian rhythms.

Although there is evidence that supports the effects of time pressure as having a linear relationship to performance, other studies have shown non-linear results. Weaver suggests that
there is something unique about the influence of time pressure on performance in varying environments, which requires further research (Weaver, 1995).

Research on the effects of stressors other than time pressure is limited. Research on areas of ambiguity, resource demand, uncertainty, and threats has provided inconclusive evidence to indicate performance change. Other research has shown that the influence of automation and leader characteristics, as stressor factors, can degrade performance. The extent of performance deterioration under threat is likely to be strongly influenced by the salience of the threat; and the link between stress and performance is more visible in a team process than in individual performance (Urban, et al, 1995; Kanki, 1996; and Flin, 1996).

2.2.1 Factors that Affect Stress

Stress can be caused by noise, vibrations, heat, lighting, rapid acceleration of work pace, anxiety, fatigue, frustration, and anger (Svenson and Maule, 1993). These forces typically have one or more of three manifestations: they produce a phenomenological experience; they produce a change in physiology; and they affect characteristics of information processing (Hart and Hauser, 1987).

These stress factors might have external or internal influences on human performance that can be seen in the quality of information received by the receptors or the precision of response. Factors that have been studied in the past that affect stress levels include the threat of shock, temperature, noise, sleep loss, and time pressure (Hockey, 1986).

Researchers have shown that the effects of stress on performance have the greatest influence on the different information-processing components. Arousal is one of the easiest ways to measure the quantitative stress levels, and can be detected through heart rate, pupil
diameter, or the output of catecholamine in the blood stream or urine. Stressful events outside the work environment (such as financial or family concerns) are diversions to thinking about job-related information, and thus reduce processing capabilities (Alkov, Borowsky, Gaynor, 1982; Wickens & Holland, 2000).

There are four major adaptive responses that a person will use to cope with perceived stress affects: they will recruit more resources; they will remove the stressor; they will change the goals of the task; or they will do nothing (Driskell, 1991, Wickens & Holland, 2000).

In 1976, Gardell suggested that occupational stress in work environments can create a feeling of powerlessness or alienation of the workers. Factors affecting a worker’s stress include: personal vulnerabilities (Kendall, 2000), characteristics of the job (Kendall, 2000; Greiner, 2004), organizational climate (Kendall, 2000; Milton, 1994), job conflict (Kendall, 2000; Danielson, 2003), perceptions and appraisal by the worker (Kendall, 2000; Milton, 1994; NIOSH, 2004), work load (Kendall, 2000), resource management practices (Kendall, 2000), work or job demands (Palmer and Cooper, 2001; Soderfeldt, 2000; Danielson, 2003; Milton, 1994; Greiner, 2004), level of control over the job (Palmer and Cooper, 2001; Milton, 1994; NIOSH, 2004), work role (Palmer and Cooper, 2001; Danielson, 2003; Milton, 1994; NIOSH, 2004), environmental changes (Palmer and Cooper, 2001), management style (NIOSH, 2004, Cooper and Payne, 1998), work relationships (Palmer and Cooper, 2001; Milton, 1994; Kendall, 2000), level of support (Palmer and Cooper, 2001; Milton, 1994), job strain (Solderfeldt, 2000; Greiner, 2004), lack of financial rewards (Danielson, 2003), lack of career guidance (Danielson, 2003; NIOSH, 2004), overspecialization (Danielson, 2003), time pressure (Danielson, 2003; Milton, 1994; Greiner, 2004), job complexity (Danielson, 2003; Milton, 1994; Greiner, 2004), bureaucracy (Danielson, 2003), working environmental conditions, such as noise, temperature,
and lighting (Danielson, 2003; Milton, 1994; NIOSH, 2004), and job satisfaction (Cooper and Payne, 1998).

Of the aforementioned variables, only job demands, job control, noise levels, job workload, work roles, job strain, and level of bureaucracy are considered occupationally-related factors.

Job demands are among the most frequently cited occupational stressors for full-time employees who are experiencing increased levels of work-related stress (MacDonald, 2003). Uncertainties concerning performance requirements have shown increased job stress. Job demands also encompass the volume and complexity of the work in addition to shift work (Palmer and Cooper, 2001; Soderfeldt, 2000; Danielson, 2003; Milton, 1994; and Greiner, 2004).

Noise has been shown to increase stress levels. The effects of noise depend on many variables, such as the noise parameters, the experimental design, the situation, the personality and motivation of the subject, and the nature of the cognitive and motor demands of the task (Koelega, H. et al, 1986).

Personality factors that might alter stress responses can be related to either the level of arousal or the level of perceived control the individual believes he or she has over the situation (Cox and Ferguson, 1989). Some of the individual factors that influence stress responses include: locus of control, self efficacy, tolerance to ambiguity, behavior pattern, personality type (that is, whether the individual is introverted or extroverted) and coping strategies (Cuevas, 2003). Individuals with an external locus of control show greater vulnerability to stress and poorer performance under stress.

Job satisfaction has been cited as the critical moderator of the relationship between stress and satisfaction. The Job Descriptive Index (JDI) was developed to measure job satisfaction,
level of stress, and control. Elsass and Veiga (1997) cited general lack of consensus as a stress factor, and found that low levels of job control are associated with higher levels of job strain. Bedeian and Armenakis (1981) included tension and dissatisfaction as outcomes of role conflict and role ambiguity. Jackson and Schuler (1995) cited a strong correlation between satisfaction with work and role clarity as a source of stress. Karasek’s demands-control model suggests that a highly demanding job provides many opportunities for control and decision-making; however, these demanding jobs have greater dissatisfaction and increased stress levels (Karasek, 1979).

Control has been shown as an important construct to include in a study of job stress. However, Stanton et al, 2002, found that tapping stress is not easily separated from work satisfaction.

Job workload, described in quantitative terms, is considered to be excessive when the volume of work exceeds the ability of a worker to meet the demands over a specified period of time (French and Caplan, 1973). Additionally, it can be described as the requirements of the work exceeding the ability, skills, and knowledge of the worker.

At NASA, as many of the first console operators begin to retire, the “history”, or knowledge, of the systems is leaving. This creates knowledge gaps within systems, requiring larger workload demands on newer operators (Kendall, 2000). Time pressure can be manifested as deadlines, production rates, or completion deadlines change due to schedule realignment.

Work roles that affect stress are defined by NIOSH as conditions that have conflicting or uncertain job expectations, too much responsibility, or when a person has too many roles and responsibilities. High levels of occupational stress, manifested in work rules, are evident in organizations in which there are elevated levels of role ambiguity and role conflict (Anderson, 1991). The effects of these are negative job-related attitudes and passive behaviors. Role
ambiguity exists when an individual lacks information about the requirements of his or her role, how the role requirements are to be met, and the evaluative procedures available to verify that the role is being performed successfully. For example, this is evident when engineers are unable to determine which system is responsible for problem reports or who to report to for job completions on the orbiter-processing floor (Palmer and Cooper, 2001; Danielson, 2003; and Milton, 1994). Work role conflict has a negative impact on a worker’s stress level. Role conflict can include conflicts in job demands, and divisions among multiple supervisors or managers.

Characteristics of a job also affect stress levels. Monotonous conditions are conditions that demand continuous visual attention during work performance, in combination with repetitive movements or information processing for at least 30 consecutive minutes (Greiner, 2004). An example is console duty, in which a worker must view a computer screens with scrolling data for many hours. When investigating stress, monotonous working conditions are measured in minutes of duration per day.

Bureaucracy is characterized as organizational rules that help ensure uniformity and stability, positional hierarchy, and centralized authority and emotionless management (Danielson, 2003). Positional hierarchy is evident in the control room layout, in which senior management faces the engineering consoles three levels above the floor. It is understood that the level of control decreases the further a console is from the management level. Additionally, all engineering consoles report to one management director who enables actions to be carried out. During launch, only certified personnel are permitted into the firing rooms to help ensure knowledge adequacy among the operators.

Job satisfaction has been cited as one of the main causes of work stress. Satisfaction can be regarded as the quality of work an operator produces in the time required to complete a task
In Return-to-Flight mode, job satisfaction is a concern for management because console operators are writing job procedures just in time for new operations to be completed or are having to process large numbers of troubleshooting activities on flight hardware that must be completed prior to launch.

Job strain occurs when job demands are high and job decision latitude is low. The "job strain" model dictates that a combination of high job demands and low job decision latitude will lead to negative physical health outcomes, such as hypertension and cardiovascular disease (CVD). Chronic adaptation to low-control and low-demand situations (passive jobs) can result in reduced ability to solve problems or tackle challenges, and feelings of depression, or learned helplessness. Conversely, when high job demands are matched with greater authority and skill use (controllable stressors, or active jobs), more active learning and greater internal locus of control develop. This can enable individuals to develop a broader range of coping strategies (Schnall PL, Landsbergis PA, Baker D. 1994).

### 2.2.2 Tools to Evaluate Stress

The US Army has developed a battery of cognitive measures to address the need to evaluate changes in cognitive processes related to stress. The focus of the Cognitive Performance Assessment for Stress and Endurance (CPASE) test was to develop a battery of tests amenable to evaluate a large group of participants in a field setting. It includes four tests of high cognitive functioning that represent a range of skills including verbal memory recall, logical reasoning, working memory, and spatial manipulation. The test takes 5 minutes to complete and there are multiple versions. This helps ensure that participants cannot memorize answers in repeated measure design. The verbal memory section tests the affects of sleep loss on memory.
Short-term memory is evaluated with words taken from a list of 12 words. The reasoning test evaluates the participant’s understanding of grammatical transformation of sentences of various complexities. The test is balanced for positive versus negative, active versus passive, and order of statement and letters in pairs. The addition task is used to test working memory. There are 15 problems, consisting of three-digit number manipulation. The spatial rotation section tests the ability of a participant to complete two-dimensional mental rotation tasks adapted from Shepard’s 1978 work. All of the cognitive tasks, except logical reasoning, show significant main effects across the session, with performance showing a decline until the lowest point late at night. Additionally, CPASE has been found to be sensitive to changes in individual stress levels. The methodology used in this study provides a battery of measures that, when used with stress assessment techniques, can help researchers further understand the relation between stress and cognitive performance (Mullins, L. 2002).

Traditional approaches to defining stress have followed a physiological stimulus-response model that either focus on the stimuli in the environment (noise, motion, or workload) or emphasize the physiological response (such as heart rate or anxiety) of the individual to the putative stressor (Cuevas, 2003).

In blood samples, cortisol levels indicate the activity of the adreno-cortical system; prolactin levels relate to the activity of the dopaminergic and serotonergic systems, and immunoglobulin G levels relate to the immune system functioning. These factors are chosen as stress indicators because of their relatively slow reactions to changes in psychological stress, thereby indicating stress over time.

Stress indicators such as catecholemines, glycosylated haemoglobin, and lipids are excluded because they are sensitive to food habits and physical activity (Solderfeldt, 2000).
Another quantitative method for determining the affects of job stress includes productivity data, sickness and absence data, and staff turnover rate (Palmer and Cooper, 2001).

Some of the psychological measures for stress include feelings of irritation, sadness, depression, and low job satisfaction. These indicators can be measured through psychological testing and brain activity levels (Cooper and Payne, 1998). Additionally, high cholesterol level and ECG abnormalities have been cited as indicators of stress (Cooper and Payne, 1998).

2.2.3 Summary

Based on the above literature review, the following variables will be considered for dependent measure inclusion: noise, motion, workload, heart rate, anxiety, productivity data, irritatibility, sadness, depression, job satisfaction, job strain, work roles, and job demands.

2.3 Workload and Task Demands

Workload has been described as a hypothetical construct that is widely used in Human Factors and various measurement techniques to evaluate equipment and work systems in terms of the workload experienced by people using them. Many researchers recognize that mental workload is an important factor in determining human performance capabilities in complex systems. It has been identified that optimizing the allocation of mental workload to individuals can reduce human errors and lead to increased productivity (Xie and Salvendy, 2000, Moray, 1988, Gopher and Donchin, 1986). Although many people understand mental workload in general terms, extensive research has been conducted to quantify mental workload. The most common definition given for workload is, “the amount of work assigned to or expected from a worker in a specified time period” (Dictionary online, 2005). However, a more precise
definition of mental workload reflects the depletion of human internal resources to accomplish a
task or job (Xie and Salvendy, 2000). Specifically, it is the amount of work done by a particular
individual and the performance achieved depending on the task demands in relation to work
capacity (Bainbridge, 1997). When reviewing the literature, many definitions are given but none
pass the tests of widespread acceptance or quantitative verification. What researchers do agree
on is that workload is a multidimensional variable affected by many factors. Additionally,
exerts agree that space capacity and mental workload are inversely related (Kantowitz, 1987).

Mental workload can be related to physiological states of stress and effort, to subjective
experiences of stress, mental effort and time pressure, to objective measures of performance
levels and to breakdowns in performance. These various aspects of workload have led to distinct
means for assessing workload, including physiological criteria (including heart rate and
evocation of potentials), performance criteria (quantity and quality of performance) and
subjective criteria (such as rating of level of effort). According to performance criteria, a given
task will not necessarily lead to a particular level of performance or workload, because factors
such as S-R compatibility, practice, fatigue, talent, or skill will affect task workload
(Schvaneveldt et al, 2004).

On the theoretical side of the problem, understanding workload relates primarily to
research in attention, processing capacity, dual-task performance, and allocation of mental
resources (Gopher and Donchin, 1986). Assessing workload has involved measuring
performance, subjective impressions of workload, and physiological indicators of work and
stress. It is also important to consider that subjective workload represents the degree to which an
individual experiences workload demands, and this experience itself has potential consequence
for performance and stress levels. It is valuable to measure how much mental effort is
experienced in performing various tasks and to predict when performance will deteriorate due to overload (Schvaneveldt, et al, 2004, Xie and Salvendy, 2000). However, one of the basic problems in studying mental workload is that the behavior is not directly observable; rather, research examines synthetic descriptions of what is the assumed underlying behavior (Bainbridge, 1974).

In 1969, Schvaneveldt demonstrated that performance of relatively simple tasks can be degraded when coupled with complex, independent tasks. In 1991, Mory, Dessouky, Kijowski, and Adapathya, showed that there are clear limits to performance in the context of scheduling multiple tasks. Therefore, there is reason to believe that the requirement to perform multiple tasks is a major contributing factor to performance levels and hence workload (Wickens and Yeh, 1982, and Kantowitz, 1987).

The consequences of task performance over a prolonged period, such as fatigue increment and vigilance decrement, have a complex relationship with task demands, when the demand in primarily mental. In 1988, Jex defined mental workload as, “the operator’s evaluation of attention load margin”. Wickens (1992) wrote that “the concept of workload is fundamentally defined by the relationship between resource supply and task demand”. There are many measures sensitive to mental workload: heart rate variability, event-related potentials (ERP), dual-task methods, SWAT, and NASA-TLX. Europeans define mental workload in terms of mental fatigue, monotony, reduced vigilance, and mental satiation (International Standardization Organization, 1991). Researchers have found that for mental workload, accumulated size of the effort might not correspond to the measured size of momentary workload (Haga, et al 2002).
Some of the factors that can impact mental workload include: 1) skill of the operator; 2) training; 3) operating procedures; 4) operating conditions; 5) staffing levels and competence; 6) task allocations; 7) job task demands; 8) organizational expectations; 9) task complexity; and 10) work pace (Ridley, 2004, Cuevas, 2003, Kantowitz, 1987, and Bainbridge, 1974). Task details and workplace design can constrain the operating strategy used and the capacity for processing individual operation. The operator’s basic capacity for performance (i.e. speed and accuracy trade-off) can be affected by the level of task demands. A suggested method to determine task difficulty is to count the number of operations in a strategy and add the number of items of work storage required, while ignoring the time for individual operations (Bainbridge, 1974).

Task complexity is used to describe any modification of an experimental task that either increases the time required to perform a task or decreases the accuracy or efficiency of task performance (Kantowitz, 1987). Increasing task complexity that requires no space capacity should reflect no increase in mental load. However, increasing task difficulty always increases mental workload, thus requiring additional mental capacity (Kantowitz, 1987).

Human performance in a system can be divided into four major categories or activities: perceptual, mediational, communication, and motor. The first three categories play a major role in automated systems. Mediation includes such activities as logic, reasoning, decision making, and judgment.

There are three principle methods available to measure mental workload capacity: subjective ratings, objective secondary task techniques, and bio-cybernetic indices (psychophysiological methods). Psychophysiological assessment methods measure changes in the operator’s physiology that are associated with cognitive demands. These include heart rate, oxygen consumption, on-going EEG, and evoked potentials. Even though efforts have been
made to develop objective measures of workload, subjective workload assessment techniques continue to be popular due to their ease of use, general non-intrusiveness, low cost, high-face validity and known sensitivity to workload variations (Moray, 1998).

Heart rate variability is the most common physiological measure taken. It is usually found to decrease as load increases, particularly that variability which cycles with a period around 10 seconds (Mulder and Mulder, 1981). Pupil diameter has been found to correlate quite closely with the resource demand of a large number of diverse cognitive activities, including mental arithmetic, short-term memory load, traffic control monitoring (Jorna, 1997), and logic problem solving. As well as pupil diameter, the direction of pupil gaze can contribute to workload modeling. Dwell time can also serve as an index of the resource required for information extraction from a single source (for example, in information-rich systems) (Wickens, 2000). Yeh and Wickens, 1988, concluded that a very strong influence on subjective workload is exerted by the number of task that must be performed at once.

2.3.1 Techniques and Methods for Assessment

Research on mental workload can be divided into three different contexts: workload prediction, the assessment of workload that is imposed by equipment, and the assessment of workload experienced by the human operator. When workload experienced by an operator is evaluated, it is for the purposes of choosing between operators or to provide further testing. To assess operator differences, the level of skill or automation achieved by different operators in their primary task performance can be compared. Additionally, operators can be monitored online in a real-task environment by using intelligent computer based systems. However, primary task measures should always be examined first. Computer data entry speed, learning
comprehension with a particular method of instruction, or deviation from the center of a lane while driving are tasks that are often used to evaluate mental workload.

There are drawbacks to only measuring primary tasks. These include an inability to obtain good measures (for example, with decision making), the fact that tasks might lie in the under-load area of the supply demand space, and the fact that two primary tasks might differ in their performance, not by the resource demanded to achieve that performance but by the differences in data limitation. Therefore, secondary task performance (such as rhythmic tapping, time production, and time estimation), physiological measures (such as heart rate variability, pupil diameter, and visual scanning), and subjective measures are also used to measure workload.

Subjective ratings have dominated the field of workload investigation because of the ease of obtaining data, the minimal disruptions of primary task performance, and minimal equipment requirements. Some common subjective tools are the Cooper-Harper Scale, SWAT, and NASA TLX.

The secondary-task paradigm attempts to obtain direct estimates of spare capacity by requiring additional tasks to be performed in concert with the primary task of interest. The major advantage is objectivity and the availability of theoretical models for attention. Techniques for assessing subjective workload fall into either rating scales procedures or psychometric techniques, involving procedures such as magnitude estimation, paired comparisons, or conjoint measurements and scaling.

The sequential reaction-time tasks provide an interesting dual task with tracking because SRT can be manipulated in structural complexity. It has been known for some time that people are sensitive to the sequential order of events in reaction-time tasks (Schvaneveldt and Chase,
Hyman showed that reaction time varies with the probability of events when overall or sequential probability is manipulated.

In 1989, Linton classified the methods of mental workload assessment into two categories, empirical methods and analytic methods. Empirical methods encompass operator opinion, primary task, secondary task, and physiological techniques. The analytic methods are designed to be both predictive and evaluative. These areas can be subdivided into five categories: 1) comparison, 2) expert opinion, 3) mathematical models, 4) task analysis, and 5) computer simulations. These categories can be grouped into two larger classifications: projective techniques and task-analytic techniques.

Bio-cybernetic indices of mental workload include heart rate, pulse wave, skin temperature, electromyograms, evoked potentials, magnetic-evoked potentials, and pupil diameter. Another possible measurement is primary task performance, with decrements indicating increased mental workload (Kantowitz, 1987). Some of the physiological measures that have been used over the years to determine workload changes include respiration rate, heart rate mean and standard deviations, eye blinks, and fixation fraction. Eye blink and fixation fraction have found to be sensitive to mediational load when studied in simulated military environments (Weirwille, et al 1985).

Timesharing, which is the ability to utilize information obtained by shifting between two or more channels of information, has also been demonstrated to have an effect on workload demands. Perceptual speed has also been shown to result in performance deterioration in vigilance tasks. Researchers have observed that, as time passes, the ability to detect signals correctly decreases. However, Levine observed that performance deteriorates up to a certain
point in time; but when a task requires selective attention or timesharing, performance increases (Levine, et al, 1973).

Heart rate has been reported to vary as mental workload increases. The beat-to-beat variability of the heart rhythm has been used to measure mental effort and is reported to decrease with increases in mental demands in changing environments. Respiration measures have also been applied to the work environment. Respiration is reported to change with differing levels of mental effort. Several investigators have also reported reductions in blink rates in visually demanding situations.

Blink rate has also been shown to decrease significantly as tasks become more difficult. The beat-to-beat variability of the heart rhythm has been used to measure mental effort and is reported to decrease with increases in mental demands in changing environments. Because blink rate and respiration can be recorded continuously and are non-intrusive, they can be used as online monitors of cognitive demands during normal working conditions without interfering with the primary task (Brookings, J, 1996).

Baron and Corker, 1989, have conducted extensive research in applying control theory models to estimate workload. To estimate human workload, a system variable must be defined as an indicator of human workload (for example, the presence of lags, delays, or instabilities). This application has generally been restricted to environments involving continuous controlling tasks (Xie and Salvendy, 2000).

Task-analysis methods are most often used for estimating workload in the preliminary design process. Workload task-analysis methods usually examine operator performance requirements as a function of time within the context of a specific scenario. A relatively new technique is the task analysis/workload methodology developed by Hamilton and Bierbaum.
Other developed techniques used to predict mental workload in multiple environments are the workload model (VCAP by Aldrick, Szabo, and Bierbaum, 1989) and workload index (W/Index by North and Riley, 1989). Each of these models assumes that parallel processing can occur.

Sarno and Wickens developed a hybrid model from these three models using the “optimal” assumption concerning the five timesharing issues. To apply these models, a detailed knowledge of the task sequence and time requirements of each component is required (Xie and Salvendy, 2000).

Mental workload measures have been compared mostly in terms of their sensitivity. Weirwille and Connor define sensitivity as the ability to discriminate between different load conditions. Research has demonstrated that combining information processing and perceptual control theory models provide the greatest promise for estimating operator loading (Hendy, Farrel, East, 2001). The combined model integrates knowledge about operator workload, performance, and error production with situational awareness. The model suggests that the underlying stressor that determines operator performance, error production, and workload perception is time pressure.

The information processing load of any human activity can be characterized in terms of the amount of uncertainty to be resolved and the number of bits of information (Sanders, 1979 & Miller, 1971). The amount of information to be processed is a function of the strategies chosen by the human in formulating a solution. The essential claims of the IP model stem from two equations:

\[
\text{Task Load} \div \text{Processing Rate} = \text{Decision Time}
\]

\[
\text{Decision Time} \div \text{Time Available} = \text{Time Pressure}
\]
Experiments have shown using the IP/PRT models are associated with the limited capacity of the human processing structure. The model has been validated in network simulations, human-machine-human interactions, aviation, and team performance experiments.

Within Human Factors, the validity of TLX workload measurement scales is well established and validated. These scales do not include a range of factors that are either components or moderators of the overall workload of a job, such as various types of control and support, lack of role clarity, and job insecurity. Additionally, TLX does not adequately assess the affective states that are associated with the experience of workload. Therefore, the wider use of objective measures of work demands and other stressors are recommended to complement the self-reporting methods (MacDonald, 2003).

### 2.3.2 Tools for measurement

Tools for measuring mental workload vary from continuous to discrete scales with varying sensitivity. NASA-TLX is a multidimensional scale, for which the overall mental workload is described as a function of mental demand, physical demand, temporal demand, performance, effort, and frustration dimensions within a continuum. SWAT is also a multidimensional scale, but its dimensions of time load (T), mental effort lead (E), and psychological stress load (S) are at three discrete levels. NASA-TLX is superior to SWAT in terms of sensitivity, especially for low mental workloads.

In a comparison study between SWAT, NASA-TLX, and six derivations of SWAT, it was found that ASWAT with continuous dimensions has the highest sensitivity. The DSWAT scale is not as sensitive as the continuous scale; but it has some advantage because of the interval
property in the scale as a result of conjoint scaling. Furthermore, the sensitivity of the $D_{SWAT}$ scale could be improved by increasing the number of levels in each of the SWAT dimensions.

A piece-wise comparison (PWC) procedure takes significantly less time than the card sorting procedure. The card sorting procedure requires more decisions to be made than the PWC procedure; hence it is more error prone. However, the card sorting procedure can be used in the development of individual workload scales. In general, the studies found that with increasingly difficult tasks, the participant’s estimate of the mental workload increased, requiring a continuous scale of estimation (for example, with arithmetic tasks). The ranking of the SWAT scales in terms of sensitivity from least to most sensitive were: SWAT, $D_{SWAT}$, $W_o$, $W_1$, $Pc$, and $A_{SWAT}$ (Luximon and Goonetilleke, 2001). The experiment used simple arithmetic to determine the differences among the variations of the SWAT scales.

The ANAM Readiness Evaluation (ARES) system is a battery of tests that include simple reaction time, logical reasoning, match to sample, and a six-item Sternberg memory task to determine workload. ARES is a selection of Automated Neuropsychological Assessment Metric tasks and has been used in military applications to detect workload changes (Harris and Hancock, 2003).

Boeing’s maintenance error decision aid (MEDA) has more than 70 listed contributing factors, including fatigue, inadequate knowledge, and time constraints, to determine mental workload (Rankin and Allen, 1996). Use of MEDA has been limited to Boeing-applicable work.

The Multi-descriptor scale examines attentional demand, error level, difficulty, task complexity, mental work, and stress level as factors affecting workload demands (Weirwille, et al 1985). The scale was proven to be sensitive to mediational loading when used in airplane simulators.
Job Content Questionnaire (JCQ) has been seen as the most comprehensive tool to capture job demands subjectively. Cox and his co-workers have included various types of job demands within the standard set of psychosocial hazards of work, which include work overload or under load, time pressure, high work pace, short work cycle, and high level of uncertainty.

Another, recently developed, scale is the Pressure Management Indicator. William and Cooper (1998) indicated other sources of pressure that included home-work balance, managerial role, daily problems, personal responsibility, organizational climate, relationships, and level of recognition (MacDonald, 2003).

The Job Stress Survey examines job pressure items including meeting deadlines, frequent interruptions, excessive paperwork, frequent changes, critical on-the-spot decision, being assigned increased responsibility, and insufficient personal time as contributors to increased workload among teachers, police, and fireman. Carayon and Zijlstra showed that when the effects of different levels of control are analyzed independently, higher levels of instrumental control (amount and rate of work) are related to lower levels of work pressure, whereas higher levels of decision control (influence over organizational processes) are related to higher work pressure.

Most of the models available are descriptive and cannot be used to predict mental workload. Not all the models consider multi-task situations or model individual factors. Additionally, many of the models have only been validated on airline pilots and therefore have limited applicability to other industries.
2.3.3 Current Studies on Mental Workload

In a study by Haga to determine the affects of task difficulty and time-on-task on mental workload, it was found that memory task performance mean reaction time increased as time-on-task became longer in second-order (acceleration) control conditions. When tracking became more difficult, the weighted workload (WWL) score for the task became higher; WWL scores for memory task were not affected by the difficulty of the primary task simultaneously performed or by time-on-task; and fatigue scores increased as a function of blocks under any of the difficult conditions.

The study concluded that WWL scores of NASA-TLX and ERP evoked by secondary task stimuli were sensitive only to the factor of task difficulty and would not be affected by time-on-task. However, mean heart rate dropped and fatigue ratings on the CLMC scales rose as a function of time-on-task (Haga, et al 2002).

Schvaneveldt and Gomez and Reid conducted a study investigating models for monitoring and predicting subjective workload in the control of complex systems. Three different tasks were used to predict mental workload: 1) a continuous tracking task with a random forcing function and three different updating speeds; b) a discrete tracking task, in which response keys were pressed to indicate the position of a target in one of four different locations; and c) a tone-counting task which required the number of high pitched tones in a series of tones of 800 to 1200 Hz. The average accuracy from an individual subject model was better than that obtained with group data. This suggested that individual models are a more promising direction to pursue. The study recommended adding physiological measures collected during the performance of a task to assist in predicting workload.
To determine the mental workload of pilots, Wierwille conducted an evaluation of 16 measures of mental workload using a simulated flight task emphasizing mediational activity. He used respiration rate captured by a proximity transducer, heart rate mean and standard deviation captured by a plethysmography system, pupil diameter captured by CCTV, and eye blinks captured with CCTV along with fixation fracture. The primary task was to maintain straight and level flight combinations. Results showed only eye blink and fixation fracture measure were reliable in determining mediational load. Differences between low and high, as well as medium and high, load levels could be detected. Mediational reaction time, the time from problem presentation to correct response, showed great sensitivity. Also, secondary tasks, physiological, and primary tasks all produced changes in workload as a function of loading.

A study focusing on impairments of manual tracking performance during space-flight analyzed the performance decrement seen during a mission. The performance functions that were assessed included basic and complex cognitive processes involving working-memory or spatial process and higher-attention functioning in space flights.

On a MIR flight, it was noted that no impairments of speed or accuracy were found in single-task memory-search or grammatical reasoning. However, clear disturbances of step tracking were reflected in a slowing of movement time across different input devices. These tasks were very similar to those of Manzey’s study that found significant disturbances in critical tracking performance in two astronauts. The astronauts showed impairments in dual-task performance and in an attention-switching task. The dual-task performance decrements observed in space may be attributed to attention selectivity and narrowing affects, that is, a reduced capacity to divide attention between concurrent stimuli, tasks, or task goals (Manzey, et al 2000).
Benke assessed the performance of one cosmonaut in several cognitive tasks three times during a six-day mission to the MIR space station. The performance tasks used included a simple-reaction time task, a choice-reaction time task, a Stroop-like interference task, a spatial memory task, and a spatial perception task. Comparing in-flight performance with pre- and post-flight performance, none of the tasks revealed significant performance decrements during the stay in space (Benke, 1993). However, in 1997, Lathan and Newman did not find any impairments of memory search performance. They did find clear disruptions of tracking movements reflected in increased movement tones across all input devices.

Performance assessments were conducted by applying batteries of performance tasks, based on theoretical models of information processing and demonstrated to react sensitively to environmental stressors. The performance functions assessed included elementary and complex cognitive processes involving working memory (for example, choice-reaction time, memory-search, logical reasoning, or mathematical processing) or special processing (such as mental rotation and spatial memory), perceptual motor function (such as tracking) and/or high attentional function (including attention switching and dual-task performance).

In order to probe elementary cognitive functions (logical reasoning and memory retrieval), perceptual-motor functions, and higher-attention functions, a subset of four tasks were selected: 1) grammatical reasoning, 2) memory search, 3) unstable tracking, and 4) dual-task, consisting of unstable tracking with concurrent memory-search. Obvious disturbances of fine manual control movements emerged in the unstable tracking task.

During pre-flight operations, it was found that significant impairments of elementary cognitive functions, assessed by the grammatical reasoning task, were found only during the three days prior to launch. Impairments of dual-task performance were observed only during
some single experimental sessions. Although this did not confirm the far more pronounced impairments found during short-term flights, it was striking to find that these dual-task affects, if any, also occurred during the two weeks in space and after the return to Earth.

Despite a comparatively small number of studies, a fairly consistent pattern of effects can be derived: whereas no or only slight impairment of elementary and complex cognitive functions or spatial processing was detected in space, clear disturbances could be identified in visio-motor tracing and dual-task performance.

A linear function to represent human behavior in a first-order compensatory tracking task, such as the one used in the above study by Manzet, is described by a two-parameter function that takes the form \( u(t)=K_se(t-\tau_e) \).

In this function, \( u(t) \) represents the human output at time \( t \), \( e(t-\tau_e) \) represents the tracking error displayed to the subject \( \tau_e \) seconds before, and \( K_s \) represents the human’s tracking gain. The parameter \( \tau_e \) represents the time-lag between a displayed tracking error and the initiation of a corrective response and is referred to as effective time-delay. This time-delay can be regarded as an indicator of the speed of visio-motor transformations that are needed to transform the displayed tracking signal into appropriate corrective movement of the input device. According to Wickens (1976), it appears to reflect a functional processing limitation given by the internal processing time, and is always maintained at some minimum value in order to activate maximal tracking performance.

According to Wickens, 1976, and Wickens and Gopher, 1977, the most consistent finding is that reduced attention resources and decreased effort during tracking are reflected in reduction of tracking gain, that is, reduction of amplitude of corrective movements, and/or increase of the remnant. It can be expected that tracking decrements due to workload and/or attention-related
effects are associated with a decreased tracking gain and/or an increase in remnant, and that increase of effective time delay under these conditions is less likely to occur.

In 2003, Hobbs and Williamson examined the association between errors and contributing factors in aircraft maintenance. Their study found that each type of error was associated with a particular set of contributing factors and with specific occurrence outcomes. Among the associations were links between memory lapses and fatigue and between rule violations and time pressure.

Maintenance workers routinely contend with inadequately-designed documentation, time pressures, shift work, and environmental extremes (International Civil Aviation Organization, 1995). In a 1995 study, Hobbs and Williamson conducted critical incident interviews with airline maintenance personnel and found that error factors included technical problems, communication breakdowns, inadequate supervision, and the physical environment. Predmore and Werner (1997), also asked senior airline mechanics to identify the challenges of their jobs, and found the most common answers provided concerned dealing with people and time pressures.

Major problems of performance monitoring studies concern small sample sizes, the ability to generalize results, and the explanation of effects. However, in contrast to other experiments, performance-monitoring approaches provide the advantage of a number of repeated measurements, which enable an application of statistical single-subject methods with comparatively high statistical power. Also of concern is the identification of the specific causes for the performance effects found in the different studies (Manzey, 1998).

The mathematical and psychological models that have been developed to describe human tracking behavior, such as the quasi-linear cross-over model or the optimal control model, are
well-validated and provide a sound theoretical basis for modeling and predicting human performance in manual control. In order to obtain a clearer picture of possible changes of cognitive and attention processes in space, analyses of cognitive task performance should be enriched by analyses of accompanying changes in brain electrical activity (Manzey, 1998 and 2000).

The approach most often taken to dual-task manipulation of workload is to assess the effect of a secondary task, such as Sternberg memory-scanning tasks, or scheduling tasks on a continuous primary task. One difficulty with this approach is that there is no way of verifying that subjects will treat the primary task as primary and the secondary task as secondary.

In contrast to a rule-based model, neural networks compute by using interconnected networks of simple contrasting units. These simple units receive information from external sources, sum this information, and then propagate an activation level to all connected nodes. Perhaps the crux of neural network modeling is the application of appropriate learning algorithms in approaching processing network topologies such that a set of connection weights is found that lead to desired performance. Hebbian contiguity or association rule states that, if two simple processors are simultaneously active and are connected, then the relationship between them should be strengthened.

Learning with hidden layers requires using back propagation to modify the weights in the network. Back propagation is termed a gradient-descent method, in that the learning algorithm is reducing the measure of error for every weight in the network. Just as with any gradient-descent method, the back propagation procedure is subject to becoming trapped in a local minimum and consequently failing to find the best solution for a problem.
The relationship between personality and fatigue has suggested a positive relationship between fatigue and neuroticism, including emotional exhaustion, and a negative association between extraversion and fatigue (De Vries, et al 2002). Early studies have shown that extraversion, agreeableness, and emotional stability are negatively correlated to fatigue. To determine if this relationship is true, a study by De Vries used the Checklist Individual Strength-20 and the Emotional Exhaustion (EE) scale to examine fatigue.

The CIS-20 measures four aspects of fatigue: subjective experience of fatigue, reduction in concentration (objective), reduction in motivation, and physical activity level (objective). The EE scale consists of five items that measure the case aspect of burnout: emotional exhaustion. The study found that extraversion, autonomy, and emotional stability are firmly related to fatigue. Conscientiousness was shown to be negatively correlated to fatigue (De Vries, 2002).

2.3.4 Summary of Workload

The primary dependent measures that were considered include task complexity, job demand, completion time, number of problem, and type of problems. Changes in heart rate were captured on a continuous basis using a heart rate monitor. Subjective measures that were used included NASA TLX, which has been validated and accepted as a standard tool for collecting subjective measures of workload.

2.4 Fuzzy Set Theory

In mathematical modeling, researchers anticipate that the data results will be non-redundant and unambiguous. Additionally, the model should include all terms that are important and relevant. This is a problem because human thinking and feeling has more concepts than can
be fully comprehended using everyday language. The use of mathematical representation for modeling purposes is undisputed; however, there are limits to its usefulness. Real situations are not often crisp and deterministic; therefore, they can not be described precisely; and the complete description of a real system often requires more detailed data than a human being could ever recognize and simultaneously process and understand (Schwartz, 1962 and Zimmermann 1991).

Non-controlled environments are often difficult to describe because of the lack of controlled external factors or unknown future states. This uncertainty has been handled by probability theory and statistics. Kolmogoroff-type probability and Koopman’s probability assume that the events are well defined. However, fuzziness is found in human judgment, evaluation, and decision. This is due partly to our communication taking place using language and words that can have vague or differing meanings depending on the concept. Occasionally, concepts are fuzzy because a description requires a large number of descriptors. Additionally, traditional modeling requires quantitative data rather than qualitative data for model inputs. Section 3.4.4 will discuss how Fuzzy Set Theory (FST) was used to covert qualitative date into quantitative data that could be used for modeling purposes.

One of the important traditional theories describing the phenomenon of uncertainty is probability theory. However, this view is ill-conceived because probability and fuzzy set describe different kinds of uncertainty. Probability theory deals with the expectation of future events, based on something known. Additionally, probability theory is concerned with the likelihood of events. FST, on the other hand, is not concerned with events at all. Rather, it is concerned with concepts and whether or not an individual matches the meaning of the concept in question (Klir, G. J et al 1997).
FST provides, “a convenient point of departure for the construction of a conceptual framework, which parallels in many respects the framework used in the case of ordinary sets, but is more general,” and proves to be more useful in the fields of pattern classification and information processing (Zadeh, 1965). Fuzzy logic was developed for problems that have components without smooth boundaries or that have imprecise or contain vague information. FST is not restricted by binary membership, but rather enables membership to be defined over an interval [0, 1]. The membership functions are characteristics of the data being analyzed and can take on many geometrical forms, such as S, pi, trapezoidal, triangular, or wedge shapes. The selection of shape is dependent on the characteristics of the data (Crumpton-Young, Mc-Caulley-Bell et al, 1996). Essentially, FST provides a framework for dealing with problems in which the source of imprecision is the absence of sharply defined criteria of class membership rather than the presence of random variables. FST provides a strict mathematical framework through which vague conceptual phenomena can be precisely studied (Zimmermann, 1991).

FST is based on the idea that variables have varying levels of influence on the components. The dichotomous nature of conventional logic is inadequate in representing the stages that a person undergoes as they transition from a state with no performance decrements to a performance decrement. However, the multivariate property of FST enables representation of a decrement as it develops (McCauley-Bell et al 1996). In traditional modeling techniques, a variables is designated with a zero value if it is deemed not significant, and designated with a value of one if significant. FST uses an interval to grade the variables membership. This enables variables that are deemed insignificant with traditional techniques to be included in the model.
FST is also used for solving problems that have imprecise data or uncontrollable data, such as human tasks or variations in job task performance. Additionally, FST is used for problems where there is a possibility of response, as in the case of a participant’s style of communication. FST can therefore be used to predict the presence or absence of a component such as fatigue.

FST is suitable for expressing ambiguity of meaning found in natural language. When discussing FST, there are two categories to consider: set models and fuzziness. In ordinary sets, sets are groups made from the constants, variables, and function of the object system. The expressions are macroscopic and more ambiguous then models that are not based on groupings. “The conversion to fuzzy sets is performed by gradation of the boundaries of the states, relationships, constraints, and goals of the system made with ordinary sets” (Terrano, et al, 1992). The unnaturalness of dividing the meanings of natural language and the truth of propositions into two values is canceled when using fuzziness.

There are two methods for developing fuzzy models: the law of cause and effect and transitions. The law of cause and effect makes use of the laws for operations with sets, so the rules for reasoning and composition express the relationship among the variables expressed in the sets. Transition uses ordinary equations to express cause-and-effect relationships, and fuzzy sets are used for the variables. In this case, the meaning of the model is clear; therefore, the results of the conversion to fuzzy sets are easy to explain.
CHAPTER THREE: METHODOLOGY

3.1 Research Approach

The research approach discussed in the following paragraphs and depicted in Figure 4 was utilized to accomplish the stated aims of the proposed research effort. This research approach enabled the development of a fuzzy set model that will help to predict, prevent, control, and mitigate the occurrence of task demands that negatively influence human performance. The fuzzy set model index developed consists of three indices: stress, fatigue, and workload.

Figure 4: Modeling Method

The model depicts the approach taken and the methodology used to determine how the combined affects of stress, fatigue, and workload impact human performance.

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3.2 Participants

Twenty-five participants were selected from the operations centers of NASA. Participants’ jobs required involvement in launch simulation activities in a control room. Sixty-four percent of the participants were male. Ninety percent of the participants were government employees. All participants held a bachelor degree, and over half of the participants held a masters degree. The participants ranged in age from 20 to 54 years.

The participants were recruited using a letter distributed to management. Managers were initially contacted by the principle investigator, who described the study and the purpose of the research. When potential participants were identified, they were provided with additional information about the study. Each participant was provided with two written informed consent forms (UCF and NASA IRB forms) prior to participating in the experiment. (The consent forms are shown in Appendix A.)

To participate in the study, subjects were required to have a level 1 engineering certification and to have completed basic console certification. These pre-requisites are necessary for an engineer to write work steps and participate in simulations. The certifications include single-system knowledge proficiency, basic procedure and documentation information retrieval and writing, and basic system integration knowledge.

Subject Matter Experts (SMEs) were recruited for the study. The role of the SMEs was to help identify pertinent factors to this study of stress, fatigue and workload and to determine relative variable weight. The individuals chosen have domain knowledge in fatigue, stress, and workload. One SME has a doctorate in a Human Factors (HF) and teaches human factors and ergonomics at a renowned university. Another has a doctorate in Human Factors Psychology,
and teaches human factors (and is seen as a NASA agency expert in human factors). The SMEs also included a team of human factors experts from the aerospace industry.

### 3.3 Apparatus

Participants donned a Polar S610i heart rate monitor to continuously collect heart rate data. Participants blood pressure readings were taken using an OMRON oscillometric digital blood pressure monitor (model HEM-815 F). Environmental measures such as lighting and noise levels were taken using Extech Instruments Noise Dosimeter (model 407354) and Extech Instruments Easy View Light Meter (model EA31).

### 3.4 Experimental Task

#### 3.4.1 Experiment Variables

Data on Twenty-one independent variables was collected in the study. A summary of the variables used in the study is located in Table 1. Five of the independent variables, lack of motivation, sleepiness, physical discomfort, physical exertion, lack of energy are sub-components of the Swedish Occupational Fatigue Inventory (SOFI) survey that was completed by each participant pre- and post-simulation. SOFI was developed to measure fatigue in five dimensions. It obtains measurement of mental and physical fatigue and level of sleepiness. Participants answered questions spontaneously and marked the number that corresponded to how they felt at the time of the survey. The numbers varied between 0 (not
at all) and 6 (to a very high degree). The questions below represent a subset of the entire survey, which can be found in Appendix B.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>High degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 2 3 4 5 6</td>
<td></td>
</tr>
<tr>
<td>Palpitations</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Lack of concern</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Worn out</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Tense muscles</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Falling asleep</td>
<td>0 1 2 3 4 5 6</td>
</tr>
</tbody>
</table>

Figure 5: Example of SOFI Questions

Six of the independent variables: mental demand, physical demand, temporal demand, effort, performance, and frustration are sub-components from the NASA TLX survey, which was completed by each participant pre- and post-simulation. NASA TLX is an empirical and multi-criteria self-assessment technique based on the weighted sum of the scores obtained for the different criteria. Sample questions that participants completed included:

- The factor that represents the more important contributor to workload for the task is: Mental Demand or Effort
- The factor that represents the more important contributor to workload for the task is: Effort or Performance

The NASA TLX survey in its entirety can be found in Appendix B.

Heart rate was collected on a continuous basis during the simulation exercises. Heart rate data collection began on each participant as soon as they were at their work station. Recording stopped after the final de-brief session of the simulation. Blood pressure readings were also
taken after the simulation period. A baseline blood pressure reading was provided to the principle investigator by the participant on the post simulation survey.

Two pre-test surveys were given to participants to capture job satisfaction and demographic information. The job satisfaction survey captured a participant’s level of satisfaction with their current position. Participants rated their agreement with questions posed using the 5-point Likert scale (i.e. strongly disagree to strongly agree)

Sample questions participants answered included:

- I am satisfied with how often I analyze data.
- I am satisfied with how often I learn new information.

After the simulation, participants were asked to complete a final survey that asked the participants what they felt about the merit of the simulation run.

Table 1: Independent Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Collection Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of Motivation</td>
<td>SOFI</td>
</tr>
<tr>
<td>Sleepiness</td>
<td>SOFI</td>
</tr>
<tr>
<td>Physical Discomfort</td>
<td>SOFI</td>
</tr>
<tr>
<td>Physical Exertion</td>
<td>SOFI</td>
</tr>
<tr>
<td>Lack of Energy</td>
<td>SOFI</td>
</tr>
<tr>
<td>Mental Demand</td>
<td>NASA TLX</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>NASA TLX</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>NASA TLX</td>
</tr>
<tr>
<td>Effort</td>
<td>NASA TLX</td>
</tr>
<tr>
<td>Performance</td>
<td>NASA TLX</td>
</tr>
<tr>
<td>Frustration</td>
<td>NASA TLX</td>
</tr>
<tr>
<td>Physical Fatigue</td>
<td>Yoshitake Type I and II Fatigue</td>
</tr>
<tr>
<td>Mental Fatigue</td>
<td>Yoshitake Type I and II Fatigue</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>Polar Heart Rate Monitor</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>Blood Pressure Monitor</td>
</tr>
<tr>
<td>Job Satisfaction</td>
<td>J.S. Survey</td>
</tr>
<tr>
<td>Repeated Performance</td>
<td>Post Simulation Survey</td>
</tr>
<tr>
<td>Problem Identification</td>
<td>Post Simulation Survey</td>
</tr>
<tr>
<td>Problem Resolution</td>
<td>Post Simulation Survey</td>
</tr>
<tr>
<td>Effective Communication</td>
<td>Post Simulation Survey</td>
</tr>
</tbody>
</table>
3.4.2 Field Experiment

The experiment was conducted in a control room in which simulation and launch operations are routinely performed. The tasks observed included a launch countdown, rendezvous on orbit with ISS, and assent and re-entry of the Space Shuttle. Operations varied depending on simulation schedule and availability of participants. Tasks observed were those completed during the simulation exercise.

All participants were classified into one of the following task groups based on job responsibilities: 1) Engineering Task Leader (ETL); 2) Subsystem Engineer (SSE); 3) System Engineer (SE) and 4) Prime System Engineer (PSE).

3.5 Procedures

One week prior to a participant’s assigned simulation run, subjects were introduced to the study and the equipment to be used in the experiment. During this period, participants were given the pre-test questionnaires, a detailed description of the experiment, and consent forms to read and complete. Additionally, participants were able to contact the principle investigator to discuss questions or concerns regarding the study or equipment. The participants were informed that the purpose of the study was to understand the impact of fatigue, stress, and workload on performance in a control room setting. It was also explained to each participant that the method of data collection was to observe the participant performing normally-assigned work tasks in a simulation, and that the data collected would be confidential and not linked to their name. In addition, the participants were informed that the data collection tools would not increase the risk level of the task (that is, they would not increase workload, cause computer glitches due to
electromagnetic interference, or cause other problems). Most importantly, all participants were informed that they were free to terminate the observational analysis at any time.

The day prior to the simulation, the participant was provided with a heart rate monitor and instructions about how to operate the monitor. If the participant required further assistance, the principle investigator or the manufacturer was contacted. Additionally, the participant provided the principle investigator with a base line blood pressure reading.

On the day of the simulation, the participant was contacted by the principle investigator to check whether any further questions had arisen with regard to the equipment or experiment. The participant was provided with a contact number where the principle investigator could be reached during the simulation. Prior to the start of the simulation, the participant donned the heart rate monitor. A final check was performed to verify data was being collected at the correct rate and that no unexpected interference with equipment had arisen.

During the simulation, the principle investigator gathered information about the type of problem, problem resolution plan, completion time, effectiveness of communication, and how decisions were made when a participant resolved a problem. Information regarding the problems inputted into the simulation was captured from discussion with the simulation team, and saved for further analysis. Additionally, the simulation supervisory team provided problem information to the principle investigator to aid in analysis. Debrief information by the simulation team was also captured.

After a participant completed a simulation run, he or she returned the heart rate monitor to the principle investigator and had a blood pressure reading taken. Because of locality differences, the participants were given three post-simulation surveys to complete and return within two weeks to the principle investigator.
All data collected was stored with a unique identification number for each participant. Raw data and data collection forms were scanned and saved to a memory stick that was stored in a secure location. The original data collection forms were destroyed.

3.6 Study Design

The methodology consisted of analyzing a data set for the development of a fuzzy model to quantify the impact of stress, fatigue, and workload on human performance. The data set was broken into two sets. Of the data, 70 percent was used for model development. The remaining 30 percent was used for model validation.

3.6.1 SME Analysis

The stages in developing a Linguistic Risk level and associated membership functions needed for Fuzzy Set Theory (FST) application for the combined effect of fatigue, stress and workload included the following:

3.6.1.1 Knowledge Acquisition

3.6.1.2 Application of FST

3.6.1.1 Knowledge Acquisition

The first step in developing a valid, accurate, and reliable model for describing how stress, workload, and fatigue impact on human performance was to determine which factors within each component were relevant to the research area. An in-depth literature review was performed to identify factors associated stress, fatigue, and workload in task demanding
environment. The results of the literature review suggested two prominent categories within each primary factor to be studied: subjective (quality of supervision, room temperature, or discomfort) and objective (such as heart rate, skin temperature, or blink rate). Secondary factors were identified as either being quantitative (such as number of problems, hours on console, and number of cups of coffee or caffeine in a given time) or qualitative (including sleepiness, lack of energy, or lack of motivation). The identified secondary factors were reviewed and placed into the appropriate secondary categories. Questionnaires used in the study were modified based on the factors that could be captured.

The variables to consider for inclusion in the model were gathered from the literature. Emphasis was placed on identifying both subjective and objective measures for each factor. Each identified variable was reviewed to determine if the variable could be controlled occupationally. Additionally, SMEs were consulted to verify that the variables identified through the literature encompassed each aspect of fatigue, stress, and workload. The SMEs were asked to compare those factors that were shown to be significant from the regression analysis.

Having the ability to control a variable occupationally was imperative to developing a model that managers could use in regular work situations. Most models currently available require data to be collected in laboratory settings (such as sleep deprivation data) or require extensive medical equipment to gather the data (for example, EKG data). Equipment used to capture the data was subjected to electromagnetic interference testing because of the sensitive nature of the console equipment and the age of the hardware.

Interviews with simulation development personnel were conducted to determine which variables from those identified from the literature were already captured in current performance reviews and which factors could be added to provide greater insight for the simulation participant.
or simulation development personnel. Additionally, further refinements of variables to be collected were identified or variables were removed based on the results of interviews.

Table 2: Variables used for AHP Comparison

<table>
<thead>
<tr>
<th>Stress</th>
<th>Fatigue</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion Time</td>
<td>Completion Time</td>
<td>Completion Time</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>Heart Rate</td>
<td>Heart Rate</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>Blood Pressure</td>
<td>Blood Pressure</td>
</tr>
<tr>
<td>Number of Problems</td>
<td>Number of Problems</td>
<td>Number of Problems</td>
</tr>
<tr>
<td>Hours on Console</td>
<td>Hours on Console</td>
<td>Hours on Console</td>
</tr>
<tr>
<td>Years of Experience</td>
<td>Years of Experience</td>
<td>Years of Experience</td>
</tr>
<tr>
<td>Effort</td>
<td>Mental Fatigue</td>
<td>Mental Demand</td>
</tr>
<tr>
<td>Frustration</td>
<td>Physical Fatigue</td>
<td>Physical Demand</td>
</tr>
<tr>
<td>Job Satisfaction</td>
<td>Job Satisfaction</td>
<td>Temporal Demand</td>
</tr>
<tr>
<td>Mental Demand</td>
<td>Lack of Energy</td>
<td>Effort</td>
</tr>
<tr>
<td>Lack of Motivation</td>
<td>Physical Exertion</td>
<td>Frustration</td>
</tr>
<tr>
<td>Discussion Traffic</td>
<td>Physical Discomfort</td>
<td>Performance</td>
</tr>
<tr>
<td></td>
<td>Lack of Motivation</td>
<td>Workload</td>
</tr>
<tr>
<td></td>
<td>Sleepiness</td>
<td>Job Satisfaction</td>
</tr>
<tr>
<td></td>
<td>Type of Job</td>
<td>Type of Job</td>
</tr>
<tr>
<td></td>
<td>Discussion Traffic</td>
<td>Discussion Traffic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Body Fatigue</td>
</tr>
</tbody>
</table>

The SME responses for each factor within a given primary category were weighted by relative importance using the pair-wise comparison algorithm, ranging from very low importance (designated by the value 1) to very high importance (designated by the value 5). The rate of relative importance for each secondary factor was averaged, normalized, and defined as follows, (according to Mc-Cauley-Bell, Crumpton-Young, and Badiru, 1999), where:

Factors within the fatigue category

\[ F_i = \text{factor as determined by the SME}, \]
\[ a_i = \text{relative weights for each factors as determined by the SME}, \]
\[ i = 1, 2, 3, \ldots n \]
Factors within the stress category
\[ S_i = \text{factor as determined by the SME,} \]
where \( i = 1, 2, 3 \ldots n \)
\[ b_i = \text{relative weight for each factor was determined by the SME,} \]
where \( i = 1, 2, 3 \ldots n \)

Factors within the workload category
\[ W_i = \text{factor as determined by the SME,} \]
where \( i = 1, 2, 3 \ldots n \)
\[ c_i = \text{relative weight for each factor was determined by the SME,} \]
where \( i = 1, 2, 3 \ldots n \)

### 3.6.1.2 Role of Stress, Fatigue and Workload

The variables within stress, fatigue, and workload that have an affect on human performance in a control room have been identified through this research. The FAA and nuclear power industry have begun to understand how fatigue, workload, and stress independently affect human performance; however the combined effects had not been studied prior to this research. It is important for all industries with console operations to identify the factors and mitigate the impact.

Ergonomics seeks to understand the human and the task, through assessment and the identification of factors that have an effect on human performance. Until now, there has been no developed mathematical model that identified the factors impacting human performance that could be occupationally controlled.

### 3.6.1.3 Variables to Study

The primary dependent measures that were selected to describe workload included task complexity, job demand, time sharing, heart rate, blood pressure, effort, temporal demand, physical demand, mental demand, level of frustration, number of problems, discussion traffic,
problem identification, decision making, performance, number of hours on console, job satisfaction, and repeated performance. A heart rate monitor captured continuous heart rate data. Blood pressure was measured after each simulation.

Because NASA TLX has been well-validated and accepted by the academic community as a tool to capture workload, NASA TLX was used to assess the change in workload from pre-simulation to post-simulation. The use of both objective and subjective measures provided a more accurate and comprehensive assessment for workload.

The fatigue variables that were considered for inclusion in the model to describe fatigue included age, blood pressure, completion time, decision making, discussion traffic, heart rate, number of hours on console, number of problems, workload, and years of experience. SOFI was also used to assess fatigue levels before and after the simulation. SOFI separates fatigue measurements into five main categories: sleepiness, lack of motivation, lack of physical exertion, lack of physical exertion, and lack of energy. Additionally, the Yoshitake Type I and II fatigue survey was used to help describe a participant's fatigue. Only those variables that were identified as having a significant contribution to the overall affect on fatigue, as determined by the regression analysis, were used in the final model.

Stress factors identified in the literature review that could be controlled occupationally to describe stress included: workload, heart rate, productivity data, job satisfaction, job strain, and job demands. Those variables that were found to be significant contributors to stress were included in the model development.

To determine which factors significantly contributed to describing stress, fatigue, and workload, a regression model was built for each factor, using Minitab. All variables that were identified through the literature review and SME interviews were placed into the regression analysis.
analysis. To determine which variables significantly contributed to the model where the backwards regression method was used where individual factors were removed individually until the mean squared error no longer increased and the Durbin-Watson indicator was less than two.

3.6.2 Developing the Model

Fuzzy Set Theory (FST) was used to develop the quantifiable model to determine if a performance decrement can be predicated because of changes in fatigue, stress, and workload. Traditional modeling techniques attempt to explain or eliminate uncertainty of a system and many methods have been proposed to deal with the approximation concept. These include FST, which characterizes a concept approximately based on membership functions between 0 and 1, the Rough Set Theory, which provides the lower and upper approximations of a concept, and the Bayesian decision theoretic framework, which provides a plausible unification of the fuzzy set and rough set approaches for approximating a concept (Yao, Y.Y and Wong, S. K. M., 1992).

The impact of each of the variables on the system and the interaction between each variable was determined using FST. For each variable, stress, fatigue and workload, individual fuzzy models were developed. Individual factor variable weights were obtained through AHP. The proposed three individual factor models were then aggregated into one final model to describe the combined affect of stress, fatigue and workload.

The model was developed as a function of n factors, and, in generic form, was expressed in the following equation: (The operands within the equation were determined empirically based on the first two steps.)
Fatigue, stress, and workload combined affect

\[ \text{SFWI} = F(a_1x_1 \oplus w_2x_2 \oplus ...w_ix_i) \oplus S(a_1x_1 \oplus w_2x_2 \oplus ...w_ix_i) \oplus W (a_1x_1 \oplus w_2x_2 \oplus ...w_ix_i) \]

Where:

- \( f \)—aggregate factor of stress, fatigue or workload
- \( w_i \)—relative weight of factor \([0, 1]\)
- \( x_i \)—level of factor \( i \) at the time of evaluation \([x_i=0, 1, 2]\)
- \( i \)—is the number of subcomponents considered in this category
- \( \oplus \)—mathematical operation to be determined in previous research step

### 3.6.2.1 Methodology for Determining Variable Weight

One of the main motivators for using FST is to represent imprecise concepts. The degree of membership of an individual variable in a fuzzy set expresses the degree of membership the concept represents in the fuzzy set. The difficulty with constructing the membership function is a problem of knowledge acquisition (Klir, et al, 1997).

Knowledge can be elicited through personal interaction, questionnaires, group interactive sessions, or interviews. The knowledge that is elicited is in terms of propositions expressed in natural language. In the second stage of knowledge gathering, the knowledge engineer attempts to determine the meaning of each linguistic term employed by these prepositions. It is during this second stage that fuzzy set functions and operations on fuzzy sets are constructed.

Fuzzy sets are characterized by functions of the form \([0,1]\). Because an individual variable’s membership in a set is uncertain, its membership is a matter of degree. The degree of membership of an individual in a fuzzy set expresses the degree of compatibility of the individual with the concept represented by the fuzzy set (Klir, et al, 1997).
There are various direct and indirect methods to construct membership functions. Direct methods include experts providing answers to the types of questions that explicitly pertain to the constructed membership function. Indirect methods include asking experts more general questions that are less sensitive to the various biases of subjective judgment, which pertain to the constructed membership function only. With either direct or indirect methods, one or multiple experts can be used to gather the information. In this case, because of the complexity of the research that was conducted, three experts were used to determine the membership functions (Klir, Yuan, 1995; Terano et al 1992).

Other techniques exist to obtain the weighting of factors. These techniques included rating scales and analytic hierarchy processing (AHP). AHP uses pair-wise algorithms to obtain factor weights. Also, AHP takes into consideration all known factors; however, the technique has been criticized because the validity of the relative weights depends upon identification of additional inputs.

During concept mapping, membership functions are developed to represent the Linguistic Risk Level (LRL) of each of the risk factors. In McCauley-Bell’s study, it was found there existed ambiguity and variation across and within the expert analysis of the cut-off points. Therefore, each expert was asked to identify three values: 1) the absolute minimum value for inclusion in the set; 2) the value that was considered to have complete membership in the set; and, 3) the absolute maximum point of membership in the set.

The determination of the values with complete membership in the set was accomplished by taking a weighted average of the value. The purpose of the weighing was to provide the expert whose primary area of expertise was that into which the factor falls with the largest
amount of input in the development of the membership function. The mean value was determined by assigning a weight determined through consultation with the experts.

In an AHP analysis, the rating is used to define the degree of preference of one variable (x) over another (y) (Mc-Cauley-Bell, in Leondes, 1999). A rating of one represents equal importance of the two variables, whereas a rating of nine suggests that X is more important than Y. The inverse of the values can be used if the expert determines that an inverse relationship exists among the variables.

During a concept mapping session, SMEs performed a pair-wise comparison involving all risk factors within each category that were deemed to be significant from the regression analysis. Each SME was asked to make comparisons in their field of expertise. The pair-wise comparisons were used to determine the relative importance of each risk factor. The importance was quantified on a scale (one to nine), showing the strength with which one factor dominated another. Comparisons were made within modules to determine the relationship between the factors.

When the pair-wise matrix was completed, the relative weights were obtained from Expert Choice, an AHP tool. (Mc-Cauley-Bell, in Leondes, 1999). In a study conducted by Relvini in 2003, the relative weight for each factor was determined by the SME, averaged, and then normalized. For each factor, the grade of membership was defined through a review of the literature, and developed with graphical representation. Each factor within the set had an associated value that indicated the degree to which the factor was a member of the set. Research completed by McCauley-Bell and Badiru used knowledge acquisition (preliminary analysis, text analysis, traditional interviews analysis, and concept mapping interviews) to obtain factor
relevance. Clustering was used to detect natural subgroups. The clusters were based on similarities, difference, distance, and other factors. (McCauley-Bell et al. 1996).

After the discussed readings and literature search, the approach used by Relvini and McCauley-Bell to determine factor weights was replicated for use in this research. The methodology used to capture the weights of the factors followed the following process: 1) knowledge acquisition; 2) development of linguistic variables; 3) development of membership functions; and 4) AHP analysis.

### 3.6.2.2 Advantages and Disadvantages of Using Relative Weights

There are various techniques used to obtain the weighting of factors. These techniques include rating scales, AHP, congruency analysis, SME input, neural networks, Bayesian approach, pair-wise comparisons and Response Surface Methodology (RSM).

AHP integrates subjective judgments with numerical data and simplifies a complex problem into simple pair-wise comparisons. The advantages of using AHP are that multiple criteria can be accommodated, AHP is intuitive, and AHP is mathematically rigorous. However, the length of the process increases as the number of levels increases, therefore resulting in the requirement for more pair-wise decisions.

Congruency Analysis is a simple approach, in which research resources are allocated to a particular commodity according to an indicator of importance such as area affected, the value of lost work time, or number of persons affected. The advantages of using congruency analysis for priority setting is that it is simple, transparent, and cheap; however, it is difficult to compare resource factors to each other (ICRA Learning Resources, 2004).
Pair-wise comparisons result in a specific point value. This enables a researcher to determine the relative order (ranking) of a group of items. This approach is often used as part of a process of assigning weights to criteria in a design concept evaluation.

SMEs are also used to determine the relative weights of the variables. There are a number of methods of constructing membership functions, which include direct and indirect methods. Direct methods include experts giving answers to various kinds of questions that explicitly pertain to the constructed membership function. Indirect methods ask experts questions that are more general and less sensitive to the various biases of subjective judgment (Klir, Yuan, 1995; Terano et al. 1992). One drawback to this method is the subjective nature of the ratings. However, because many of the concepts are multi-faceted and linguistic in nature, the use of a SME provides a means to help quantify qualitative measures.

This research conducted an AHP analysis using a pair-wise comparison algorithm within Expert Choice to obtain the relative weight of the factors using SME input.

3.6.3 Qualitative Data Converted into Quantitative Data

Finding a method of bridging the gap between quantitative and qualitative research has been a concern for many researchers. Quantitative research focuses on the degree to which a phenomena possesses certain properties, states, or characteristics. In contrast, qualitative research is concerned with the state, character, and properties of the phenomena. The word qualitative implies that emphasis is placed on the processes and their meaning.

There are three general classes of qualitative research methods: in-depth interviews, projective techniques (word association and sentence completion), and observations, such as audits and diaries (Ma 71007, Labuschagne, A. 2003). Qualitative data can be analyzed using
content analysis, word association, sentence completion tests, coding, and diagramming. These tests are used to investigate the relationships between people, gain contextual insight, and to check the match between stated and actual behavior (Ma71007).

In many psychological human performance studies, qualitative data is analyzed by coding and developing a categorical system. Computer programs such as NUDIST, ATLAS, and Ethnograph are popular qualitative data analysis tools (Johnson, H., retrieved 2004). In 1979, Spradley developed a table of universal semantic relationships that can be used to develop relationship categories. Diagramming can also be used to organize and summarize qualitative data. Network models are most commonly used.

In the common case of knowledge-based systems in which vague concepts and imprecise data are handled, possibility theory and fuzzy logic provide tools to manage imprecision and uncertainty. Linguistic modifiers are important issues in the treatment of data by means of fuzzy logic. The interest in the linguistic modifiers lies in three areas. First, the modifier can be used symbolically, stressing the fact that possibility theory provides an interface between numerical and symbolic descriptions of events. Modifiers also help to give elements of comparison for fuzzy implications and yield a kind of classification of the available tools. They also enable gradual knowledge to be used in the context of deduction rules (Meunier, 1992).

The theory of fuzzy sets has been used for the development of the linguistic approach. In this approach, all variables are treated as a linguistic variable. A linguistic value is composed of a syntactic value or label, a sentence belonging to a term set, and its semantic value (Bonissone, 1980).

It is necessary to define the relationship between analytical results (physical measures) and a subject’s judgment of sensory attributes related to the analysis. For example, a person
might have a decreased blink rate, which is associated with high workload demands. The subject makes an assessment of the workload without any knowledge of the analytical results. Membership functions are developed for sets within the domain of the analytical values. The membership functions are developed by analyzing the literature and through the use of experts (Whitnell, et al 1991).

Using AHP, weights can be assigned to each stress or fatigue risk factor based on expert opinion. For example, the level of risk a person is exposed to can be determined using a Likert scales, ranging from no effect to very high risk (McCauley-Bell chapter). Additionally, FST can be used to translate linguistic terms into numeric values to be used to obtain aggregate measures given several inputs.

To derive the fuzzy measures, a review of the literature and a knowledge acquisition session was completed. In the knowledge acquisition session, SMEs identified the ranges in which a variable could fall. SMEs also assigned a particular linguistic value to the interval. To determine the intervals, SME were asked what the break points (end points) should be for each interval. Additionally, the SMEs were asked to partition the interval into as many sub-intervals as required to describe the condition. To help with the sub division process, literature results and other expert opinions were considered. To address the differences among SMEs, membership functions were developed.

The development of membership functions was performed using mapping functions. The purpose of mapping functions was to map subjective real world phenomenon into a membership domain [0,1]. The mapping function provided a way to view the progression of changes in state of a given variable over a membership function. The membership functions were characteristic of the dataset under analysis.
As with most FST, developing membership functions was challenging because of the inherent subjectivity. Therefore, a standard methodology was used by each SME and for each of the factors. In a study performed by McCauley-Bell et al, FST was used to determine linguistic variable contribution. In the study, two membership functions were defined for the variables concerning occupational injuries. The first membership function developed was designed to graphically represent the linguistic risk levels. In the second stage, the knowledge acquisition session, varied ambiguity across and within the expert’s analysis of the cut-off points for identifying each LRL was found. In this study, the approach used by McCauley-Bell, in which the SMEs defined three values, was used. The determination of the values with complete membership in the set was accomplished by taking a weighted average of the value. The purpose of the weighing was to give the expert whose primary area of expertise the largest amount of input in the development of the membership function. The mean was determined by assigning a weight determined through consultation with the experts. The same approach was used in this study.

3.6.4 Determining the Level of Dependence of Factor Variables

When building a model, it is essential to determine which variables add predictive value. Residual plots are helpful in checking for assumptions. Diagnostic checks are useful for identifying influential outlying observations and multi-collinearity. Different selection techniques to determine the predictor variables (x) that best predict the response variables (y) are described below.
When building the model it is also important to remember the parsimony principle. This states that an empirical model must be kept as simple as possible, both in the number of predictors it contains and in its functional form.

The all-possible regression procedure calls for considering all possible subsets of the pool of potential x variables and identifying a few “good” subsets for detailed examination, according to a criterion deduced from SME inputs. The detailed examination leads to the selection of a final model (Neter, 1996).

The $R^2_p$ criterion calls for the use of the coefficient of multiple determinations, $R^2$, to identify several good subsets of the x variable, in other words, the x variables where $R^2$ is high. The $R^2_p$ is equivalent to using the error sum of squares, SSEp, as the criterion. $R^2_p$ is maximized when all potential x variables are included in the model. $C_p$ is concerned with the total mean squared error of the n fitted values for each subset of the model.

The PRESSp (prediction sum of squares) criterion measures how well the fitted values in a model predict the observed y variable. Models with a small PRESSp are considered good candidate models.

Forward stepwise regression procedure is the most widely used of the automatic search methods. This search method develops a sequence of regression models by adding or deleting an x variable at each step. The criteria for adding or deleting a variable can be stated as an eigen value in terms of error sum of squares, coefficient of partial correlation, t statistic, or F statistic. A difference between the automatic search procedure and the all-possible regression procedure is that the automatic search procedure ends with the identification of a single model (Neter, 1996).

Stepwise variable selection adds variables to a model based on statistical significance. Stepwise selection is often used because it provides a concise model based on variable
significance. However, it is prone to overstating the importance of a variable retained in the model. Additionally, using this technique does not solve the problem of having too many variables in the model. Additionally, if there are too few subjects, what appears as an insignificant variable can be dropped because of an apparent lack of association (Harrell, 1997).

Other automatic search procedures include forward selection and backward elimination. The forward selection procedure adds variables to the model when a variable has a smaller p value than alpha. When a variable is added to a model, the variable is not removed when using forward selection.

The backward elimination search procedure is the opposite of the forward selection. This procedure begins with the model containing all potential x variables and then removes variables, one at a time. If the minimum F value is less than the predetermined limit, then the x variable is dropped (Neter, 1996). No variable can be re-entered once removed.

The plot of the residual against the fitted values is useful for assessing the appropriateness of the regression model and the constancy of the variance of the error terms. It is also useful for providing information about outliers. The residual plots can be analyzed to determine if the model assumptions are correct. Additionally, these plots can help check for normality and determine the best fit of curves for the data. A plot of the absolute residual or the squared residuals against the fitted values is useful for examining the constancy of the variance of the error terms (Neter, 1996).

### 3.7 Application of Fuzzy Set Theory

The SME data collected in interviews and through a literature review was analyzed using fuzzy logic. The properties of FST enable the evaluation of the grey area within stress, fatigue,
and workload. FST was used to measure the degree to which the factors can contribute to human
performance in a console operation. As McCauley-Bell, Crumpton-Young, and Badiru stated in
1999, “FST has provided a consistent and proved means to model many real-world
environments. FST does not sharply define sets as traditionally done in ordinary set theory. FST
deals with the imprecision associate with many variables by permitting a grade of membership to
be defined over the interval [0,1]. The grade of membership expresses the degree of strength
which a particular element belongs to a fuzzy set. FST has been used to translate linguistic terms
into numeric values that can be used to aggregate measure given several input factors”.

The fuzzy set is defined by ratings pertaining to questions answered by the SME. For
each factor, the grade of membership was defined through the literature review. Each factor
within the set had an associated value, which indicated the degree to which the factor was a
member of the set (McCauley-Bell, Crumpton-Young, & Badiru, 1999).

3.8 Model Validation

The final step was to validate the fuzzy model. There are three primary traditional
approaches to validation: independent verification; splitting of the sample; or re-sampling (Good
and Hardin, 2003). In the simulation area, validation is accomplished through creation of
random data within a confined space. This study used both splitting the sample and simulated
data. In addition, during model validation, the components and subcomponents were evaluated
for dependence, correlation, and interaction.

Model validation involves checking the model against independent factors (Neter, 1996). To
develop the model, a data–split was completed. The data-split split the observations from the
data into two random parts. The first dataset (70 percent) was used to develop the model and the second data set (30 percent) was used to measure predictive accuracy (Harrell, 1997).

Cross validation is used to estimate generalization error or it can be used for model selection by choosing one of several models that has the smallest estimated generalization error (Faqs, 2004 & Neter, 1996).

In a k-fold cross validation, the data is divided into k subsets of equal size (Faqs, 2004). This same technique was performed in a military application, in which researchers were trying to validate the Cultural Modeling of Command and Control models. A model developer created the model using a preliminary dataset (the first set of data) and validated the model using a second set of data collected during the initial data collection session. The model was developed using the data of the operational users of the model (Young, 2003).

Additionally, a second, simulated independent set of data was created using random numbers, within a given set of bounds, to validate the model. This second set of data was divided into three equal sections: high, medium, and low. It included double the number of data points, one point per participant, than the original data. Participants labeled high were given values for each variable with a corresponding high rating (such as, completion time, 2 hours). The participant data was then evaluated using the fuzzy model to determine if the model was accurate.

The simulation modeling community often validates models through simulated data within an specific intended domain (Sargent, 1998). A series of numbers are randomly created through a number generator within the confined bounds set by the SME. When the data is compiled, it is run through the model in the same manner as the original data (Kleijnen, 1999; DeVos and Bosker, 1999).
The sensitivity, specificity, and accuracy of the fuzzy stress, fatigue, and workload model were calculated. The consistency of pair-wise judgments provided by the SME was also calculated. As the number of pair-wise comparison increases, it becomes more difficult to achieve consistency. In fact, some degree of inconsistency is expected in any set of pair-wise comparisons. If the consistency ratio is less than 0.10, the pair-wise comparisons are considered reasonable (Anderson, Sweeney, Williams, 2003).
CHAPTER FOUR: RESULTS

4.1 Graphs of Data

4.1.1 Engineering Test Leads

The charts in this section reflect the results of participants whose primary job is to perform data retrievals to aid in problem resolution. Part of their job may include review of Launch Commit Criteria, OMRSD limits, and to retrieve drawings. Additionally, these participants have multiple certifications. These participants are typically senior engineers within their respective disciplines.

4.1.1.1 Yoshitake Type I and II Fatigue

Figures five through sixteen of this document reflect the results obtained from administering Yoshitake Type I and II Fatigue surveys to research participants. Each participant completed the checklist of subjective symptoms of fatigue pre- and post-simulation. Participants either checked yes if they felt the symptom or no if they did not feel the symptom. Answers of yes were given a score of one; answers of no were given a score of zero. Under each type of fatigue, the boxes were totaled and combined to ascertain an overall fatigue score.
Figure 6: Physical Fatigue Associated with Number of Problems

The highest value of physical fatigue possible is 1, whereas, the highest value obtained was 0.17. Figure 6 illustrates that the value of physical fatigue remained low even though the number of problems increased.

Figure 7: Level of Mental Fatigue Associated with the Time to Complete a Problem

Figure 7 demonstrates that as the time required to complete a problem increased, the physical fatigue levels decreased. Possible reasons for higher levels of fatigue include system constraints which forces individuals to determine problem resolution plans quicker.
Figure 8: Physical Fatigue Associated with the Ability to Identify Problems

Figure 8 illustrates that the changes in physical fatigue levels remained minimal, 0.17 on a scale from 0 to 1. The two participants who did not correctly identify the problem given to them during the simulation indicated changes in physical fatigue that ranged from 0 to 0.08.

Figure 9: Physical Fatigue Associated with the Ability to Communicate Effectively

Figure 9 depicts a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results showed that those who chose words carefully, rating of 3, and were well spoken showed increases in physical fatigue. Participants chose words carefully to increase technical understanding within the community and provide necessary data to other affected groups.
Figure 10: Physical Fatigue vs. the Correct Problem Resolution Plan

Figure 10 illustrates those participants who correctly determined the proper problem resolution plan had higher physical fatigue values than the one participant who did not correctly determine the proper resolution plan. The increase in physical fatigue could be attributed to the pressure associated with peer performance evaluations and professional image within the flight team.

Figure 11: Physical Fatigue Associated with Repeated Performance

Figure 11 demonstrates that some of the participants indicated a change in physical fatigue levels even though the problems presented to them were problems received in past simulation runs. However, the associated physical fatigue change was minimal.
Figure 12: Mental Fatigue Associated with Number of Problems

Figure 12 indicates that the value of mental fatigue remained low even as the number of problems increased. The highest value possible is 1, whereas, the highest value obtained was 0.25. Some individuals increase in mental fatigue can be associated with completing two problems simultaneously.

Figure 13: Level of Mental Fatigue Associated with the Time to Complete a Problem

Figure 13 depicts that as the time required to complete a problem increased, the mental fatigue levels decreased. Possible reasons for higher levels of fatigue include system constraints
which forces individuals to determine problem resolution plans quicker and time constraints for other orbit operations.

![Graph](image1)

Figure 14: Mental Physical Fatigue Associated with the Ability to Identify Problems

Figure 14 indicated that whether or not participants were able to correctly identify the problem, on a scale from 0 to 1, mental fatigue remained low. Some participants indicated no change in mental fatigue. Those participants who did not correctly identify the problem given to them during the simulation indicated changes in mental fatigue between 0 and +0.12.

![Graph](image2)

Figure 15: Mental Fatigue Associated with the Ability to Communicate Effectively

Figure 15 indicates a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results showed that those who chose words carefully and were well spoken showed increases in mental fatigue. Participants chose
words carefully to increase technical understanding within the community and provide necessary data to other affected groups.

![Graph](image1.png)

Figure 16: Mental Fatigue vs. the Correct Problem Resolution Plan

Figure 16 demonstrates those participants who correctly determined the proper problem resolution plan had higher mental fatigue values. These increases in mental fatigue can be attributed to the pressure associated with peer performance evaluations and professional image within the flight team. If participants receive negative peer performance evaluations, additional simulations could be required for flight certification.

![Graph](image2.png)

Figure 17: Physical Fatigue Associated with Repeated Performance
Figure 17 illustrates that some of the participants indicated a change in mental fatigue levels even though the problems presented to them were problems received in past simulation runs. Results show low level of changes in mental fatigue.

4.1.1.2 Overall Job Satisfaction

Participants completed a subjective job satisfaction survey prior to the simulation that focused on job and organizational-related satisfiers. Participants were given a series of questions, which asked them to rank their response on a scale from one to five with one being strongly disagreed with a statement and five being strongly agreed with the statement. The results are shown below is figures 18 to 23. Most participants indicated a rating of four on the survey signifying that they were satisfied with their job.

Figure 18 depicts that despite the number of problems a participant was given, a participants overall level of job satisfaction remained high. Even those participants who received six problems still had a high level of job satisfaction.
Figure 19: Job Satisfaction Associated with the Time to Complete a Problem

Figure 19 illustrates that the problem that took the longest time to solve showed a high level of job satisfaction which was also true for problems that took the least amount of time to solve. The high level of job satisfaction could be attributed to the people the participant works with, the technical content a participant is exposed to and the cultural environment.

Figure 20: Job satisfaction Associated with the Ability to Identify Problems

Figure 20 demonstrates that regardless of the ability to correctly identify a problem, the participant still had a high level of job satisfaction. Those participants, who did not correctly identify the problem given to them in the simulation, still indicated a rating of four for their overall job satisfaction level.
Figure 21: Job Satisfaction Associated with the Ability to Communicate Effectively

Figure 21 depicts a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results showed that those who chose words carefully and were well spoken showed the same level of job satisfaction as individuals who chose their words less careful. Participants chose words carefully to increase technical understanding within their respective discipline (i.e. mechanical) and provide necessary data to other affected technical disciplines.

Figure 22: Job Satisfaction vs. the Correct Problem Resolution Plan

Figure 22 data indicates participants who correctly determined the proper problem resolution plan showed the same job satisfaction levels as those individuals who did not chose
the correct problem resolution plan. The high ratings of job satisfaction can be attributed to the technical material participants are able to work with and the enthusiasm for space exploration.

Figure 23: Job Satisfaction Associated with Repeated Performance

Figure 23 illustrates that job satisfaction was above average even though participants had received their problems in previous simulation runs. All but one participant received their problem during a previous simulation and indicated an above average job satisfaction rating. The average overall level of job satisfaction rating was 4.

4.1.1.3 NASA TLX

NASA TLX, multi-dimensional rating procedure that generates an overall workload value based on six subscales, is a subjective assessment tool used to determine levels of workload. NASA TLX provided the principal investigator with a tool to perform subjective workload assessment on jobs that require the participant to interface with human-machine systems (i.e. computers). Charts 19 through 60 present the results from the NASA TLX analysis.

Participants completed a NASA TLX survey pre and post simulation. This study looked at the changes of the six subscales and overall workload. The possible values that TLX produced ranged from 0 to 100. If a participant delta rating is negative, this indicates a participant’s pre-
simulation values were higher than the post simulation values. If the delta is positive, the post simulation values are greater than the pre-simulation values.

Figure 24: Mental Demand Value Associated with Number of Problems

Figure 24 illustrates the change in mental demand associated with the number of problems a participant received during the simulation. The data indicates the participant who received six problems indicated no change in mental demand. The participants with negative delta values showed higher mental demand prior to the simulation whereas, the participants with a positive delta value showed higher post test mental demands.

Figure 25: Mental Demand Value associated with the time to complete a problem

Figure 25 indicates as the time required to complete a problem increased, mental demand increased. The problem that took the longest to solve showed a higher post test mental demand
value. The participant that took the least time to solve the problem showed no change in mental demand values.

![Mental Demand Value vs. Problem Identification](image)

**Figure 26:** Mental Demand Value Associated with the Ability to Identify Problems

Figure 26 indicates that three participants where not able to correctly identify a problem given to them during the simulation. These participants indicated changes in mental demand that ranged from -10 to +30. Only one participant did not correctly identify their problems and indicated higher post simulation scores. The largest change in mental demand was -45, indicating the participant was subjected to lower mental demands after the simulation.

![Mental Demand Value vs. Discussion Traffic](image)

**Figure 27:** Mental Demand Value Associated with the Ability to Communicate Effectively
Figure 27 illustrates the change mental demand due to the ability to communicate a problem and the resolution to the simulation team. Participants with excellent communication skills showed higher changes in mental demand values (−45), over participants with poor communication skills. Participants with poor communication skills indicated no change in mental demand. Participants with good communication skills showed little change in mental demand (−10) or no change.

![Mental Demand Value vs. Decision Making](image)

**Figure 28:** Mental Demand Value vs. the Correct Problem Resolution Plan

In figure 28, two participants did not choose the correct course of action and both showed changes in mental demand. One participant that correctly identified the problem showed no change in physical demand. The negative change can be attributed to the time critical to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.
Figure 29: Mental Demand Associated with Repeated Performance

Figure 29 depicts the change in mental demand associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and could be found in the data bank of simulation problem sets. The one participant who identified a new problem experienced no change in mental demand.

Figure 30: Physical Demand Compared to the Number of Problems Completed

Figure 30 compares the number of problems completed to the change in physical demand. Participants who received two or fewer problems showed less change in physical demand over participants who were assigned three or more problems. The difference in how much change in physical demand a participant felt could be attributed to the time of day the
simulation was run or the environment (i.e. temperature, lighting). The largest change in physical demand was 45, which is average.

![Physical Demand Value vs. Completion Time](image1)

**Figure 31:** Physical Demand Value Associated with the Time to Complete a Problem

Figure 31 indicates that as the time required to complete a problem increased, physical demand also increased. The problem that took the longest to solve showed a higher post-simulation physical demand. On a scale from 0 to 100, 100 indicating a very physically demanding task, the participant who took the longest to solve a problem indicated a change of 45.

![Physical Demand Value vs. Problem Identification](image2)

**Figure 32:** Physical Demand Value Associated with the Ability to Identify Problems
Figure 32 illustrates the relationship between the ability to identify a problem correctly to the change in the physical demand. Only two participants who correctly identified the problems had higher pre simulation scores. Participants who did not correctly identify their problems indicated no or higher post simulation scores. The largest change in mental demand was 45, on a scale of 0 to 100.

![Physical Demand Value vs. Discussion Traffic](image)

**Figure 33: Physical Demand Value Associated with the Ability to Communicate Effectively**

Figure 33 depicts the change physical demand due to the ability to communicate a problem and the resolution to the simulation team. Participants with excellent communication skills showed higher changes in mental demand values (45), over participants with poor communication skills. Participants with poor communication skills, rating of 1, indicated no change in physical demand. Participants with good communication skills showed average to minimal change in physical demand (-30 to 5).
Figure 34: Physical Demand Value vs. the Correct Problem Resolution Plan

Figure 34 indicates that two participants did not determine the correct course of problem resolution and indicated a higher level of physical demand after the simulation. The negative change can be attributed to the time critical to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.

Figure 35: Physical Demand Associated with Repeated Performance

Figure 35 illustrates the change in physical demand associated with the type of problem given to the participant during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem experienced higher pre simulation physical demand.
Figure 36: Performance Value Associated with Number of Problems

Figure 36 depicts the change in a participant’s satisfaction associated with the number of problems identified during the simulation. Over half of the participants indicated high confidence prior to the simulation indicated by a negative delta performance value. The highest change in performance was -35, indicating higher confidence prior to the simulation.

Figure 37: Performance Value Associated with the Time to Complete a Problem

Figure 37 indicates that as completion time increased, post simulation satisfaction decreased. The performance value is associated with a participant’s level of performance satisfaction and success. The participant who took the longest to a solve problem indicated higher levels of satisfaction prior to the simulation. Some of the factors that account for higher
pre simulation scores include how a participant did in a past performance or the participant’s self confidence.

![Temporal Demand Value vs Problem Identification](image1)

**Figure 38: Performance Value Associated with the Ability to Identify Problems**

Figure 38 illustrates the relationship between the ability to identify a problem correctly to the change in a participant’s satisfaction. The largest change in performance satisfaction was -35, indicating higher pre-simulation performance satisfaction.

![Temporal Demand Value vs. Discussion Traffic](image2)

**Figure 39: Performance Value Associated with the Ability to Communicate Effectively**

Figure 39 depicts the change in performance satisfaction due to the ability to communicate a problem and the resolution plan to the simulation team. Participants with poor
communication skills indicated a small change in performance satisfaction (10). Participants with excellent communication skill indicated higher pre-simulation performance satisfaction ratings (-35).

Figure 40: Performance Value vs. the Correct Problem Resolution Plan

Figure 40 illustrates that one participant did not identify the correct course of problem resolution and indicated higher levels of satisfaction prior to the simulation. The negative change in performance can be attributed to the pressure associated with the time to complete the problem, peer performance evaluation, and the professional image within the flight team.

Figure 41: Performance Value Associated with Repeated Performance
Figure 41 indicates the change in a participant’s satisfaction associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem experienced a higher post simulation satisfaction.

![Figure 41: Performance Value vs. Number of Problems](image)

Figure 42: Temporal Demand Value Associated with Number of Problems

Figure 42 compares the number of problems a participant received to the change in how much pressure a participant felt during the simulation. Only three participants noted higher temporal demands post simulation. The participants who received the most problems indicated no change in pressure. Temporal demand describes how much time pressure a participant felt and the pace at which a participant was required to complete a problem. The increase in pre-simulation pressure may be attributed to not knowing the problems being given or the pace at which the problem occurred.
Figure 43: Temporal Demand Value associated with the time to complete a problem

Figure 43 indicates that as completion time increased, participants indicated an increase in pressure. As completion time decreased, participants indicated higher levels of pre-simulation pressure.

Figure 44: Temporal Demand Value Associated with the Ability to Identify Problems

Figure 44 depicts those participants who did not correctly identify their problem indicated no change in temporal demands. Participants who did correctly identify the problem given to them in the simulation indicated changes in temporal demand that ranged from -40 to +20.
Figure 45: Temporal Demand Value Associated with the Ability to Communicate Effectively

Figure 45 indicates the change in the time pressure a participants felt due to the ability to communicate a problem and the resolution to the simulation team. Temporal demand is associated with the amount of time pressure a participant feels during a given period of time. Participants with poor communication skills indicated no change in pressure. Participants with good communication either indicated no change in pressure or indicated higher pressure levels prior to the simulation.

Figure 46: Temporal Demand Value vs. the Correct Problem Resolution Plan
Figure 46 indicates one participant did not choose the correct problem resolution path and that participant reported higher temporal demands after the simulation. The increase in post simulation pressure could be attributed to the rate at which tasks were given to the participant.

![Performance Value vs. Repeated Performance](image)

**Figure 47:** Temporal Demand Value Associated with Repeated Performance

Figure 47 illustrates the change in stress a participant experienced compared to the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The participant who had not been exposed to their problem in a prior simulation indicated higher pressure levels prior to the simulation.

![Effort Value vs. Number of Problems](image)

**Figure 48:** Effort Value Associated with Number of Problems
Figure 48 depicts the change in efforts related to the number of problems a participant received during the simulation. The participant with the most problems indicated more effort was required prior to the simulation (-5). The negative effort value could be associated the amount of preparation a participant does before the simulation, the anticipation of how hard, mentally, the simulation will be or the level of effort required to complete the task.

![Effort Value vs. Completion Time](image1)

Figure 49: Effort Value associated with the time to complete a problem

Figure 49 depicts that the problem that took the longest to solve, that participant indicated no change in effort. The participant who solved a problem between 30 and 65 minutes indicated no change in effort or higher effort levels pre-simulation.

![Effort Value vs. Problem Identification](image2)

Figure 50: Effort Value Associated with the Ability to Identify Problems
Figure 50 demonstrates that those participants, who did not properly identify a problem given to them during the simulation, indicated no change in effort or more effort was required pre-simulation. Participants who did properly identify a problem given to them during the simulation indicated a change in effort that ranged from -10 to +5. Over half of the participants indicated more effort was required prior to the simulation.

![Effort Value vs. Discussion Traffic](image)

Figure 51: Effort Value Associated with the Ability to Communicate Effectively

Figure 51 indicates the change in effort due to the ability to communicate a problem and the resolution to the simulation team. The participant with poor communication felt more effort was required pre simulation (-5). Participants with excellent communication had higher pre simulation score with the exception of two, where one indicated no change in effort and the other felt more effort was required post simulation (5).
Figure 52: Effort Value vs. the Correct Problem Resolution Plan

Figure 52 indicates that two participants did not determine the correct course of problem resolution for the given simulation problem. One of the participants indicated no change in the effort. The other participant felt more effort was required prior to the simulation. The participants that correctly chose the pre-planned problem resolution plan had varying results on when more effort was required.

Figure 53: Effort Value Associated with Repeated Performance

Figure 53 indicates the change in a participants effort associated with the type of problem received during the simulation. All but one participant received problems that were completed in
previous simulation runs and in the data bank of problem sets. The one participant who received a new problem felt more effort was required prior to the simulation.

Figure 54: Frustration Value Associated with Number of Problems

Figure 54 depicts the number of problems completed compared to the contentment a participant experienced during the simulation. The participant who received the greatest number of problems indicated lower relaxation levels prior to the simulation. Most participants felt more relaxed and less irritated prior to the simulation with the exception of three participants.

Figure 55: Frustration Value Associated with the Time to Complete a Problem
Figure 55 indicates that participant who took the longest to solve a problem indicated more stress or increased levels of irritation after the simulation. Additionally, as completion time increased, frustration levels also increased.

![Frustration Value vs. Problem Identification](image)

**Figure 55: Frustration Value vs. Problem Identification**

**R^2 = 0.4118**

Figure 56 depicts all but three participants correctly identified a problem during the simulation. The participants, who did not properly identify the problem, indicated higher frustration levels after the simulation (+25). The participants, who properly identified the problems given to them during the simulation, indicated changes in frustration that ranged from -20 to +30.

![Frustration Value vs. Discussion Traffic](image)

**Figure 56: Frustration Value Associated with the Ability to Identify Problems**

**Figure 57: Frustration Value Associated with the Ability to Communicate Effectively**
Figure 57 illustrates the change in frustration due to a participant’s ability to communicate a problem and the resolution path to the simulation team. Participants with poor communication indicated higher frustration levels prior to simulation (-15). Participants with good communication also indicated increased frustration prior to the simulation (-20).

![Figure 57: Frustration Value vs. Decision Making](image)

Figure 58: Frustration Value vs. the Correct Problem Resolution Plan

Figure 58 illustrates that one participant did not correctly identify the problem given to them during the simulation and indicated higher frustration after the simulation. Participants in a post simulation interview stated some of the possible reasons for higher frustration levels included: not being content with their performance, poor performance due to extraneous circumstance, or insecurity about the performance.

![Figure 58: Frustration Value vs. Repeated Performance](image)

Figure 59: Frustration Value Associated with Repeated Performance
Figure 59 illustrates the change in frustration compared with the type of problem a participant received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The participant who had not exposed to their problem in a prior simulation indicated higher frustration levels after the simulation.

![Graph showing Total Workload Value vs. Number of Problems](image)

R\(^2\) = 0.19

Figure 60: Workload Value Associated with Number of Problems

Figure 60, indicates the change in workload associated with the number of problems a participant received during the simulation. The participant with the most problems to complete, six, indicated higher workloads prior to the simulation (-7).

![Graph showing Total Workload Value vs. Completion Time](image)

R\(^2\) = 0.5011

Figure 61: Workload Value Associated with the Time to Complete a Problem
Figure 61 indicates that as the time required to complete a problem increased, the amount of work required to complete the problem also increased. Problems that took more than 60 minutes to complete, participant indicated an increase in workload.

Figure 62: Workload Value Associated with the Ability to Identify Problems

Figure 62 depicts that two participants did not correctly identify a problem during the simulation and reported higher workload values after the simulation (+2 and +4). Participants who did correctly identify a problem indicated a change in workload that ranged from -20 to +4.

Figure 63: Workload Value Associated with the Ability to Communicate Effectively

Figure 63 depicts the change in workload due to the ability to communicate a problem and the resolution to the simulation team. Participants with poor communication indicated
higher pre simulation workload levels (-7). Participants with good communication also indicated higher workloads prior to the simulation (-20 to -7).

![Total Workload Value vs. Decision Making](image1)

**Figure 64: Workload Value Associated with the Ability to Determine the Correct Problem Resolution**

Figure 64 indicates that two participants did not choose the correct course of problem resolution and noted higher workloads after the simulation. Some of the participants that correctly identified the right problem resolution path had higher pre simulation workload values (-20 to -7). Other participants that correctly identified the problem indicated more work was required after the simulation (+2 and +4).

![Total Workload Value vs. Repeated Performance](image2)

**Figure 65: Workload Value Associated with Repeated Performance**

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Figure 65 depicts the change in workload associated with the type of problem received during the simulation. One participant received a problem that was not in a previous simulation run and indicated more work was required post simulation (2).

4.1.1.4 SOFI

The Swedish Occupation Fatigue Inventory (SOFI) is a subjective tool that describes fatigue using five dimensions: lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness. The dimensions represent the perceptions of how participants feel at a given point in time. The participants completed the inventory pre- and post-simulation. The results of the inventory are included in charts 61 through 96.

This study looked at the change in the five dimensions. The possible values that SOFI produced ranged from 0 to 10. If a participant delta rating is negative, this indicates a participant’s pre-simulation values were higher than the post simulation values. If the delta is positive, the post simulation values are greater than the pre-simulation values.

![Lack of Energy vs. Number of Problems](image)

Figure 66: Lack of Energy Compared to Number of Problems
Figure 66, indicates as the number of problems increased, more energy was required to complete a problem. The participant with the most number of problems to solve indicated more energy was required prior to the simulation. The largest change in energy was -0.68, which is relatively small on a scale from 0 to 10.

![Lack of Energy vs. Completion Time](image1)

Figure 67: Lack of Energy Associated with Completion Time

Figure 67 demonstrated that participants who took the longest time to solve a problem during the simulation indicated less energy after the simulation. The participant who took the least amount of time to complete a problem also felt less energy post simulation (0.44).

![Lack of Energy vs. Problem Identification](image2)

Figure 68: Lack of Energy Associated with the Ability to Identify Problems
Figure 68 indicates two participants were not able to correctly identify the problem given to them during the simulation. One of participants who did not properly identify the problem indicated no change energy while the other participant indicated less energy after the simulation. Participants who were able to correctly identify their problem indicated small changes in energy levels (-0.75 to 0.44).

Figure 69: Lack of Energy Associated with the Ability to Communicate Effectively

Figure 69 illustrates the change in energy levels due to the ability to communicate a problem and the resolution to the simulation team. Those participants with poor communication felt they had less energy before the simulation. Those participants with good communication either felt no change in energy after the simulation or had less energy prior to the simulation.

Figure 70: Lack of Energy vs. the Correct Problem Resolution Plan
Figure 70 indicates two participants did not choose the correct course of problem resolution. One of those participants did indicate experiencing less energy after the simulation. The other participant indicated no change in energy levels. Half of the participants that chose the correct problem resolution path felt more energy was required prior to the simulation.

![Lack of Energy vs. Repeated Performance](image)

**Figure 71: Lack of Energy Associated with Repeated Performance**

Figure 71 depicts the change in a participant’s energy level associated with the type of problem received during the simulation. Participants who had not been previously exposed to the problem indicated less energy after the simulation (0.4). Participants who had previously experienced a problem indicated changes in energy levels that ranged from -0.75 to +0.4.

![Physical Exertion vs. Number of Problems](image)

**Figure 72: Physical Exertion Compared to Number of Problems**
Figure 72 indicates as the number of problems increased, more physical energy was required to complete the problem. The participants with the fewest number of problems to complete indicated no change in the physical energy.

![Physical Exertion vs. Completion Time](image)

Figure 73: Physical Exertion Associated with the Time to Complete a Problem

Figure 73 demonstrated the participant who took the longest to solve a problem indicated no change in physical exertion. The participant who took the short amount of time to complete a problem indicated more physical exertion was required before the simulation. The tasks presented in the simulation are mental rather than physical in nature which could explain why some participants did not indicate any change in physical exertion.

![Physical Exertion vs. Problem Identification](image)

Figure 74: Physical Exertion Associated with the Ability to Identify Problems
Figure 74 illustrates that the participant who did not correctly identify a problem given to them during the simulation indicated no change in physical exertion. The graph also illustrates that those individuals who were able to correctly identify a problem given to them in the simulation indicated a change in physical exertion that ranged from -0.25 to +0.25.

![Physical Exertion vs. Discussion Traffic](image)

**Figure 75: Physical Exertion Associated with the Ability to Communicate Effectively**

Figure 75 indicates the change in physical exertion due to the ability to communicate a problem and the resolution to the simulation team. Participants, who exhibited poor communication skills, rating of 1, indicated more physical exertion was required after the simulation.

![Physical Exertion vs. Decision Making](image)

**Figure 76: Physical Exertion vs. the Correct Problem Resolution Plan**

Figure 76 indicates one participant did not choose the correct course of problem resolution, denoted no change in physical energy. Participants who did chose the correct
resolution plan indicated changes in physical exertion that ranged from -0.25 to +0.25. The lack of change in physical energy could be attributed to the type of problem the individual was given.

Figure 77: Physical Exertion Associated with Repeated Performance

Figure 77 depicts the change in a participant’s level of physical energy associated with the type of problem received during the simulation. Participants who had not been exposed to a problem indicated higher physical exertion levels post-simulation (0.25).

Figure 78: Physical Discomfort Compared to Number of Problems

Figure 78 illustrates the participant with the most problems to solve indicated an increase in physical discomfort after the simulation. Participants who received 3 or fewer problems indicated a change in physical discomfort that ranged from -2.25 to 3.
Figure 79: Physical Exertion Associated with the Time to Complete a Problem

Figure 79 indicates that the participant who completed a problem in the longest amount of time experienced more physical discomfort prior the simulation. The participant, who took the least amount of time to complete a problem, experienced more physical discomfort after the simulation.

Figure 80: Physical Discomfort Associated with the Ability to Identify Problems

Figure 80 indicates that only one participant did not correctly identify a problem given to them during the simulation. This participant experienced higher physical discomfort prior to the simulation. Participants who did correctly identify a problem indicated changes in physical discomfort that ranged from -2.25 to +3. Participants may have felt more physical discomfort
prior to the simulation due exhaustion because of carrying material over to the simulation room or tense muscles because of computer position.

![Physical Discomfort vs. Discussion Traffic](chart1.png)

Figure 81: Physical Discomfort Associated with the Ability to Communicate Effectively

Figure 81 illustrates the change in physical discomfort due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication felt more discomfort after the simulation.

![Physical Discomfort vs. Decision Making](chart2.png)

Figure 82: Physical Discomfort vs. the Correct Problem Resolution Plan

Figure 82 indicates that one participant did not choose the correct course of problem resolution. This participant noted more physical discomfort prior to the simulation. Over half of the participants who correctly identified the problem resolution path noted more physical discomfort prior to the simulation. All participants did identify a change in physical exertion.
Figure 83: Physical Discomfort Associated with Repeated Performance

Figure 83 illustrates the change in a participant’s level of physical discomfort associated with the type of problem received during the simulation. Participants who had not been exposed to their problem in past simulation runs indicated more physical discomfort prior to the simulation (-2.25).

Figure 84: Lack of Motivation Compared to Number of Problems

Figure 84 indicates as the number of problems increased, lack of motivation also increased. The participant with the largest number of problems to solve indicated higher motivation levels prior to the simulation. Participants with three or fewer problems indicated no change or a small changes in motivation (-.25 to .25).
Figure 85: Lack of Motivation Associated with the Time to Complete a Problem

Figure 85 illustrates the participants who took longest to solve a problem indicated no change in motivation during the simulation. The participant who solved a problem in the shortest amount of time indicated a decrease in motivation after the simulation (0.25).

Figure 86: Lack of Motivation Associated with the Ability to Identify Problems

Figure 86 demonstrates three participants did not correctly identify a problem and indicated feeling less motivated after the simulation or indicated no change in motivation. Participants may have felt less motivated after the simulation due to their performance during the simulation or the results from peer and/or director evaluations.
Figure 87: Lack of Motivation Associated with the Ability to Communicate Effectively

Figure 87 indicates the change in motivation due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication felt less motivated after the simulation.

Figure 88: Lack of Motivation vs. the Correct Problem Resolution Plan

Figure 88 indicates two participants did not choose the correct course of problem resolution and indicated no or a small change in motivation post-simulation. Over half of the participants who did chose the correct course of problem resolution indicated feeling less motivated after the simulation.
Figure 89: Lack of Motivation Associated with Repeated Performance

Figure 89 illustrates the change in a participant’s level of motivation associated with the type of problem received during the simulation. Participants who had not been exposed their problem in past simulation runs felt less motivated after the simulation (0.5). All changes in the level of motivation were small, less than 1.5, on a scale from 0 to 10.

Figure 90: Sleepiness Compared to Number of Problems

Figure 90 illustrates the number of problems a participant completed against the level of sleepiness experienced during the simulation. Participants with three problems indicated high levels of tiredness after the simulation. All changes in sleepiness were small, no value larger than 3, on a scale from 0 to 10.
Figure 91: Sleepiness Associated with Completion Time

Figure 91 demonstrated, participants who took the longest to solve a problem indicated higher levels of sleepiness prior to simulation. The participant who solved a problem in the shortest amount of time indicated higher levels of sleepiness after the simulation (2.5).

Figure 92: Sleepiness Associated with the Ability to Identify Problems

Figure 92 indicated two participants did not correctly identify a problem and noted higher levels of sleepiness prior to the simulation. The participants who were able to correctly identify a problem during the simulation indicated change in sleepiness that ranged from -2.75 to +2.5.
Figure 93: Sleepiness Associated with the Ability to Communicate Effectively

Figure 93 indicates the change in sleepiness due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication felt less sleepy after the simulation.

Figure 94: Sleepiness vs. the Correct Problem Resolution Plan

Figure 94 indicates two participants were not able to choose the correct course of problem resolution and noted higher levels of sleepiness after the simulation. Only one participant did choose the correct course of problem resolution and indicated higher levels of sleepiness after the simulation.
Figure 95: Sleepiness Associated with Repeated Performance

Figure 95 indicates the change in a participant’s level of sleepiness associated with the type of problem received during the simulation. Participants who had not received their problem in past simulation runs indicated feeling higher levels of tiredness after the simulation (0.25).

4.1.1.5 Heart Rate and Blood Pressure

Heart rate readings were collected on a continuous basis during the simulation. Data was downloaded onto a laptop for analysis. Blood pressure readings were taken after the simulation.

Figure 96: Change in Heart Rate Compared to Number of Problems
Figure 96 indicated as the number of problems a participant had to complete increased, heart rate also increased. The participant who solved two problems indicated the greatest change in heart rate (52 bpm). The participant who solved four problems to indicated the smallest change in heart rate (11 bpm).

![Change in HR vs Completion Time](image)

Figure 97: Change in Heart Rate Associated with Completion Time

Figure 97 indicated participants who took 20 minutes to solve a problem produced the largest change in heart rate. The participant who took the longest time to solve a problem produced a change in heart rate of 35 bpm.

![Change in Heart Rate vs. Problem Identification](image)

Figure 98: Change in Heart Rate Associated with the Ability to Identify Problems
Figure 98 indicated three participants did not correctly identify a problem given to them during the simulation. One of the participants who did not correctly identify a problem produced the largest change in heart rate (52 bpm). The participant who correctly identified a problem produced the smallest change in heart rate.

Figure 99: Change in Heart Rate Associated with the Ability to Communicate Effectively

Figure 99 illustrates the change in heart rate due to the ability of a participant to communicate a problem and the resolution to the simulation team. The participant who exhibited poor communication produced the largest change in heart rate. The participant with the smallest change in heart rate exhibited good communication skills.

Figure 100: Change in Heart Rate vs. the Correct Problem Resolution Plan
In Figure 100, two participants did not choose the correct course of problem resolution and produced a change in heart rate between 20 and 30 bpm. The participants who were able to choose the correct course of problem resolution exhibited the smallest and largest change in heart rate.

![Change in Heart Rate vs. Repeated Performance](image)

**Figure 101: Change in Heart Rate Associated with Repeated Performance**

Figure 101 illustrates the change in a participant’s heart rate associated with the type of problem received during the simulation. The participant who had not received their problem in past simulation run indicated the largest change in heart rate. The participant with the smallest change in heart rate had previously experienced the problem.

![Blood Pressure vs. Number of Problems](image)

**Figure 102: Blood Pressure Compared to Number of Problems**
Figure 102 indicates as the number of problems a participant had to complete increased, blood pressure remained constant. The participant who solved five problems reported the highest blood pressure. The participant who solved only three problems reported the lowest blood pressure.

![Blood Pressure vs. Completion Time](image)

Figure 103: Blood Pressure Associated with Completion Time

Figure 103 indicated participants who took over 100 minutes to solve a problem reported blood pressure reading of 125 mmHg. The participant solved a problem in the shortest amount of time, reported the highest blood pressure reading, 130 mmHg.

![Blood Pressure vs. Problem Identification](image)

Figure 104: Blood Pressure Associated with the Ability to Identify Problems
Figure 104 indicates three participants did not correctly identify a simulation problem. The participants who did not correctly identify a problem reported blood pressure readings between 103 and 126 mmHg. The participant who correctly identified a problem reported the highest blood pressure reading.

![Blood Pressure vs. Discussion Traffic](chart1)

**Figure 105**: Blood Pressure Associated with the Ability to Communicate Effectively

Figure 105 illustrates how blood pressure was associated with a participant’s ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication reported one of the highest blood pressure readings. The participants with the lowest blood pressure readings exhibited good and excellent communication skills.

![Blood Pressure vs. Decision Making](chart2)

**Figure 106**: Blood Pressure vs. the Correct Problem Resolution Plan
In figure 106, two participants did not choose the correct course of problem resolution and reported blood pressure readings of 103 mmHg and 125 mmHg. The participants who were able to choose the correct course of problem resolution exhibited the smallest and largest blood pressure readings.

Figure 107: Blood Pressure Associated with Repeated Performance

Figure 107 indicated a participant’s blood pressure reading associated with the type of problem received during the simulation. The participant who had not been exposed to that a problem in past simulation run indicated a blood pressure reading of 126 mmHg. The participant with the smallest blood pressure reading had previously experienced their problem in a pervious simulation.

4.1.2 NASA System Engineers

The charts in this section reflect the results of participants whose primary job is to review initial data. Additionally, the individual determines whether information is pertinent to problem resolution. These participants are frequently junior engineers within their respective disciplines and may only have one console certification.
4.1.2.1 Heart Rate and Blood Pressure

Heart rate readings were collected on a continuous basis during the simulation. Data was downloaded onto a laptop for analysis. Blood pressure readings were taken after the simulation.

![Change in Heart Rate vs. Number of Problems](image1)

Figure 108 Change in Heart Rate Compared to Number of Problems

Figure 108 indicated as the number of problems a participant had to complete, heart rate also increased. The participant who solved three problems reported the largest change in heart rate (38 bpm). The participant with two problems to solve showed the smallest change in heart rate (10 bpm).

![Change in Heart Rate vs. Completion Time](image2)

Figure 109 Change in Heart Rate Associated with Completion Time
Figure 109 indicated the participant who took 18 minutes to solve a problem produced the largest change in heart rate (38 bpm). The participant who took the longest time, 42 minutes, to solve the problem indicated a change in heart rate of 25 bpm.

![Change in Heart Rate vs. Problem Identification](image)

Figure 109 Change in Heart Rate Associated with the Ability to Identify Problems

Figure 109 illustrates the relationship between the ability to identify a problem correctly to the change in a participant’s heart rate. One participant improperly identified a problem, reported a change in heart rate of 21 bpm. The participants who reported the smallest and largest change in heart rate correctly identified a problem given to them in the simulation.

![Change in Heart Rate vs. Discussion Traffic](image)

Figure 111 Change in Heart Rate Associated with the Ability to Communicate Effectively

Figure 111 illustrates the change in heart rate due to the ability to communicate a problem and the resolution to the simulation team. All participants received either good or excellent communication skill ratings. The participant who reported largest change in heart rate
exhibited excellent communication skills. The participant who reported the smallest change in heart rate exhibited good communication skills.

![Graph](image1)

**Figure 112 Changes in Heart Rate vs. the Correct Problem Resolution Plan**

Figure 112 indicates one participant did not choose the correct course of problem resolution and had a change in heart rate of 25 bpm. The participants who were able to choose the correct course of problem resolution reported the smallest and largest change in heart rate.

![Graph](image2)

**Figure 113 Change in Heart Rate Associated with Repeated Performance**

Figure 113 illustrates the change in a participant’s heart rate associated with the type of problem received during the simulation. The participant who had not received their problem in past simulation runs indicated the largest change in heart rate, 38 bpm. The participant who reported the smallest change in heart rate, 10 bpm, had previously experienced the problem.
Figure 114: Blood Pressure Compared to Number of Problems

Figure 114 indicated as the number of problems a participant had to complete increased, blood pressure remained stable. The participants who solved two and three problems reported the highest blood pressure readings. The participant with only one problem to solve reported the lowest blood pressure.

Figure 115: Blood Pressure Associated with Completion Time

Figure 115 indicated the participant who solved a problem in over 40 minutes, reported a blood pressure reading of 125 mmHg. The participant, who solved a problem in the shortest amount of time, reported a blood pressure reading 126 mmHg.
Figure 116: Blood Pressure Associated with the Ability to Identify Problems

Figure 116 indicates three participants did not correctly identify the problem given to them during the simulation. The participant who did not correctly identify the problem had blood readings between 126 mmHg. The participant who correctly identified their problem had the highest blood pressure reading.

Figure 117: Blood Pressure Associated with the Ability to Communicate Effectively

Figure 117 illustrates how blood pressure is associated with a participant’s ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication had a blood pressure reading of 110 mmHg. The participant with the lowest blood pressure readings exhibited good communication skills.
Figure 118: Blood Pressure vs. the Correct Problem Resolution Plan

In figure 118 one participant did not choose the correct course of problem resolution and reported a blood pressure reading of 110 mmHg. The participants who did choose the correct course of problem resolution reported the largest blood pressure readings.

Figure 119: Blood Pressure Associated with Repeated Performance

Figure 119 illustrated the association of a participant’s blood pressure reading to the type of problem received during the simulation. The participant who had not been exposed to a problem in past simulation runs, reported a blood pressure reading of 123 mmHg. The participant with the smallest blood pressure reading had previously experienced the problem.
4.1.2.2 Yoshitake Type I and II Fatigue

Figures 120 through 132 of this document reflect the results obtained from administering Yoshitake Type I and II Fatigue surveys to research participants. Each participant completed the checklist of subjective symptoms of fatigue pre- and post-simulation. Participants either checked yes if they felt the symptom or no if they did not feel the symptom. Answers of yes were given a score of one; answers of no were given a score of zero. Under each type of fatigue, the boxes were totaled and combined to ascertain an overall fatigue score.

Figure 120 Physical Fatigue Associated with Number of Problems

The highest value of physical fatigue possible is 1, whereas, the highest value obtained was 0.25. Figure 120 indicates the value of physical fatigue remained low even as the number of problems increased. Four participants indicated no change in physical fatigue.
Figure 121 Level of Physical Fatigue Associated with the Time to Complete a Problem

Figure 121 illustrates, as the time required to complete a problem increased, physical fatigue levels decreased. Some participants indicated no change in physical fatigue. Possible reasons for higher levels of fatigue include system constraints which forces individuals to determine problem resolution plans quicker. The participant who solved a problem in the shortest among of time indicated no change in physical fatigue.

Figure 122 Physical Fatigue Associated with the Ability to Identify Problems

Figure 122 illustrates physical fatigue levels remained low overall, 0.25. The one participant who did not correctly identify the problem given to them during the simulation indicated a change in physical fatigue of 0.025.
Figure 123 Physical Fatigue Associated with the Ability to Communicate Effectively

Figure 123 depicts a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results indicated that those who chose words carefully and were well spoken, rating of 3, showed increases in physical fatigue. All participants had either good or excellent communication skills.

Figure 124: Physical Fatigue vs. the Correct Problem Resolution Plan

Figure 124 indicates that participants who correctly determined the proper problem resolution plan had higher physical fatigue values than the one participant who did not correctly identify the problem resolution for the problem given to him. The increase in physical fatigue could be attributed to the pressure associated with peer performance evaluations and professional image within the flight team.
Figure 125 Physical Fatigue Associated with Repeated Performance

Figure 125 illustrates some participants indicated a change in physical fatigue levels on problems presented to them in past simulation runs. However, the associated physical fatigue change was minimal. The participant who received a new problem indicated no change in physical fatigue.

Figure 126 Mental Fatigue Associated with Number of Problems

Figure 126 indicates the value of mental fatigue remained low, as the number of problems increased. The largest change in mental fatigue obtained was -0.25 from the participant who received four problems. The participant who only received one problem indicated a change in mental fatigue of +0.12. Some individuals increase in mental fatigue can be associated with completing two problems simultaneously.
Figure 127 Level of Mental Fatigue Associated with the Time to Complete a Problem

Figure 127 illustrates as the time required to complete a problem increased, mental fatigue increased. The participant who took the longest time to solve a problem indicated a change in mental fatigue of +0.12. The participant who took the shortest amount of time to complete a problem indicated a change in mental fatigue of -0.25. Possible reasons for higher levels of mental fatigue include system constraints which forces individuals to determine problem resolution plans quicker and time constraints for other orbit operations.

Figure 128 Mental Fatigue Associated with the Ability to Identify Problems

Figure 128 depicts one participant did not correctly identify the problem given to them during the simulation and indicated a change in mental fatigue of +0.12. Some participants indicated higher levels of mental fatigue prior to the simulation.
Figure 129 Mental Fatigue Associated with the Ability to Communicate Effectively

Figure 129 illustrates a participant’s ability to communicate effectively with the team compared in mental fatigue. Participants were graded by the simulation directors and results showed that those who chose words carefully and were well spoken reported a variation in changes of mental fatigue. Participants chose words carefully to increase technical understanding within the community and provide necessary data to other affected groups.

Figure 130  Mental Fatigue vs. the Correct Problem Resolution Plan

Figure 130 indicates those participants who had correctly determined the proper problem resolution plan reported mental fatigue values that ranged from -0.25 to +0.12. The participant who did not correctly determine the proper problem resolution plan indicated a change in mental fatigue of -0.25.
Figure 131 Mental Fatigue Associated with Repeated Performance

Figure 131 depicts some participants indicated a change in mental fatigue levels on problems presented to them from past simulation runs. Results show low level of changes in mental fatigue. One participant who received a new problem indicated no change in mental fatigue.

4.1.2.3 Overall Job Satisfaction

Participants completed a subjective job satisfaction survey prior to the simulation that focused on job and organizational-related satisfiers. Participants were given a series of questions, which asked them to rank their response on a scale from one to five with one being strongly disagreed with a statement and five being strongly agreed with the statement. The results are shown below is figures 132 to 137. Most participants indicated a rating of four on the survey signifying that they were satisfied with their job.
Figure 132: Job Satisfaction Associated with Number of Problems

Figure 132 depicts that despite the number of problems a participant was given, the overall level of job satisfaction remained high. Those participants who received four problems reported a high level of job satisfaction, four. The minimum indicated overall satisfaction rating was three, given by a participant who received one problem.

Figure 133: Job Satisfaction Associated with the Time to Complete a Problem

Figure 133 indicates the participant who took the greatest amount of time to solve a problem reported a job satisfaction rating of 3. The participant who took the least amount of time to solve a problem reported a 4 for overall job satisfaction. The high level of job satisfaction could be attributed to the people the participant works with, the technical content a participant is exposed to and the cultural environment.
Figure 134: Job Satisfaction Associated with the Ability to Identify Problems

Figure 134 depicts the participant who did not correctly identify a problem given to them during the simulation indicated an above average overall level of job satisfaction. Those participants who did correctly identify a problem indicated a range of job satisfaction ratings from 3.2 to 4.3.

Figure 135: Job Satisfaction Associated with the Ability to Communicate Effectively

Figure 135 depicts a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results indicated that those who chose words carefully and were well spoken showed the same level of job satisfaction as individuals who chose their words less careful. Participants chose words carefully to increase technical understanding within the community and provide necessary data to other affected groups.
Figure 136: Job Satisfactions vs. the Correct Problem Resolution Plan

Figure 136 data indicates participants who had correctly determined the proper problem resolution plan showed the same job satisfaction levels as those individuals who did not chose the correct problem resolution plan. The participant who did not determine the proper problem resolution plan had an above average job satisfaction level, 3.8. The high ratings of job satisfaction can be attributed to the technical material participants are able to work with and the enthusiasm for space exploration.

Figure 137: Job Satisfaction Associated with Repeated Performance

Figure 137 illustrates that job satisfaction was above average even though participants had received their problems in previous simulation. All but one participant had experienced their
problem and reported an overall job satisfaction rating of 3.2. The overall level of job satisfaction rating was 3.8.

4.1.2.4 NASA TLX

NASA TLX, multi-dimensional rating procedure that generates an overall workload value based on six subscales, is a subjective assessment tool used to determine levels of workload. NASA TLX provided the principal investigator with a tool to perform subjective workload assessment on jobs that require the participant to interface with human-machine systems (i.e. computers). Charts 138 through 179 present the results from the NASA TLX analysis.

Participants completed a NASA TLX survey pre- and post-simulation. This study looked at the changes of the six subscales and overall workload. The possible values that TLX produced ranged from 0 to 100. If a participant delta rating is negative, this indicates a participant’s pre-simulation values were higher than the post simulation values. If the delta is positive, the post simulation values are greater than the pre-simulation values.

![Mental Demand Value vs. Number of Problems](image)

Figure 138: Mental Demand Value Associated with Number of Problems
Figure 138 illustrates the change in mental demand associated with the number of problems a participant received during the simulation. The participant who received four problems indicated a small change in mental demand, 5. The participant who received one problem indicated increased mental demand prior to the simulation. The participants with negative delta values showed higher mental demand prior to the simulation whereas, the participants with a positive delta value showed higher post simulation mental demands.

![Mental Demand Value vs. Completion Time](image)

**Figure 139: Mental Demand Value Associated with the Time to Complete a Problem**

Figure 139 indicates that as the time required to complete a problem increased, mental demand increased. The problem that took the longest to solve showed a higher pre test mental demand value. The participant that took the least time to solve the problem showed a higher post test mental demand value. One participant indicated no change in mental demand.

![Mental Demand Value vs. Problem Identification](image)

**Figure 140: Mental Demand Value Associated with the Ability to Identify Problems**
Figure 140 depicts the relationship between the ability to identify a problem correctly and the change in the mental demand. One participant that correctly identified a problem reported higher mental demands after the simulation. All other participants that correctly identified the problems had higher pre-simulation scores or indicated no change in mental demand. The one participant who did not correctly identify the problem reported higher mental demands before the simulation.

![Mental Demand Value vs. Discussion Traffic](image)

Figure 141: Mental Demand Value Associated with the Ability to Communicate Effectively

Figure 141 illustrates the change mental demand due to the ability to communicate a problem and the resolution to the simulation team. Participants with excellent communication skills indicated higher changes in mental demand values (-35), over participants with good communication skills. Participants with good communication skills reported changes in mental demand that ranged from -20 to +5.
In figure 142, one participant did not choose the correct course of action and indicated a change in mental demand of -5. One participant that correctly identified the problem indicated no change in mental demand. The negative change can be attributed to the time critical to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.

Figure 143 depicts the change in mental demand associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem experienced higher in mental demands prior to the simulation.
Figure 144: Physical Demand Compared to the Number of Problems Completed

Figure 144 compares the number of problems completed to the change in physical demand. Participants who received one problem noted either no change in physical demand or indicated higher physical demand prior to the start of the simulation. The participant who received four problems indicated higher physical demands after the simulation, +10. The difference in how much change in physical demand a participant felt could be attributed to the time of day the simulation was run or the environment (i.e. temperature, lighting).

Figure 145: Physical Demand Value associated with the time to complete a problem

Figure 145 illustrates as the time required to complete a problem increased, physical demand increased. The problem that took the longest to solve, the participant indicated no
change in physical demand. The participant who took the shortest amount of time to solve a problem indicated higher physical demands after the simulation.

![Physical Demand Value vs. Problem Identification](image)

Figure 146: Physical Demand Value Associated with the Ability to Identify Problems

Figure 146 illustrates the relationship between the ability to identify a problem correctly to the change in the physical demand. Only one participant did not correctly identify a problem and indicated no change in physical demands. The largest change in mental demand was -20, on a scale of 0 to 100.

![Physical Demand Value vs. Discussion Traffic](image)

Figure 147: Physical Demand Value Associated with the Ability to Communicate Effectively

Figure 147 depicts the change physical demand due to the ability to communicate a problem and the resolution to the simulation team. Participants with excellent communication skills reported higher changes in mental demand values (-20), over participants with good
communication skills. Participants with good communication skills reported changes in physical demand that ranged from -5 to +10.

Figure 148: Physical Demand Value vs. Decision Making

Figure 148 indicates one participant did not determine the correct course of problem resolution and reported no change in physical demand. Some participants indicated more physical demand was required prior to the simulation (-20). The negative change can be attributed to the time critical to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.

Figure 149: Physical Demand Associated with Repeated Performance

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Figure 149 illustrates the change in physical demand associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem experienced higher physical demands post simulation.

![Performance Value vs. Number of Problems](image)

**Figure 150: Performance Value Associated with Number of Problems**

Figure 150 depicts the change in a participant’s satisfaction associated with the number of problems identified during the simulation. Over half of the participants indicated high confidence prior to the simulation indicated by a negative delta performance value. The highest change in performance was -45, indicating higher confidence prior to the simulation.

![Performance Value vs. Completion Time](image)

**Figure 151: Performance Value associated with the time to complete a problem**
Figure 151 indicates that as completion time increased, post simulation satisfaction increased. The performance value is associated with satisfaction and success. The problem that took a participant the shortest and longest time to solve indicated higher levels of satisfaction after the simulation. Some of the factors they may account for higher pre simulation scores include how a participant did in a past performance or the participant’s self confidence.

![Performance Value vs. Problem Identification](image)

Figure 152: Performance Value Associated with the Ability to Identify Problems

Figure 152 illustrates the relationship between the ability to identify a problem correctly to the change in a participant’s satisfaction. The largest change in performance satisfaction was -45 indicating higher pre simulation performance satisfaction. The participant who did not correctly identify the problem given to them during the simulation indicated higher levels of satisfaction after the simulation.
Figure 153: Performance Value Associated with the Ability to Communicate Effectively

Figure 153 depicts the change in performance satisfaction due to the ability to communicate a problem and the resolution plan to the simulation team. Participants with excellent communication skill had stronger pre simulation performance satisfaction (-45) than post simulation satisfaction (15). The participant with good communication skills indicated the higher level of satisfaction after the simulation (+20).

Figure 154: Performance Value vs. the Correct Problem Resolution Plan

Figure 154 illustrates that one participant did not identify the correct course of problem resolution and indicated higher levels of satisfaction prior to the simulation. The participant who did correctly identify the problem indicated the highest satisfaction prior to the simulation (-45).
Figure 155: Performance Value Associated with Repeated Performance

Figure 155 indicates the change in a participant’s satisfaction associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem experienced a higher pre simulation satisfaction.

Figure 156: Temporal Demand Value Associated with Number of Problems

Figure 156 compares the number of problems a participant received to the change in how much pressure a participant felt during the simulation. The participants who received the most problems indicated higher pressure after the simulation. Temporal demands describe how much time pressure a participant felt and the task pace a participant was required to complete.
problems. The increase in pre-simulation pressure may be attributed to not knowing the problems being given or the pace at which the problem occurred.

![Temporal Demand Value vs. Completion Time](image1.png)

**Figure 157: Temporal Demand Value Associated with the Time to Complete a Problem**

Figure 157 indicates that as completion time increased, participants indicated an increase in pressure. The participant who took the least amount of time to solve a problem indicated higher levels of pre-simulation pressure. The participant who took the longest to solve a problem indicated more pressure after the simulation.

![Temporal Demand Value vs. Problem Identification](image2.png)

**Figure 158: Temporal Demand Value Associated with the Ability to Identify Problems**
Figure 158 depicts those participants who did not correctly identify their problem indicated no change in temporal demands. Over half of the participants who did correctly identify a problem indicated higher temporal demands after the simulation.

![Temporal Demand Value vs. Discussion Traffic](image)

**Figure 159: Temporal Demand Value Associated with the Ability to Communicate Effectively**

Figure 159 indicates the change in the time pressure a participants felt due to the ability to communicate a problem and the resolution to the simulation team. Temporal demand is associated with the amount of time pressure a participant feels. Participants with good communication skills indicated a change in pressure that ranged from -40 to +40. Participants with excellent communication skills indicated a change in pressure that ranged from -40 to +25.

![Temporal Demand Value vs. Decision Making](image)

**Figure 160: Temporal Demand Value vs. the Correct Problem Resolution Plan**
Figure 160 indicates one participant did not choose the correct problem resolution path and reported higher temporal demands after the simulation. The increase in post simulation pressure could be attributed to the rate at which tasks were given to the participants.

![Temporal Demand Value vs. Repeated Performance](image)

**Figure 161: Temporal Demand Value Associated with Repeated Performance**

Figure 161 illustrates the change in stress a participant experienced compared to the type of problem received during the simulation. All but one participant received the problems that were completed in previous simulation runs and in the data bank of problem sets. The participant who had not received their problem in a prior simulation indicated more pressure after the simulation.

![Effort Value vs. Number of Problems](image)

**Figure 162: Effort Value Associated with Number of Problems**

Figure 162 depicts the change in efforts related to the number of problems a participant received during the simulation. From the graph, half of the participants indicated no change in
effort. Additionally, the participant with the most problems did not indicate a change in effort was required to meet the desired performance level. The participants who only received one problem indicated more effort was required after the simulation.

![Effort Value vs. Completion Time](image1)

Figure 163: Effort Value Associated with the Time to Complete a Problem

Figure 163 illustrates the participant who solved a problem in longest amount of time, indicated no change in effort. The problem that took the shortest amount of time to solve, that participant also indicated no change in effort. The largest change in effort, +20, was indicated by a participant who completed a problem in 20 minutes.

![Effort Value vs. Problem Identification](image2)

Figure 164: Effort Value Associated with the Ability to Identify Problems

Figure 164 demonstrates participants who did not properly identify a problem given to them during the simulation, indicated no change in effort. Participant who correctly identified problems given to them indicated a change in effort that ranged from -10 to +20. Over half of the participants, indicated no change in effort.
Figure 165: Effort Value Associated with the Ability to Communicate Effectively

Figure 165 depicts the change in effort due to the ability to communicate a problem and the resolution to the simulation team. The participants with good communication indicated changes in effort that ranged from -10 to +20. Participants with excellent communication also indicated changes in effort that ranged from -10 to +15. Some participants with good and excellent communication indicated no change in effort.

Figure 166: Effort Value vs. the Correct Problem Resolution Plan

Figure 166 indicates that one participant did not determine the correct course of problem resolution for a problem and indicated no change in the effort. The participants that correctly chose the pre-planned problem resolution plan indicated changes in effort that ranged from -10 to +20.
Figure 167: Effort Value Associated with Repeated Performance

Figure 167 indicates the change in a participants effort level associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant who received a new problem indicated no change in effort.

Figure 168: Frustration Value Associated with Number of Problems

Figure 168 depicts how relaxed or content a participant was during their task to the number of problems given during the simulation. The participant who received the most problems indicated they were less relaxed prior to the simulation. Most participants felt more relaxed and less irritated after the simulation with the exception of one participant who indicated no change in frustration.
Figure 169: Frustration Value associated with the time to complete a problem

Figure 169 indicates the participant who took the longest to solve a problem reported no change in frustration. The participant who took the shortest amount of time to complete the problem indicated higher levels of frustration after the simulation (+25).

Figure 170: Frustration Value Associated with the Ability to Identify Problems

Figure 170 illustrates the relationship between the ability to identify a problem correctly to the change in a participant’s frustration level. The graph indicates all but one participant correctly identified the problem given to them during the simulation. The participants who did not correctly identify a problem reported feeling more frustration after the simulation (+20).
Figure 171: Frustration Value Associated with the Ability to Communicate Effectively

Figure 171 depicts the change in frustration due to the ability to communicate a problem and the resolution to the simulation team. Participants with good communication reported more frustrated after the simulation or indicated no change in frustration. Participants with excellent communication also reported feeling more frustration after the simulation.

Figure 172: Frustration Value vs. the Correct Problem Resolution Plan

Figure 172 depicts one participant did not correctly identify the problem and indicated higher frustration after the simulation (+20). Participants who correctly identified the problem indicated changes in frustration that ranged from +5 to +35. Additionally, one participant who correctly identified the problem given to them indicated no change in frustration. Participants in a post simulation interview stated some of the possible reasons for higher frustration levels post
simulation include a participant not being content with their performance, participant felt they could have done a better job during the simulation or the participant felt insecure about their performance.

![Frustration Value vs. Repeated Performance](attachment:frustration_value_vs_repeated_performance.png)

Figure 173: Frustration Value Associated with Repeated Performance

Figure 173 illustrates the change in frustration compared with the type of problem received during the simulation. All but one participant received the problems completed in previous simulation runs and in the data bank of problem sets. The participant who was not exposed to their problem in a prior simulation indicated more frustrated after the simulation (+20).

![Workload Value vs. Number of Problems](attachment:workload_value_vs_number_of_problems.png)

Figure 174: Workload Value Associated with Number of Problems

Figure 174 indicates the change in workload associated with the number of problems a participant received during the simulation. The participant who received the most problems...
indicated higher workloads after to the simulation (+10). Participants who only received one problem indicated changes in workload that ranged from -11 to +25.

![Graph: Workload Value vs. Completion Time](image)

**Figure 175: Workload Value Associated with the Time to Complete a Problem**

Figure 175 indicates as the time required to complete a problem increased, the amount of work required to complete the problem also increased. The participant who took the longest time to solve a problem showed a change in workload of +5. The participant, who solved a problem in the shortest amount of time, indicated a change in workload of +10.

![Graph: Total Workload Value vs. Problem Identification](image)

**Figure 176: Workload Value Associated with the Ability to Identify Problems**

Figure 176 depicts one participant did not correctly identify a problem and indicated higher workloads after the simulation (+10). Participants who did correctly identify a problem indicated a change in workload that ranged from -25 to +13.
Figure 177: Workload Value Associated with the Ability to Communicate Effectively

Figure 177 depicts the change in workload due to the ability to communicate a problem and the resolution to the simulation team. Participants with good communication indicated higher workloads after the simulation with the exception of one participant who reported higher workload prior to the simulation (-25). Participants with excellent communication indicated higher workload prior to the simulation with the exception of one participant who reported higher workloads after the simulation (+10).

Figure 178: Workload Value Associated with the Ability to Determine the Correct Problem Resolution

Figure 178 indicated one participant did not choose the correct course of problem resolution and noted higher workloads after the simulation. The participants who correctly
identified the right problem resolution path indicated higher pre simulation workload values (-25).

![Workload Value vs. Repeated Performance](image)

**Figure 179: Workload Value Associated with Repeated Performance**

Figure 179 depicts the change in workload associated with the type of problem received during the simulation. One participant received a problem that was not in a previous simulation run and indicated more work was required post simulation (+10). Participants who received the problem given to them in a previous simulation run indicted changes in workload that ranged from -25 to +12.

**SOFI**

The Swedish Occupation Fatigue Inventory (SOFI) is a subjective tool that describes fatigue using five dimensions: lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness. The dimensions represent the perceptions of how participants feel at a given point in time. The participants completed the inventory pre- and post-simulation. The results of the inventory are included in charts 180 through 209.

This study looked at the change in the five dimensions. The possible values that SOFI produced ranged from 0 to 10. If a participant delta rating is negative, this indicates a
participant’s pre-simulation values were higher than the post simulation values. If the delta is positive, the post simulation values are greater than the pre-simulation values.

![Graph: Lack of Energy vs. Number of Problems](image)

Figure 180: Lack of Energy Compared to Number of Problems

Figure 180, indicates one participant who received the most number of problems reported an increase in energy required to complete the problem. The participants with only one problem to solve indicated a change in the amount of energy required to complete the problem that ranged from -0.25 to +0.25.

![Graph: Lack of Energy vs. Completion Time](image)

Figure 181: Lack of Energy Associated with Completion Time

Figure 181 demonstrated participants who took the longest time to solve a problem indicated less energy prior to the simulation (-2.25). The participant who took the least amount
of time to complete a problem indicated less energy after the simulation (3). All participants did indicate a change in energy.

Figure 182: Lack of Energy Associated with the Ability to Identify Problems

Figure 182 indicates one participant did not correctly identify a problem given to them during the simulation and reported more energy was required after the simulation (+3). Participants who were able to correctly identify a problem indicated a change in energy that ranged from -.2.5 to 3.

Figure 183: Lack of Energy Associated with the Ability to Communicate Effectively

Figure 183 illustrates the change in energy levels due to the ability to communicate a problem and the resolution to the simulation team. Those participants with good communication, half of the participants reported having less energy after the simulation. Those
participants with excellent communication skills indicated less energy prior to the simulation with the exception of one participant who indicated having less energy after the simulation.

![Graph](image)

**Figure 184: Lack of Energy vs. the Correct Problem Resolution Plan**

Figure 184 indicates one participant did not choose the correct course of problem resolution and reported having less energy after the simulation. Half of the participants that chose the correct problem resolution path reported more energy was required prior to the simulation.

![Graph](image)

**Figure 185: Lack of Energy Associated with Repeated Performance**

Figure 185 depicts the change in a participant’s energy level associated with the type of problem received during the simulation. Participants who had not been previously exposed to a
problem reported less energy prior to the simulation (-0.75). Participants who previously experienced a problem indicated changes in energy levels that ranged from -2.25 to +3.

Figure 186: Physical Exertion Compared to Number of Problems

Figure 186 indicates as the number of problems increased, more physical energy was required to complete the problem. The participants who received only one problem indicated changes in the amount of physical energy required to complete the simulation that ranged from -2 to +1.5. Some participants indicated no change in physical exertion.

Figure 187: Physical Exertion Associated with the Time to Complete a Problem

Figure 187 demonstrated the participant who took the longest to solve a problem reported more physical exertion was required prior to the simulation. The participant who took the short amount of time to complete a problem reported more physical exertion was required after the
simulation. The tasks presented are a mental exercise rather than physical in nature which could explain why some participants did not note any change in physical exertion.

Figure 188: Physical Exertion Associated with the Ability to Identify Problems

Figure 188 illustrates one participant did not identify correctly identify a problem given to them during the simulation and indicated higher physical exertion was required prior to the simulation. The graph depicts those individuals who were able to correctly identify a problem indicated changes in physical exertion that ranged from -0.5 to 1.5.

Figure 189: Physical Exertion Associated with the Ability to Communicate Effectively

Figure 189 indicates the change in physical exertion due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited good communication skills indicated higher levels of physical exertion were required after the simulation or indicated no change in physical exertion.
Figure 190: Physical Exertion vs. the Correct Problem Resolution Plan

Figure 190 indicates one participant who did not choose the correct course of problem resolution noted no change in the level of physical energy needed to complete the simulation. Participants who did choose the correct resolution plan indicated changes in physical exertion that ranged from -2 to +1.5. The lack of change could be attributed to the type of problem the individual was given since all tasks were mentally demanding in nature.

Figure 191: Physical Exertion Associated with Repeated Performance

Figure 191 depicts the change in a participant’s level of physical energy associated with the type of problem received during the simulation. The participant, who had not been previously exposed to the problem in past simulation runs, indicated no change in physical exertion.
Figure 192: Physical Discomfort Compared to Number of Problems

Figure 192 illustrates the one participant with the most problems to solve indicated an increase in physical discomfort prior the simulation. Participants who only solved one problem indicated a change in physical discomfort that ranged from -3 to 0. All participants indicated higher levels of physical discomfort prior to the simulation with the exception of one participant who indicated no change in physical discomfort.

Figure 193: Physical Discomfort Associated with the Time to Complete a Problem

Figure 193 indicates the one participant who took the longest to solve a problem reported more physical discomfort prior the simulation (-2). The participant, who took the least amount
of time to complete their problem, also reported more physical discomfort prior the simulation (-0.75).

Figure 194: Physical Discomfort Associated with the Ability to Identify Problems

Figure 194 indicates only one participant did not correctly identify a problem and reported more physical discomfort prior to the simulation (-0.75). Participants who did correctly identify a problem indicated higher physical discomfort prior to the simulation or indicated no change. Participants may have felt more physical discomfort prior to the simulation due exhaustion because of carrying material over to the simulation room, muscles are tense because of computer position or due to numbness of joints.

Figure 195: Physical Discomfort Associated with the Ability to Communicate Effectively
Figure 195 illustrates the change in physical discomfort due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited good communication felt more discomfort prior to the simulation or indicated no change in physical discomfort.

![Figure 195: SOFI-Physical Discomfort vs. Decision Making](image)

Figure 196: Physical Discomfort vs. the Correct Problem Resolution Plan

Figure 196 indicates one participant did not choose the correct course of problem resolution. This participant noted more physical discomfort prior to the simulation (-0.25). Participants who did correctly identify the correct course of problem resolution indicated changes in physical discomfort that ranged from 0 to -3.

![Figure 196: SOFI-Physical Discomfort vs. Repeated Performance](image)

Figure 197: Physical Discomfort Associated with Repeated Performance
Figure 197 illustrates the change in a participant’s level of physical discomfort associated with the type of problem received during the simulation. The participants who were not previously exposed to the problem indicated more physical discomfort prior to the simulation (-0.75).

![Figure 197](image)

Figure 198 Lack of Motivation Compared to Number of Problems

Figure 198 indicates as the number of problems a participant has to complete increased, lack of motivation also increased. The participant, with the most number of problems to solve, reported higher levels of motivation after the simulation. Participants with one problem to complete indicated a change in levels of motivation that ranged from (-3.25 to 1.25).

![Figure 198](image)

Figure 199: Lack of Motivation Associated with the Time to Complete a Problem

![Figure 199](image)
Figure 199 showed that the participants who took longest to solve their problem indicated less motivation prior to the simulation (-3.25). The participant who solved the problem in the shortest amount of time felt less motivated after the simulation (.75). All participants did indicate some change in motivation.

![Graph showing SOFI-Lack of Motivation vs. Problem Identification](image)

Figure 200: Lack of Motivation Associated with the Ability to Identify Problems

Figure 200 indicates one participant did not correctly identify a problem, reported lower levels of motivation prior the simulation (-1.25). Participants may have felt less motivated after the simulation due to their performance during the simulation or the results from peer and/or director evaluations.

![Graph showing SOFI-Lack of Motivation vs. Discussion Traffic](image)

Figure 201: Lack of Motivation Associated with the Ability to Communicate Effectively

Figure 201 depicts the change in motivation due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited good communication
indicated change in motivation that ranged from -3.25 to +0.75. Participants who exhibited excellent communication indicated changes in motivation that ranged from -2.75 to +1.25.

![SOFI-Lack of Motivation vs. Decision Making](image)

**Figure 202: Lack of Motivation vs. the Correct Problem Resolution Plan**

Figure 202 data indicates no relation can be drawn from the ability of a participant to determine the correct course of problem resolution on to the change in the participant’s level of motivation.

![SOFI-Lack of Motivation vs. Repeated Performance](image)

**Figure 203: Lack of Motivation Associated with Repeated Performance**

Figure 203 indicates one participant did not chose the correct course of problem resolution and reported less motivation prior to the simulation (-1.25). Over half of the participants who did chose the correct course of problem resolution felt less motivated prior the simulation.
Figure 204: Sleepiness Compared to Number of Problems

Figure 204 illustrates the number of problems a participant has to complete against the level of sleepiness experienced during the simulation. Participants with three problems indicated higher levels of sleepiness after the simulation. All changes in sleepiness were small, no value larger than 3, on a scale from 0 to 10. All participants who only received one problem indicated higher levels of sleepiness prior to the simulation.

Figure 205: Sleepiness Associated with Completion Time

Figure 205 demonstrated the participants who took longest to solve a problem indicated higher levels of sleepiness after the simulation (+0.5). The participant who solved the problem in the shortest amount of time reported high levels of sleepiness after the simulation (+0.5).
Figure 206: Sleepiness Associated with the Ability to Identify Problems

Figure 206 indicates one participant did not correctly identify a problem and reported higher levels of sleepiness after to the simulation. The participants who were able to correctly identify the problem during the simulation indicated change in sleepiness that ranged from -3 to +0.5.

Figure 207: Sleepiness Associated with the Ability to Communicate Effectively

Figure 207 indicates the change in sleepiness due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited good communication reported changes in sleepiness that ranged from -3 to +0.5. Participants with excellent communication, rating of 3, indicated changes in sleepiness that ranged from -1.25 to +0.5.
Figure 208: Sleepiness vs. the Correct Problem Resolution Plan

Figure indicates one participant was not able to choose the correct course of problem resolution and reported higher levels of sleepiness after the simulation. Over half of the participants who did choose the correct course of problem resolution reported higher levels of sleepiness prior the simulation.

Figure 209: Sleepiness Associated with Repeated Performance

Figure 209 illustrates a participant’s level of sleepiness associated with the type of problem received during the simulation. The participant who had not seen the problem in a previous simulation run indicated higher levels of sleepiness after the simulation (+0.5).
4.1.3 Prime System Engineer

Prime System Engineers, the main console operators, make the initial call to the flight or launch director to explain a problem and initiate the troubleshooting plans. These individuals will also make recommendations and summarize the troubleshooting plans and results with the flight and launch directors. Additionally, these are the individuals who have the primary speaking role.

4.1.3.1 Heart Rate and Blood Pressure

Heart rate readings were collected on a continuous basis during the simulation. Data was downloaded onto a laptop for analysis. Blood pressure readings were taken after the simulation.

![Change in Heart Rate vs. Number of Problems](image)

Figure 210: Change in Heart Rate Compared to Number of Problems

Figure 210 indicates as the number of problems a participant has to complete increased, heart rate also increased. The participant who solved two problems reported the greatest change in heart rate (50 bpm). The participant with four problems to solve indicated the smallest change in heart rate (8 bpm).
Figure 211: Change in Heart Rate Associated with Completion Time

Figure 211 indicated the participants who took 10 minutes to solve a problem reported the largest change in heart rate. The participant who took the longest time to solve a problem reported a change in heart rate of 17 bpm. Most participants change in heart rate varied from 10 to 20 bpm.

Figure 212: Change in Heart Rate Associated with the Ability to Identify Problems

Figure 212 depicts the relationship between the ability to identify a problem correctly and a change in a participant’s heart rate. One participant who did not correctly identify the problem reported a change in heart rate of 17 bpm. The participant who correctly identified a problem given to them indicated the smallest and largest change in heart rate.
Figure 213: Change in Heart Rate Associated with the Ability to Communicate Effectively

Figure 213 illustrates the change in heart rate due to the ability of a participant to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication reported a change in heart rate of 14 bpm. The participant with the smallest and largest change in heart rate exhibited good communication skills, rating of 2.

Figure 214: Change in Heart Rate vs. the Correct Problem Resolution Plan

In figure 214, one participant did not choose the correct course of problem resolution and reported a change in heart rate of 20 bpm. The participants who were able to choose the correct course of problem resolution exhibited the smallest and largest change in heart rate.
Figure 215: Change in Heart Rate Associated with Repeated Performance

Figure 215 illustrates the change in a participant’s heart rate associated with the type of problem received during the simulation. The participant who had not been exposed to their problem in previous simulation runs reported a change in heart rate of 28 bpm. The participant with the smallest change in heart rate had previously experienced the problem.

Figure 216: Blood Pressure Compared to Number of Problems

Figure 216 indicates a participant who had four problems to solve reported the highest blood pressure. The participant with five problems to solve had blood pressure reading of 116 mmHg. The participant with three problems to solve reported the smallest blood pressure reading.
Figure 217: Blood Pressure Associated with Completion Time

Figure 217 indicates participants who greater than 40 minutes to solve a problem reported blood pressure readings of less than 115 mmHg. The participant who solved a problem in the shortest amount of time reported the higher blood pressure reading, 118 mmHg.

Figure 218: Blood Pressure Associated with the Ability to Identify Problems

Figure 218 indicates one participant did not correctly identify a problem given to them during the simulation. The participant who did not correctly identify a problem reported a blood pressure reading of 118 mmHg. The participant who correctly identified a problem reported the highest blood pressure reading.
Figure 219: Blood Pressure Associated with the Ability to Communicate Effectively

Figure 219 illustrates how blood pressure is associated with a participant’s ability to communicate a problem and the resolution to the simulation team. The participant who exhibited poor communication skills reported a blood pressure reading of 118 mmHg. The participant with the lowest blood pressure reading exhibited good communication skills.

Figure 220: Blood Pressure vs. the Correct Problem Resolution Plan

In figure 220, one participant did not choose the correct course of problem resolution and reported a blood pressure reading of 130 mmHg, which is one of the largest readings. The participants who were able to choose the correct course of problem resolution exhibited a blood pressure reading s between 130 mmHg to 112 mmHg.
Figure 221: Blood Pressure Associated with Repeated Performance

Figure 221 indicates one participant was not exposed to their problem in past simulation. This participant reported a blood pressure reading of 116 mmHg. The participant with the smallest blood pressure reading had seen their problem in a previous simulation.

4.1.3.2 Yoshitake Type I and II Fatigue

Figures 216 through 227 of this document reflect the results obtained from administering Yoshitake Type I and II Fatigue surveys to research participants. Each participant completed the checklist of subjective symptoms of fatigue pre- and post-simulation. Participants either checked yes if they felt the symptom or no if they did not feel the symptom. Answers of yes were given a score of one; answers of no were given a score of zero. Under each type of fatigue, the boxes were totaled and combined to ascertain an overall fatigue score.
The highest value of physical fatigue possible is 1, whereas, the highest value obtained was 0.17. Figure 222 indicates the value of physical fatigue remained low even as the number of problems increased. The participant who received the most number of problems indicated a change in physical fatigue of +0.17.

Figure 223 demonstrates that as the time required to complete a problem increased, the physical fatigue levels increased. The participant who took the longest to solve a problem noted +0.085 change, very small, in physical fatigue. Possible reasons for higher levels of fatigue include system constraints which forces individuals to determine problem resolution plans quicker.
Figure 224: Physical Fatigue Associated with the Ability to Identify Problems

Figure 224 indicates the change physical fatigue levels remained low -0.25. The participant, who had not seen the problem given to them in a previous simulation run, indicated higher levels of physical fatigue prior to the simulation.

Figure 225: Physical Fatigue Associated with the Ability to Communicate Effectively

Figure 225 depicts a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results indicated that those participants who chose words carefully and were well spoken showed increases in physical fatigue or indicated no change in physical fatigue. The participant, with poor communication, rating of one, indicated no change in physical fatigue. Participants chose carefully to increase technical understanding within the community and provide necessary data to other affected groups.
Figure 226: Physical Fatigue vs. the Correct Problem Resolution Plan

Figure 226 illustrates those participants who did not correctly determined the proper problem resolution plan indicated higher physical fatigue values after the simulation, +0.17. The participants who did correctly determine the proper problem resolution plan indicated changes in physical fatigue that ranged from -0.25 to +0.17.

Figure 227: Physical Fatigue Associated with Repeated Performance

Figure 227 indicates some participants reported a change in physical fatigue levels even though the problems presented to them were problems experienced in past simulation runs. However, the associated physical fatigue changes were minimal. The participant who did not see the problem given to them in a previous simulation run indicated a +0.085 change in physical fatigue.
Figure 228: Mental Fatigue Associated with Number of Problems

Figure 228 indicates as the number of problems increased for a participant, mental fatigue also increased. The participant, who received the most number of problems, indicated a 0.375 change in mental fatigue. The participant, who received four problems, indicated no change in mental fatigue.

Figure 229: Level of Mental Fatigue Associated with the Time to Complete a Problem

Figure 229 depicts as the time required to complete a problem increased, the mental fatigue levels decreased. Some participants indicated no change in mental fatigue. The participant who solved a problem in the longest amount of time indicated a + 0.13 change in mental fatigue. Possible reasons for higher levels of fatigue include system constraints which forces individuals to determine problem resolution plans quicker and time constraints for other orbit operations.
Figure 230: Mental Physical Fatigue Associated with the Ability to Identify Problems

Figure 230 depicts one participant did not correctly identify a problem, and indicated a change in mental fatigue of 0.13. Some participant who did correctly identify the problem given to them during the simulation indicated no change in mental fatigue.

Figure 231: Mental Fatigue Associated with the Ability to Communicate Effectively

Figure 231 illustrates a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results indicated those participants who chose words carefully and were well spoken reported increases in mental fatigue. The participant, with poor communication, rating of 1, indicated no change in mental fatigue. Participants chose words carefully to increase technical understanding within the community and provide necessary data to other affected groups.
Figure 232: Physical Fatigue vs. the Correct Problem Resolution Plan

Figure 232 indicates those participants who had correctly determined the proper problem resolution plan reported higher mental fatigue values. The participant who did not correctly chose the proper problem resolution plan indicated no change in mental fatigue.

Figure 233: Physical Fatigue Associated with Repeated Performance

Figure 233 illustrates some participants indicated a change in mental fatigue levels even though the problems presented to them were problems seen in past simulation runs. The participant who received a new problem during the simulation indicated a change in mental fatigue of 0.13.
4.1.3.3 Overall Job Satisfaction

Participants completed a subjective job satisfaction survey prior to the simulation that focused on job and organizational-related satisfiers. Participants were given a series of questions, which asked them to rank their response on a scale from one to five with one being strongly disagreed with a statement and five being strongly agreed with the statement. The results are shown below is figures 234 to 239. Most participants indicated a rating of four on the survey signifying that they were satisfied with their job.

![Overall Job Satisfaction vs. Number of Problems](image)

Figure 234: Job Satisfaction Associated with Number of Problems

Figure 234 illustrates that for the range of the number of problems a participant was given, the overall level of job satisfaction was high. All participants reported job satisfaction ratings above 4 on a scale from 1 to 5, with five being the top rating. The participant who received four problems reported a 4.4 overall job satisfaction level.
Figure 235: Job Satisfaction Associated with the Time to Complete a Problem

Figure 235 depicts the participant who solved a problem in the longest amount of time reported a high level of job satisfaction, 4.85, which was also true for the participant who solved a problem in the least amount of time, 4.05. The high level of job satisfaction could be attributed to the people the participant works with, the technical content a participant is exposed to and the cultural environment.

Figure 236: Job satisfaction Associated with the Ability to Identify Problems

Figure 236 demonstrates that regardless of the ability to correctly identify a problem, the participant still had a high level of job satisfaction. Those participants who did not correctly identify still indicated a rating of 4.05 for his overall job satisfaction level.
Figure 237 Job Satisfaction Associated with the Ability to Communicate Effectively

Figure 237 depicts a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results showed that those who chose words carefully and were well spoken showed the same level of job satisfaction as individuals who chose their words less careful. Participants, with good communication skills, rating of 2, reported the highest job satisfaction. The participants, with the poor communication, reported the lowest job satisfaction. 4.05.

Figure 238 Job Satisfactions vs. the Correct Problem Resolution Plan

Figure 238 indicates participants who had correctly determined the proper problem resolution plan reported higher levels of job satisfaction. The participant who did not correctly chose the proper resolution plan indicated a 4.4 level of job satisfaction on a scale from 1 to 5.
The high ratings of job satisfaction can be attributed to the technical material participants are able to work with and the passion for the industry.

![Overall Job Satisfaction vs. Repeated Performance](image)

Figure 239: Job Satisfaction Associated with Repeated Performance

Figure 239 illustrates that regardless of participants being able to correctly identify the problem, job satisfaction was above average. All but one participant was previously exposed to their problem in a past simulation and indicated a 4.2 overall job satisfaction.

### 4.1.3.4 NASA TLX

NASA TLX, multi-dimensional rating procedure that generates an overall workload value based on six subscales, is a subjective assessment tool used to determine levels of workload. NASA TLX provided the principal investigator with a tool to perform subjective workload assessment on jobs that require the participant to interface with human-machine systems (i.e. computers). Charts 217 through 258 present the results from the NASA TLX analysis.

Participants completed a NASA TLX survey pre- and post-simulation. This study looked at the changes of the six subscales and overall workload. The possible values that TLX produced ranged from 0 to 100. If a participant delta rating is negative, this indicates a participant’s pre-
simulation values were higher than the post simulation values. If the delta is positive, the post simulation values are greater than the pre-simulation values.

Figure 240: Mental Demand Value Associated with Number of Problems

Figure 240 illustrates the change in mental demand associated with the number of problems a participant received during the simulation. The data indicates the one participant who received five problems reported more mental demand was needed after the simulation, +15. Some participants indicated no change in mental demand.

Figure 241: Mental Demand Value Associated with the Time to Complete a Problem

Figure 241 indicates the participant who took the longest to solve a problem reported no change in mental demand. The participant that took the least amount of time to solve the problem indicated higher levels of mental demand were need prior to the simulation.
Figure 242: Mental Demand Value Associated with the Ability to Identify Problems

Figure 242 illustrates the relationship between the ability to identify a problem correctly to the change in the mental demand. Only one participant that correctly identified a problem reported higher post simulation scores. All other participants that correctly identified the problems had higher pre-simulation scores. The largest change in mental demand was +15, indicating the participant required more mental demand prior to the simulation. The participant who did not correctly identify the problem given to them during the simulation indicated more mental demand was required prior the simulation.

Figure 243: Mental Demand Value Associated with the Ability to Communicate Effectively

Figure 243 illustrates the change mental demand due to the ability to communicate a problem and the resolution to the simulation team. Participants with excellent communication
skills reported higher changes in mental demand values (+15), over participants with poor communication skills (-5). Participants with good communication skills showed a change in mental demand that ranged from -10 to +15.

![Mental Demand Value vs. Decision Making](image1)

Figure 244: Mental Demand Value vs. the Correct Problem Resolution Plan

In figure 244, one participant did not choose the correct course of action and indicated no change in mental demand. One participant that correctly identified the problem showed no change in physical demand. The negative change can be attributed to the time critical to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.

![Mental Demand vs. Repeated Performance](image2)

Figure 245: Mental Demand Associated with Repeated Performance
Figure 245 illustrates the change in mental demand associated with the type of problem. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem indicated more mental demand was needed prior to the simulation.

![Physical Demand Value vs. Number of Problems](image_url)

Figure 246: Physical Demand Compared to the Number of Problems Completed

Figure 246 compares the number of problems completed to the change in physical demand. The participant who received the most number of problems indicated higher physical demands after the simulation. The participants who received three problems indicated no change in physical demand or felt more physical demand was needed after the simulation.

![Physical Demand Value vs. Completion Time](image_url)

Figure 247: Physical Demand Value Associated with the Time to Complete a Problem
Figure 247 indicates the problem that took the longest to solve, the participant indicated no change in physical demand. The problem that took the shortest amount of time to solve, the participant indicated more physical demand was needed after the simulation.

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**Figure 248: Physical Demand Value Associated with the Ability to Identify Problems**

Figure 248 depicts only one participant did not correctly identify the problem given to them during the simulation and indicated no change in physical demand. The largest change in mental demand was +15, on a scale of 0 to 100. Some participants who did correctly identify the problem given to them during the simulation also indicated no change in physical demand.

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**Figure 249: Physical Demand Value Associated with the Ability to Communicate Effectively**

Figure 249 illustrates the change physical demand due to the ability to communicate a problem and the resolution to the simulation team. Participants with excellent communication
skills reported higher changes in physical demand after the simulation. Participants with poor communication indicated higher levels of physical demand after the simulation.

![Physical Demand Value vs. Decision Making]

Figure 250: Physical Demand Value vs. the Correct Problem Resolution Plan

Figure 250 indicates one participant did not determine the correct course of problem resolution and reported no change in physical demand. Participants who choose the correct problem resolution plan indicated changes in physical demand that ranged from -5 to +15. The negative change can be attributed to the time critical to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.

![Physical Demand Value vs. Repeated Performance]

Figure 251: Physical Demand Associated with Repeated Performance
Figure 251 depicts the change in physical demand associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem indicated no change in physical demand.

![Performance Value vs. Number of Problems](image1)

Figure 252: Performance Value Associated with Number of Problems

Figure 252 indicates participant that received the most number of problems reported higher performance values after the simulation. The participant who received the fewest number of problems also indicated a better performance after the simulation. The performance value measures how successful a person thought they were going to be during a performance period and how satisfied a person was with their performance. Over half of the participants reported a better performance after the simulation indicated by a positive delta value.

![Performance Value vs. Completion Time](image2)

Figure 253: Performance Value Associated with the Time to Complete a Problem
Figure 253 illustrates as the time required to complete a task increased, post simulation satisfaction also increased. The performance value is associated with satisfaction and success. The participant who took the longest to solve a problem indicated higher levels of satisfaction after the simulation. The problem that took the least amount of time, that participant indicated no change in performance.

![Performance Value vs. Problem Identification](image)

Figure 254: Performance Value Associated with the Ability to Identify Problems

Figure 254 indicates one participant was not able to identify a problem given to them during the simulation indicated no change in performance. Those participants who correctly identified the problem indicated changes in performance that ranged from -4 to +10.

![Performance Value vs. Discussion Traffic](image)

Figure 255: Performance Value Associated with the Ability to Identify Problems
Figure 255 illustrates the change in performance satisfaction due to the ability to communicate a problem and the resolution to the simulation team. Participants with poor communication skills, rating of 1, indicated no change in performance satisfaction. Participants with excellent communication skill indicated higher performance satisfaction after the simulation (+5) or indicated no change in performance satisfaction.

![Performance Value vs. Decision Making](image)

Figure 256: Performance Value vs. the Correct Problem Resolution Plan

Figure 256 illustrates one participant did not determine the correct course of problem resolution and indicated higher levels of satisfaction prior to the simulation (-5). The negative change can be attributed to the time pressure associated with the need to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team. Over half of the participants indicated higher levels of performance satisfaction after the simulation.
Figure 257: Performance Value Associated with Repeated Performance

Figure 257 indicates the change in a participant’s satisfaction associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem experienced a higher post simulation satisfaction (+5).

Figure 258: Temporal Demand Value Associated with Number of Problems

Figure 258 compares the number of problems a participant received to the change in how much pressure a participant felt during the simulation. All participants indicated higher temporal demands post simulation. The participants who received the most problems indicated a change
temporal demand of +30. The increase in pre-simulation pressure may be attributed to not knowing the problems being given or the pace at which the problem occurred.

Figure 259: Temporal Demand Value Associated with the Time to Complete a Problem

Figure 259 indicates the participant who took the longest to solve a problem, indicated higher temporal demands after the simulation. Participants who took the least amount of time to solve problems reported higher levels of temporal demand after the simulation. All participants indicated higher temporal demands after the simulation.

Figure 260: Temporal Demand Value Associated with the Ability to Identify Problems

Figure 260 illustrates those participants who did not correctly identify their problem indicated higher post simulation scores (+5). Participants who did correctly identify the problem
given to them in the simulation indicated a change in temporal demand that ranged from +5 to +30.

Figure 261: Temporal Demand Value Associated with the Ability to Communicate Effectively

Figure 261 indicates the change in the time pressure a participants felt due to the ability to communicate a problem and the resolution to the simulation team. Participants, with poor communication, rating of 1, indicated more pressure after the simulation. Participants, with good communication, rating of 2, indicated higher pressures after the simulation that ranged from +5 to +30.

Figure 262: Performance Value vs. the Correct Problem Resolution Plan
Figure 239 indicates one participant did not choose the correct course of action and reported higher temporal demand after the simulation (+20). The increase in post simulation pressure could be attributed to the rate at which tasks were given to the participants.

Figure 263: Performance Value Associated with Repeated Performance

Figure 263 depicts the change in stress a participant felt compared with the type of problem received during the simulation. All but one participant received the problems that were completed in previous simulation runs and in the data bank of problem sets. The participant who had not seen the problem given to them in a prior simulation felt more pressure after the simulation (+5).

Figure 264: Effort Value Associated with Number of Problems

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Figure 264 indicates as the number of problems increased for a participant, effort values decreased. The participant with the most problems to solve indicated no change in effort. All participants indicated higher effort values after the simulation.

![Delta-Effort Value vs. Completion Time](image1)

Figure 265: Effort Value Associated with the Time to Complete a Problem

Figure 265 depicts the change in efforts related to the number of problems a participant saw during the simulation. One participant who took the longest to solve a problem indicated no change in effort. The problem that took a participant the shortest amount of time to complete indicated higher effort values after the simulation (+30).

![Effort Value vs Problem Identification](image2)

Figure 266: Effort Value Associated with the Ability to Identify Problems
Figure 266 demonstrates that those participants, who did not properly identify a problem given to them during the simulation, indicated no change in effort. Participants who did correctly identify the problem given to them during the simulation indicated changes in effort that ranged from 0 to +30.

Figure 267: Effort Value Associated with the Ability to Communicate Effectively

Figure 267 indicates the change in effort due to the ability to communicate a problem and the resolution to the simulation team. The participant with poor communication skills indicated more effort was required after the simulation (+30). Participants, with excellent communication, rating of 3, indicated higher effort values after the simulation that ranged from +10 to +30.

Figure 268: Effort Value vs. the Correct Problem Resolution Plan
Figure 268 indicates one participant did not determine the correct course of problem resolution for the problem they were given. This participant indicated no change in the effort required to complete simulation. The participants that correctly chose the pre-planned problem resolution plan indicated more effort was required after the simulation.

![Effort Value vs. Repeated Performance](image)

Figure 269: Effort Value Associated with Repeated Performance

Figure 269 depicts the change in a participants effort level associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant who received a new problem indicated no change in effort.

![Frustration Value vs. Number of Problems](image)

Figure 270: Frustration Value Associated with Number of Problems
Figure 270 depicts as the number of problem increased, frustration also increased. The participant who received the most problems indicated feeling less relaxed after the simulation (+20). Most participants felt more relaxed and less irritated after the simulation with the exception of three participants. All participants indicated some change in frustration.

![Frustration Value vs. Completion Time](image1)

Figure 271: Frustration Value Associated with the Time to Complete a Problem

Figure 271 indicates that participant who took the longest to solve a problem indicated more stress or increased levels of irritation after the simulation (-45). The participant who took the shortest amount of time to complete a problem given to them during the simulation indicated higher frustration levels after the simulation (+30).

![Frustration Value vs. Problem Identification](image2)

Figure 272: Frustration Value Associated with the Ability to Identify Problems
Figure 272 indicates all but one participant correctly identified the problem given to them during the simulation. The participant who did not correctly identify the problem given to them in the simulation indicated more frustration after the simulation (+10). Most participants indicated higher levels of frustration after the simulation.

![Frustration Value vs. Discussion Traffic](image1)

**Figure 273: Frustration Value Associated with the Ability to Communicate Effectively**

Figure 273 illustrates the change in frustration due to the ability to communicate a problem and the resolution to the simulation team. Participants with poor communication, rating of 1, indicated more frustration after the simulation (+30). Participants, with excellent communication, rating of 3, also indicated more frustration after the simulation (+20 to +30).

![Frustration Value vs. Decision Making](image2)

**Figure 274: Frustration Value vs. the Correct Problem Resolution Plan**

Figure 274 indicates that one participant did not correctly identify the problem and reported more frustration after the simulation. Participants in a post simulation interview stated
some of the possible reasons for higher frustration levels post simulation include a participant not being content with their performance, participant felt they could have done a better job during the simulation or the participant felt insecure about their performance.

![Image](image1.png)

**Figure 275: Frustration Value Associated with Repeated Performance**

Figure 275 depicts the change in frustration compared with the type of problem a participant received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The participant who had not been previously exposed to their problem indicated more frustration after the simulation (+10).

![Image](image2.png)

**Figure 276: Workload Value Associated with Number of Problems**

Figure 276, indicates the change in workload associated with the number of problems a participant received during the simulation. The participant with the most problems to complete
indicated higher workloads after the simulation (+23). The participants who received three problems also indicated higher workloads after the simulation.

**Figure 277: Workload Value Associated with the Time to Complete a Problem**

Figure 277 indicates as the time required to complete a problem increased, the amount of work required to complete the problem decreased. The participant the most time to complete a problem indicated a change in workload of +0.034. The participant who took the shortest amount of time to complete the problem indicated a change in workload of +11.35.

**Figure 278: Workload Value Associated with the Ability to Identify Problems**

Figure 278 indicates one participant did not correctly identify a problem given to them during the simulation and reported higher workload values prior to the simulation (-1.67).
Participants who did correctly identify a problem had a broad range in the change in the amount of work that was required to complete the simulation (-1.67 to +23.35).

Figure 279: Workload Value Associated with the Ability to Communicate Effectively

Figure 279 depicts the change in workload due to the ability to communicate a problem and the resolution to the simulation team. Participants, with poor communication, rating of 1, indicated higher post simulation workload levels (+11.3). Participants with good communication also indicated higher workloads after the simulation (+11.3 to +22.3).

Figure 280: Workload Value Associated with the Ability to Determine the Correct Problem Resolution

Figure 280 indicates one participant did not choose the correct course of problem resolution and noted higher workloads after the simulation (+0.33). Most participants that
correctly identified the right problem resolution path had higher post simulation workload values.

![Total Workload Value vs. Repeated Performance](image)

Figure 281: Workload Value Associated with Repeated Performance

Figure 281 depicts the change in workload associated with the type of problem received during the simulation. One participant received a problem that was not in a previous simulation run and indicated more work was required post simulation (+0.33).

### 4.1.3.5 SOFI

The Swedish Occupation Fatigue Inventory (SOFI) is a subjective tool that describes fatigue using five dimensions: lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness. The dimensions represent the perceptions of how participants feel at a given point in time. The participants completed the inventory pre- and post-simulation. The results of the inventory are included in charts 259 through 288.

This study looked at the change in the five dimensions. The possible values that SOFI produced ranged from 0 to 10. If a participant delta rating is negative, this indicates a participant’s pre-simulation values were higher than the post simulation values. If the delta is positive, the post simulation values are greater than the pre-simulation values.
Figure 282: Lack of Energy Compared to Number of Problems

Figure 282, indicates as the number of problems increased, more energy was required to complete a problem. The participant with the most problems to solve indicated more energy was required after the simulation than after (+3.25). The largest change in energy was +4. Some participants indicated no change in energy.

Figure 283: Lack of Energy Associated with Completion Time

Figure 283 illustrates the participant who took the longest time to solve a problem reported less energy after the simulation (+4). The participant who took the least amount of time to complete the problem indicated no change in energy.
Figure 284: Lack of Energy Associated with the Ability to Identify Problems

Figure 284 indicates one participant was not able to correctly identify the problem given to them during the simulation and reported no change in energy. Participants who were able to correctly identify the problem given to them during the simulation indicated less energy after the simulation.

Figure 285: Lack of Energy Associated with the Ability to Communicate Effectively

Figure 285 illustrates the change in energy levels due to the ability to communicate a problem and the resolution to the simulation team. Those participants, with poor communication, rating of 1, indicated no change in energy. Those participants with good communication either, 2, felt no change in energy after the simulation or had less energy after the simulation (+3.25 to +4).
Figure 286: Lack of Energy vs. the Correct Problem Resolution Plan

Figure 286 indicates one participant did not choose the correct course of problem resolution and indicated no change in energy. All of the participants that chose the correct problem resolution path indicated more energy was required after the simulation or indicated no change.

Figure 287: Lack of Energy Associated with Repeated Performance

Figure 287 depicts the change in a participant’s energy level associated with the type of problem received during the simulation. The participant who had not seen the problem given to them in past simulation runs indicated no change in energy levels. Participants who had seen the
problem given to them in a previous simulation indicated changes in energy levels that ranged from 0 to +0.4.

![Physical Exertion vs. Number of Problems](image)

Figure 288: Physical Exertion Compared to Number of Problems

Figure 288 indicates as the number of problems increased, more physical energy was required to complete the problem. Participants who received three problems indicated changes in physical exertion that ranged from -2 to +0.5. The participant who received the most number of problems indicated no change in physical exertion.

![Physical Exertion vs. Completion Time](image)

Figure 289: Physical Exertion Associated with the Time to Complete a Problem

Figure 289 demonstrated the participant who took the longest to solve a problem indicated no change in physical exertion. The participant who took the shortest amount of time to complete a problem indicated more physical exertion was required after the simulation. The
tasks presented are a mental exercise rather than physical in nature which could explain why some participants did not note any change in physical exertion.

Figure 290: Physical Exertion Associated with the Ability to Identify Problems

Figure 290 indicates one individual was not able to correctly identify the problem given to them during the simulation and reported no change in physical exertion. The participant who did correctly identify the problem given to them during the simulation indicated changes in physical exertion that ranged from -2 to +0.5.

Figure 291: Physical Exertion Associated with the Ability to Communicate Effectively

Figure 291 depicts the change in physical energy due to the ability to communicate a problem and the resolution to the simulation team. Participants, who exhibited poor communication skills, rating of 1, reported more physical energy was required after the
Participants, who exhibited excellent communication skills, rating of 3, indicated a change in physical exertion that ranged from 0 to +0.5.

Figure 292: Physical Exertion vs. Decision Making

Figure 292 indicates one participant did not choose the correct course of problem resolution and reported higher levels of physical exertion prior to the simulation (-2). Participants who did chose the correct resolution plan indicated change in physical exertion that ranged from -2 to +0.5. The lack of change could be attributed to the type of problem the individual was given since all tasks were mentally demanding in nature.

Figure 293: Physical Exertion Associated with Repeated Performance
Figure 293 depicts the change in a participant’s level of physical energy associated with the type of problem received during the simulation. Participants who had not seen their problem in past simulation runs indicated no change in physical exertion.

![Physical Discomfort vs. Number of Problems](image1)

**Figure 294: Physical Discomfort Compared to Number of Problems**

Figure 294 indicates participant with the most problems to solve reported an increase in physical discomfort after the simulation (+0.5). Participants who received three problems indicated higher physical discomfort prior to the simulation.

![Physical Discomfort vs. Completion Time](image2)

**Figure 295: Physical Discomfort Associated with the Time to Complete a Problem**

Figure 295 indicates the participant who took the longest to solve a problem reported more physical discomfort prior the simulation (-1.5). The participant, who took the least amount of time to complete a problem, reported more physical discomfort after the simulation (+0.75).
Figure 296: Physical Discomfort Associated with the Ability to Identify Problems

Figure 296 indicates the participant who did not correctly identify a problem reported higher physical discomfort prior to the simulation (-1.5). The participants who did correctly identify a problem indicated changes in physical discomfort that ranged from -1.5 to +0.75. Participants may have felt more physical discomfort prior to the simulation due exhaustion because of carrying material over to the simulation room, muscles are tense because of computer position or due to numbness of joints.

Figure 297: Physical Discomfort Associated with the Ability to Communicate Effectively

Figure 297 indicates the change in physical discomfort due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication, rating of 1, indicated more discomfort after the simulation (+0.75). The
participants with excellent communications indicated changes in physical discomfort that ranged from +0.5 to +0.75.

Figure 298: Physical Discomfort vs. the Correct Problem Resolution Plan

Figure 298 indicates one participant did not choose the correct course of problem resolution and reported more physical discomfort after the simulation (+0.5). Participants who did correctly identify the correct course of problem resolution, over half indicated more physical discomfort after the simulation. All participants did identify a change in physical exertion.

Figure 299: Physical Discomfort Associated with Repeated Performance

Figure 299 illustrates the change in a participant’s level of physical discomfort associated with the type of problem received during the simulation. Participants who had not seen their problem in past simulation runs felt more physical discomfort after the simulation (+0.5).
Figure 300: Lack of Motivation Compared to Number of Problems

Figure 300 indicates the participant with the most problems to solve reported feeling less motivated after the simulation. Participants who solved three problems indicated changes in motivation that ranged from -0.2 to +1.

Figure 301: Lack of Motivation Associated with the Time to Complete a Problem

Figure 301 indicates the participants who took longest to solve a problem reported less motivation after the simulation (+1). The participant who solved a problem in the shortest amount of time felt less motivated prior to the simulation (-0.2).
Figure 302: Lack of Motivation Associated with the Ability to Identify Problems

Figure 302 indicates one participant did not correctly identify a problem and reported lower levels of motivation prior the simulation (-0.2). Participants may have felt less motivated after the simulation due to their performance during the simulation or the results from peer and/or director evaluations.

Figure 303: Lack of Motivation Associated with the Ability to Communicate Effectively

Figure 303 illustrates the change in motivation due to the ability to communicate a problem and the resolution to the simulation team. Participants, who exhibited poor communication, rating of 1, indicated less motivation prior to the simulation.
Figure 304: Lack of Motivation vs. the Correct Problem Resolution Plan

Figure 304 depicts one participant did not choose the correct course of problem resolution and indicated a small change in motivation. Over half of the participants who did choose the correct course of problem resolution indicated less motivation after the simulation.

Figure 305: Lack of Motivation Associated with Repeated Performance

Figure 305 indicates the change in a participant’s level of motivation associated with the type of problem received during the simulation. Participants who had not seen their problem in past simulation runs indicated less motivation after the simulation (+0.25). All changes in the level of motivation were small, less than 1.5, on a scale from 0 to 10.
Figure 306: Sleepiness Compared to Number of Problems

Figure 306 indicates as the number of problems a participant has to complete increased, sleepiness decreased. The participant who received the most number of problems indicated higher levels of sleepiness prior to the simulation (-0.5). Some participants indicated no change in sleepiness. All changes in sleepiness were small, no value larger than 2, on a scale from 0 to 10.

Figure 307: Sleepiness Associated with Completion Time

Figure 307 indicated the participant who took longest to solve a problem reported higher levels of sleepiness prior to the simulation (-0.5). The participant who solved the problem in the shortest amount of time indicated no change in sleepiness.
Figure 308: Sleepiness Associated with the Ability to Identify Problems

Figure 308 indicates one participant did not correctly identify the problem given to them during the simulation and reported higher levels of sleepiness prior to the simulation (-0.5). Most participants also indicated higher levels of sleepiness prior to the simulation. A few participants did indicate no change in sleepiness.

Figure 309: Sleepiness Associated with the Ability to Communicate Effectively

Figure 309 illustrates the change in sleepiness due to the ability to communicate a problem and the resolution to the simulation team. Participants, who exhibited poor communication, rating of 1, indicated no change in sleepiness. Participants, with excellent communication skills, indicated either no change in sleepiness or felt higher levels of sleepiness prior to the simulation.
Figure 310: Sleepiness vs. the Correct Problem Resolution Plan

Figure 310 indicates one participant was not able to choose the correct course of problem resolution and reported no change in sleepiness. Participants who did choose the correct course for problem resolution indicated changes in sleepiness that ranged from -2 to +0.25.

Figure 311: Sleepiness Associated with Repeated Performance

Figure 311 illustrates the change in a participant’s level of sleepiness associated with the type of problem received during the simulation. Participants who had not seen their problem in past simulation runs indicated higher levels of sleepiness prior to the simulation (-0.5).
4.1.4 System Specialist Engineers

The charts in this section reflect the results of participants whose primary job is the coordination of all console operators and technical problem resolution. A sub-system engineer (SSE) coordinates the troubleshooting plans with the Engineering Test Lead and the Prime System Engineer. Additionally, the SSE relays information to the PSE to aid in communication with upper management and other systems who may be affected by a problem.

4.1.4.1 Heart Rate and Blood Pressure

Heart rate readings were collected on a continuous basis during the simulation. Data was downloaded onto a laptop for analysis. Blood pressure was taken after the simulation and the participant provided the principle investigator with a baseline measurement under normal operating conditions.

![Number of Problems vs Change in HR](image)

Figure 312: Change in Heart Rate Compared to Number of Problems

Figure 312 indicates the participant with the most number of problems to solve, reported a change in heart rate of 28 bpm. The participant with two problems to solve showed the
greatest change in heart rate (41 bpm). Another participant with two problems to solve showed the smallest change in heart rate (10 bpm).

![Completion Time vs Change in HR](image)

**Figure 313: Change in Heart Rate Associated with Completion Time**

Figure 313 indicates the participants who took 12 minutes to solve the problem reported the largest change in heart rate (41 bpm). The participant who took the longest time to solve a problem only had a change in heart rate of 29 bpm.

![Change in Heart Rate vs. Problem Identification](image)

**Figure 314: Change in Heart Rate Associated with the Ability to Identify Problems**

Figure 314 indicates one participant did not correctly identify a problem and reported a 21 bmp change in heart rate. The participant who correctly identified a problem given to them during the simulation reported the lowest change in heart rate.
Figure 315: Change in Heart Rate Associated with the Ability to Communicate Effectively

Figure 315 illustrates the change in heart rate due to the ability to communicate a problem and the resolution to the simulation team. Participants, who exhibited poor communication, rating of 1, reported changes in heart rate that ranged from 10 to 37 bpm. The participant with the largest change in heart rate exhibited good communication skills, rating of 2. Participants with good communication skills, rating of 3, had changes in heart rate less than 20 bpm.

Figure 316: Change in Heart Rate vs. the Correct Problem Resolution Plan

Figure 316 indicates one participant did not choose the correct course of problem resolution and reported a change in heart rate of 21 bpm. The participants who were able to choose the correct course of problem resolution exhibited the smallest and largest change in heart rate.
Figure 317: Change in Heart Rate Associated with Repeated Performance

Figure 317 indicates the change in a participant’s heart rate associated with the type of problem received during the simulation. The participant who had not seen the problem in past simulation runs reported a change in heart rate of 37 bpm. The participant with the smallest change in heart rate previously experienced the problem.

Figure 318: Blood Pressure Compared to Number of Problems

Figure 318 indicates as the number of problems a participant has to complete increased, blood pressure remained constant. The participants with one and two problems to solve had the highest blood pressure. The participant with only one problem to solve had the lowest blood pressure. The participant who received five problems had a blood pressure of 124 mmHg.
Figure 319: Blood Pressure Associated with Completion Time

Figure 319 indicates one participant took 32 minutes to solve a problem reported a blood pressure reading of 124 mmHg. The participant who took the shortest amount of time to solve their problem had a higher blood pressure reading 146 mmHg.

Figure 320: Blood Pressure Associated with the Ability to Identify Problems

Figure 320 indicates one participant did not correctly identify the problem given to them during the simulation. The participant who did not correctly identify a problem reported a blood reading of 146 mmHg. The participant who correctly identified a problem reported the highest blood pressure reading.
Figure 321: Blood Pressure Associated with the Ability to Communicate Effectively

Figure 321 indicates how blood pressure is associated with a participant’s ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication reported blood pressure readings that ranged from of 110 to 184 mmHg. The participant with the lowest blood pressure readings exhibited good communication skills.

Figure 322: Blood Pressure vs. the Correct Problem Resolution Plan

In figure 322 one participant did not choose the correct course of problem resolution and reported blood pressure readings of 146 mmHg. The participants who were able to choose the correct course of problem resolution exhibited the largest blood pressure readings.
Figure 323: Blood Pressure Associated with Repeated Performance

Figure 323 illustrates a participant’s blood pressure reading associated with the type of problem received during the simulation. The participant who had not seen their problem in past simulation runs had a blood pressure reading of 184 mmHg. The participant with the smallest blood pressure reading had seen their problem in a previous simulation.

4.1.4.2 Yoshitake Type I and II Fatigue

Figures 324 through 335 of this document reflect the results obtained from administering Yoshitake Type I and II Fatigue surveys to research participants. Each participant completed the checklist of subjective symptoms of fatigue pre- and post-simulation. Participants either checked yes if they felt the symptom or no if they did not feel the symptom. Answers of yes were given a score of one; answers of no were given a score of zero. Under each type of fatigue, the boxes were totaled and combined to ascertain an overall fatigue score.
The highest value of physical fatigue possible is 1, whereas, the highest value obtained was 0.08. Figure 324 depicts the value of physical fatigue remained low even as the number of problems increased. The participant who received the most number of problems indicated higher levels of physical fatigue prior to the simulation.

Figure 325 indicates the participant who took the longest to solve a problem reported higher physical fatigue values prior to the simulation. The participant who completed a problem in the shortest amount of time indicated higher levels of physical fatigue after the simulation. Possible reasons for higher levels of fatigue include system constraints which forces individuals to determine problem resolution plans quicker than normal.
Figure 326: Physical Fatigue Associated with the Ability to Identify Problems

Figure 326 indicates regardless of participants being able to correctly identify the problem, on a scale from 0 to 1, physical fatigue levels are very low at 0.08. The participant who did not correctly identify the problem given to them indicated higher physical fatigue levels after the simulation.

Figure 327: Physical Fatigue Associated with the Ability to Communicate Effectively

Figure 327 depicts a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results indicated those participants who chose words carefully and were well spoken showed increases in physical fatigue. Participants with poor communication indicated changes in physical fatigue that ranged from -0.8 to 0.
Participants chose carefully to increase technical understanding within the community and provide necessary data to other affected groups.

![Physical Fatigue vs. Decision Making](image)

**Figure 328:** Physical Fatigue vs. the Correct Problem Resolution Plan

Figure 328 illustrates those participants who had correctly determined the proper problem resolution plan indicated change in physical fatigue that ranged from -0.8 to +0.8. This can be attributed to the pressure associated with peer performance evaluations and professional image within the flight team. Two participants did not choose the correct resolution plan.

![Physical Fatigue vs. Repeated Performance](image)

**Figure 329:** Physical Fatigue Associated with Repeated Performance

Figure 329 demonstrates that some of the participants indicated a change in physical fatigue levels even though the problems presented to them were problems seen in past simulation.

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runs. However, the associated physical fatigue change was minimal. The participant who received a new problem indicated higher physical fatigue levels prior to the simulation (-0.8).

![Mental Fatigue vs. Number of Problems](image1)

**Figure 330**: Mental Fatigue Associated with Number of Problems

Figure 330 indicates the value of mental fatigue remained low even as the number of problems increased. The highest value possible is 1; whereas, the largest change in mental demand was 0.25. Some individuals increase in mental fatigue can be associated with completing two problems simultaneously. The participant who received the most number of problems indicated a change in mental fatigue of -0.125. The participant who received the fewest number of problems indicated no change in mental fatigue.

![Mental Fatigue vs. Completion Time](image2)

**Figure 331**: Level of Mental Fatigue Associated with the Time to Complete a Problem
Figure 331 indicates as the time required to complete a problem increased, mental fatigue levels increased. The participant who took the longest to solve a problem indicated higher mental fatigue levels prior to the simulation. The participant who took the shortest amount of time to solve a problem indicated higher mental demand loads after the simulation.

![Mental Fatigue vs. Problem Identification](image)

Figure 332: Mental Fatigue Associated with the Ability to Identify Problems

Figure 332 indicated the largest change in physical fatigue, 0.25, was reported by a participant who had experience the problem in a previous simulation. The one participant who did not correctly identify the problem given to them indicated higher mental fatigue after the simulation.

![Mental Fatigue vs. Discussion Traffic](image)

Figure 333: Mental Fatigue Associated with the Ability to Communicate Effectively
Figure 333 illustrates a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results indicated those who chose words carefully and were well spoken showed increases in mental fatigue. Participants chose words carefully to increase technical understanding within the community and provide necessary data to other affected groups. Participants with poor communication, rating of 1, indicated changes in mental fatigue that ranged from -0.125 to +0.25.

![Mental Fatigue vs. Decision Making](image)

Figure 334: Mental Fatigue vs. the Correct Problem Resolution Plan

Figure 334 demonstrates those participants who correctly determined the proper problem resolution plan had higher mental fatigue values. This can be attributed to the pressure associated with peer performance evaluations and professional image within the flight team. The participant who did not determine the correct resolution plan indicated higher mental fatigue levels after the simulation.
Figure 335: Mental Fatigue Associated with Repeated Performance

Figure 335 illustrates that some of the participants indicated a change in mental fatigue levels even though the problems presented to them were problems seen in past simulation runs. Results show small changes in mental fatigue. The participant who received a new problem indicated higher mental fatigue values after the simulation.

4.1.4.3 Overall Job Satisfaction

Participants completed a subjective job satisfaction survey prior to the simulation that focused on job and organizational-related satisfiers. Participants were given a series of questions, which asked them to rank their response on a scale from one to five with one being strongly disagreed with a statement and five being strongly agreed with the statement. The results are shown below is figures 336 to 341. Most participants indicated a rating of four on the survey signifying that they were satisfied with their job.
Figure 336: Job Satisfaction Associated with Number of Problems

Figure 336 illustrates for the range of the number of problems a participant was given, the overall level of job satisfaction was high. Even those participants who received five problems still had a high level of job satisfaction.

Figure 337: Job Satisfaction Associated with the Time to Complete a Problem

Figure 337 indicates the participant who took the longest time to solve a problem reported a high level of job satisfaction. This was also true for the participant who solved a problem in the least amount of time. The high level of job satisfaction could be attributed to the people the participant works with, the technical content a participant is exposed to and the cultural environment.
Figure 338: Job satisfaction Associated with the Ability to Identify Problems

Figure 338 demonstrates that regardless of the ability to correctly identify a problem, participants still had a high level of job satisfaction. Those participants who did not correctly identify still indicated a rating of 4.1 for overall job satisfaction.

Figure 339: Job Satisfaction Associated with the Ability to Communicate Effectively

Figure 339 illustrates a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results indicated that those who chose words carefully and were well spoken showed the same level of job satisfaction as individuals who chose their words less careful. Participants chose words carefully to increase technical understanding within the community and provide necessary data to other affected groups.
Figure 340: Job Satisfactions vs. the Correct Problem Resolution Plan

Figure 340 indicates participants who had correctly determined the proper problem resolution plan reported the same job satisfaction levels as those individuals who did not chose the correct problem resolution plan. The high ratings of job satisfaction can be attributed to the technical material participants are able to work with and the passion for the industry.

Figure 341: Job Satisfaction Associated with Repeated Performance

Figure 341 illustrates that job satisfaction was above average even though participants had received their problems in previous simulation runs. All but one participant had seen their problem in a past simulation. The overall level of job satisfaction rating was 4.1.
4.1.4.4 NASA TLX

NASA TLX, multi-dimensional rating procedure that generates an overall workload value based on six subscales, is a subjective assessment tool used to determine levels of workload. NASA TLX provided the principal investigator with a tool to perform subjective workload assessment on jobs that require the participant to interface with human-machine systems (i.e. computers). Charts 342 through 413 present the results from the NASA TLX analysis.

Participants completed a NASA TLX survey pre and post simulation. This study looked at the changes of the six subscales and overall workload. The possible values that TLX produced ranged from 0 to 100. If a participant delta rating is negative, this indicates a participant’s pre-simulation values were higher than the post simulation values. If the delta is positive, the post simulation values are greater than the pre-simulation values.

![Mental Demand Value vs. Number of Problems](image)

Figure 342: Mental Demand Value Associated with Number of Problems

Figure 342 illustrates the change in mental demand associated with the number of problems a participant received during the simulation. The data indicated the participant who received five problems reported higher mental demand after the simulation. The participant who only received two problems indicated higher levels of mental demand prior to the simulation.
Figure 343: Mental Demand Value Associated with the Time to Complete a Problem

Figure 343 indicates as the time required to complete a problem increased, mental demand values also increased. The problem that took the longest to solve showed a higher post test mental demand value (+15). The participant that took the least time to solve the problem showed no change in mental demand values.

Figure 344: Mental Demand Value Associated with the Ability to Identify Problems

Figure 344 indicates one participant did not correctly identify a problem and reported no change in mental demand. Participants that correctly identified the problems given to them, indicated changes in mental demand that ranged from -25 to +15.
Figure 345: Mental Demand Value Associated with the Ability to Communicate Effectively

Figure 345 depicts the change mental demand due to the ability to communicate a problem and the resolution to the simulation team. Participants with excellent communication skills indicated changes in mental demand values that ranged from -25 to 0. Participants, with poor communication skills, rating of 1, indicated higher mental demand values after the simulation with the exception of one who indicated higher mental demand values before the simulation. Participants with good communication skills showed small changes in mental demand (+15) or no change.

Figure 346: Mental Demand Value vs. the Correct Problem Resolution Plan

In figure 346, one participant did not choose the correct course of action and indicated no changes in mental demand. One participant that correctly identified the problem reported no
change in physical demand. The negative change can be attributed to the time critical to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.

![Graph: Mental Demand Value vs Repeated Performance](image)

**Figure 347:** Mental Demand Associated with Repeated Performance

Figure 347 illustrates the change in mental demand associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem experienced no change in mental demand.

![Graph: Physical Demand Value vs Number of Problems](image)

**Figure 348:** Physical Demand Compared to the Number of Problems Completed

Figure 348 depicts the change in physical demand compared to the number of problems completed. Over half of the participants indicated higher physical demand values prior to the
simulation. The difference in how much change in physical demand a participant felt could be attributed to the time of day the simulation was run or the environment (i.e. temperature, lighting). The largest change in physical demand was +20. The participant who received the most number of problems indicated higher physical demand requirements prior to the simulation.

Figure 349: Physical Demand Value Associated with the Time to Complete a Problem

Figure 349 indicates the participant who took the longest to solve a problem reported higher physical demands prior to the simulation (-5). The participant who took the shortest amount of time to solve a problem also indicated a change in physical demand of -5.

Figure 350: Physical Demand Value Associated with the Ability to Identify Problems

Figure 350 illustrates the relationship between the ability to identify a problem correctly to the change in the physical demand. Only one participant did not correctly identify a problem.
given to them in the simulation and indicated higher physical demand loads prior to the simulation. The largest change in mental demand was +20, on a scale of 0 to 100.

Figure 351: Physical Demand Value Associated with the Ability to Communicate Effectively

Figure 351 depicts the change physical demand due to the ability to communicate a problem and the resolution to the simulation team. Participants with excellent communication skills indicated changes in mental demand values that ranged from -5 to +20. Participants with poor communication skills, rating of 1, indicated changed in mental demand that ranged from -15 to +20.

Figure 352: Physical Demand Value vs. the Correct Problem Resolution Plan

Figure 352 indicates one participant did not determine the correct course of problem resolution and reported higher levels of physical demand prior to the simulation. Participants
who choose the correct course of action indicated changes in physical demand that ranges from -15 to +20. The negative change can be attributed to the time critical to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.

![Physical Demand vs Repeated Performance](image)

**Figure 353**: Physical Demand Associated with Repeated Performance

Figure 353 depicts the change in physical demand associated with the type of problem received during the simulation. All but one participant received problems that were completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem experienced higher pre simulation physical demand (-5).

![Performance Value vs. Number of problems](image)

**Figure 354**: Performance Value Associated with Number of Problems
Figure 354 depicts the change in a participant’s satisfaction associated with the number of problems identified during the simulation. Over half of the participants reported a better performance prior to the simulation. Those who felt they had a better performance post test indicated a change of 5. The highest change in performance was -20, indicating the participant had higher pre simulation performance values. The participant who received the most number of problems indicated higher satisfaction levels before the simulation.

![Performance Value vs. Completion Time](image)

Figure 355: Performance Value Associated with the Time to Complete a Problem

Figure 355 indicates as the time required to complete a task increased, post simulation satisfaction decreased. The performance value is associated with satisfaction and success. The participant who took the longest to solve a problem showed higher levels of satisfaction prior to the simulation (-10). The participant who solved a problem in the shortest amount of time indicated no change in satisfaction. Some of the factors they may account for higher pre simulation scores include how a participant did in a past performance or the participant’s self confidence.
Figure 356: Performance Value Associated with the Ability to Identify Problems

Figure 356 indicates one participant was not able to correctly identify a problem and reported no change in satisfaction. The largest change in performance satisfaction was -20 indicating higher pre simulation performance satisfactions.

Figure 357: Performance Value Associated with the Ability to Identify

Figure 357 depicts the change in performance satisfaction due to the ability to communicate a problem and the resolution to the simulation team. Participants with poor communication skills, rating of 1, indicated changes in performance satisfaction that ranged from -20 to +5. Participants, with excellent communication skills, rating of 3, indicated more satisfaction prior to the simulation or indicated no change.
Figure 358: Performance Value vs. Decision Making

Figure 358 indicates one participant did not determine the correct course of problem resolution and reported no change in satisfaction. Participants who did correctly choose the problem resolution path indicated changes in satisfaction that ranged from -20 to +5. The negative change can be attributed to the time pressure associated with the need to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.

Figure 359: Performance Value Associated with Repeated Performance

Figure 359 illustrates the change in a participant’s satisfaction associated with the type of problem received during the simulation. All but one participant received problems that were
completed in previous simulation runs and in the data bank of problem sets. The one participant that received a new problem experienced a higher pre simulation satisfaction.

Figure 360: Temporal Demand Value Associated with Number of Problems

Figure compares the number of problems a participant received to the change in how much pressure a participant felt during the simulation. Only three participants noted higher temporal demands post simulation. The participants who received the most problems indicated higher temporal demands prior to the simulation. The increase in pre-simulation pressure may be attributed to not knowing the problems being given or the pace at which the problem occurred.

Figure 361: Temporal Demand Value Associated with the Time to Complete a Problem
Figure 361 indicates as the time required to complete a problem increased, participants felt an increase in pressure to complete the problem. The participant who took the longest to solve a problem indicated higher temporal demands prior to the simulation. The participant who solved a problem in the least amount of time indicated higher levels of post simulation pressure.

![Temporal Demand Value vs. Problem Identification](image1)

**Figure 362: Temporal Demand Value Associated with the Ability to Identify Problems**

Figure 362 indicates the participant who did not correctly identify a problem reported higher temporal demand values. Participants who did correctly identify the problem given to them in the simulation indicated a change in temporal demand that ranged from -15 to +5.

![Temporal Demand Value vs. Discussion Traffic](image2)

**Figure 363: Temporal Demand Value Associated with the Ability to Communicate Effectively**

Figure 363 indicates the change in the time pressure a participants felt due to the ability to communicate a problem and the resolution to the simulation team. Temporal demand is
associated with the amount of time pressure a participant feels. Participants, with poor communication, rating of 1, indicated higher temporal demands prior to the simulation. Participants with good communication, rating of 2, indicated changes in temporal demand that ranged from -15 to +5.

![Temporal Demand Value vs. Decision Making](image)

**Figure 364: Performance Value vs. the Correct Problem Resolution Plan**

Figure 364 indicates one participant did not choose the correct course of action and reported higher temporal demands after the simulation. The increase in post simulation pressure could be attributed to the rate at which tasks were given to the participants.

![Temporal Demand vs. Repeated Performance](image)

**Figure 365: Performance Value Associated with Repeated Performance**

Figure 365 depicts the change in stress to the type of problem a participant received during the simulation. All but one participant received the problems that were completed in
previous simulation runs and in the data bank of problem sets. The participant who had not seen their problem in a prior simulation felt more pressure prior to the simulation (-5).

Figure 366: Effort Value Associated with Number of Problems

Figure 366 depicts the change in efforts related to the number of problems a participant saw during the simulation. The participant with the most problems to solve indicated no change in effort. The participant who received the fewest number of problems indicated more effort was required prior to the simulation. The negative values could be associated the preparation time of participant does before the simulation, the anticipation of how hard, mentally, the simulation will be or the level of effort required to complete the task.

Figure 367: Effort Value Associated with the Time to Complete a Problem
Figure 367 depicts the participant who took the longest to solve a problem indicated no change in effort. The participant who solved a problem in the shortest amount of time indicated more effort was required after the simulation (+10).

![Effort Value vs. Problem Identification](image)

Figure 368: Effort Value Associated with the Ability to Identify Problems

Figure 368 indicates one participant did not correctly identify a problem and reported more effort was required after the simulation. The participants who did correctly identify the problem indicated changes in effort that ranged from -60 to +10.

![Effort Value vs. Discussion Traffic](image)

Figure 369: Effort Value Associated with the Ability to Communicate Effectively

Figure 369 illustrates the change in effort due to the ability to communicate a problem and the resolution to the simulation team. The participants with poor communication, rating of
indicated changes in effort that ranged from -60 to +10. Participants, with excellent communication, rating of 3, indicated higher effort values after the simulation (+10).

Figure 370: Effort Value vs. the Correct Problem Resolution Plan

Figure 370 indicates that one participant did not determine the correct course of problem resolution for a given problem. This participant indicated higher effort values after the simulation. The participants that correctly chose the pre-planned problem resolution plan had varying results on when more effort was required (-60 to +10).

Figure 371: Effort Value Associated with Repeated Performance

Figure 371 depicts the change in a participants effort level associated with the type of problem received during the simulation. All but one participant received problems that were
completed in previous simulation runs and in the data bank of problem sets. The one participant who received a new problem indicated no change in effort.

Figure 372: Frustration Value Associated with Number of Problems

Figure 372 depicts the number of problems completed compared to the contentment a participant experienced during the simulation. The participant who received the most problems indicated they were less relaxed prior to the simulation. The participant who received the fewest problems indicated more frustration prior to the simulation or indicated no change (-5 or 0 respectively).

Figure 373: Frustration Value Associated with the Time to Complete a Problem
Figure 373 indicates the participant who took the longest to solve a problem reported feeling more stress or irritation prior to the simulation. The problem that took the least amount of time to solve, that participant indicated higher frustration after the simulation.

![Frustration Value vs. Problem Identification](image)

Figure 374: Frustration Value Associated with the Ability to Identify Problems

Figure 374 indicates the all but one participant correctly identified a problem given to them during the simulation. The participants who did not correctly identify the problem given to them in the simulation felt more frustration after the simulation (+50).

![Frustration Value vs. Discussion Traffic](image)

Figure 375: Frustration Value Associated with the Ability to Communicate Effectively

Figure 375 illustrates the change in frustration due to the ability to communication a problem and the resolution to the simulation team. Participants with poor communication
indicated more frustration prior to simulation (-30) or indicated no change. Participants with good communication indicated changes in frustration that ranged from -30 to +50.

![Figure 376: Frustration Value vs. Decision Making](image)

**Figure 376: Frustration Value vs. the Correct Problem Resolution Plan**

Figure 376 indicates that one participant did not correctly identify the problem and reported more frustration after the simulation (+50). Participants in a post simulation interview stated some of the possible reasons for higher frustration levels post simulation include a participant not being content with their performance, participant felt they could have done a better job during the simulation or the participant felt insecure about their performance.

![Figure 377: Frustration Value Associated with Repeated Performance](image)

**Figure 377: Frustration Value Associated with Repeated Performance**

Figure 377 depicts the change in how much frustration a participant experienced compared with the type of problem received during the simulation. All but one participant
received the problems that were completed in previous simulation runs and in the data bank of
problem sets. The participant who had not seen their problem in a prior simulation felt more
frustrated prior to the simulation.

![Graph of Workload Value vs Number of Problems]

Figure 378: Workload Value Associated with Number of Problems

Figure 378 indicates the change in workload associated with the number of problems a
participant received during the simulation. The participant with the most problems to complete
indicated that the workload was higher after the simulation (+4). The participant who received
the fewest number of problems indicated higher workloads prior to the simulation (-13).

![Graph of Workload Value vs Completion Time]

Figure 379: Workload Value Associated with the Time to Complete a Problem

Figure 379 indicates as the time required to complete a problem increased, the amount of
work required to complete the problem also increased. The participant who took the longest to
solve a problem indicated higher workload after the simulation. The participant who took the shortest amount of time to solve a problem also indicated higher workloads after the simulation.

![Workload Value vs. Problem Identification](image1)

**Figure 380 Workload Value Associated with the Ability to Identify Problems**

Figure 380 depicts one participant did not correctly identify a problem and indicated higher workload values after the simulation (+5). Participants who did correctly identify the problems given to them during the simulation indicated changes in workload that ranged from -20 to +5.

![Workload Value vs. Discussion Traffic](image2)

**Figure 381: Workload Value Associated with the Ability to Communicate Effectively**

Figure 381 illustrates the change in workload due to the ability to communicate a problem and the resolution to the simulation team. Participants with poor communication, rating
of 1, indicated changes in workload that ranged from -20 to +5. Participants with excellent communication, rating of 3, indicated changes in workload that ranged from -13 to +5.

Figure 382: Workload Value Associated with the Ability to Determine the Correct Problem Resolution

Figure 382 depicts one participant did not choose the correct course of problem resolution and noted higher workloads after the simulation. The participants that correctly identified the right problem resolution path indicated changes in workload that ranged from -20 to +5.

Figure 383: Workload Value Associated with Repeated Performance
Figure 383 depicts the change in workload associated with the type of problem received during the simulation. One participant received a problem that was not in a previous simulation run and felt more work was required post simulation (+4).

4.1.4.5 SOFI

The Swedish Occupation Fatigue Inventory (SOFI) is a subjective tool that describes fatigue using five dimensions: lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness. The dimensions represent the perceptions of how participants feel at a given point in time. The participants completed the inventory pre- and post-simulation. The results of the inventory are included in charts 384 through 413.

This study looked at the change in the five dimensions. The possible values that SOFI produced ranged from 0 to 10. If a participant delta rating is negative, this indicates a participant’s pre-simulation values were higher than the post simulation values. If the delta is positive, the post simulation values are greater than the pre-simulation values.

Figure 384: Lack of Energy Compared to Number of Problems

Figure 384, indicates as the number of problems increased; participants indicated less energy prior to the simulation. The participant with the most problems to solve indicated less
energy prior to the simulation (-0.018). The participant who received the fewest number of problems indicated less energy after the simulation.

![Graph: Lack of Energy vs. Completion Time]

Figure 385: Lack of Energy Associated with Completion Time

Figure 385 indicates participants who took the longest time to solve a problem reported less energy prior to the simulation. The participant who took the least amount of time to complete a problem indicated less energy prior to the simulation (-0.2).

![Graph: Lack of Energy vs. Problem Identification]

Figure 386: Lack of Energy Associated with the Ability to Identify Problems

Figure 386 indicates one participant was not able to correctly identify a problem given to them during the simulation and reported less energy prior to the simulation (-0.02). All participant felt less energy prior to the simulation with the exception of two participants.
Participants who were able to correctly identify their problem had small changes in energy levels (-0.02 to -0.0075).

![Lack of Energy vs. Discussion Traffic](image)

Figure 387: Lack of Energy Associated with the Ability to Communicate Effectively

Figure 387 illustrates the change in energy levels due to the ability to communicate a problem and the resolution to the simulation team. Those participants with poor communication, rating of 1, indicated changes in energy that ranged from -0.02 to +0.0075. Those participants with good communication either, rating of 2, indicated less energy prior to the simulation.

![Lack of Energy vs Decision Making](image)

Figure 388: Lack of Energy vs. the Correct Problem Resolution Plan

Figure 388 indicates one participant did not choose the correct course of problem resolution and reported less energy prior to the simulation. The participants who choose the correct course of problem resolution indicated changes in energy that ranged from -0.02 to +0.08.
Figure 389: Lack of Energy Associated with Repeated Performance

Figure 389 depicts the change in a participant’s energy level associated with the type of problem received during the simulation. Participants who had not seen the problem given to them in past simulation runs reported less energy prior to the simulation (-0.02). Participants who had seen the problem given to the them in a previous simulation indicated changes in energy levels that ranged from -0.02 to +0.08.

Figure 390: Physical Exertion Compared to Number of Problems

Figure 390 indicates as the number of problems increased, more physical energy was required to complete the problem. The participants with the fewest number of problems to complete indicated more physical exertion was required prior to the simulation.
Figure 391: Physical Exertion Associated with the Time to Complete a Problem

Figure 391 demonstrates the participant who took the longest to solve a problem indicated more physical exertion was required after the simulation. The participant who took the short amount of time to complete a problem also indicated more physical energy was required after the simulation. The tasks presented are a mental exercise rather than physical in nature which could explain why some participants did not note any change in physical exertion.

Figure 392: Physical Exertion Associated with the Ability to Identify Problems

Figure 392 indicates one participant was not able to correctly identify a problem given to them during the simulation and reported more physical exertion was required after the simulation (+0.012). The graph depicts that those individuals who were able to correctly identify a problem indicated change in physical exertion that ranged from -0.013 to +0.012.
Figure 393: Physical Exertion Associated with the Ability to Communicate Effectively

Figure 393 illustrates the change in physical energy due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication skills, rating of 1, indicated changes in physical exertion that ranged from -0.013 to +0.003.

Figure 394: Physical Exertion vs. the Correct Problem Resolution Plan

Figure 394 indicates one participant who did not choose the correct course of problem resolution noted more physical exertion was required after the simulation (+0.012). Participants who did choose the correct resolution plan indicated changes in physical exertion that ranged from -0.013 to +0.012. The lack of change could be attributed to the type of problem the individual was given since all tasks were mentally demanding in nature.
Figure 395: Physical Exertion Associated with Repeated Performance

Figure 395 illustrates the change in a participant’s level of physical energy associated with the type of problem received during the simulation. Participants who had not seen their problem in past simulation runs felt more physical exertion was required after the simulation (+0.012).

Figure 396: Physical Discomfort Compared to Number of Problems

Figure 396 depicts the participant with the most problems to solve indicated an increase in physical discomfort after the simulation. Participants who received 2 problems indicated changes in physical discomfort that ranged from -0.003 to +0.008. Some of the participants had more physical discomfort before the simulation while other had more physical discomfort after the simulation.
Figure 397: Physical Discomfort Associated with the Time to Complete a Problem

Figure 397 indicates one participant who took the longest to solve a problem reported more physical discomfort after the simulation. The participant, who took the least amount of time to complete their problem, also felt more physical discomfort after the simulation. All participants indicated more physical discomfort after the simulation.

Figure 398 Physical Discomfort Associated with the Ability to Identify Problems

Figure 389 indicates one participant did not correctly identify a problem and reported higher physical discomfort after the simulation (+0.018). Participants may have felt more physical discomfort prior to the simulation due exhaustion because of carrying material over to the simulation room, muscles are tense because of computer position or due to numbness of joints.
Figure 399: Physical Discomfort Associated with the Ability to Communicate Effectively

Figure 399 illustrates the change in physical discomfort due to the ability to communicate a problem and the resolution to the simulation team. Participants, who exhibited poor communication, rating of 1, felt more discomfort after the simulation. Participants, with good communication, rating of 2, had the largest spread in the change of physical discomfort.

Figure 400: Physical Discomfort vs. the Correct Problem Resolution Plan

Figure 400 indicates one participant did not choose the correct course of problem resolution and reported more physical discomfort after the simulation (+0.018). All participants did identify a change in physical exertion.
Figure 401: Physical Discomfort Associated with Repeated Performance

Figure 401 illustrates a change in a participant’s level of physical discomfort associated with the type of problem received during the simulation. Participants who had not seen a problem in past simulation runs indicated more physical discomfort after the simulation (+0.015).

Figure 402: Lack of Motivation Compared to Number of Problems

Figure 402 indicates participant with the most problems to solve reported more motivation prior to the simulation. Participants with two problems indicated change in motivation that ranged from -0.003 to +0.002. All changes in motivation were small.
Figure 403: Lack of Motivation Associated with the Time to Complete a Problem

Figure 403 indicates the participants who took longest to solve a problem reported less motivation prior to the simulation. The participant who solved a problem in the shortest amount of time felt less motivated prior to the simulation (-0.013).

Figure 404: Lack of Motivation Associated with the Ability to Identify Problems

Figure 404 indicates one participant did not correctly identify a problem and reported lower levels of motivation prior to the simulation. Participants may have felt less motivated after the simulation due to their performance during the simulation or the results from peer and/or director evaluations.
Figure 405: Lack of Motivation Associated with the Ability to Communicate Effectively

Figure 405 illustrates the change in motivation due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication, rating of 1, indicated changes in motivation that ranged from -0.08 to +0.08. Participant, with good communication skills, rating of 2, indicated the largest change in motivation.

Figure 406: Lack of Motivation vs. the Correct Problem Resolution Plan

Figure 406 indicates one participant did not choose the correct course of problem resolution and reported a small change in motivation need to complete the simulation (-0.014). Over half of the participants who did chose the correct course of problem resolution felt less motivated after the simulation.
Figure 407: Lack of Motivation Associated with Repeated Performance

Figure 407 illustrates the change in a participant’s level of motivation associated with the type of problem received during the simulation. Participants who had not seen their problem in past simulation runs felt less motivated after the simulation (+0.002). All changes in the level of motivation were small, less than 0.015, on a scale from 0 to 10.

Figure 408: Sleepiness Compared to Number of Problems

Figure 408 indicates the participant with the most number of problems to complete reported higher levels of sleepiness prior to the simulation. Participants with three problems to complete reported being more tired prior the simulation. All changes in sleepiness were small, no value larger than 0.004, on a scale from 0 to 10.
Figure 409: Sleepiness Associated with Completion Time

Figure 409 indicated the one participant who took longest to solve a problem reported higher levels of sleepiness prior to the simulation (-0.002). The participant who solved a problem in the shortest amount of time also felt sleepy prior to the simulation.

Figure 410: Sleepiness Associated with the Ability to Identify Problems

Figure 410 illustrates the change in a participant’s level of sleepiness compared to the ability to identify a problem. The participant who did not correctly identify a problem indicated higher levels of sleepiness prior to the simulation (-0.0013).
Figure 411: Sleepiness Associated with the Ability to Communicate Effectively

Figure 411 depicts the change in sleepiness due to the ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication skills, rating of 1, indicated small changes in sleepiness (-0.0043 to +0.0003). All participants with good communication skills, rating of 2, felt more sleepy prior to the simulation.

Figure 412: Sleepiness vs. the Correct Problem Resolution Plan

Figure 412 indicates one participant was not able to choose the correct course of problem resolution and reported feeling sleepier prior to the simulation. Only one participant who did chose the correct course of problem resolution indicted they were sleepier after the simulation.
Figure 413: Sleepiness Associated with Repeated Performance

Figure 413 illustrates the change in a participant’s level of sleepiness associated with the type of problem received during the simulation. Participants who had not seen a problem in past simulation run reported feeling more tired prior to the simulation (-0.0023). All changes in sleepiness were small.

4.1.5 All Four Task Groups Combined

The following set of graphs, 413- 515 combines all four task groups onto one graph. This will help aid in determining if any patterns can be seen between the groups.

4.1.5.1 Heart Rate and Blood Pressure

Heart rate readings were collected on a continuous basis during the simulation. Data was downloaded onto a laptop for analysis. Blood pressure was taken after the simulation and the participant provided the principle investigator with a baseline measurement under normal operating conditions.
Figure 414: Change in Heart Rate vs. Number of Problems

Figure 414 depicts the change in heart rate for all four task groups compared to the number of problems each participant completed. The participant with the greatest change in heart was from the Engineering Test Lead (ETL) task group. Additionally, the participant who received the most number of problems also came from the ETL task group. The participant with the smallest change in heart rate was from the prime system engineering task group.

Figure 415: Change in Heart Rate vs. Completion Time
Figure 415 illustrates the change in heart rate for all four tasks groups compared to the time it took for each participant to complete a problem. The participant who took the longest time to solve their problem is an ETL. The participant who took the shortest amount of time to complete their time was a PSE.

![Change in Heart Rate vs. Problem Identification](image_url)

Figure 416: Change in Heart Rate vs. Problem Identification

Figure 416 illustrates the change in participant’s heart rate for all four task groups compared to the ability of the participant to identify a problem correctly. Six participants did not correctly identify their problem. Of those participants, the participant with the greatest change in heart also did not solve their problem correctly. The participant with the smallest change in heart rate also did not solve their problem correctly.
Figure 417: Change in Heart Rate vs. Discussion Traffic

Figure 417 indicates the change in participant’s heart rate for all four task groups due to the ability to communicate a problem and the resolution to the simulation team. The participants who exhibited poor communication had the largest change in heart rate. The participant with the smallest change in heart rate also exhibited poor communication skills. Those participants who exhibited excellent communication skills change in heart rate ranges from 13 to 45 bpm.

Figure 418: Change in Heart Rate vs. the Correct Problem Resolution Plan

Figure 418 indicates those participants who were able to choose the correct course of problem resolution exhibited both the smallest and largest change in heart rate. Participants that
did not correctly identify the problem exhibited a change in heart rate between 20 and 27 bpm.

Only five participants did not correctly identify the problem given to them during the simulation.

Figure 419: Change in Heart Rate Associated with Repeated Performance

Figure 419 illustrates the change in a participant’s heart rate for all four task groups associated with the type of problem received during the simulation. Four participants had not seen their problem in past simulation runs. The participants with the smallest change in heart rate had seen their problem in a pervious simulation. The participant with the largest change in heart rate had not seen their problem in a past simulation run.

Figure 420: Blood Pressure Compared to Number of Problems
Figure 420 indicates as the number of problems a participant has to complete increased, blood pressure remained nearly constant. The participant who was in the ETL task group had the highest blood pressure. The participant with only one problem to solve had the lowest blood pressure and was in the ELT task group. The participant who received six problems had a blood pressure of 126 mmHg.

![Blood Pressure vs. Completion Time](image)

Figure 421: Blood Pressure Associated with Completion Time

Figure 421 indicates the participant who took 125 minutes to solve a problem reported a blood pressure reading of 110 mmHg. Two participants took six minutes to solve a problem and reported blood pressure readings of 118 and 146 mmHg respectively.

![Blood Pressure vs. Problem Identification](image)

Figure 422: Blood Pressure Associated with the Ability to Identify Problems
Figure 422 indicates all four task groups had participants who did not correctly identify the problem given to them during the simulation. The participants who did not correctly identify the problem had blood readings between 118 and 146 mmHg. The participant who correctly identified their problem had the highest blood pressure reading.

![Blood Pressure vs. Discussion Traffic](image)

**Figure 423: Blood Pressure Associated with the Ability to Communicate Effectively**

Figure 423 illustrates how blood pressure is associated with a participant’s ability to communicate a problem and the resolution to the simulation team. Participants who exhibited poor communication had blood pressure readings that ranged from 110 to 184 mmHg. The participant with the lowest blood pressure readings exhibited good or excellent communication skills.
In figure 424, at least one participant from each task group did not choose the correct course of problem resolution. Those participants had blood pressure readings that ranged from 110 to 146 mmHg. The participant who exhibited the largest blood pressure readings was able to choose the correct course of problem resolution.

Figure 425 depicts a participant’s blood pressure reading associated with the type of problem received during the simulation. The participants who had not seen their problem in past simulation runs had a blood pressure reading that ranged from 116 to 184 mmHg. The
participant with the smallest blood pressure reading had seen their problem in a previous simulation.

4.1.5.2 Yoshitake Type I and II Fatigue

Yoshitake Type I and II Fatigue, in figures 6 through 17, show the results from the analysis. The checklist of subjective symptoms of fatigue were completed by each individual pre- and post-simulation. Participants either checked yes if they felt the symptom or no. Answers of yes were given a score of one; no were given a score of zero. Under each type of fatigue, the boxes were totaled to get an overall fatigue score.

![Change in Physical Fatigue vs. Problem Identification](image)

Figure 426: Physical Fatigue Associated with Number of Problems

From figure 426, the highest value of physical fatigue possible is 1, whereas, the highest value obtained was 0.17. Figure 426 indicates the value of physical fatigue remained low even as the number of problems increased. The graph integrates all four task groups and indicates that participants who received the most number of problems, five, reported a change in physical fatigue of 0.17.
Figure 427: Level of Mental Fatigue Associated with the Time to Complete a Problem

Figure 427 compares the time required to complete a problem to the changes physical fatigue levels for all four task groups. From the chart, the participant who took the longest to complete their problem indicated no change in physical demand. The participant took the shortest amount of time to complete their problem also indicated no change in physical demand.

Figure 428: Physical Fatigue Associated with the Ability to Identify Problems

Figure 428 indicates physical fatigue levels remained low for all four task groups (0.25). Six participants did not correctly identify their problem. The participant, a PSE, who reported the greatest change in physical fatigue, did not identify a problem correctly and noted a change of -0.25.
Figure 429: Physical Fatigue Associated with the Ability to Communicate Effectively

Figure 429 indicates a small trend in the data between physical fatigue levels and the ability to communicate effectively with other team members. The trend that is shown in the graph suggests an initial gradual down slope then a sharp increase. All four task groups had participants that received poor communication scores. The figure also indicates most participants were more physically fatigued after the simulation.

Figure 430: Physical Fatigue vs. the Correct Problem Resolution Plan

Figure 430 illustrates the change in physical fatigue in all four tasks groups as it relates to a participant’s ability to correctly identify the problem resolution plan. Five participants did not
correctly identify the problem resolution plan. The participant, who received the largest change in physical demand, correctly identified their problem.

Figure 431: Physical Fatigue Associated with Repeated Performance

Figure 431 indicates some of the participants, in all four task groups, indicated a change in physical fatigue levels even though the problems presented to them were problems seen in past simulation runs. However, the associated physical fatigue change was minimal.

Figure 432: Mental Fatigue Associated with Number of Problems

Figure 432 indicates the value of mental fatigue remained low even as the number of problems increased for all four task groups. The highest value possible is 1, whereas, the highest
value obtained was 0.375. Some individuals increase in mental fatigue can be associated with completing two problems simultaneously.

![Change in Mental Fatigue vs. Completion Time](image1)

**Figure 433: Level of Mental Fatigue Associated with the Time to Complete a Problem**

Figure 433 illustrates an initial increase, then decrease, and again an increase trend in the amount of mental fatigue a participant experiences when compared to the time needed to complete a problem. The participant, that took the longest time to solve the given problem, indicated no change in mental demand. The participant that took the shortest amount of time to complete the problem given to them during the simulation also indicated no change in mental demand. Both participants are engineering test leads (ETL).

![Change in Mental Fatigue vs. Problem Identification](image2)

**Figure 434: Mental Fatigue Associated with the Ability to Identify Problems**
Figure 434 depicts the change in mental demand as related to a participant’s ability to correctly identify a problem. On a scale from 0 to 1, physical fatigue levels, as reported by for all four task groups, were low (0.375).

![Change in Mental Fatigue vs. Discussion Traffic](chart)

Figure 435: Mental Fatigue Associated with the Ability to Communicate Effectively

Figure 435 illustrates a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results indicated that those who chose words carefully and were well spoken reported increases in mental fatigue. Participants chose words carefully to increase technical understanding within the community and provide necessary data to other affected groups. The SSE task group had the most participants who were given a poor communication scores.
Figure 436: Mental Fatigues vs. the Correct Problem Resolution Plan

Figure 436 indicates those participants who had correctly determined the proper problem resolution plan in relation to the change in mental fatigue values, reported changes in mental fatigue that ranged from -0.25 to +0.4. All four tasks groups had participants who did not correctly identify the proper problem resolution plan.

Figure 437: Mental Fatigue Associated with Repeated Performance

Figure 437 indicates some of the participants reported a change in mental fatigue levels even though the problems presented to them were problems seen in past simulation runs. Results
show low level of changes in mental fatigue for all four task groups. The largest change in mental demand was experienced by the SE task group.

### 4.1.5.3 Overall Job Satisfaction

Participants completed a subjective job satisfaction survey prior to the simulation that focused on job and organizational-related satisfiers. Participants were given a series of questions, which asked them to rank their response on a scale from one to five with one being strongly disagreed with a statement and five being strongly agreed with the statement. The results are shown below is figures 438 to 433. Most participants indicated a rating of four on the survey signifying that they were satisfied with their job.

![Jobs Satisfaction vs. Number of Problems](image)

Figure 438: Job Satisfaction Associated with Number of Problems

Figure 438 illustrates for the range of problems a participant was given, the overall level of job satisfaction was high for all four task groups. Even those participants who received six problems reported a high level of job satisfaction. The individual with the highest job satisfaction was a PSE, where the participant with the lowest job satisfaction was a SE. The SE
only received one problem during the simulation time. The participant with the highest satisfaction level received three problems during the simulation.

Figure 439: Job Satisfaction Associated with the Time to Complete a Problem

Figure 439 illustrates the relationship between the time it took a participant to solve a problem and overall job satisfaction. The participant who took the longest to solve a problem reported a satisfaction level of 4.13, on a scale of 1 to 5. The participant with the shortest completion time also rated their satisfaction level above four. The lowest satisfaction score was indicated by a SE.

Figure 440: Job satisfaction Associated with the Ability to Identify Problems
Figure 440 illustrates how the ability to correctly identify a problem effects a participant’s job satisfaction. Those participants who did not correctly identify a problem reported an overall job satisfaction level of 4. Only five participants did not correctly identify a problem.

![Overall Job Satisfaction vs. Discussion Traffic](image)

Figure 441: Job Satisfaction Associated with the Ability to Communicate Effectively

Figure 441 depicts a participant’s ability to communicate effectively with the team. Participants were graded by the simulation directors and results indicated, those who chose words carefully and were well spoken showed the same level of job satisfaction as individuals who chose their words less careful. Participants chose words carefully to increase technical understanding within the community and provide necessary data to other affected groups. Despite the level of communication, participants reported an above average job satisfaction level.
Figure 442: Job Satisfaction vs. the Correct Problem Resolution Plan

Figure 442 indicates participants who had correctly determined the proper problem resolution plan reported similar satisfaction levels as those individuals who did not choose the correct problem resolution plan. The high ratings of job satisfaction can be attributed to the technical material participants are able to work with and the passion for the industry. The average job satisfaction level still remained around 4, which is above average.

Figure 443: Job Satisfaction Associated with Repeated Performance

Figure 443 depicts the change in job satisfaction associated with a participant’s ability to correctly identify a problem. The lowest job satisfaction level is associated with the participant
who had not seen the problem in a previous simulation. The participant with the highest level of job satisfaction had previously experienced the problem.

4.1.5.4 NASA TLX

NASA TLX, multi-dimensional rating procedure that generates an overall workload value based on six subscales, is a subjective assessment tool used to determine levels of workload. NASA TLX provided the principal investigator with a tool to perform subjective workload assessment on jobs that require the participant to interface with human-machine systems (i.e. computers). Charts 444 through 485 present the results from the NASA TLX analysis.

Participants completed a NASA TLX survey pre and post simulation. This study looked at the changes of the six subscales and overall workload. The possible values that TLX produced ranged from 0 to 100. If a participant delta rating is negative, this indicates a participant’s pre-simulation values were higher than the post simulation values. If the delta is positive, the post simulation values are greater than the pre-simulation values.

![Change in Mental Demand vs. Number of Problems](image)

Figure 444: Mental Demand Value Associated with Number of Problems
Figure 444 depicts the change in mental demand associated with the number of problems a participant was given to solve. The ETL group reported the largest change in mental demand. The PSE group reported the smallest overall change in mental demand. The participant that received the most number of problems indicated no change in mental demand.

Figure 445: Mental Demand Value Associated with the Time to Complete a Problem

Figure 445 illustrates the time required to complete a problem as it relates to mental demand for all four task groups. As the time to complete a problem increased, mental demand also increased. The PSE task group mental demand value closely centered around zero indicating no change in mental demand even as completion time increased. The ETL task group indicated the greatest change in mental demand. The participants that took the least time to solve the problem showed no or a small change in mental demand values.
Figure 446: Mental Demand Value Associated with the Ability to Identify Problems

Figure 446 depicts the ability to identify a problem correctly to the change in the mental demand for all four task groups. No pattern can be distinguished for all four task groups. The largest change in mental demand was -45, indicating the ETL participant had a small post simulation mental demand. The PSE task group participants showed the smallest change in mental demand associated with the ability to identify the problems correctly.

Figure 447: Mental Demand Value Associated with the Ability to Communicate Effectively

Figure 447 depicts the change mental demand due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. Participants with
excellent communication skills reported higher changes in mental demand values (-45), over participants with poor communication skills. Participants with poor communication indicated changes in mental demand that ranged from -25 to +15. Participants with good communication skills, rating of 2, indicated changes in mental demand that ranged from -45 to +15.

Figure 448: Mental Demand Value vs. the Correct Problem Resolution Plan

In figure 448, six participants did not choose the correct course of action and all reported changes in mental demand. The ETL task groups reported the largest change in mental demand while the PSE reported the smallest change in mental demand. Some participants from all task groups indicated no change in mental demand. The negative change can be attributed to the time critical to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.
Figure 449: Mental Demand Associated with Repeated Performance

Figure 449 depicts the change in mental demand associated with the type of problem seen for all four task groups. All participants who received a new problem experienced no change in mental demand or indicated more mental demand was required prior to the simulation. Participants who had seen the problems in previous simulation runs and in the data bank of problem sets indicated changes in mental demand that ranges from -45 to +35. The ETL task group had the largest change overall in mental demand while the PSE group had the smallest change overall in mental demand.

Figure 450: Physical Demand Compared to the Number of Problems Completed
Figure 450 depicts the change in physical demand associated with the number of problems a participant has to complete. Participants from each task group who received three or more problems indicated the largest change in physical demand. The difference in how much change in physical demand a participant felt could be attributed to the time of day the simulation was run or the environment (i.e. temperature, lighting). The largest change in physical demand was +45, which is average.

![Change in Physical Demand vs. Completion Time](image1)

Figure 451: Physical Demand Value Associated with the Time to Complete a Problem

Figure 451 indicates as the time required to complete a problem increased, physical demand also increased. On a scale from 0 to 100, 100 indicating a very physically demanding task, the participant who took the longest to solve a problem indicated a change of 45. The participant who took the shortest amount of time to complete a problem indicated a small change in physical demand, +15. Over half of the participants indicated either no change or felt more physical demand was needed prior to the simulation.
Figure 452: Physical Demand Value Associated with the Ability to Identify Problems

Figure 452 depicts the relationship between the ability to identify a problem correctly to the change in the physical demand for all four task groups. Only five participants did not correctly identify a problem. Three of the five participants reported greater physical demands after the simulation. The largest change in mental demand was 45, on a scale of 0 to 100. Eleven participants indicated no change in physical demand.

Figure 453: Physical Demand Value Associated with the Ability to Communicate Effectively

Figure 453 illustrates the change physical demand due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. Participants with excellent communication skills reported higher changes in mental demand values (45), over
participants with poor communication skills. Participants with poor communication indicated changes in mental demand that ranged from -15 to +20. Participants with good communication skills showed average to minimal change in mental demand (-30 to 15).

Figure 454: Physical Demand Value vs. the Correct Problem Resolution Plan

Figure 454 indicates five participants did not determine the correct course of problem resolution and reported higher physical demands after the simulation for all of the task groups. The largest change in physical demand was +45, indicated by an ETL participant. The PSE task group received the smallest overall change in physical demand. The negative change can be attributed to the time critical to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.
Figure 455: Physical Demand Associated with Repeated Performance

Figure 455 illustrates the change in physical demand associated with the type of problem seen for all four task groups. All but four participants received problems that were completed in previous simulation runs and in the data bank of problem sets. Three of the four participants who received new problems indicated no change or indicated the physical demand was greater prior to the simulation.

Figure 456: Performance Value Associated with Number of Problems

Figure 456 depicts the change in performance satisfaction associated with the number of problems a participant completed. Over half of the participants reported a better performance prior to the simulation as indicated by a negative value. Those who reported a better
performance post test indicated a change of no more than +20. The highest change in performance was -45 from a SE participant, indicating the participant had higher pre simulation performance values.

Figure 457: Performance Value associated with the time to complete a problem

Figure 457 illustrates as the time required to complete a task increased, post simulation satisfaction decreased. The performance value is associated with satisfaction and success. The participant who took the longest time to solve a problem reported higher levels of satisfaction prior to the simulation. The participant who solved a problem the quickest indicated higher level of satisfaction post simulation. Some of the factors they may account for higher pre simulation scores include how a participant did in a past performance or the participant’s self confidence.
Figure 458: Performance Value Associated with the Ability to Identify Problems

Figure 458 depicts the relationship between the ability to identify a problem correctly to the change in a participant’s satisfaction for all four task groups. The largest change in performance satisfaction was -45, by a SE, indicating higher pre simulation performance satisfaction. The PSE task group reported the smallest overall change in satisfaction.

Figure 459: Performance Value Associated with the Ability to Communicate Effectively

Figure 459 depicts the change in performance satisfaction due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. Participants with poor communication skills indicated changes in performance values that ranged from -20 to +10. Participants with excellent communication skill had stronger pre simulation
performance satisfaction (-45) than post simulation satisfaction (+20).

![Change in Performance Value vs. Decision Making](image)

**Figure 460: Performance Value vs. the Correct Problem Resolution Plan**

Figure 460 indicates four participants did not determine the correct course of problem resolution and reported changes in satisfaction. Two of the four participants indicated higher levels of satisfaction prior the simulation, while one indicated high levels of satisfaction after the simulation. The negative change can be attributed to the time pressure associated with the need to complete the problem, the pressure associated with peer performance evaluation, and the professional image within the flight team.

![Change in Performance Value vs. Repeated Performance](image)

**Figure 461: Performance Value Associated with Repeated Performance**
Figure 461 illustrates the change in a participant’s satisfaction associated with the type of problem seen for all four task groups. All but four participants received problems that were completed in previous simulation runs and in the data bank of problem sets. The two of the four participants that received a new problem indicated a higher post simulation satisfaction while the other two participants were just the opposite.

![Change in Temporal Demand Value vs. Number of Problems](image)

Figure 462: Temporal Demand Value Associated with Number of Problems

Figure 462 depicts the change in how much pressure a participant felt during the simulation associated with the number of problems a participant was given to solve. Less than half of the participants noted higher temporal demands post simulation. The participants who received the most problems indicated no change in pressure. The increase in pre-simulation pressure may be attributed to not knowing the problems being given or the pace at which the problem occurred.
Figure 463: Temporal Demand Value Associated with the Time to Complete a Problem

Figure 463 illustrates as the time required to complete a task increased, post temporal demands also increased. The participant who took the longest to solve a problem reported higher temporal demand scores post simulation. The participant who took the shortest amount of time to complete a problem also indicated higher temporal demands post simulation. Some of the factors they may account for higher pre simulation scores include how a participant did in a past performance or the participant’s self confidence.

Figure 464: Temporal Demand Value Associated with the Ability to Identify Problems
Figure 464 depicts the relationship between the ability to identify a problem correctly to the change in pressure a participant felt during the simulation for all four task groups. Participants who did not correctly identify a problem indicated no change or higher post simulation scores (+25). The largest change in temporal demand was -40.

Figure 465: Temporal Demand Value Associated with the Ability to Communicate Effectively

Figure 465 depicts the change in the time pressure a participants felt due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. Temporal demand is associated with the amount of time pressure a participant feels during a testing period. Participants with poor communication, three of the four participants indicated no change or higher pre simulation time pressure demands. The SE task groups indicated the largest overall change in temporal demand. The SSE task group indicated the smallest overall change in temporal demands.
Figure 466: Temporal Demand Value vs. the Correct Problem Resolution Plan

Figure 466 indicates four participants did not choose the correct course of action and reported higher temporal demands after the simulation. The largest change in temporal demand was indicated by a SE participant (-40). The increase in post simulation pressure could be attributed to the rate at which tasks were given to the participants.

Figure 467: Temporal Demand Value Associated with Repeated Performance

Figure 467 indicates the change in stress a participant felt compared with the type of problem seen for all four task groups. All but four participants received the problems that were completed in previous simulation runs and in the data bank of problem sets. Two of the four participants who had not seen their problem in a prior simulation reported more pressure prior to the simulation while the other two participants reported more pressure prior to the simulation.
Figure 468: Effort Value Associated with Number of Problems

Figure 468 illustrates the change in effort associated with the number of problems a participant received for all four task groups. The participant with the most problems reported more effort was required prior to the simulation (-5). The largest change in effort was indicated by a SSE, -60, who received three problems. The negative values could be associated with the preparation time of a participant before the simulation, the anticipation of how hard, mentally, the simulation will be or the level of effort required to complete the task.

Figure 469: Effort Value Associated with the Time to Complete a Problem

Figure 469 indicates the participant who took the longest to solve a problem reported no change in effort. The participant who took the shortest amount of time to complete a problem
indicated more effort was required post simulation. Problems that took over an hour to solve showed either no change or indicated more effort was required prior to the simulation.

![Change in Effort Value vs. Problem Identification](image1)

**Figure 470: Effort Value Associated with the Ability to Identify Problems**

Figure 470 illustrates the relationship between the ability to identify a problem correctly to the change in effort required to accomplish the task for all four task groups. Participants who did not correctly identify the problem indicated no change in effort or felt more effort was required pre simulation with the exception of one of the participants. The largest change in effort was indicated by a SSE, -60.

![Change in Effort Value vs. Discussion Traffic](image2)

**Figure 471: Effort Value Associated with the Ability to Communicate Effectively**
Figure 471 indicates the change in effort due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. The majority of participants with poor communication reported more effort was required pre simulation. Participants with excellent communication had higher pre simulation scores, with the exception of three participants, where one indicated no change in effort and the other two felt more effort was required post simulation (5).

![Change in Effort Value vs. Decision Making](image)

Figure 472: Effort Value vs. the Correct Problem Resolution Plan

Figure 472 indicates that five participants did not determine the correct course of problem resolution for the problem they were given. Three of those participants indicated no change in the effort required to complete simulation. The participants that correctly chose the pre-planned problem resolution plan had varying results on when more effort was required.
Figure 473: Effort Value Associated with Repeated Performance

Figure 473 depicts the change in a participants effort level associated with the type of problem seen for all four task groups. All but five participants received problems that were completed in previous simulation runs and in the data bank of problem sets. Three participants who received a new problem felt more effort was required after the simulation. The other two participants who received new problem indicated no change in effort or indicated more effort was required prior to the simulation.

Figure 474: Frustration Value Associated with Number of Problems

Figure 474 depicts the number of problems completed to how relaxed or content a participant was during their task for all four task groups. The participant who received the most
problems indicated they were less relaxed prior to the simulation. Participants who received the few problems indicated no change or high frustration values after the simulation. The SSE task group had the overall largest change in frustration values. The SE task group had the smallest overall change in frustration.

![Change in Frustration Value vs. Completion Time](image)

Figure 475: Frustration Value associated with the time to complete a problem

Figure 475 indicated participant who took the longest to solve their problem, an ETL, reported more stress or irritation after the simulation. The participant who took the shortest amount of time to complete a problem, a PSE, also indicated higher frustration values after the simulation.

![Change in Frustration Value vs. Problem Identification](image)

Figure 476: Frustration Value Associated with the Ability to Identify Problems
Figure 476 illustrates the change in a participant frustration level to the ability of a participant to correctly identify a problem, in all four task groups. The graph indicates all but six participants correctly identified the problem. The participants who did not correctly identify the problem given to them in the simulation felt more frustration after the simulation. Participants who correctly identified the problem given to them during the simulation indicated changes in frustration values that ranged from -45 to +50.

![Change in Frustration Value vs. Discussion Traffic](image)

Figure 477: Frustration Value Associated with the Ability to Communicate Effectively

Figure 477 depicts the change in frustration due to the ability to communication a problem and the resolution to the simulation team for all four task groups. Participants with poor communication reported more frustration prior to simulation with the exception of one participant. Participants with excellent communication skills, 3, indicated changes in frustration values that ranged from -20 to +45.
Figure 478: Frustration Value vs. the Correct Problem Resolution Plan

Figure 478 indicates that four participants did not correctly identify the problem and reported more frustration after the simulation. Participants in a post simulation interview stated some of the possible reasons for higher frustration levels post simulation include a participant not being content with their performance, participant felt they could have done a better job during the simulation or the participant felt insecure about their performance. Participants who did correctly identify the problem given to them during the simulation indicated changes in frustration values that ranged from -45 to +50.

Figure 479: Frustration Value Associated with Repeated Performance
Figure 479 depicts the change in how much frustration a participant reported compared with the type of problem seen for all four task groups. All but four participants received the problems that were completed in previous simulation runs and in the data bank of problem sets. The participants who had not seen their problem in a prior simulation felt more frustrated after the simulation with the exception of one participant who felt more frustrated prior to the simulation.

![Change in Total Workload Value vs. Number of Problems](image)

Figure 480: Workload Value Associated with Number of Problems

Figure 480, illustrates the change in workload associated with the number of problems a participant received for all four task groups. The participant with the most problems to complete indicated that the workload was more prior to the simulation. Most participants felt the workload was higher post simulation.
Figure 481: Workload Value associated with the time to complete a problem

Figure 481 indicates as the time required to complete a problem increase, the amount of work required to complete the problem also increased. Problems that took more than 60 minutes to complete also showed an increase in workload post simulation. The participant who solved a problem in the shortest amount of time also indicated higher levels of workload post simulation.

Figure 482: Workload Value Associated with the Ability to Identify Problems

Figure 482 depicts the relationship between the ability to identify a problem correctly to the change in the workload for all four task groups. The graph indicates participants who did not
correctly identify a problem reported higher workload values post simulation. Participants who did correctly identify a problem reported a broad range in the amount of work that was required to complete the simulation (-25 to +25)

![Change in Total Workload Value vs. Discussion Traffic](image)

Figure 483: Workload Value Associated with the Ability to Communicate Effectively

Figure 483 indicates the change in workload due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. Participants with poor communication reported higher pre simulation workload levels with the exception of two participants. Over half of the participants with good communication indicated higher workloads post simulation.
Figure 484 Workload Value Associated with the Ability to Determine the Correct Problem Resolution

Figure 484 indicates five participants did not choose the correct course of problem resolution and noted higher workloads after the simulation for all four task groups. Over half of the participants that correctly identified the right problem resolution path had higher pre-simulation workload values. The participants who did not choose the correct course of problem resolution indicated no change or had high post-simulation workload values.

Figure 485: Workload Value Associated with Repeated Performance

Figure 485 indicates the change in workload associated with the type of problem for all four task groups. Four participants received a problem that was not in a previous simulation run and reported more work was required post-simulation or indicated no change in workload. The
participants who received past problems indicated a change in workload that ranged from -35 to +25.

4.1.5.5 SOFI

The Swedish Occupation Fatigue Inventory (SOFI) is a subjective tool that describes fatigue using five dimensions: lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness. The dimensions represent the perceptions of how participants feel at a given point in time. The participants completed the inventory pre- and post-simulation. The results of the inventory are included in charts 486 through 515.

This study looked at the change in the five dimensions. The possible values that SOFI produced ranged from 0 to 10. If a participant delta rating is negative, this indicates a participant’s pre-simulation values were higher than the post-simulation values. If the delta is positive, the post-simulation values are greater than the pre-simulation values.

Figure 486: Lack of Energy Compared to Number of Problems

Figure 486, illustrates as the number of problems increased; more energy was required to complete the problems. The participant with the most problems to solve reported more energy
was required prior to the simulation than after. The participant with the fewest number of problems to solve indicated more energy was required prior to the simulation.

Figure 487: Lack of Energy Associated with Completion Time

Figure 487 indicates participants who took the longest time to solve a problem reported less energy after the simulation. The participant who took the least amount of time to complete a problem indicated a change in energy. All of the PSE participants either indicated no change in energy or reported less energy after the simulation.

Figure 488: Lack of Energy Associated with the Ability to Identify Problems

Figure 488 illustrates the relationship between the ability to identify a problem correctly to the change in a participant’s energy level for all four task groups. Participants who were not
able to correctly identify their problem reported no change or indicated less energy after the simulation. Participant who correctly identified a problem reported change in energy that ranged from -2.5 to 4.

Figure 489: Lack of Energy Associated with the Ability to Communicate Effectively

Figure 489 illustrates the change in energy levels due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. Those participants with poor communication reported less energy before the simulation or indicated no change. Those participants with good communication, 2, indicated changes in energy that ranges from -2.5 to +4.
Figure 490: Lack of Energy vs. the Correct Problem Resolution Plan

Figure 490 indicates five participants did not choose the correct course of problem resolution. Three of those participants did indicate experiencing less energy after the simulation. One of the other participants indicated no change in energy levels. Half of the participants that chose the correct problem resolution path reported more energy was required prior to the simulation.

Figure 491: Lack of Energy Associated with Repeated Performance

Figure 491 illustrates the change in a participant’s level of energy associated with the type of problem seen for all four task groups. Three participants who had not seen the problem
given to them in a past simulation runs indicated either no change in energy or indicated more energy was required post simulation. The participants previously experienced the problem indicated change in energy levels that ranged from -2.5 to +4.

Figure 492: Physical Exertion Compared to Number of Problems

Figure 492 illustrates as the number of problems increased, more physical energy was required to complete the problem. The participants with the fewest number of problems to complete, indicated changes in physical energy that ranged from -2 to +1.5. Participants who completed five problems either indicated no change in physical exertion or indicated more physical exertion was required prior to the simulation.

Figure 493: Physical Exertion Associated with the Time to Complete a Problem
Figure 493 indicates the participant who took the longest to solve a problem reported no change in the physical energy required to compete the simulation. The participant who took the short amount of time to complete a problem reported more physical energy was required after the simulation. The tasks presented are a mental exercise rather than physical in nature which could explain why some participants did not note any change in physical exertion.

Figure 494 illustrates the relationship between the ability to identify a problem correctly compared to the change in the amount of physical energy a participant exerted for all four task groups. The graph indicates those individuals who were not able to correctly identify their problem had higher or no change in the physical energy required to complete the simulation with the exception of three participants. Those participants who did not correctly identify the problem given to them indicated no change or had higher physical exertion after the simulation with the exception on one participant.
Figure 495: Physical Exertion Associated with the Ability to Communicate Effectively

Figure 495 depicts the change in physical energy due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. Participants who exhibited poor communication skills reported more physical energy was required after the simulation or indicated no change. Participant with excellent communication skills, rating of 3, indicated changes in physical exertion that ranged from -0.5 to 1.5.

Figure 496: Physical Exertion vs. the Correct Problem Resolution Plan

Figure 496 indicates four participants did not chose the correct course of problem resolution and three of those participants noted no change in the level of physical energy need to complete the simulation. Participants who did chose the correct resolution plan indicated
changes in physical demand that ranged from -2 to +1.5. The lack of change in physical exertion could be attributed to the type of problem the individual was given since all tasks were mentally demanding in nature.

![Change in Physical Exertion vs. Repeated Performance](image)

**Figure 497: Lack of Energy Associated with Repeated Performance**

Figure 497 illustrates the change in a participant’s level of physical energy associated with the type of problem seen for all four task groups. Participants who had not seen their problem in past simulation runs reported more physical energy was required to complete the simulation or indicated no change in physical exertion.

![Change in Physical Discomfort vs. Number of Problems](image)

**Figure 498: Physical Discomfort Compared to Number of Problems**
Figure 498 indicates participants with the most problems to solve reported an increase in physical discomfort after the simulation. Participants who received 3 or fewer problems indicated a change in physical discomfort. Some of the participants had more physical discomfort before the simulation while other had more physical discomfort after the simulation. The ETL task groups showed the largest overall change in physical discomfort.

![Change in Physical Discomfort vs. Completion Time](image)

Figure 499: Physical Exertion Associated with the Time to Complete a Problem

Figure 499 indicates participants who took the longest to solve a problem reported more physical discomfort prior the simulation. The participant, who took the least amount of time to complete their problem, reported more physical discomfort after the simulation. Most participants indicated they felt more physical discomfort prior to the simulation. The SSE task group participants showed almost no change in physical discomfort.
Figure 500: Physical Discomfort Associated with the Ability to Identify Problems

Figure 500 depicts the relationship between the ability to identify a problem correctly to the change in a participant’s level of physical discomfort for all four task groups. Participants who did not correctly identify the problem reported higher physical discomfort prior to the simulation or indicated no change. Participants may have reported more physical discomfort prior to the simulation due exhaustion because of carrying material over to the simulation room, muscles are tense because of computer position or due to numbness of joints.

Figure 501: Physical Discomfort Associated with the Ability to Communicate Effectively

Figure 501 depicts the change in physical discomfort due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. Participants who
exhibited poor communication reported more discomfort after the simulation or indicated no change in physical discomfort. Most of the participants with excellent communication indicated more physical discomfort prior to the simulation.

![Graph: Change in Physical Discomfort vs. Decision Making](image)

**Figure 502: Physical Discomfort vs. the Correct Problem Resolution Plan**

Figure 502 indicates four participants did not choose the correct course of problem resolution and reported changes in physical discomfort. Participants who did correctly identify the correct course of problem resolution, over half reported more physical discomfort prior the simulation.

![Graph: Change in Physical Discomfort vs. Repeated Performance](image)

**Figure 503: Lack of Physical Discomfort Associated with Repeated Performance**
Figure 503 depicts the changes in a participant’s level of physical discomfort associated with the type of problem seen for all four task groups. Participants who had not seen a problem in past simulation runs felt more or indicated no change physical discomfort prior to the simulation with the exception of one participant.

![Change in Lack of Motivation vs. Number of Problems](image)

**Figure 504: Lack of Motivation Compared to Number of Problems**

Figure 504 indicates as the number of problems a participant has to complete increased, lack of motivation also increased. The participant with the most problems to solve reported more motivation prior to the simulation. Participants with only one problem to solve, indicated changes in motivation that ranged from -3.25 to +1.25.

![Change in Lack of Motivation vs. Completion Time](image)

**Figure 505: Lack of Motivation Associated with the Time to Complete a Problem**
Figure 505 indicates participants who took longest to solve a problem reported no change in motivation during the simulation. The participant who solved the problem in the shortest amount of time reported less motivation before the simulation. The SE task group had the largest overall change in motivation levels. The SSE task group indicated no change in motivation.

![Change in Lack of Motivation vs. Problem Identification](image_url)

Figure 506: Lack of Motivation Associated with the Ability to Identify Problems

Figure 506 illustrates the relationship between the ability to identify a problem correctly to the change in a participant’s level of motivation for all four task groups. Participants who did not correctly identify the problem reported lower levels of motivation after the simulation with the exception of one participant. Participants may have felt less motivated after the simulation due to their performance during the simulation or the results from peer and/or director evaluations.
Figure 507: Lack of Motivation Associated with the Ability to Communicate Effectively

Figure 507 depicts the change in motivation due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. Participants who exhibited poor communication reported less motivation after the simulation with the exception of one participant. Those participants with excellent communication skills, rating of 3, indicated changes in motivation that ranged from -3.25 to +1.5.

Figure 508: Lack of Motivation vs. the Correct Problem Resolution Plan

Figure 508 indicates five participants did not chose the correct course of problem resolution and noted no or a small change in motivation need to complete the simulation in all
four task groups. Over half of the participants who did chose the correct course of problem resolution reported less motivation after the simulation or identified no change in motivation levels.

![Change in Lack of Motivation vs. Repeated Performance](image)

**Figure 509: Lack of Motivation Associated with Repeated Performance**

Figure 509 depicts that change in a participant’s level of motivation associated with the type of problem seen for all four task groups. Participants who had not seen their problem in past simulation runs reported less motivation after the simulation or indicated no change. Over half of the participants who had seen the problem given to them in a previous simulation indicated lower levels of motivation after the simulation.

![Change in Sleepiness vs. Number of Problems](image)

**Figure 510: Sleepiness Compared to Number of Problems**
Figure 510 indicates the number of problems a participant has to complete increased, sleepiness decreased during the simulation. Participants who received three or fewer problems indicated higher levels of sleepiness prior to simulation with the exception an SE participant. Participants who received only one problem indicated higher levels of sleepiness prior to the simulation.

![Change in Sleepiness vs. Completion Time](image1)

**Figure 511: Sleepiness Associated with Completion Time**

Figure 511 illustrates participants who took longest to solve a problem indicated a higher level of sleepiness prior to the simulation although it was very small. The participant who solved the problem in the shortest amount of time indicated no change in sleepiness.

![Change in Sleepiness vs. Problem Identification](image2)

**Figure 512: Sleepiness Associated with the Ability to Identify Problems**
Figure 512 depicts the relationship between the ability to identify a problem correctly to the change in a participant’s level of sleepiness for all four task groups. Participants who did not correctly identify the problem had no change or were more sleepy prior to the simulation with the exception of two participants.

![Change in Sleepiness vs. Discussion Traffic](image)

Figure 513: Sleepiness Associated with the Ability to Communicate Effectively

Figure 513 illustrates the change in sleepiness due to the ability to communicate a problem and the resolution to the simulation team for all four task groups. Participants who exhibited poor communication reported feeling less sleepy after the simulation or indicated no change. Participants who exhibited excellent communication skills reported sleepiness ratings that ranged from -2 to +2.5.
Figure 514: Sleepiness vs. the Correct Problem Resolution Plan

Figure 514 indicates five participants were not able to chose the correct course of problem resolution. Four of the five participants indicted either no change sleepiness or indicated they felt less sleepy after the simulation. The participants who did chose the correct course of problem resolution indicated a range of sleepiness (-3 to +2.5).

Figure 515: Sleepiness Associated with Repeated Performance

Figure 515 depicts the change in a participant’s level of sleepiness associated with the type of problem seen for all four task groups. Participants who had not seen the problem give to them in past simulation runs reported feeling more tired after the simulation with the exception
Most participants who had seen the problem given to them in a previous simulation indicated higher levels of sleepiness prior to the simulation.

### 4.2 Test for Analysis of Variance Assumptions

To determine if a difference exists between the means of a variable, an Analysis of Variance (ANOVA) analysis was conducted using Minitab. An ANOVA was chosen to determine if a task group mean is significant.

The null hypothesis for this analysis was:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$$

The alpha level used for acceptance and rejection was $\alpha = .05$.

If the ANOVA showed significance and the null hypothesis was rejected, it was assumed that at least one population mean was different from at least one other populating mean. For example, mean heart rate for the SE participants was different from the mean heart rate of ETL participants. To determine which means was different, a Tukey HSD test was completed.

#### 4.2.1 Analysis of Heart Rate

The table below indicates the results of the ANOVA analysis performed on the heart rate data of the participant groups.
Table 3: Heart Rate ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1392.2</td>
<td>3</td>
<td>464.0665</td>
<td>3.050841</td>
<td>0.03605</td>
<td>2.772537</td>
</tr>
<tr>
<td>Within Groups</td>
<td>8366.106</td>
<td>55</td>
<td>152.111</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9758.305</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Since $F_{0.05,3,55}=2.78$, $H_0$ is rejected at an alpha level of .05 ($F=3.050841$). To determine the significant difference between the $\mu$’s, Tukey’s post hoc analysis was completed.

Table 4: Tukey’s HSD Analysis of Heart Rate

| Level | N    | Mean | StDev | Individual 95% CIs For Mean Based on Pooled StDev |
|-------|------|------|-------|-------------------------------------------------
| ETL   | 20   | 33.45| 16.16 | (-------*-------) |
| SE    | 9    | 21.11| 9.25  | (-----------*-----------) |
| PSE   | 15   | 26.67| 10.74 | (--------*--------) |
| SSE   | 15   | 22.93| 8.89  | (--------*--------) |
| 14.0  | 21.0 | 28.0 | 35.0  | +---------+---------+---------+
| XSE   | 21.11| XSEE | 22.93 | 26.67 | XETL |
| SSE   | 25.94| 26.67| 33.45 |

The results from the Tukey analysis are shown in Table 5. The results indicate that the change in heart rate for the SE and SSE task group participants are not significantly different from one another. However, they are both significantly different from the change in heart rate for the ETL task group participants. Heart rates for participants in the SSE task group were not significantly different from the SE or PSE task group participants; however, they were significantly different from those for the ETL task group participants. Heart rates for the
participants in the PSE task group were not significantly different from the heart rate of participants in the SSE or SE or ETL task groups. The heart rate for participants in the ETL task group were not significantly different from the heart rate of participants in the PSE task group but were significantly different from the heart rate of participants in the SSE and SE task groups.

### 4.2.2 Analysis of Completion Time

Table six depicts the results of the ANOVA analysis performed on the time it took a participant to complete a problem, or completion time. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is not rejected at level .05 ($F=1.845592$). Thus, there was no significant difference between the mean completion times of the individual task groups.

Table 5: Completion Time ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1506.717</td>
<td>3</td>
<td>502.2389</td>
<td>1.845592</td>
<td>0.149406</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>15239.22</td>
<td>56</td>
<td>272.1289</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>16745.93</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4.2.3 Analysis of Number of Problems

Table 7 indicates the results of the ANOVA analysis performed on the number of problems a participant received during the simulation period. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is not rejected at level .05 ($F=0.948709$). Thus, there was no significant difference between the mean number of problems a participant was given in the individual task groups.

Table 6: Number of Problems ANOVA
4.2.4 Analysis of Problem Identification

Problem identification refers to a participant’s ability to correctly identify a problem given to him/her during the simulation. Table 8 depicts the results of the ANOVA analysis performed on problem identification. Since $F_{0.05, 3, 56} = 2.78$, $H_0$ is not rejected at level .05 ($F=0.292581$). Thus, there was no significant difference between the average problem identification rating in the individual task groups.

Table 7: Problem Identification ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.0833333</td>
<td>3</td>
<td>0.027778</td>
<td>0.292581</td>
<td>0.830578</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>5.316667</td>
<td>56</td>
<td>0.09494</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5.4</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2.5 Analysis of Discussion Traffic

Discussion traffic is used to describe how effectively a participant communicates a problem with other team members and the resolution plan. Table 9 indicates the results of the ANOVA analysis performed on how effectively a participant was able to communicate a problem to other team members and the effectiveness of the communication. Since $F_{0.05}$,
$F=7.369275$. To determine the significant difference between the $\mu$'s, Tukey’s post hoc analysis was completed.

Table 8: Discussion Traffic ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>7.56667</td>
<td>3</td>
<td>2.52222</td>
<td>7.369275</td>
<td>0.000302</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>19.16667</td>
<td>56</td>
<td>0.34226</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>26.73333</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9: Tukey’s HSD Analysis of Discussion Traffic

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETL</td>
<td>20</td>
<td>2.6000</td>
<td>0.5982</td>
</tr>
<tr>
<td>SE</td>
<td>10</td>
<td>2.5000</td>
<td>0.5270</td>
</tr>
<tr>
<td>PSE</td>
<td>15</td>
<td>2.0667</td>
<td>0.4577</td>
</tr>
<tr>
<td>SSE</td>
<td>15</td>
<td>1.7333</td>
<td>0.7037</td>
</tr>
</tbody>
</table>

The results of Tukey’s HSD analysis are shown in table 10 and indicate the mean discussion traffic scores for the SE and ETL task groups were not significantly different from one another; however, they were significantly different from the mean discussion traffic scores of PSE and SSE task group participants.

The mean discussion traffic scores for the SSE and PSE task group participants were significantly different from all other task groups. The mean discussion traffic scores for participants in the SE task group were not significantly different from the mean discussion traffic scores of ETL task group participants but were significantly different from the mean discussion traffic scores of PSE and SSE task group participants.
4.2.6 Analysis of Decision Making

Decision making refers to the process a participant made to determine a resolution plan and the correctness of that resolution plan. Table 11 indicates the results of the ANOVA analysis performed on a participant’s ability to correctly determine the proper problem resolution plan. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is not rejected at level .05 ($F=0.115942$). Thus, there is not a significant difference between the mean decision-making capabilities of participants in the individual task groups.

Table 10: Decision Making ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.033333</td>
<td>3</td>
<td>0.011111</td>
<td>0.115942</td>
<td>0.950401</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>5.366667</td>
<td>56</td>
<td>0.095833</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5.4</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2.7 Analysis of Repeated Performance

Table 12 depicts the results of the ANOVA analysis performed on reported performance to determine if a difference exits in the means of the task groups. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is not rejected at level .05 ($F=0.220307$). Thus, there is not a significant difference between the means indicated performance scores in the individual task groups. Some participants received new problems that were created for that specific simulation run, whereas others were given problems from the data bank of problems created by the simulation team.
Table 11: Repeated Performance ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.033333</td>
<td>3</td>
<td>0.011111</td>
<td>0.220907</td>
<td>0.881482</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>2.816667</td>
<td>56</td>
<td>0.050298</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2.85</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2.8 Analysis of Physical Fatigue

Table 13 depicts the results of the ANOVA analysis performed on the mean change in physical fatigue. A participant completed a survey before and after the simulation to determine if any changes in physical fatigue occurred because of the activities in the simulation. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is rejected at level .05 ($F=2.92051$). Thus, there is not a significant difference between the mean changes in physical fatigue indicated by participants in the individual task groups.

Table 12: Physical Fatigue ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.095175</td>
<td>3</td>
<td>0.031725</td>
<td>2.92051</td>
<td>0.041838</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>0.608319</td>
<td>56</td>
<td>0.010863</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.703494</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 13: Tukey’s HSD Analysis of Physical Fatigue

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETL</td>
<td>20</td>
<td>0.0708</td>
<td>0.0559</td>
</tr>
<tr>
<td>SE</td>
<td>10</td>
<td>0.0646</td>
<td>0.0929</td>
</tr>
<tr>
<td>PSE</td>
<td>15</td>
<td>0.0056</td>
<td>0.1710</td>
</tr>
<tr>
<td>SSE</td>
<td>15</td>
<td>-0.0222</td>
<td>0.0666</td>
</tr>
</tbody>
</table>

The results from a Tukey HSD Analysis, shown in Table 14, indicate there is no difference in the level of physical fatigue a SSE task group participant reported from PSE task group participants. Additionally, the physical fatigue levels experienced by participants in the SE task group were not significantly different from the physical fatigue levels of ETL task group participants. However, the physical fatigue levels experienced by participants in the ETL task group were significantly different from the physical fatigue levels experienced by participants in the PSE and SSE task groups. A significant difference in physical fatigue levels was also found between participants in the SE task group, SSE task group, and PSE task group.

4.2.9 Analysis of Mental Fatigue

Table 15 depicts the results of the ANOVA analysis performed on the mean mental fatigue a participant indicated before and after the simulation. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is rejected at level .05 ($F=5.191011$).
Table 14: Mental Fatigue ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.3094</td>
<td>3</td>
<td>0.1031</td>
<td>5.191</td>
<td>0.0031</td>
<td>2.7694</td>
</tr>
<tr>
<td>Within Groups</td>
<td>1.1125</td>
<td>56</td>
<td>0.0199</td>
<td>1.001</td>
<td>0.326</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.4219</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 15: Tukey’s HSD Analysis of Mental Fatigue

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>Individual 95% CIs For Mean Based on Pooled StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETL</td>
<td>20</td>
<td>0.075</td>
<td>0.094</td>
<td>(--*------)</td>
</tr>
<tr>
<td>SE</td>
<td>10</td>
<td>-0.075</td>
<td>0.158</td>
<td>(--*------)</td>
</tr>
<tr>
<td>PSE</td>
<td>15</td>
<td>0.150</td>
<td>0.171</td>
<td>(--*------)</td>
</tr>
<tr>
<td>SSE</td>
<td>15</td>
<td>0.050</td>
<td>0.148</td>
<td>(--*------)</td>
</tr>
</tbody>
</table>

The Tukey HSD analysis results, shown in Table 16, indicate that the average change in mental fatigue for participants in the SSE task group was not significantly different from the mental fatigue scores of ETL task group participants. However, there was a significant difference in the average change in mental fatigue of participants in the PSE task group to those participants in the ETL, SSE, and SE task groups. Additionally, a significant difference in average change in mental demand was found between participants in the SE task group and all other task groups. A significant difference was also found in the change in mental fatigue between participants in the ETL task group and the PSE and SE task group participants.
4.2.10 Analysis of Overall Job Satisfaction

Table 17 indicates the results of the ANOVA analysis performed on the mean of a participant’s job satisfaction. Since $F_{0.05,3,56}=2.78$, $H_0$ is rejected at level .05 ($F=9.050882$).

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>2.320222</td>
<td>3</td>
<td>0.773407</td>
<td>9.050882</td>
<td>5.57E-05</td>
</tr>
<tr>
<td>Within Groups</td>
<td>4.785259</td>
<td>56</td>
<td>0.085451</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7.105481</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 17: Tukey’s HSD Analysis of Job Satisfaction

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>P-value F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETL</td>
<td>20</td>
<td>3.9350</td>
<td>0.3100</td>
<td>(-----*-----)</td>
</tr>
<tr>
<td>SE</td>
<td>10</td>
<td>3.8600</td>
<td>0.2989</td>
<td>(------*-------)</td>
</tr>
<tr>
<td>PSE</td>
<td>15</td>
<td>4.3867</td>
<td>0.2900</td>
<td>(-----*------)</td>
</tr>
<tr>
<td>SSE</td>
<td>15</td>
<td>3.9533</td>
<td>0.2850</td>
<td></td>
</tr>
</tbody>
</table>

The Tukey HSD analysis results, shown in Table 18, indicate that the average score for participant job satisfaction was not significantly different for participants in the SSE and ETL task groups. There were significant differences between the PSE task group participant jobs satisfaction ratings and the other task group job satisfaction ratings. Additionally, a significant difference in job satisfaction was found between the SE task group participants and all other task group participants. A significant difference in job satisfaction was also found between the job...
satisfaction ratings of ETL task group participants and the job satisfaction ratings of PSE and SE task group participants.

### 4.2.11 Analysis of Lack of Energy

Lack of Energy is associated with how worn out, spent or exhausted a participant felt during the simulation period. Table 19 depicts the results of the ANOVA analysis performed on the mean change in energy indicated by the participants. Since $F_{0.05, 3, 56} = 2.78$, $H_0$ is rejected at level .05 ($F=8.398614$).

#### Table 18: Lack of Energy ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$P$-value</th>
<th>$F$ crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>39.49129</td>
<td>3</td>
<td>13.16376</td>
<td>8.398614</td>
<td>0.000106</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>87.7729</td>
<td>56</td>
<td>1.567373</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>127.2642</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Table 19: Tukey’s HSD Analysis of Lack of Energy

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>Individual 95% CIs For Mean Based on Pooled StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETL</td>
<td>20</td>
<td>-0.069</td>
<td>0.392</td>
<td>(------*------)</td>
</tr>
<tr>
<td>SE</td>
<td>10</td>
<td>0.750</td>
<td>2.034</td>
<td>(---------------*---------------)</td>
</tr>
<tr>
<td>PSE</td>
<td>15</td>
<td>1.883</td>
<td>1.844</td>
<td>(---------------*---------------)</td>
</tr>
<tr>
<td>SSE</td>
<td>15</td>
<td>-0.015</td>
<td>0.010</td>
<td>(---------------*---------------)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$X_{SE}$</th>
<th>$X_{SSE}$</th>
<th>$X_{ETL}$</th>
<th>$X_{PSE}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.075</td>
<td>0.05</td>
<td>0.075</td>
<td>0.15</td>
</tr>
</tbody>
</table>
The Tukey HSD analysis results, shown in Table 20, demonstrate no significant difference in energy levels indicated by participants could be found between the SE and SSE task group’s participants or between SE and ETL task group participants. Additionally, no significant difference in energy levels was identified between participants in the SSE and ETL task groups. There were significant difference in energy levels between the PSE task group participants and the SSE and SE task group participants. Additionally, there was no significant difference in energy levels for participants in the ETL task group and PSE task group.

4.2.12 Analysis of Lack of Physical Exertion

Lack of Physical Exertion is associated with how sweaty, out of breath, or warm a participant felt during the simulation period. Table 21 indicates the results of the ANOVA analysis performed on the change in physical exertion a participant experienced during the simulation. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is not rejected at level .05 ($F=2.020576$). Thus, there is not a significant difference between the average levels of physical exertion a participant experienced during the simulation.

Table 20: Lack of Physical Exertion ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>2.625019</td>
<td>3</td>
<td>0.875006</td>
<td>2.020576</td>
<td>0.121433</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>24.25069</td>
<td>56</td>
<td>0.433048</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>26.8757</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.2.13 Analysis of Change in Physical Discomfort

Physical discomfort relates to stiff joints, tense muscle or numbness a participant may have felt because of activities associated with the simulation testing. Table 22 depicts the results of the ANOVA analysis performed on the change in physical discomfort a participant experienced during the simulation. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is not rejected at level .05 ($F=1.968001$). Thus, there was no significant difference in the levels of discomfort a participant felt in the individual task groups.

Table 21: Physical Discomfort ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>7.650462</td>
<td>3</td>
<td>2.550154</td>
<td>1.968001</td>
<td>0.129242</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>72.56532</td>
<td>56</td>
<td>1.295809</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>80.21578</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2.14 Analysis of Lack of Motivation

Lack of motivation is associated with passiveness, lack of concern, or being disinterested in the subject under discussion or review. Table 23 illustrates the results of the ANOVA analysis performed on the mean change in motivation a participant indicated during the testing period. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is not rejected at level .05 ($F=1.841216$). Thus, there was no significant difference in the level of motivation a participant felt between the four different task groups.

Table 22: Lack of Motivation ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>4.947628</td>
<td>3</td>
<td>1.649209</td>
<td>1.841216</td>
<td>0.150181</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>50.16018</td>
<td>56</td>
<td>0.895717</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>55.10781</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.2.15 Analysis of Sleepiness

Sleepiness is associated with falling asleep, yawning, and having a general feeling of laziness. Table 24 depicts the results of the ANOVA analysis performed on the mean change in sleepiness indicated before and after the simulation. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is not rejected at level .05 ($F=0.91033$). Thus, there was no significant difference in how tired a participant felt between the four different task groups.

Table 23: Sleepiness ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>3.370611</td>
<td>3</td>
<td>1.123537</td>
<td>0.91033</td>
<td>0.441925</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>69.11565</td>
<td>56</td>
<td>1.234208</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>72.48626</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2.16 Analysis of Mental Demand

Mental demand is associated with analytical and decision making functions. Table 25 depicts the results of the ANOVA analysis performed on the mean change in mental demand captured by NASA TLX. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is not rejected at level .05 ($F=0.706167$). Thus, there was no significant difference between the mental demands experienced by participants in the four different task groups.

Table 24: Mental Demand ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>604.1667</td>
<td>3</td>
<td>201.3889</td>
<td>0.706167</td>
<td>0.552361</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>15970.42</td>
<td>56</td>
<td>285.186</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>16574.58</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.2.17 Analysis of Physical Demand

Physical demand is associated with the physical energy a participant expended because of the activities associated with the simulation. Examples of activities include relocation of resources required to complete a simulation or reconfiguration of a work console from the configuration left by a previous computer operator. Table 26 indicates the results of the ANOVA analysis performed on the mean change in physical demand captured by NASA TLX. Since $F_{0.05, 3, 56} = 2.78$, $H_0$ is not rejected at level .05 ($F=0.46811$). Thus, there was no significant difference between physical demand values for participants in the different task groups.

Table 25: Physical Demand ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>682.0833</td>
<td>3</td>
<td>227.3611</td>
<td>0.8584</td>
<td>0.46811</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>14832.5</td>
<td>56</td>
<td>264.8661</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15514.58</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2.18 Analysis of Temporal Demand

Temporal Demand is associated with the pace a participant had to work to complete a problem during the simulation. The temporal demand measure also captured the time pressure associated with completing the problems given during the simulation. Table 27 indicates the results of the ANOVA analysis performed on the change in temporal demand captured by NASA TLX. Since $F_{0.05, 3, 56} = 2.78$, $H_0$ is rejected at level .05 ($F=7.52888$).
Table 26: Temporal Demand ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>8229.167</td>
<td>3</td>
<td>2743.056</td>
<td>7.522888</td>
<td>0.000257</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>20419.17</td>
<td>56</td>
<td>364.628</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28648.33</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 27: Tukey’s HSD Analysis of Temporal Demand

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>Individual 95% CIs For Mean Based on Pooled StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETL</td>
<td>20</td>
<td>-10.00</td>
<td>20.46</td>
<td>(------*------)</td>
</tr>
<tr>
<td>SE</td>
<td>10</td>
<td>1.50</td>
<td>33.83</td>
<td>(---------*---------)</td>
</tr>
<tr>
<td>PSE</td>
<td>15</td>
<td>9.33</td>
<td>9.98</td>
<td>(---------*---------)</td>
</tr>
<tr>
<td>SSE</td>
<td>15</td>
<td>-6.33</td>
<td>7.43</td>
<td>(--------*-------)</td>
</tr>
</tbody>
</table>

The Tukey HSD analysis results, shown in Table 28, indicate no significant difference in temporal demand for participants in the ETL and SSE task groups or between participants in the SSE and SE task groups. However, the temporal demands of participants in the PSE task group were significantly different from participants in all other task groups. No significant differences in temporal demands were found between participants in the ETL task group and participants in the SE task groups.

4.2.19 Analysis of Performance

The performance variable measured how successful a participant felt they were during the simulation. Table 29 depicts the results of the ANOVA analysis performed on the mean change in performance captured by NASA TLX. Since $F_{0.05, 3, 56} = 2.78$, $H_0$ is not rejected at level
.05 (F=1.449506). Thus, there was no significant difference in the performance variable for participants in the four task groups.

Table 28: Performance ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1075.417</td>
<td>3</td>
<td>358.4722</td>
<td>1.449506</td>
<td>0.238188</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>13849.17</td>
<td>56</td>
<td>247.3065</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14924.58</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4.2.20 Analysis of Effort

The effort value is associated with how much effort a participant had to put forth to complete a problem during the simulation. Table 30 indicates the results of the ANOVA analysis performed on the change in effort captured by NASA TLX. Since F.05,3,56=2.78, Ho is rejected at level .05 (F=4.722462).

Table 29: Effort ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>3473.75</td>
<td>3</td>
<td>1157.917</td>
<td>4.722462</td>
<td>0.005235</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>13730.83</td>
<td>56</td>
<td>245.1935</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17204.58</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Tukey HSD analysis results, shown in Table 31, indicate the change in effort reported by participants in the SSE task group was not significantly different from participants in the SE task group. However, the change in effort for participants in the PSE task group was significantly different from participants in all the other task groups. Additionally, there was a significant difference in the change in effort indicated by participants in the ETL task group from that indicated by participants in the SSE and SE task groups.

4.2.21 Analysis of Frustration

The frustration value is associated with how relaxed or stressed a participant felt before and after the simulation. Table 32 depicts the results of the ANOVA analysis performed on the mean change in frustration level captured by NASA TLX. Since $F_{0.05, 3, 56}=2.78$, $H_0$ is not rejected at level .05 ($F=2.7599$). Thus, there was no significant difference in frustration for participants in the four task groups.
Table 31: Frustration ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>4501.667</td>
<td>3</td>
<td>1500.556</td>
<td>2.759945</td>
<td>0.050563</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>30446.67</td>
<td>56</td>
<td>543.6905</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>34948.33</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2.22 Analysis of Workload

The workload value is the compilation of the six factors that have an effect on how much work a person must accomplish. Table 33 indicates the results of the ANOVA analysis performed on the change in workload value captured by NASA TLX. Since $F_{0.05, 3, 56} = 2.78$, $H_0$ is not rejected at level .05 ($F=7.042463$).

Table 32: Workload ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>2462.89</td>
<td>3</td>
<td>820.9632</td>
<td>7.042463</td>
<td>0.000423</td>
<td>2.769431</td>
</tr>
<tr>
<td>Within Groups</td>
<td>6528.105</td>
<td>56</td>
<td>116.5733</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8990.995</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 33: Tukey’s Analysis HSD for Workload

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>Individual 95% CIs For Mean Based on Pooled StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETL</td>
<td>20</td>
<td>-6.43</td>
<td>7.22</td>
<td>(--------*--------)</td>
</tr>
<tr>
<td>SE</td>
<td>10</td>
<td>-2.70</td>
<td>16.58</td>
<td>(--------*--------)</td>
</tr>
<tr>
<td>PSE</td>
<td>15</td>
<td>9.67</td>
<td>11.08</td>
<td>(--------*--------)</td>
</tr>
<tr>
<td>SSE</td>
<td>15</td>
<td>-4.04</td>
<td>9.81</td>
<td>(--------*--------)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X_{ETL}</th>
<th>X_{SSE}</th>
<th>X_{SE}</th>
<th>X_{PSE}</th>
</tr>
</thead>
<tbody>
<tr>
<td>-6.43</td>
<td>-4.04</td>
<td>-2.70</td>
<td>9.67</td>
</tr>
</tbody>
</table>
The Tukey HSD analysis results, shown in Table 34, indicate the workload value for participants in the ETL task group was not significantly different from participants in the SSE task group. There was also no significant difference in the workload value between participants in the SSE task group and participants in the SE task group; or between participants in the ETL task group and participants in the SE task group. However, there were significant differences between the workload values for participants in the PSE task group and the workload values for all other task groups.

4.3 Regression Analysis and Models

A regression analysis was performed on the factors that influence stress, fatigue, and workload. The analyses detailed below encompassed the use of a dataset that was inclusive of the participant groups. Regression models were developed to describe fatigue, workload, and stress independently. Those variables that were found to contribute to each component were initially inputted into the analysis. When a variable was found to have a high p-value, the variable was removed and the analysis was re-run. (The p-value is the probability that the Null Hypothesis (Ho) is true. If the p-value is low, it is an indication that the null hypothesis is not true and therefore the coefficient is different from zero. Variables with a large p-value are removed because these terms are not statistically significant.)

4.3.1 Workload

Figure 516 depicts the regression model for all participant groups developed to ascertain which variables contribute significantly to determine participant workload during a simulation.
Factors that were included in the regression model were change in heart rate, number of problems, completion time, if a problem had been seen previously (repeated performance), decision making, age, blood pressure, discussion traffic, years of experience, task group membership, mental demand, physical demand, temporal demand, effort, frustration, and hours on console.

Values from a survey completed by the participant were inputted into the NASA TLX program to determine the overall workload. The NASA TLX workload value was then used to determine which factors were significant predictors of workload. Factors were removed from analysis based on the p-value in the table of coefficients.

An analysis was run, as shown in Figure 516, with a majority of the factors that influenced workload. After analysis, number of problems and completion time were both removed because both p-values were 0.676. In addition to examining p-values, when a variable is removed, if the mean squared error (MSE) increases, the variable is re-entered into the equation. The Durbin-Watson statistic is also considered to determine if additional variables need to be removed. Variables were removed until the MSE increased or no other factors had large p-values (p>.005).
The regression equation is
\[
\text{Delta-Total Workload Value} = 9.66 + 0.174 \text{ number of problems} \\
- 0.149 \text{ Completion time} \\
+ 0.480 \text{ Delta-Mental Demand Value/hour} \\
- 0.324 \text{ Delta-Physical Demand Value} \\
+ 0.222 \text{ Delta-Temporal Demand Value} \\
+ 0.131 \text{ Delta-Performance Value} \\
+ 0.236 \text{ Delta-Effort Value} \\
+ 0.155 \text{ Frustration Value (NASA TLX)} - 0.399 \\
\text{overall job satisfaction} \\
- 0.230 \text{ Repeated Performance (problem seen in previous performance)} \\
- 0.0565 \text{ blood pressure} - 0.0825 \text{ hours on console} \\
- 0.115 \text{ Task Group}
\]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>9.658</td>
<td>1.880</td>
<td>5.14</td>
<td>0.000</td>
</tr>
<tr>
<td>number of problems</td>
<td>0.1741</td>
<td>0.4128</td>
<td>0.42</td>
<td>0.676</td>
</tr>
<tr>
<td>Completion time</td>
<td>-0.1487</td>
<td>0.3516</td>
<td>-0.42</td>
<td>0.676</td>
</tr>
<tr>
<td>Delta-Mental Demand Value/hour</td>
<td>0.48035</td>
<td>0.04779</td>
<td>10.05</td>
<td>0.000</td>
</tr>
<tr>
<td>Delta-Physical Demand Value</td>
<td>-0.32370</td>
<td>0.06298</td>
<td>-5.14</td>
<td>0.000</td>
</tr>
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<td>3.44</td>
<td>0.002</td>
</tr>
<tr>
<td>Delta-Performance Value</td>
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<td>0.04779</td>
<td>2.31</td>
<td>0.028</td>
</tr>
<tr>
<td>Delta-Effort Value</td>
<td>0.23565</td>
<td>0.04212</td>
<td>5.59</td>
<td>0.000</td>
</tr>
<tr>
<td>Delta-Frustration Value</td>
<td>0.15533</td>
<td>0.03623</td>
<td>4.29</td>
<td>0.000</td>
</tr>
<tr>
<td>overall sat</td>
<td>-0.3993</td>
<td>0.3386</td>
<td>-1.18</td>
<td>0.248</td>
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<td>Repeated Performance</td>
<td>-0.2304</td>
<td>0.2558</td>
<td>-0.90</td>
<td>0.375</td>
</tr>
<tr>
<td>blood pressure</td>
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<td>0.01018</td>
<td>-5.54</td>
<td>0.000</td>
</tr>
<tr>
<td>hours on console</td>
<td>-0.08246</td>
<td>0.07851</td>
<td>-1.05</td>
<td>0.302</td>
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<tr>
<td>Task Group</td>
<td>-0.11530</td>
<td>0.07556</td>
<td>-1.53</td>
<td>0.138</td>
</tr>
</tbody>
</table>

\[ S = 0.385226 \quad \text{R-Sq} = 96.9\% \quad \text{R-Sq(adj)} = 95.6\% \]

Analysis of Variance

<table>
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<tr>
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<td>10.448</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
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<td>140.129</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Durbin-Watson statistic = 1.41135

Figure 516: Workload Regression Analysis

In the model shown in Figure 517 below, all variables with high p-values were removed. The remaining variables were those with the largest influence on workload. Some of the remaining variables had high p-values; however, when they were removed, the MSE increased and the Durbin-Watson statistics was larger than two. Therefore, those variables were added
back into the model. The final model was chosen based on all variables having small p-values and the MSE value only increasing when additional variables were removed.

**Regression Analysis: Delta-Total versus Delta-Mental, Delta-Physic, ...**

The regression equation is

\[
\text{Delta-Total Workload Value} = 7.27 + 0.439 \text{ Delta-Mental Demand Value/hour} - 0.340 \text{ Delta-Physical Demand Value} + 0.244 \text{ Delta-Temporal Demand Value} + 0.198 \text{ Delta-Effort Value} + 0.192 \text{ Delta-Frustration Value} - 0.0603 \text{ blood pressure} + 0.0977 \text{ Delta-Performance Value} + 0.269 \text{ number of problems}
\]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>7.266</td>
<td>1.143</td>
<td>6.35</td>
<td>0.000</td>
</tr>
<tr>
<td>Delta-Mental Demand Value/hour</td>
<td>0.43866</td>
<td>0.03427</td>
<td>12.80</td>
<td>0.000</td>
</tr>
<tr>
<td>Delta-Physical Demand Value</td>
<td>-0.33991</td>
<td>0.05712</td>
<td>-5.95</td>
<td>0.000</td>
</tr>
<tr>
<td>Delta-Temporal Demand Value</td>
<td>0.24387</td>
<td>0.05350</td>
<td>4.56</td>
<td>0.000</td>
</tr>
<tr>
<td>Delta-Effort Value</td>
<td>0.19849</td>
<td>0.03317</td>
<td>5.98</td>
<td>0.000</td>
</tr>
<tr>
<td>Delta-Frustration Value</td>
<td>0.19240</td>
<td>0.02531</td>
<td>7.60</td>
<td>0.000</td>
</tr>
<tr>
<td>blood pressure</td>
<td>-0.060263</td>
<td>0.009636</td>
<td>-6.25</td>
<td>0.000</td>
</tr>
<tr>
<td>Delta-Performance Value</td>
<td>0.09770</td>
<td>0.04717</td>
<td>2.07</td>
<td>0.046</td>
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<tr>
<td>number of problems</td>
<td>0.2693</td>
<td>0.3799</td>
<td>0.71</td>
<td>0.483</td>
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\[ S = 0.384357 \quad \text{R-Sq} = 96.4\% \quad \text{R-Sq(adj)} = 95.6\% \]

**Analysis of Variance**

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<tr>
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<td>135.106</td>
<td>16.888</td>
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<td>Residual Error</td>
<td>34</td>
<td>5.023</td>
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<td>0.148</td>
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</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>140.129</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Durbin-Watson statistic** = 1.50233

**Figure 517: Workload Regression Analysis 1**

The results for workload showed that number of problems, mental demand, physical demand, temporal demand, effort, frustration, and blood pressure were significant. R-square adjusted was used to account for the number of variables in the models, and the overall R-squared adjusted value was determined to be 0.956. The Durbin-Watson test statistics were calculated to determine if any additional factors had to be removed. This test determined that no additional factors had to be removed from the regression analysis, because D was less than two.
4.3.2 Fatigue

As shown in Figure 518, a regression model was developed to establish which variables contributed significantly to participant change in fatigue. The dependent variable used for the analysis was total body fatigue. This was calculated using the following formula:

\[ F_{ijk} = W_1HR_{ijk} + W_2TT_{ijk} + W_3LT_{ijk} + W_4MFS_{ijk} + W_5PFS_{ijk} \]

where \( F_{ijk} \) = Overall fatigue level
\( W_{1-5} \) = Relative weighted value of each fatigue indicator
\( HR_{ijk} \) = Change in heart rate membership value
\( TT_{ijk} \) = Tone task reaction time membership value
\( LT_{ijk} \) = Level of tiredness membership value
\( MFS_{ijk} \) = Number of mental fatigue symptoms reported membership value
\( PFS_{ijk} \) = Number of physical fatigue symptoms reported membership value

Factors inputted into the regression included change in heart rate, number of problems, completion time, repeated performance, decision making, age, blood pressure, years of experience, hours on console, change in mental and physical fatigue, sleepiness, lack of motivation, physical discomfort, physical exertion, lack of energy, and type I and II fatigue. The fatigue values obtained ranged from 2.7 to 10.5.

An analysis was run with the majority of the factors that influence fatigue. The model is shown in figure 518. From the analysis, task groups was removed as a factor, because the p-value was large (p = 0.940).
The regression equation is
\[ TBF = 9.20 - 2.64 \text{ number of problems} + 3.34 \text{ Completion time} + 0.761 \text{ disc traffic} + 4.08 \text{ Delta SOFI-Sleepiness} + 5.34 \text{ Delta SOFI-Lack of Motivation} + 0.095 \text{ Delta-Total Workload Value} + 0.0252 \text{ Change in Heart Rate} - 1.17 \text{ Repeated Performance} - 1.14 \text{ overall sat} - 0.29 \text{ Decision Making} + 0.793 \text{ age} + 0.028 \text{ Task Group} - 0.0443 \text{ years of experience} \]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
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</thead>
<tbody>
<tr>
<td>Constant</td>
<td>9.200</td>
<td>5.572</td>
<td>1.65</td>
<td>0.110</td>
</tr>
<tr>
<td>number of problems</td>
<td>-2.641</td>
<td>1.977</td>
<td>-1.34</td>
<td>0.192</td>
</tr>
<tr>
<td>Completion time</td>
<td>3.342</td>
<td>2.040</td>
<td>1.64</td>
<td>0.112</td>
</tr>
<tr>
<td>disc traffic</td>
<td>0.7610</td>
<td>0.5685</td>
<td>1.34</td>
<td>0.191</td>
</tr>
<tr>
<td>Delta SOFI-Sleepiness</td>
<td>4.076</td>
<td>2.663</td>
<td>1.53</td>
<td>0.137</td>
</tr>
<tr>
<td>Delta SOFI-Lack of Motivation</td>
<td>5.343</td>
<td>2.841</td>
<td>1.88</td>
<td>0.070</td>
</tr>
<tr>
<td>Delta-Total Workload Value</td>
<td>0.0946</td>
<td>0.2579</td>
<td>0.37</td>
<td>0.716</td>
</tr>
<tr>
<td>Change in Heart Rate</td>
<td>0.02520</td>
<td>0.03487</td>
<td>0.72</td>
<td>0.476</td>
</tr>
<tr>
<td>Repeated Performance</td>
<td>-1.166</td>
<td>1.230</td>
<td>-0.95</td>
<td>0.351</td>
</tr>
<tr>
<td>overall sat</td>
<td>-1.143</td>
<td>1.252</td>
<td>-0.91</td>
<td>0.369</td>
</tr>
<tr>
<td>Decision Making</td>
<td>-0.290</td>
<td>1.499</td>
<td>-0.19</td>
<td>0.848</td>
</tr>
<tr>
<td>age</td>
<td>0.7931</td>
<td>0.5717</td>
<td>1.39</td>
<td>0.176</td>
</tr>
<tr>
<td>Task Group</td>
<td>0.0279</td>
<td>0.3652</td>
<td>0.08</td>
<td>0.940</td>
</tr>
<tr>
<td>years of experience</td>
<td>-0.04430</td>
<td>0.07836</td>
<td>-0.57</td>
<td>0.576</td>
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\[ S = 1.93755 \quad R-Sq = 38.4\% \quad R-Sq(adj) = 10.8\% \]

Analysis of Variance

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<td>5.226</td>
<td>1.39</td>
<td>0.222</td>
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<td>Residual Error</td>
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</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>176.805</td>
<td></td>
<td></td>
<td></td>
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</table>
| Durbin-Watson statistic = 2.15623

Figure 518: Regression Model for Fatigue

In the final model, which is shown in Figure 519, below, all variables with high p-values were removed. The remaining variables were those with the largest influence on workload.

Some of the variables have a high p-value, but when removed, the MSE increased and the Durbin-Watson statistics was larger than two. Therefore, the variable was reintroduced into the analysis.
The regression equation is
\[
TBF = 7.08 - 2.77 \text{ number of problems} - 0.61 \text{ Completion time} \\
+ 4.39 \text{ Delta SOFI-Lack of Motivation} + 0.0393 \text{ Change in Heart Rate} \\
- 0.151 \text{ Delta-Effort Value}
\]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
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</thead>
<tbody>
<tr>
<td>Constant</td>
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<td>6.92</td>
<td>0.000</td>
</tr>
<tr>
<td>number of problems</td>
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<td>1.474</td>
<td>-1.88</td>
<td>0.068</td>
</tr>
<tr>
<td>Completion time</td>
<td>-0.608</td>
<td>1.472</td>
<td>-0.41</td>
<td>0.682</td>
</tr>
<tr>
<td>Delta SOFI-Lack of Motivation</td>
<td>4.390</td>
<td>1.861</td>
<td>2.36</td>
<td>0.024</td>
</tr>
<tr>
<td>Change in Heart Rate</td>
<td>0.03932</td>
<td>0.02518</td>
<td>1.56</td>
<td>0.127</td>
</tr>
<tr>
<td>Delta-Effort Value</td>
<td>-0.15148</td>
<td>0.09869</td>
<td>-1.53</td>
<td>0.134</td>
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</table>

\[ S = 1.58793 \quad R-Sq = 29.4\% \quad R-Sq(adj) = 19.3\% \]

Analysis of Variance

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<table>
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</thead>
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<tr>
<td>Completion time</td>
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</tr>
<tr>
<td>Delta SOFI-Lack of Motivation</td>
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<td>12.056</td>
</tr>
<tr>
<td>Change in Heart Rate</td>
<td>1</td>
<td>9.694</td>
</tr>
<tr>
<td>Delta-Effort Value</td>
<td>1</td>
<td>5.940</td>
</tr>
</tbody>
</table>

Durbin-Watson statistic = 1.90200

Figure 519: Fatigue Regression Model

The results showed that number of problems, completion time, lack of motivation, change in heart rate, and effort were significant factors for fatigue. The R-squared adjusted value was determined to be 0.193. R-square adjusted was used to account for the number of variables in the models. The Durbin-Watson test statistics were calculated to determine if any additional factors had to be removed. The test determined that no additional factors had to be removed from the regression analysis because D was less than two.
4.3.3 Stress

To establish which variables were significant in determining the amount of stress that a participant experienced and noted during the simulation, a regression model was developed.

Blood pressure was the response variable used to predict stress.

An analysis was run, with a majority of the factors that influenced stress. This is shown in Figure 520. From the analysis, completion time was removed as a factor, because the p-value was large (0.646).

The regression equation is:

\[
\text{blood pressure} = 150 + 15.8 \times \text{number of problems} - 3.79 \times \text{Completion time} - 4.94 \times \text{overall sat} + 0.112 \times \text{Change in Heart Rate} + 8.5 \times \text{Decision Making} + 6.70 \times \text{disc traffic} - 13.8 \times \text{prob id} - 1.83 \times \text{hours on console} - 5.38 \times \text{age} + 0.188 \times \text{years of experience} - 0.70 \times \text{Task Group}
\]

| Predictor                   | Coef  | SE Coef | T     | P
|-----------------------------|-------|---------|-------|---
| Constant                    | 149.63| 23.76   | 6.30  | 0.000
| number of problems          | 15.842| 7.900   | 2.01  | 0.054
| Completion time             | -3.794| 8.189   | -0.46 | 0.646
| overall sat                | -4.945| 4.380   | -1.13 | 0.268
| Change in Heart Rate       | 0.1119| 0.1439  | 0.78  | 0.443
| Decision Making            | 8.52  | 10.49   | 0.81  | 0.423
| disc traffic               | 6.696 | 2.452   | 2.73  | 0.010
| prob id                    | -13.768| 7.264  | -1.90 | 0.067
| hours on console           | -1.829| 1.124   | -1.63 | 0.114
| age                        | -5.379| 2.538   | -2.12 | 0.042
| years of experience        | 0.1881| 0.3227  | 0.58  | 0.564
| Task Group                 | -0.699| 1.433   | -0.49 | 0.629

\[
S = 8.05361 \quad \text{R-Sq} = 45.5\% \quad \text{R-Sq(adj)} = 26.2\%
\]

Analysis of Variance

<table>
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<tr>
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<td>1680.44</td>
<td>152.77</td>
<td>2.36</td>
<td>0.030</td>
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<td>Residual Error</td>
<td>31</td>
<td>2010.68</td>
<td>64.86</td>
<td></td>
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</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>3691.12</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Durbin-Watson statistic = 1.07883

Figure 520: Stress Regression Model

In the final model, as shown in Figure 521, all variables with high p-values were removed. The remaining variables were those with the largest influence on workload. Some of
the variables have high p-value, but when removed, the MSE increased and the Durbin-Watson statistics was larger than two. Therefore, the variable was reintroduced into the analysis.

The regression equation is

\[
\text{blood pressure} = 124 + 7.11 \text{ number of problems} + 0.0861 \text{ Change in Heart Rate} - 3.39 \text{ Delta-Effort Value} - 12.3 \text{ Completion time}
\]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>124.369</td>
<td>4.094</td>
<td>30.38</td>
<td>0.000</td>
</tr>
<tr>
<td>number of problems</td>
<td>7.106</td>
<td>5.857</td>
<td>1.21</td>
<td>0.235</td>
</tr>
<tr>
<td>Change in Heart Rate</td>
<td>0.08606</td>
<td>0.09424</td>
<td>0.91</td>
<td>0.369</td>
</tr>
<tr>
<td>Delta-Effort Value</td>
<td>-3.3891</td>
<td>0.9488</td>
<td>-3.57</td>
<td>0.001</td>
</tr>
<tr>
<td>Completion time</td>
<td>-12.343</td>
<td>4.710</td>
<td>-2.62</td>
<td>0.014</td>
</tr>
</tbody>
</table>

\[
S = 5.48343 \quad \text{R-Sq} = 43.7\% \quad \text{R-Sq(adj)} = 35.7\%
\]

Analysis of Variance

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<th>MS</th>
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<th>P</th>
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<td>654.16</td>
<td>163.54</td>
<td>5.44</td>
<td>0.002</td>
</tr>
<tr>
<td>Residual Error</td>
<td>28</td>
<td>841.90</td>
<td>30.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
<td>1496.06</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Durbin-Watson statistic = 1.21712

Figure 521: Stress Regression Analysis

The results of the regression analysis for stress showed that number of problems, change in heart rate, effort, and completion time contributed significantly to stress. The overall R-squared adjusted value was determined to be 0.357. R-square adjusted was used to account for the number of variables in the models. The Durbin-Watson test statistics were calculated to determine if any factors had to be excluded. The test determined that no additional factors had to be removed from the regression analysis because D was less than two.

### 4.4 Overlapping Membership Functions

The following section defines the membership function \((a_i, b_i, c_i)\) for each factor determined to be significant from the regression analysis. The risk levels were constructed using five
categories: very low, low, median, high, and very high. For each of the levels, the lower, upper, and optimal points for membership were defined. In graphs 522-533, the results of the linguistic risk levels are shown.

4.4.1 Change in Heart Rate

In console operation, an individual is engaged in mental exercise as opposed to physical exercise. Activities that an individual might complete while on console include trouble shooting of a problem, inputs into a daily console log to tie in individuals on different shifts, interaction with another console to complete operations, interactions with backroom operators to verify vehicle operations are nominal, and communication with management or crew to execute an operation. Figure 522 indicates the linguistic membership functions for the change in heart rate based on the literature review. The change in participant heart rate was calculated as the difference between peak heart rate for a given problem and the participant’s heart rate at rest.

![Change in Heart Rate Overlapping Membership Function](image)

Figure 522: Change in Heart Rate Overlapping Membership Function
4.4.2 Blood Pressure

Blood pressure varies between individuals. These variations are due to a variety of factors, including, but not limited to, sex, age, culture, diet, and genetics. Additionally, a individual’s blood pressure changes daily. It is lowest during sleep and rises when active, nervous, and excited, or during exercise (National Heart, Lung, and Blood Institute, 2006).

During working hours, body postures has no to minimal influences on an individuals’ blood pressure. The ideal pressure reading is 120 mmHg, systolic (National Heart, Lung, and Blood Institute, 2006). Figure 523 depicts the linguistic membership function for participant blood pressure. The categories were developed from a literature review and from consultation with the American Heart Association.

![Blood Pressure Overlapping Membership Function](image)

Figure 523: Blood Pressure Overlapping Membership Function

4.4.3 Number of Problems

The number of problems a participant received during the simulation varied from one to six, depending on the type of simulation, whether an individual was being certified, the complexity of the problem, and the interaction of the console position to other consoles. Figure
524 indicates the linguistic membership function for the number of problems a participant received during a simulation. The categories were developed from interviews with past console operators and managers of consoles. Some participants only received one problem in an eight hour simulation, and therefore experienced an average problem rate of only 0.125 problems per hour.

![Number of Problems per Hour](image)

**Figure 524: Number of Problems Overlapping Membership Function**

### 4.4.4 Hours on Console

Figure 525 depicts the linguistic membership function for the number of hours an individual participated in a simulation on console. The categories were developed from a literature review and from review of work rules and standards. Based on work rules, a participant can work a maximum of 16 hours in each 24 hour period. An individual is not permitted to work more than 10 days without a day off or to work more than 60 hours in a week, unless authorized by senior management.
Figure 5.25: Overlapping Membership Function for Hours on Console

4.4.5 Completion Time

Figure 5.26 depicts the linguistic membership function for the length of time required for a participant to resolve a simulation problem. The categories were developed from a literature review and from consultation with console managers. Problem completion time varies from system to system (such as mechanical, fluids, or avionics), the complexity of the problem (one system versus a multiple system problem), and the time within the mission at which the problem occurs (during ascent, on-orbit, or re-entry). Completion time for the experiment ranged from six minutes to two hours; however, during standard mission operations, problem can take many days to resolve.
4.4.6 Motivation

The linguistic membership function for the change in motivation a participant indicated from pre-simulation to post-simulation is shown in figure 527. SOFI characterizes lack of motivation using five factors: lack of concern, and feelings of listlessness, passivity, indifference, and disinterest. Lack of motivation was found by Ahsberg to increase as mental demand increases, and is considered a primary mental factor in describing fatigue.
### 4.4.7 Effort

Effort, as described by TLX, quantifies how hard a participant has to work, both mentally and physically, to accomplish a certain level of performance. Figure 528 depicts the linguistic membership function for the change in effort a participant indicated in the NASA TLX survey. The categories were derived from the literature of NASA TLX and from interviews with the developer of the TLX tool.

![Change in Effort per hour](image)

Figure 528: Effort Overlapping Membership Function

### 4.4.8 Frustration

Frustration describes how insecure, discouraged, irritated, stressed, and annoyed an individual feels during task completion. Figure 529 depicts the linguistic membership function for the change in frustration indicated in the NASA TLX survey. The categories were derived from the literature of NASA TLX and from interviews with the developer of the TLX tool.
4.4.9 Performance

Performance addresses how an individual felt during the simulation. The variables also convey how successful participants thought they were in accomplishing the goal of the task and how satisfied participants were with their performance in accomplishing these goals.

Figure 530 depicts the linguistic membership for the change in performance reported from NASA TLX. The categories were derived from the literature of NASA TLX and from interviews with the developer of the TLX tool.
4.4.10 Physical Demand

Physical demand is characterized by NASA TLX as how much physical activity (such as pushing, pulling, controlling, or activating) was required during a task. The factor also examines how easy or demanding, slow or brisk, slack or strenuous, restful or laborious the task was for an individual.

Figure 531 portrays the linguistic membership function for the change in physical demand reported from NASA TLX. The categories were derived from the literature of NASA TLX and from interviews with the developer of the TLX tool.

![Physical Demand Overlapping Membership Function](image)

Figure 531: Physical Demand Overlapping Membership Function

4.4.11 Mental Demand

The mental demand factor describes how much mental or perceptual activity (such as thinking, deciding, calculating, or searching) was required to perform a task. Additionally, the factor attempts to capture the difficulty level of the task, its complexity level, and its level of exactness.
Figure 532 depicts the linguistic membership function that was derived for the change in mental demand a participant indicated from pre- to post-simulation. The categories were derived from the literature of NASA TLX and from interviews with the developer of the TLX tool.

![Figure 532: Mental Demand Overlapping Membership Function](image)

### 4.4.12 Temporal Demand

Temporal demand describes how much time pressure an individual feels because of the rate or pace at which a task or task elements occur. Additionally, it describes the pace of the task; whether it is leisurely or rapid.

The linguistic membership function for a change in temporal demand denoted by NASA TLX is provided in figure 533. The categories were derived from the literature of NASA TLX and from interviews with the developer of the TLX tool.
4.5 FST Comprehensive Membership Functions

When the linguistic membership functions were defined, the fuzzy membership functions for each factor were developed. In this study, the maximum and minimum of fuzzy sets were used in determining the union and intersection. Figures 534-545 show the final membership functions for those variables that were found to contribute the combined affect of stress, fatigue, and workload.

4.5.1 Blood Pressure

Figure 534 depicts the direct increase in systolic blood pressure caused by increased demands on the human information processing system to perform a task. As blood pressure increases, the degree of membership also increases.
4.5.2 Completion Time

Figure 535 depicts the direct increase in completion caused by the demands on the human information processing system to perform a task. As completion time increases, the degree of membership also increases.

Figure 535: Comprehensive Membership Function: Completion Time
4.5.3 Hours on Console

Figure 536 depicts how an increase in hours on console correlates with an increase in the demands on the human information processing system to perform a task. Therefore, as the number of hours on console increased, the degree of membership also increased.

![Hours on Console](image)

Figure 536: Comprehensive Membership Function: Hours on Console

4.5.4 Number of Problems

Figure 537 depicts the increase in degree of membership that accompanies an increase in the number of problems a participant received during the simulation.

![Number of Problems](image)
4.5.5 Change in Heart Rate

Figure 538 indicates that, as heart rate increased, the demands on the human information processing system to perform a task also increased. As the change in heart rate increases, the degree of membership also increases.

![Change in Heart Rate](image)

Figure 538: Comprehensive Membership Function: Heart Rate

4.5.6 Motivation

Figure 539 depicts how increasing change in motivation level correlates with increasing demand on the human information processing system to perform a task. As change in motivation increases, the degree of membership increases.
4.5.7 Effort

Figure 540 indicates that, as the change in effort increases, demands on the human information processing system also increase. As change in effort becomes larger, the degree of membership increases.

Figure 540: Comprehensive Membership Function: Effort
4.5.8 Frustration

Figure 541 depicts that, as the change in frustration level increases, demands on the human information processing system also increase. When change in frustration increases, the degree of membership also increases.

![Comprehensive Membership Function: Frustration](image)

Figure 541: Comprehensive Membership Function: Frustration

4.5.9 Mental Demand

Figure 542 indicates that, as the change in mental demand increases, demands on the human information processing system to perform a task also increase. As change in mental demand increases, the degree of membership increases.
4.5.10 Performance

Figure 543 indicates how change in performance correlates with increased demands on the human information processing system. With larger changes in performance, the degree of membership increases.

Figure 542: Comprehensive Membership Function: Mental Demand

Figure 543: Comprehensive Membership Function: Performance
4.5.11 Physical Demand

Figure 544 indicates how the change in physical demand correlates with increased demands on the human information processing system. Larger changes in physical demand correlate to an increased degree of membership.

![Change in Physical Demand](image)

Figure 544: Comprehensive Membership Function: Physical Demand

4.5.12 Temporal Demand

Figure 545 depicts how, as the change in temporal demands increase, demands on the human information processing system also increase. With larger changes in temporal demand, the degree of membership increases.
A membership function was not developed for problem identification because the participant either correctly identified the problem, achieving a rating of 1, or they did not correctly identify the problem, achieving a rating of 0. Additionally, a membership function was not developed for discussion traffic because the quality of the discussion was rated as poor, good, or excellent.

### 4.6 Analytical Hierarchical Process Analysis

The AHP methodology was developed by Saaty in 1980 to solve complex problems involving multiple criteria. Satty’s AHP uses pair-wise comparison procedure to capture relative judgments in a manner that ensures consistency. It is a mathematical decision making technique that allows the consideration of both qualitative and quantitative aspects of decisions. AHP reduces complex decisions into a series of one-on-one comparisons and then synthesizes the results. Pair-wise comparison refers to the process of comparing entities in pairs to judge which of each pair is preferred. The method of pair-wise comparison is used to study preferences, attitudes, voting systems and social choices.
Each pair-wise comparison represents an estimate of the priorities of the compared
decision variables (Kwong and Bali, 2001). This method has been applied in a variety of
decisions and human judgment processes (Chen, 2006). The pair-wise comparisons require that
all essential elements relevant to the problem are covered within the hierarchy or taxonomy
structure outlined by the research. A typical form for the hierarchy is structured from the top
through the intermediate and on to the lowest level (usually the factor variable level). Once the
hierarchy has been established, the SME or decision makers begin the prioritization procedure to
determine the relative importance of the elements in each level. Elements in each level are rated
on a scale of importance from one to nine. The pair-wise comparison rations are in crisp real
numbers, however, decision variables can contain ambiguity and multiplicity of meaning
(Kwong and Bali, 2002).

One of the disadvantages with a pair-wise AHP analysis is the phenomenon of rank
reversals. More specifically, when a decision alternative is added to a decision problem, while
the assessments concerning the original decision alternatives remain unchanged, the inclusion of
the new alternative may cause rank reversals in the utility estimates of the original alternatives
(Leskinen and Kangas, 2005). Furthermore, it is also recognized that pair-wise assessments on
qualitative attributes can be subjective and thus imprecise (Kwong and Bali, 2002).

The advantages of the pair-wise comparisons include simplicity and ease of use.
Additionally, each variable is clearly identified and evaluated against each other variable to
allow for comparison of all dual variable interactions (Kwong and Bali, 2002). This method
organizes the basic rationality by breaking down a problem into smaller and smaller constituent
parts, and then guides the decision maker through a series of pair-wise comparison judgments to
express the relative strength and intensity of impact of the elements in the hierarchy (Wang, Xie, and Goh, 1998).

Therefore, pair-wise comparisons capture both subjective and objective evaluation measures, providing a mechanism for checking the consistency of the evaluation measures and alternative. It allows organizations to minimize the pitfalls of decision making processes such as lack of focus, participation or ownership which ultimately are costly distractions that can result in wrong choices (Banuelas and Antony, 2006). This research uses pair-wise comparisons to determine the relative weights of the factor variables.

Based on the results of the regression analysis, those variables that were found to be significant were inputted into Expert Choice, the software selected to aid in calculating the weight values in the AHP analysis. Three experts were consulted and asked to complete a pair-wise comparison of the significant variables, \( a_i \), for each factor component. The survey asked the SMEs to rate each factor on a scale of one to nine, where one (1) indicated that the factors were equal and nine (9) indicated that the factor was of very high importance. The resultant weights, \( w_i \), for the task related factors for stress, S, from the Expert Choice analysis are shown in Table 35.

Table 34: AHP Results for Stress

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Factor</th>
<th>( a_i )</th>
<th>Relative Weight</th>
<th>( w_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of Problems</td>
<td>( a_1 )</td>
<td>0.284</td>
<td>( w_1 )</td>
</tr>
<tr>
<td>2</td>
<td>Completion Time</td>
<td>( a_2 )</td>
<td>0.275</td>
<td>( w_2 )</td>
</tr>
<tr>
<td>3</td>
<td>Heart Rate</td>
<td>( a_3 )</td>
<td>0.27</td>
<td>( w_3 )</td>
</tr>
<tr>
<td>4</td>
<td>Effort</td>
<td>( a_4 )</td>
<td>0.104</td>
<td>( w_4 )</td>
</tr>
<tr>
<td>5</td>
<td>Blood Pressure</td>
<td>( a_5 )</td>
<td>0.067</td>
<td>( w_5 )</td>
</tr>
</tbody>
</table>
The numeric values assigned to each sub-component were inputted into Equation 1 to determine the stress, S, factor equation. To determine the operands for each component, addition and subtraction symbols were inputted into the equation because the membership functions were triangular (Klir, St. Clair, and Yuan, 1997). The final operand selection was determined by the interaction of each variable with subsequent variables.

The resultant equation was defined as:

\[ S = 0.284a_1 + 0.275a_2 + 0.27a_3 + 0.104a_4 + 0.067a_5 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots [1] \]

In Table 36, results of the AHP for task related risk factors for fatigue are listed.

Table 35: AHP Results for Fatigue

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Factor</th>
<th>( b_i )</th>
<th>Relative Weight</th>
<th>( x_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Completion Time</td>
<td>( b_1 )</td>
<td>0.339</td>
<td>( x_1 )</td>
</tr>
<tr>
<td>2</td>
<td>Number of Problems</td>
<td>( b_2 )</td>
<td>0.303</td>
<td>( x_2 )</td>
</tr>
<tr>
<td>3</td>
<td>Heart Rate</td>
<td>( b_3 )</td>
<td>0.162</td>
<td>( x_3 )</td>
</tr>
<tr>
<td>4</td>
<td>Effort</td>
<td>( b_4 )</td>
<td>0.106</td>
<td>( x_4 )</td>
</tr>
<tr>
<td>5</td>
<td>Lack of Motivation</td>
<td>( b_5 )</td>
<td>0.091</td>
<td>( x_5 )</td>
</tr>
</tbody>
</table>

The numeric values assigned to each sub-component were inputted into Equation 1 to determine the fatigue, F, factor equation. To determine the operands for each component, addition and subtraction symbols were inputted into the equation, because the membership functions were triangular based on the regression analysis outputs. (Klir, St. Clair, and Yuan, 1997). The resultant equation was defined as:

\[ F = 0.339b_1 + 0.303b_2 + 0.162b_3 + 0.106b_4 + 0.091b_5 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots [2] \]

In Table 37, results of the AHP for task related risk factors for workload are listed.
Table 36: AHP Results for Workload

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Factor</th>
<th>$c_i$</th>
<th>Relative Weight</th>
<th>$y_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mental Demand</td>
<td>$c_1$</td>
<td>0.237</td>
<td>$Y_1$</td>
</tr>
<tr>
<td>2</td>
<td>Number of Problems</td>
<td>$c_2$</td>
<td>0.177</td>
<td>$Y_3$</td>
</tr>
<tr>
<td>3</td>
<td>Temporal Demand</td>
<td>$c_3$</td>
<td>0.133</td>
<td>$Y_2$</td>
</tr>
<tr>
<td>4</td>
<td>Performance</td>
<td>$c_4$</td>
<td>0.132</td>
<td>$Y_6$</td>
</tr>
<tr>
<td>5</td>
<td>Effort</td>
<td>$c_5$</td>
<td>0.116</td>
<td>$Y_5$</td>
</tr>
<tr>
<td>6</td>
<td>Frustration</td>
<td>$c_6$</td>
<td>0.108</td>
<td>$Y_4$</td>
</tr>
<tr>
<td>7</td>
<td>Blood Pressure</td>
<td>$c_7$</td>
<td>0.063</td>
<td>$Y_7$</td>
</tr>
<tr>
<td>8</td>
<td>Physical Demand</td>
<td>$c_8$</td>
<td>0.035</td>
<td>$Y_8$</td>
</tr>
</tbody>
</table>

The numeric values assigned to each sub-component were inputted into Equation 1 to determine the workload, $W$, factor equation. To determine the operands for each component, addition and subtraction symbols were inputted into the equation, because the membership functions were triangular (Klir, St. Clair, and Yuan, 1997). The resultant equation was defined as:

$$W = .237c_1 + .177c_2 + .133c_3 + .132c_4 + .116c_5 + .108c_6 + .063c_7 + .035c_8 \ldots [3]$$

Results of AHP for the overall risk factors are shown in Table 38.

Table 37: AHP Expert Results

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Factor</th>
<th>Relative Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Workload</td>
<td>0.561</td>
</tr>
<tr>
<td>2</td>
<td>Stress</td>
<td>0.268</td>
</tr>
<tr>
<td>3</td>
<td>Fatigue</td>
<td>0.171</td>
</tr>
</tbody>
</table>

The factor weights for each variable are shown after the variable name in parenthesis. The numbers are based on a 0 to 1 scale. The analysis shows that workload (0.561) contributed the greatest affect on human performance, whereas fatigue (0.171) was shown to contribute least.
Within stress, the ability for participants to correctly identify a problem given to them during the simulation, problem identification (.484), contributed the most to participant stress levels.

After obtaining the relative weights for each factor, the consistency ratio for each rater was calculated to determine if each SME was consistent. The following table contains the consistency rating for each of the three SMEs.

<table>
<thead>
<tr>
<th></th>
<th>Stress</th>
<th>Fatigue</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>SME #1</td>
<td>0.07</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>SME #2</td>
<td>0.09</td>
<td>0.07</td>
<td>0.1</td>
</tr>
<tr>
<td>SME #3</td>
<td>0.08</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

A consistency ratio of 0.10 or less is considered acceptable. Therefore, the degree of consistency in the pair-wise comparisons for each of the raters is acceptable.

There are several techniques that can be used to determine the correct mathematical operand such as line of best fit, curve of best fit, and regression analysis. Identifying the distribution of the factor variables will determine the correct mathematical operand. The mathematical description of each factor variable consists of analytic structure and on the fundamental notions of events, realization of events, and uncertainty of events (Hohle, 1996). The line of best fit was used to determine the best approximation of all the points in the scatter plot. The curve that gave the minimum error between the data and the fit was considered the best fit. Therefore, the function identified, aided in determining the correct mathematical operands. Additionally, the factor variables operands were determined by the interaction of the factor variable to the component (i.e. stress, fatigue or workload), and the context in which the variable was collected. The combination of these three techniques allowed for mathematical operand verification (Gurley, 2006).
Equations 1, 2 and 3 were combined mathematically to derive equation 4 which described the combined affect of stress, fatigue and workload based on task demands. The mathematical operands were chosen because the cumulative effect of each variable was determined to be the most significant impact to the operator; thus creating higher potential for problems associated with increases in stress, fatigue and workload. The following equation was the result:

\[
SFWI = 0.561 \times [0.237c_1 + 0.177c_2 + 0.133c_3 + 0.132c_4 + 0.116c_5 + 0.063c_7 + 0.035c_8] + \\
0.268 \times [0.284a_1 + 0.275a_2 + 0.27a_3 + 0.104a_4 + 0.067a_5] + 1.171 \times [0.339b_1 + 0.303b_2 + 0.162b_3 + \\
0.106b_4 + 0.091b_5] 
\]

To determine the cumulative level of stress, fatigue, and workload a participant experienced during the simulation, equation four was calculated. The resultant value is categorized into one of five risk levels. The subdivision of the scale is based on the literature review and on interviews with SMEs.

**Table 39: Numeric Risk Level Categorization**

<table>
<thead>
<tr>
<th>Numeric Risk Level</th>
<th>Expected Amount of Risk Associated with Numeric Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00-0.20</td>
<td><strong>Minimal Risk:</strong> Individuals should not be experiencing any condition that would have an affect on human performance during console operations.</td>
</tr>
<tr>
<td>0.21-0.40</td>
<td><strong>Lower than Average Risk:</strong> Individuals might experience one sub-component of a main factor that can have an affect on human performance during console operations.</td>
</tr>
<tr>
<td>0.41-0.60</td>
<td><strong>Average Risk:</strong> Individuals will experience one or more sub-components of a main factor that might impact human performance on console operations.</td>
</tr>
<tr>
<td>0.61-0.80</td>
<td><strong>High Risk:</strong> An individual is expected to experience one sub-component for each of the main factors that will greatly impact human performance during console operations.</td>
</tr>
<tr>
<td>0.81-1.00</td>
<td><strong>Very High Risk:</strong> An individual is expected to experience multiple sub-components form each of the main factors that will significantly impact human performance during console operations, resulting in an irreversible decision.</td>
</tr>
</tbody>
</table>
4.6.1 T-Test and Z-Test

Changes in human performance were predicted using the decision making, problem identification, and completion time variables. The test hypothesis was as follows:

\( H_0: \) Human performance is not impacted by stress, fatigue, and workload.

\( H_a: \) Human performance is impacted by stress, fatigue, and workload

A z-test was chosen to determine if the means of SWFI and completion time or problem identification or completion time were statistically different from each other. Three z-tests were calculated and the results are shown below.

Table 40: Completion Time z-test

<table>
<thead>
<tr>
<th>Completion Time</th>
<th>SFWI</th>
<th>Completion Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.191561</td>
<td>0.687188</td>
</tr>
<tr>
<td>Variance</td>
<td>0.002362</td>
<td>0.072679</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>0.140639</td>
<td></td>
</tr>
<tr>
<td>Z Stat</td>
<td>10.4958</td>
<td></td>
</tr>
<tr>
<td>P(Z&lt;=z) twp-tail</td>
<td>9.964E-12</td>
<td></td>
</tr>
</tbody>
</table>

The calculated z-statistic for the completion time was 9.964E-12. The significant t-statistic was 10.498 and alpha was 0.025 (two-tail test). Therefore, since the two-tailed probability is much lower than the alpha, the null hypothesis is rejected.

Table 41: Problem Identification t-test

<table>
<thead>
<tr>
<th>Problem Identification</th>
<th>SFWI</th>
<th>Problem ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.191561</td>
<td>0.0875</td>
</tr>
<tr>
<td>Variance</td>
<td>0.002362</td>
<td>0.013387</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>0.263169</td>
<td></td>
</tr>
<tr>
<td>z Stat</td>
<td>5.20521</td>
<td></td>
</tr>
<tr>
<td>P(Z&lt;=z) two-tail</td>
<td>1.19E-05</td>
<td></td>
</tr>
</tbody>
</table>
The calculated t-statistic for problem identification was $1.19 \times 10^{-5}$. The significant z-statistic was 5.20521, with alpha 0.025 (two-tail test). Therefore, since the two-tailed probability is much lower than the alpha, the null hypothesis is rejected.

Table 42: Decision Making t-test

<table>
<thead>
<tr>
<th>Decision Making</th>
<th>SFWI</th>
<th>Decision Making</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.191561</td>
<td>0.041667</td>
</tr>
<tr>
<td>Variance</td>
<td>0.002362</td>
<td>0.012545</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>-0.0331</td>
<td></td>
</tr>
<tr>
<td>z Stat</td>
<td>6.862537</td>
<td></td>
</tr>
<tr>
<td>$P(Z \leq z)$ two-tail</td>
<td>1.08E-07</td>
<td></td>
</tr>
</tbody>
</table>

The calculated z statistic for problem identification was $1.08 \times 10^{-7}$. The significant t-statistic was 6.862537, with an alpha of 0.025 (two-tail). Therefore, since the two-tailed probability is much lower than the alpha, the null hypothesis is rejected.

A z-test was calculated for the sample random data. The results of these analyses are shown below. Again, the z-test was used to determine if the means of SFWI and completion time or problem identification or decision making were similar.

Table 43: Problem Identification z-test for Simulated Data

<table>
<thead>
<tr>
<th></th>
<th>SFWI</th>
<th>Problem ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.564442</td>
<td>0.853846154</td>
</tr>
<tr>
<td>Known Variance</td>
<td>0.063</td>
<td>0.12576</td>
</tr>
<tr>
<td>Observations</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>-7.59489</td>
<td></td>
</tr>
<tr>
<td>$P(Z \leq z)$ two-tail</td>
<td>3.09E-14</td>
<td></td>
</tr>
<tr>
<td>$z$ Critical two-tail</td>
<td>1.959964</td>
<td></td>
</tr>
</tbody>
</table>
The calculated z-statistic for problem identification was $3.09 \times 10^{-14}$. The significant t-statistic was 7.58 and alpha was 0.025 (two-tail test). Therefore, since alpha is larger than the calculated z value, the null hypothesis is rejected.

Table 44: Decision Making z-test for Simulated Data

<table>
<thead>
<tr>
<th></th>
<th>SFWI</th>
<th>Decision Making</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.564442</td>
<td>0.938461538</td>
</tr>
<tr>
<td>Known Variance</td>
<td>0.063</td>
<td>0.058199</td>
</tr>
<tr>
<td>Observations</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>z</td>
<td>-12.2495</td>
<td></td>
</tr>
<tr>
<td>P(Z&lt;=z) two-tail</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>z Critical two-tail</td>
<td>1.959964</td>
<td></td>
</tr>
</tbody>
</table>

The calculated z-statistic for the decision making was 0. The significant t-statistic was 12.2223 and alpha was 0.025 (two-tail test). Therefore, since the calculated z value is less than alpha, the null hypothesis is rejected.

Table 45: Completion Time z-test for Simulated Data

<table>
<thead>
<tr>
<th></th>
<th>SFWI</th>
<th>Completion Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.564442</td>
<td>0.591869231</td>
</tr>
<tr>
<td>Known Variance</td>
<td>0.063</td>
<td>0.057</td>
</tr>
<tr>
<td>Observations</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>z</td>
<td>-0.90275</td>
<td></td>
</tr>
<tr>
<td>P(Z&lt;=z) two-tail</td>
<td>0.36666</td>
<td></td>
</tr>
<tr>
<td>z Critical two-tail</td>
<td>1.959964</td>
<td></td>
</tr>
</tbody>
</table>

The calculated z-statistic for the completion time was 0.3666. The significant z-statistic was 1.959 and alpha was 0.025 (two-tail test). Therefore, since the calculated z value is larger than alpha, the null hypothesis is can not be rejected.
4.6.2 Correlation Matrix

The correlation matrix was calculated for the original and for the sample data. The correlation matrix contains the estimate for the relationships among all the variables.

Table 46: Correlation Matrix for Original Data

<table>
<thead>
<tr>
<th></th>
<th>Problem Identification</th>
<th>Decision Making</th>
<th>Completion Time</th>
<th>SFWI</th>
<th>PI and DM</th>
<th>PI and CT</th>
<th>DM and CT</th>
<th>PI and DM and CT</th>
<th>TBF</th>
<th>Stress Index</th>
<th>Fatigue Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Making</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>completion time</td>
<td>-</td>
<td>-0.534</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SFWI</td>
<td>0.203</td>
<td>-0.226</td>
<td>0.138</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PI and DM</td>
<td>0.747</td>
<td>0.747</td>
<td>0.379</td>
<td>-0.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PI and CT</td>
<td>0.847</td>
<td>0.182</td>
<td>-0.19</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM and CT</td>
<td>0.26</td>
<td>0.867</td>
<td>-0.12</td>
<td>0.67</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PI and DM and CT</td>
<td>0.683</td>
<td>0.683</td>
<td>-0.16</td>
<td>0.91</td>
<td>0.74</td>
<td>0.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBF</td>
<td>0.067</td>
<td>-0.176</td>
<td>-0.07</td>
<td>0.724</td>
<td>-0.2</td>
<td>-0.1</td>
<td>0.12</td>
<td>-0.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress</td>
<td>0.001</td>
<td>-0.448</td>
<td>0.102</td>
<td>-0.07</td>
<td>0.35</td>
<td>0.1</td>
<td>0.43</td>
<td>-0.35</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TLX</td>
<td>0.182</td>
<td>0.309</td>
<td>-0.22</td>
<td>0.31</td>
<td>0.01</td>
<td>0.16</td>
<td>0.194</td>
<td>0.05</td>
<td>-0.103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress Index</td>
<td>0.269</td>
<td>-0.244</td>
<td>0.262</td>
<td>0.887</td>
<td>0.28</td>
<td>-0.2</td>
<td>0.11</td>
<td>-0.15</td>
<td>0.54</td>
<td>-0.1</td>
<td>0.13</td>
</tr>
<tr>
<td>Fatigue Index</td>
<td>0.144</td>
<td>0.02</td>
<td>0.016</td>
<td>0.227</td>
<td>0.15</td>
<td>0.14</td>
<td>0.01</td>
<td>0.137</td>
<td>0.09</td>
<td>0.109</td>
<td>0.16</td>
</tr>
<tr>
<td>Workload Index</td>
<td>-0.02</td>
<td>-0.073</td>
<td>0.162</td>
<td>0.728</td>
<td>-0.1</td>
<td>-0.2</td>
<td>0.07</td>
<td>-0.1</td>
<td>0.73</td>
<td>-0.038</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

The correlation matrix indicates that a negative correlation exists between the fuzzy stress index and problem identification (-0.269), the fuzzy stress index and decision making (-0.244), the fuzzy workload index and problem identification (-0.02), the fuzzy workload index and decision making (-0.073), the fuzzy workload index and completion time (-0.162), SFWI and problem identification (-0.203), and SFWI and decision making (-0.226). A slight positive relationship
exists between the fuzzy fatigue index and decision making (0.02) and the fuzzy fatigue index and completion time (0.016).

A correlation matrix was also computed for the simulated data. The results are shown in Table 48. The raw data can be found in Appendix D.

Table 47: Correlation Matrix for Simulated Data

<table>
<thead>
<tr>
<th></th>
<th>Prob ID</th>
<th>Decision Making</th>
<th>Completion Time</th>
<th>PI and DM</th>
<th>PI and CT</th>
<th>DM and CT</th>
<th>PI, CT, DM</th>
<th>TBF</th>
<th>Stress</th>
<th>TLX</th>
<th>Stress Index</th>
<th>Fatigue Index</th>
<th>Workload Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prob ID</td>
<td>1</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Decision Making</td>
<td>-0.11</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completion Time</td>
<td>0.066</td>
<td>0.017135</td>
<td>1</td>
<td></td>
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</tr>
<tr>
<td>PI and DM</td>
<td>0.808</td>
<td>0.500152</td>
<td>0.0681</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PI and CT</td>
<td>0.697</td>
<td>-0.05485</td>
<td>0.7028</td>
<td>0.574</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM and CT</td>
<td>0.004</td>
<td>0.523546</td>
<td>0.8394</td>
<td>0.314</td>
<td>0.55</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PI, CT, DM</td>
<td>0.611</td>
<td>0.377909</td>
<td>0.6325</td>
<td>0.756</td>
<td>0.89</td>
<td>0.745</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBF</td>
<td>0.019</td>
<td>0.018044</td>
<td>0.9392</td>
<td>0.028</td>
<td>0.63</td>
<td>0.785</td>
<td>0.56</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress</td>
<td>0.009</td>
<td>0.072846</td>
<td>-0.560</td>
<td>0.035</td>
<td>0.39</td>
<td>-0.42</td>
<td>0.31</td>
<td>-0.6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TLX</td>
<td>0.036</td>
<td>-0.00093</td>
<td>0.8958</td>
<td>0.03</td>
<td>0.61</td>
<td>0.738</td>
<td>0.54</td>
<td>0.94</td>
<td>-0.565</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress Index</td>
<td>0.006</td>
<td>-0.04328</td>
<td>0.5579</td>
<td>0.021</td>
<td>-0.39</td>
<td>0.7</td>
<td>0.438</td>
<td>0.33</td>
<td>0.57</td>
<td>-0.936</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue Index</td>
<td>0.043</td>
<td>0.008716</td>
<td>0.9359</td>
<td>0.043</td>
<td>0.65</td>
<td>0.775</td>
<td>0.57</td>
<td>0.97</td>
<td>-0.573</td>
<td>0.9</td>
<td>0.5833</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workload Index</td>
<td>0.027</td>
<td>-0.0147</td>
<td>0.9157</td>
<td>0.014</td>
<td>0.61</td>
<td>0.754</td>
<td>0.53</td>
<td>0.95</td>
<td>-0.552</td>
<td>1</td>
<td>0.5618</td>
<td>0.9407</td>
<td></td>
</tr>
<tr>
<td>SFWI</td>
<td>0.037</td>
<td>0.00266</td>
<td>0.9384</td>
<td>0.03</td>
<td>0.63</td>
<td>0.777</td>
<td>0.56</td>
<td>0.97</td>
<td>-0.574</td>
<td>1</td>
<td>0.5873</td>
<td>0.976</td>
<td>0.98845</td>
</tr>
</tbody>
</table>

The correlation matrix indicates a negative correlation between the fuzzy workload index and decision making (-0.0147) and the fuzzy stress index and decision making (-0.04328). A slight positive correlation exists between the fuzzy stress index and problem identification (0.006), the fuzzy fatigue index and problem identification (0.043), the fuzzy workload index and problem identification (0.027).
identification (0.027), SFWI and problem identification (0.037), and the fuzzy fatigue index and
decision making (0.00876). A strong positive correlation was found between the fuzzy workload
index and completion time (0.9157), the fuzzy fatigue index and completion time (0.9359), the
fuzzy workload index and the fuzzy fatigue index (0.9407), the fuzzy fatigue index and SFWI
(0.976), and the fuzzy workload index and SFWI (0.98845).

4.7 Model Validation

Model validation was achieved using the thirty percent of the original data not used to
create the model, as described in Appendix C. The observations used for model validation were
randomly removed from the original data set. Each observation was inputted into the model to
determine and validate the mathematical operands used to combine each of the variables.

Twelve observations were utilized for model validation. The observations included at
least one observation from each task group. The factor membership function values \((x_i, y_i, z_i)\)
were inputted into Equation 4 to determine the numeric risk value. Table 48 contains the sample
observation data that was used to determine the relative degree of risk.
Table 48: Sample Observation Data

<table>
<thead>
<tr>
<th></th>
<th>Observation</th>
<th>Rating</th>
<th>Membership Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STRESS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Problems</td>
<td>0.353</td>
<td>0.23</td>
<td>a₁</td>
</tr>
<tr>
<td>Completion Time in Hours</td>
<td>0.2</td>
<td>0.19</td>
<td>a₂</td>
</tr>
<tr>
<td>Change in Heart Rate</td>
<td>17</td>
<td>0.21</td>
<td>a₃</td>
</tr>
<tr>
<td>Effort</td>
<td>0.133</td>
<td>0.26</td>
<td>a₄</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>126</td>
<td>0.47</td>
<td>a₅</td>
</tr>
<tr>
<td><strong>FATIGUE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completion Time in Hours</td>
<td>0.2</td>
<td>0.19</td>
<td>b₁</td>
</tr>
<tr>
<td>Effort</td>
<td>0.133</td>
<td>0.26</td>
<td>b₄</td>
</tr>
<tr>
<td>Change in Heart Rate</td>
<td>17</td>
<td>0.21</td>
<td>b₃</td>
</tr>
<tr>
<td>Lack of Motivation</td>
<td>0.5</td>
<td>0.68</td>
<td>b₅</td>
</tr>
<tr>
<td>Number of Problems per Hour</td>
<td>0.353</td>
<td>0.23</td>
<td>b₂</td>
</tr>
<tr>
<td><strong>WORKLOAD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>126</td>
<td>0.47</td>
<td>c₇</td>
</tr>
<tr>
<td>Effort</td>
<td>0.133</td>
<td>0.26</td>
<td>c₅</td>
</tr>
<tr>
<td>Frustration</td>
<td>0</td>
<td>0</td>
<td>c₆</td>
</tr>
<tr>
<td>Mental Demand</td>
<td>0</td>
<td>0</td>
<td>c₁</td>
</tr>
<tr>
<td>Number of Problems per Hour</td>
<td>0.353</td>
<td>0.23</td>
<td>c₂</td>
</tr>
<tr>
<td>Performance</td>
<td>0.067</td>
<td>0.17</td>
<td>c₄</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>0</td>
<td>0</td>
<td>c₈</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>0.67</td>
<td>0.17</td>
<td>c₃</td>
</tr>
</tbody>
</table>

Based on the data in the table, the overall human performance risk for the job was:
SWFI = .561 * [.237(0) + .177(.23) + .133(.17) + .132(.17) + .116(.26) + .108(0) + .063(.47) + .035(0)] + .268* [0.284(.23) + 0.275(0.19) + 0.27(0.21) + 0.104(0.26) + .067(0.47)]
+ .171* [.339(.19) + .303(.23) + .162(.21) + .106(.26) + .091(.68)]

= 0.2771

Based on the numeric risk level scale chosen through the literature review and through the advice of SMEs, as listed in Table 37, the task observed with an expected amount of risk of 0.2771 was categorized as lower than average. A review of notes taken by the principle investigator indicated the participant involved was given problems that had been previously experienced and was very familiar with the troubleshooting plans.

A second set of independent data that was not obtained in a laboratory setting was also used to validate the model. This data reflected a participant who was experiencing high, medium, or low stress, fatigue, and workload. Each participant was marked as high, medium, and low for each category. Values were assigned to each variable, reflecting the designated participant level. For each, a participant who was designated high would be given value similar to those shown in Table 50.
Table 49: Independent Sample Data

<table>
<thead>
<tr>
<th>STRESS</th>
<th>Observation</th>
<th>Rating</th>
<th>Membership Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Problems per Hour</td>
<td>1.5</td>
<td>0.85</td>
<td>a₁</td>
</tr>
<tr>
<td>Completion Time in Hours</td>
<td>0.8</td>
<td>0.66</td>
<td>a₂</td>
</tr>
<tr>
<td>Change in Heart Rate</td>
<td>60</td>
<td>0.71</td>
<td>a₃</td>
</tr>
<tr>
<td>Effort</td>
<td>0.5</td>
<td>0.748</td>
<td>a₄</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>160</td>
<td>0.74</td>
<td>a₅</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FATIGUE</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion Time in Hours</td>
<td>0.8</td>
<td>0.66</td>
<td>b₁</td>
</tr>
<tr>
<td>Effort</td>
<td>0.5</td>
<td>0.748</td>
<td>b₄</td>
</tr>
<tr>
<td>Change in Heart Rate</td>
<td>60</td>
<td>0.71</td>
<td>b₃</td>
</tr>
<tr>
<td>Lack of Motivation</td>
<td>0.52</td>
<td>0.78</td>
<td>b₅</td>
</tr>
<tr>
<td>Number of Problems per Hour</td>
<td>1.5</td>
<td>0.85</td>
<td>b₂</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WORKLOAD</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood Pressure</td>
<td>160</td>
<td>0.74</td>
<td>c₇</td>
</tr>
<tr>
<td>Effort</td>
<td>0.5</td>
<td>0.748</td>
<td>c₅</td>
</tr>
<tr>
<td>Frustration</td>
<td>0.52</td>
<td>0.782</td>
<td>c₆</td>
</tr>
<tr>
<td>Mental Demand</td>
<td>0.56</td>
<td>0.85</td>
<td>c₁</td>
</tr>
<tr>
<td>Number of Problems per Hour</td>
<td>1.5</td>
<td>0.85</td>
<td>c₂</td>
</tr>
<tr>
<td>Performance</td>
<td>0.625</td>
<td>1</td>
<td>c₄</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>0.54</td>
<td>0.51</td>
<td>c₈</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>0.625</td>
<td>1</td>
<td>c₃</td>
</tr>
</tbody>
</table>

Based on the data provided in the table, the overall human performance risk for the job was:
\[
\text{SWFI} = 0.561 \times [0.237(0.85) + 0.177(0.85) + 0.133(1) + 0.132(1) + 0.116(0.748) + 0.108(0.782) + 0.063(0.74) + 0.035(0.51)] + 0.268 \times [0.284(0.85) + 0.275(0.66) + 0.27(0.71) + 0.104(0.748) + 0.067(0.74)] + 0.171 \times [0.339(0.66) + 0.303(0.85) + 0.162(0.71) + 0.106(0.748) + 0.091(0.78)]
\]

= 0.8

Based on the numeric risk level scale, chosen through the literature review and with the advice of SMEs, as listed in Table 36, the task observed with an expected amount of risk of 0.8 was categorized as high risk. The complete dataset is in Appendix D.

The sensitivity, specificity and accuracy for each of the fuzzy models was also calculated. For each fuzzy model, stress, fatigue, and workload, the industry-recognized standard model was used for comparison. For fatigue, total body fatigue created by Crumpton-Young was used; for workload, the NASA TLX; for stress, Hackman-Oldham.

### 4.7.1 Workload Industry Standard

NASA TLX was selected as the industry standard to determine workload levels experienced by an operator. NASA TLX over the three-year development of the tool was shown to be more sensitive to experimental manipulation of workload than a global rating or a combination of subscales weighted to reflect the biases of the subject. The element missing from SWAT and Workload Profile (WP) is information about the sources of workload for a specific task that is to be evaluated. TLX has vast program of laboratory research since 1986. The instrument has proven to be sensitive to a variety of task that range from simulated flight tasks to air combat and use or remote control vehicles (Rubio, Díaz, Martin and Puente, 2004). Natauisky and Abbott, 1987, found that TLX was able to successfully discriminate workload levels associated with different flight patterns. In 1992, Hill used a flight simulation task to
compare subjective workload tools and found that TLX has the highest sensitivity among the scales, followed by Modified Cooper-Harper Scale and SWAT.

The tool can be completed in less than 10 minutes and takes no more than two minutes to obtain the factor weights for each different tasks type. The test/retest reliability was determined to be .83 (Hart, 1988). The tool has shown good concurrent validity when examining the degree of agreement between the subjective workload and performance measures. Lastly, the tool has shown that subjects are able to report adequately about the nature of the resources that a particular task demands.

Therefore, based on the extensive testing conducted using TLX in different environments, the tools proven ability to determine differences in workload levels, and the high sensitivity of the tool, TLX was chosen as the industry standard to compare the fuzzy set model that was developed in this research.

### 4.7.2 Stress Industry Standard

The Hackman-Oldham Job Diagnostic survey scale was used as the industry standard to evaluate task stress. Hackman and Oldham (1975) proposed five "core" dimensions for evaluating the immediate work environment constituting the Job Diagnostic Survey JDS. Those five dimensions are skill variety, task identity; task significance, autonomy and feedback.

Skill variety is described as 1) the degree to which a job requires a variety of challenging skills and abilities and 2) using different values skills, abilities and talents. The degree to which a job requires completion of a while and identifiable pieces is collected under task identity. Task significance described both the degree of meaningful impact the job has on other (i.e. the importance of the job) and the degree to which the job has a perceivable impact on the lives of
others. The freedom to do the work as an individual sees fit and the degree to which the job gives the individual the freedom and independence in scheduling work and how the work will be carried out was collected under autonomy. The last variable collected is feedback which looks at how clear and direct information about job outcomes or performance is given to individuals. Hackman-Oldham showed a positive relation between task design and employee motivation. Additionally it was shown that when a worker’s tasks expanded, a worker with strong higher order needs responded more favorable to the change (Couger, Zawacki, and Oppermann, 1979; & Cordery, J.L., and Sevastos, P.P, 1993).

Hackman and Oldham's Job Characteristics Model, has been applied to a varying industries ranging from hospitality to medical services. Feedback from the survey has improved the working conditions and employee morale thus reducing workplace and task stress. The survey has been applied to over 800 companies and has proven to be used since its introduction in the late 1970’s with revisions and edits along the way. The results indicated that job satisfaction was more a function of task design than was extrinsic satisfaction, task design was a significant factor in increased overall job satisfaction and improved task design led to a decrease in task related stress (Pierce and Dunham, 1976)

Based on the extensive application of the survey, the survey’s validity and reliability have been substantiated throughout the past two decades, and the task specific questions, this survey was used to aid in the validation of the fuzzy stress model developed in this research.

4.7.3 Fatigue Industry Standard

The fuzzy fatigue model developed in this research was evaluated against the Total Body Fatigue Model developed by Dr. Crumpton-Young to quantify fatigue levels based on work task
demands. The model was developed using fuzzy logic theory to estimate total body fatigue. It combines measures of mental and physical fatigue as input variables. The model’s output describes a worker’s overall level of fatigue resulting from performing a task. This model has been applied in the health care industry, office environment and military applications. The model has proven to accurately predict task fatigue over 80% of the time.

Due to the high accuracy, the required task input variables, and the wide application of use, the Total Body Fatigue Estimator was selected as the model to compare the fuzzy fatigue model developed in this research.

Each participant’s data was inputted into the model for evaluation. The corresponding value was given a ranking based on a one point continuous scale subdivided into five sub-sections. A comparison of the resultant sub-section values was used to determine if the fuzzy set model resultant values were equivalent to the recognized industry-standard values.

The results of the analysis of the observed data indicated that the fuzzy model for fatigue was 52 percent sensitive, 70 percent specific and 61 percent accurate. The fuzzy stress model was found to be 59 percent sensitive, 78 percent specific, and 60 percent accurate. The workload fuzzy model was 44 percent sensitive, 86 percent specific, and 73 percent accurate.

The same analysis was run for the simulated data and the results showed the same fuzzy model for fatigue was 89 percent sensitive, 89 percent specific, and 89 percent accurate. The fuzzy stress model was found to be 91 percent sensitive, 88 percent specific and 90 percent accurate. The workload model was 93 percent sensitive, 94 percent specific, and 94 percent accurate. Calculations for both analyses are detailed in Appendix E.
4.8 Study Variables in Real World Terms

The variables that were studied in the experiment, although unique in nomenclature to a flight simulation environment, can be collected in any environment. The following paragraphs explain the significant variables found in the stress, fatigue, and workload index describe in common terminology for industry. Two of the variables collected heart rate and blood pressure, are common terms regardless of industry and need no further explanation.

Problem identification is expressed as a participant’s ability to correctly identify a problem when presented to them during the simulation. The participant identified the problem correctly, in which case, they received a rating of 1; or they did not identify the problem and received a rating of 0. Problem identification is similar to accuracy.

Hours on console was the variable used to capture the amount of time a participant was engaged in a simulation exercise. The participant’s hours on console ranged from four to eight and a half hours. This variable for industry would capture the amount of time a participant spent at a job or office site. The average person spends eight hours of each twenty-four at work.

Number of problems captured is defined as the number of problems a participant solved during the simulation. This variable is similar to the number of tasks or exercises a participant can complete during a defined period of time.

Completion time captured the temporal difference between when a participant first received a problem, the start time, to the time when the participant either completed the troubleshooting plan for the problem or when the simulation ended because of the nature of the problem (for example, when required controllers were not available for the simulation). In other studies, this variable might be referred to as the task duration.
Effort, frustration, temporal demand, mental demand, and performance are variables defined by NASA TLX. Each variable has been verified and validated by NASA Ames researchers. Effort is associated with how hard a participant has to work to complete a task. Frustration is associated with how relaxed or stressed a participant feels during a task. Temporal demand is associated with the amount of time pressure a participant feels under to complete a task and the pace at which the participant must work. Mental demand is associated with the thinking and deciding part of the memory and functions that is required for a participant to complete a task. Performance is associated with how satisfied a participant was with their performance when completing a task, and how successful the participant believes they were in accomplishing the task objective.

Lack of Motivation was described in the SOFI. Ahsberg describes lack of motivation in terms of a participant’s passiveness, lack of concern, or disinterest in the task under consideration.
CHAPTER FIVE: DISCUSSIONS

This chapter presents the discussion from the research that was conducted to address the development of a quantifiable model to describe the impact of fatigue, stress, and workload. This section is divided into the following sub-sections:

5.1 SME AHP Analysis Results
5.2 Model Validation
5.3 Recommended Model
5.4 Real World Application of Research

5.1 SME AHP Analysis Results

Tables 32-34 show results from the AHP analysis based on SME ratings for the stress, fatigue, and workload variables. Each of the SMEs were asked to compare each factor within a category (such as fatigue) to each other and answer the question:

When thinking about fatigue, does variable x or y contribute more to fatigue?

Based on the response, the SME would then answer this question:

On a scale from 1 to 9, with 1 being low importance and 9 being the most important, how much does x contribute to fatigue?

Table 36 contains AHP results of SME comparisons of the main variables: stress, fatigue, and workload.

The results indicated that workload contributed most to a change in human performance. Fatigue was shown to contribute least to human performance. Literature has revealed that limited research has been performed on analyzing the psychological aspects of any given task because of the subjectiveness on the part of the worker. The diverse range of results suggests
that these are differences in perception of cognitive demands on the workers. The console observations that were observed were predominately mental in nature, and thus can help explain the large contribution of workload to human performance. By assessing tasks to understand how they impact the worker, management can utilize the results to re-assign workers to fit tasks more effectively.

Data was also collected on the consistency of each rater. This was important to help ensure the data used to determine the variable weights was accurate and consistent within each rater and that the data was not biased by one individual rater. Each SMEs opinion and values carried equal importance when determining the variable weight.

5.2 Model Validation

The model has been validated using two different datasets. The first set of data used for validation included 30 percent of the original data that was set aside for validation instead of model development (data splitting). The second set of data, simulated, was created randomly to represent the general population. The data points created were within the bounds established by the SMEs or by the literature review.

The observed dataset produced results that indicated all participants experienced either low or very low stress, fatigue, or workload. Additionally, no changes in human performance could be predicted based on z-test results. These results are consistent with notes taken by the principle investigator in the simulation environment.

The correlation matrix indicated that a negative correlation existed between multiple relationships. The human performance measure, problem identification, produced the largest number of negative correlation values. Participants either correctly (1) or incorrectly (0)
identified a problem during the simulation. Due to the frequency of simulation runs, the finite plausible number of potential problems, and personnel adaptation, only a very small percentage of the participants did not correctly identify a problem. Additionally, most participants in the study have been certified on console for more than three years. These factors contribute to the negative correlation obtained from the analysis.

A negative correction was also calculated between decision making and the fuzzy workload index (-0.073), decision making and fuzzy stress index (-0.244), and SFWI and decision making (-0.226). The correlation between the workload index and decision making was nearly zero, indicating minimal correlation. Decision making analyzed a participant’s ability to correctly identify the problem resolution plan and to execute that plan. Most participants had been exposed to the problems given to them during the simulation, either in a prior simulation or during an actual flight. Additionally, participants were very knowledgeable in system procedures, pre-planned troubleshooting plans, and in knowing when to seek additional support from backroom personnel. This knowledge led to participants correctly identifying problem resolution paths.

A negative correlation was also found between fuzzy workload index and completion time (-0.162). This indicates that as workload increased, completion time decreased. A possible reason for this negative correlation can be attributed to the type of workload, the complexity, and the participant’s familiarity with the problem.

The training that flight controllers are given prior to console operations is highly controlled and very competitive. Each controller spends a minimum of one year in book review and single system simulations prior to integrated mission simulations. At the completion on each phase, the controller is given a test with a pass or fails criteria. If a controller does not pass with
a certain level of proficiency, he or she must repeat the course or section. In extreme situations, the controller can be asked to seek other job opportunities.

When a controller has reached the back room for console operations, he or she has completed a minimum of one year of training, has been exposed to high stress and workload scenarios (adaptation to the environment has begun), and has an understanding of the consequences of a mistake (for example, a missed call might mean early mission termination).

The simulated data created represents the general population. Representative individuals were placed into three groups: high, medium, and low. The individuals in the high group were given data points that were high in nature, such as a long problem completion time, 2 hour. This was performed for the other groups respectively. The results of the model indicated that those participants who were labeled high had a high risk for stress, fatigue, and workload. This was representative for the other two groups. The z-test revealed that completion time, one of the human performance measures, could predict the changes in human performance.

The simulated data correlation matrix indicated negative correlations between decision making and the fuzzy stress index (-0.0432) and decision making and the fuzzy workload index (-0.0147). Both of these values are nearly zero, suggesting a minimal negative correlation. The negative correlation can be attributed to a few factors: 1) the randomly-placed simulated data not being representative; 2) the participants being over-familiarized with the given problems; and/or 3) the troubleshooting plans being clearly defined, with minimal room for error.

A minimal correlation exists between problem identification and: 1) the fuzzy stress index (0.006); 2) the fuzzy fatigue index (0.043); 3) the fuzzy workload index (0.027); and 4) SFWI (0.037). The minimal correlation can be attributed to the random selection and the
random placement of that data. For problem identification, the participant either correctly or incorrectly identified a problem. Therefore, the participant received a score of a zero or one.

The simulated data indicated higher positive correlations and improved z-scores over the observed data. These increases could be attributed to a few factors: 1) simulated data covered the entire range of possible data points; 2) observed participant data indicated minimal errors in problem identification and decision making; 3) observed participants had already become acclimatized to the simulation environment; and 4) observed participants were not exposed to high workloads.

The observed participant data indicated low or average workloads based on the number of problems given in a simulation and a minimal rate of errors. The error rates were low in relation to the frequency of simulations and years of experience. The participants had an average of four and a half years in their current employment position and eleven years with the company in an engineering position. Many of the participants have been flight controllers for their entire careers.

During the reconstruction and return to flight days after the Columbia accident, flight controllers remained proficient in console operations by attending weekly simulations and performing data reviews. During this period, senior flight controllers also reviewed past missions to verify that all seen in-flight anomalies were covered in the simulations. Additionally, engineers met with vendors and designers to verify all potential error modes were correctly modeled and identified. This helped ensure the database of simulation problems correctly identified, modeled, and trained flight controllers.

The frequencies at which participants are given a problem are dependent on a few factors: 1) the type of simulation; 2) whether the controller is being certified for a new position; and 3)
the type of problems given. If the participant is being certified for a new position, this individual will be given additional problems and more specific systems problems than individuals who are currently certified. The type of simulation will also determine how many problems a participant will be given. For example, during a ISS simulation, the booster console operator might only see one problem, whereas the consumable operator will be given multiple problems to verify the correct attitude and position of the orbiter.

The results of this study are therefore limited to tasks that require the use of console operations and that are predominately mental in nature.

5.3 Recommended Stress, Fatigue and Workload Model

A useful analysis tool, consisting of a mathematical model, was developed. This model enables managers and console operators to identify specific stress, workload, and fatigue factors that could affect the performance of the worker. This model is displayed on page 468.

The significant fatigue factors are discussion traffic, change in heart rate, hours on console, number of problems per hour, and problem identification. The stress factors that were experienced by console operators pertain to completion time in hours, discussion traffic, change in heart rate, lack of motivation, and number of problems per hour. The workload factors that were found to have an affect on human performance were change in blood pressure, effort, frustration, mental demand, number of problems per hour, performance, physical demand, and temporal demand.
5.4 Real World Application of Research

Creating a mathematical model that identifies the occupational factors that have an effect on the performance of console operators will reduce the likelihood of irreversible decisions or decisions that are costly in time and resources. There is a gap in the current literature addressing how the combined affect of stress, fatigue, and workload affect human performance. The finding of this research will help managers of console operations and tasks by providing an applicable mathematical formula which provides the following contributions:

- A mathematical formula that contains variables that can be occupationally controlled
- A Stress, Fatigue and Workload Model that assesses console operations to determine the risk level, in order to reduce or mitigate irreversible decisions that are costly both in time and resources

The findings of the analysis indicate that there is a set of factors that have an effect on the performance of console operators, causing decreased decision capabilities. With this new model, these risk factors can be significantly reduced. The model enables general industry to take a proactive stance in the identification of factors that impact on worker performance, and contribute to positively reducing those factors that result in a decrease in the performance of console operations.
CHAPTER SIX: CONCLUSIONS

This research addresses the development of a mathematical model to describe the combined affect of stress, fatigue and workload under various task conditions. Until now, this interaction has not been studied. There were four major findings drawn from this research:

- A valid task specific model for quantifying stress, fatigue and workload
- The model can predict changes in stress, fatigue and workload under various task conditions.
- All final model variables can be collected in an occupational setting without lab support.
- A quantitative model has been developed to aid managers in ensuring the best performance of an individual while decreasing stress, fatigue and workload problems

The development of a fuzzy set model to describe the combined affect of stress, fatigue and workload in a dynamic environment, has been identified as a requirement from Gawron, French, Fook, the National Science Foundation, and others. This research now provides industry with task specific models for quantifying stress, fatigue and workload. The model can aid Human Factor engineers in evaluating job risks associated with the type of task individuals complete under various work conditions.

All final factor variables included in the models can be collected without the support of laboratory equipment or personnel resources. Many of the factor variables (i.e. number of problems, completion time, or effort) can be obtained from data acquisition systems or console logs. The other variables can be collected using surveys that require less than 10 minutes to complete. Analysis of these surveys takes less than 15 minutes.

Two of the variables require an individual to have access to a heart rate monitor and a blood pressure machine. Both of these pieces of equipment can be purchased off the shelf, are
readily available and have high user satisfaction. The heart rate monitor used in this study is often purchased by runners, high performance athletes and university medical and science schools because of the simple user interface, the capability to download data to a laptop via an infrared port and the trend capabilities of the supporting software.

The stress, fatigue and workload model was developed for supervisors to pre-plan tasks and understand what factors increase stress, fatigue and workload problems prior to an employee performing a job. Completion time, problem identification and decision making were the human performance variables that were shown to be impacted by changes in stress, fatigue and workload. These three variables can be collected from console log entries or console operator notes.

The primary focus of this research was to develop a quantifiable model to represent the combined affect of stress, fatigue and workload under various task conditions. Therefore, this research directly impacts and validates the understanding in which there are subjective and objective factors within stress, fatigue, and workload that can increase the potential to make an error. Opportunities for future research in the area of stress, fatigue and workload are also addressed in this chapter. This chapter is divided into two sections:

6.1 Future Research

6.2 Summary

6.1 Future Research

Many opportunities exist for extending this research towards the expansion of literature in the area of factors that have an affect on stress, fatigue and workload. In the area of
identification and quantification of factors that affect stress, fatigue and workload, the following future research areas are suggested:

- Perform additional research in the air traffic control and nuclear reactor sectors
- Perform additional research on tools to aid in collecting EKG reading and cortisol levels that minimize participant interaction with the device
- Research tools that can collect blink rate and are NASA EMI compatible

Although NASA has a unique mission and objectives from any other agency in the nation, the business conducted at some of the operational centers, is similar to those of military divisions, nuclear power industries and other companies that support defense contracts (i.e. Lockheed Martin or Boeing). All these companies employ a percentage of individuals who are required to conduct computer console operations either for simulation exercises, equipment testing and checkout, agency functions, or for vehicle deployment and monitoring. Data from these companies and agencies can further enhance and validate the model that was developed in this research.

Additional recommendations for the utilization of the stress, fatigue and workload model include:

- NASA could adopt the model for Moon and Mars mission planning and resource allocation
- Simulation trainers could use the model to evaluate the efficiency and effectiveness of training exercises

The results of this research has shown that NASA’s training program has provided an environment in which flight controllers through numerous simulation training exercises do not
demonstrate high levels of stress, fatigue and workload that impact their performance. These simulation exercises are the most flight like environments controllers are exposed to other than actual missions. The frequency of simulation exercises controllers participate in, the number and variety of problems controllers are exposed to and the breadth of knowledge verified by a controller’s certification contributes to the low number of human performance errors. The stress, fatigue and workload fuzzy model developed in this research has the potential to aid simulation trainers in determining how effective and efficient a company’s simulation program is in meeting training objectives. Additionally, the model provides a quantitative approach that will help determine the appropriate amount of training, length of training, and content of training to ensure the best performance while reducing stress, fatigue and workload problems.

6.2 Summary

This study will serve as a framework for researchers interested in the stress, fatigue, and workload and the impact associated to performance degradation based on task demands. The quantifiable model can be used in an operational setting to aid managers in determining how workers are affected by task demands resulting from an increase in stress, fatigue and workload. Additionally, this model provides managers with a guide to develop future work schedules based on past task demands and required performance. The model inputs also do not require lab support which can be costly and time consuming for companies.

This research is a stepping stone for future research opportunities in an array of industries.
KSC/JSC Subject Consent Form

1. I, the undersigned, do voluntarily give my informed consent for participation as a test subject in the study: Stress, Fatigue, and Workload: Determining the Combined Affect on Human Performance.

I understand or acknowledge that:

The research procedures were explained to me prior to the execution of this form. I was afforded an opportunity to ask questions, and all questions were answered to my satisfaction. A layman’s description was provided to me along with this form. I can refuse to participate in the study at any stage and my refusal will not result in any penalty or loss of benefits, which I am otherwise entitled. The investigator(s) may discontinue my participation in this study for safety or other reasons. In the event of an injury requiring immediate medical treatment during the course of this study, Kennedy Space Center and its contractors will provide or arrange for necessary initial treatment.

If I have further questions, I will discuss them with the investigators or contact the Principal Investigator, Jessica Mock, at 321-861-6652. In addition, if I have concerns about this study or my participation as a subject, I can also contact the KSC Institutional Review Board (IRB) directly through the Chair, David A. Tipton, MD, at 321-867-6385.

I have read and fully understand the attached study description entitled “Stress, Fatigue and Workload: Determining the Combined Affect on Human Performance” and will receive a copy of that document and this signed document.

Signature: ____________________________       Signature: ____________________________

____________________________________  ________________________________
Test Subject      Date                  Witness      Date
2. I, the undersigned, the Principal Investigator of the investigation designated above, certify that:

I have thoroughly and accurately described the research investigation and procedures to the test subject and have provided him/her with a layman’s description of the same and a copy of this consent form.

This study entails minimal risk to the test subject. All equipment to be used has been inspected and verified safe under proper operational conditions.

Except as provided for by Agency-approved routine uses under the Privacy Act, the confidentiality of any data obtained as a result of the test subject’s participation in this study shall be maintained so that no data may be linked to him/her as an individual.

The test protocol has not been changed from that approved by the KSC Human Research IRB.

Signature:

__________________________________________
Principal Investigator Date
"UCF Informed Consent"

Please read this consent document carefully before you decide to participate in this study.

Project title: "Stress, Fatigue, and Workload: Determining the Combined Affect on Human Performance"

Researcher: Jessica Mock, graduate student in the Department of Industrial Engineering and Management Systems at the University of Central Florida under the advisement of Lesia Crumpton-Young, chair of IEMS.

Purpose of the research study: The purpose of this research study is to determine how the combined affect of stress, fatigue and workload affect human performance through the use of fuzzy set modeling. Specifically, this research will generate a quantifiable model to describe the impact of fatigue, stress, and workload on human performance. The achievement of this stated purpose will help to predict, prevent, control and mitigate the occurrence of task demands that negatively influence human performance and compromise successful launches.

What you will be asked to do in the study: Following a brief 5-minute explanation of the study, you will be provided a time for questions and answers. You will then be asked to put a heart rate monitor on. You will be provided instructions on how to wear the monitor if needed. The watch that is worn will gather you basic physiological information such as heart rate, oxygen consumption rate, body temperature, energy consumption, ventilation and respiratory rate. The P.I. will ensure that the monitor is set prior to starting the study. You will then be asked to fill out a demographic questionnaire pertaining to your job and work experience. You do not have to answer any question you do not wish to answer.

You will then be asked to take a fatigue computer based test on a provided laptop. You will be given verbal instructions with a time for question and answers. This test will set your base line measure. To assess your workload, you will be asked to take the NASA TLX questionnaire (paper or computer based).

You will then be asked to participate in the simulation exercise that you were assigned as normal. The heart rate monitor will capture all your physiological data.

The P.I. will be at the back of the room at the simulation console to view the exercise. At the end of the simulation run, you will be asked to take the same fatigue computer based test described above.

At the conclusion of the test session, you will be asked to return the heart rate monitor and fill out a post-session questionnaire.
Time required: **One (1) hour.**

Place of testing: **Testing will occur in the Launch Control Center (LCC) firing rooms at the Kennedy Space Center between Oct 1st and Dec 31st, 2005.** The test will not require you to miss any regularly scheduled work activities.

Risks: **No anticipated risk to the subject. If you have a heart condition, you will be excluded from the study.**

Benefits / Compensation: **There is no compensation or other direct benefit to you for participation, other than normal pay.**

Confidentiality: **Your identity will be kept confidential. Your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file in the supervisor faculty's office. Additionally, any videotape(s) will also be kept in a locked file with only your participant number. When the study is completed and the data has been analyzed, the list and tape(s) will be destroyed. Your name will not be used in any report. Only the principal investigator and supervising faculty will have access to the tapes.**

Voluntary participation: **Your participation in this study is voluntary. There is no penalty for not participating.**

Right to withdraw from the study: **You have the right to withdraw from the study at any time without consequence.**

Administrator: **Principal investigator**

Results of Study: **The results of this study will be shared with the NASA simulation team and the directors of the Safety and Mission Assurance branch at the Kennedy Space Center. These two groups of individuals will be provided with final results and analysis only. No individual data will be provided.**

Whom to contact if you have questions about the study: **Jessica Mock, Graduate Student and Principal Investigator, Department of Industrial Engineering, 4000 Central Florida Blvd, Engr II, Suite 312, Orlando, FL 32816; (407) 823-4696. Dr. Lesia Crumpton-Young, Faculty Supervisor, College of Engineering, The telephone number is: (407) 823-2204.**

Whom to contact about your rights in the study: **UCF IRB Office of Research & Commercialization 12201 Research Parkway, Suite 501 Orlando, FL 32826-3246. The phone number is (407) 823-2901.**

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I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

___________________________/__________________
Participant      Date

_______________I would like to receive a copy of the final report.

_______________I would not like to receive a copy of the final report.

_______________/________________

Principal Investigator      Date
APPENDIX B: SUBJECTIVE QUESTIONNAIRES
Demographic Questionnaire

1. Simulation Position Title: ____________________________ (i.e.: System Engineer, System Specialist)

2. Department: _______________________________

3. Years of Experience: In current position:_______________
   overall: _____________________

4. Are you: _____ male       _____ female

5. What is your age:
   _______18 –24     _______25-34
   _______35-44     _______45-54
   _______55-64     _______65 or over

6. What is the highest level of formal education you have completed? (Please check only one.)
   _____ Graduated High School
   _____ Attended College **without** a degree
   _____ Graduated College with a degree
       _____ Bachelor of Science
       _____ Bachelor of Arts
       _____ Associate of Arts or Science
   _____ Post-graduate study **without** a degree
   _____ Post-graduate degree

7. Have you been diagnosed with a heart condition?     _____ Yes   _____ No

8. Have you been treated for chronic stress?     _____ Yes   _____ No

9. Have you been treated for chronic fatigue?     _____ Yes   _____ No

10. Do you take Anti-Cortisol Medication?     _____ Yes   _____ No
11. You normal work week includes: (check all that apply)

☐ scheduling of work tasks  ☐ problem reporting (PR/DR/IPR)

☐ problem resolution  ☐ in vehicle processing

☐ write work procedures  ☐ training (new or refresher)

☐ paper review (not authored) ☐ running a WAD or test procedure

☐ simulations  ☐ PRTs

☐ other (please specify) ________________________________

12. The number of hours I work per week (average) is: (please only check one)

☐ 20 to 35 hours  ☐ 35 to 40 hours

☐ 41 to 45 hours  ☐ 46 to 50 hours

☐ 51 to 55 hours  ☐ 56 and over

13. On a daily basis I drink ______ cups of coffee.

14. Today, I have drunk ______ cups of coffee.

15. On a daily basis I drink _____ bottle(s) of soda that contain caffeine.

16. Today, I have drunk ______ bottle(s) of soda that contain caffeine.

17. I slept ___ hours last night.

18. On average, I sleep ___ hours per night.

19. My blood pressure reading is: Systolic pressure: ________________ 

   Diastolic pressure: ________________
NASA TLX

Please select the appropriate level associated with your daily task work level of each factor by coloring in one of the blocks.

Definitions
Mental Demand—thinking, deciding memory
Physical Demand—exertion activity
Temporal Demand—time pressure and pace
NASA TLX CONT.

Please answer the following 15 questions. Only select one answer:

1. The factor that represents the more important contributor to workload for the task is:
   Mental Demand
   Or
   Effort

2. The factor that represents the more important contributor to workload for the task is:
   Effort
   Or
   Performance

3. The factor that represents the more important contributor to workload for the task is:
   Performance
   Or
   Frustration

4. The factor that represents the more important contributor to workload for the task is:
   Effort
   Or
   Physical Demand

5. The factor that represents the more important contributor to workload for the task is:
   Temporal Demand
   Or
   Mental Demand

6. The factor that represents the more important contributor to workload for the task is:
   Performance
   Or
   Temporal Demand

7. The factor that represents the more important contributor to workload for the task is:
   Frustration
   Or
   Effort

8. The factor that represents the more important contributor to workload for the task is:
9. The factor that represents the more important contributor to workload for the task is:
   
   Mental Demand
   Or
   Physical Demand

10. The factor that represents the more important contributor to workload for the task is:

    Physical Demand
    Or
    Performance

11. The factor that represents the more important contributor to workload for the task is:

    Temporal Demand
    Or
    Frustration

12. The factor that represents the more important contributor to workload for the task is:

    Physical Demand
    Or
    Temporal Demand

13. The factor that represents the more important contributor to workload for the task is:

    Physical Demand
    Or
    Frustration

14. The factor that represents the more important contributor to workload for the task is:

    Frustration
15. The factor that represents the more important contributor to workload for the task is:

    Temporal Demand
    Or
    Effort
**Swedish Occupational Fatigue Inventory**

**Directions:** To what extent does the expression describe how you feel now, prior to completing the simulation? Answer spontaneously and mark the number that corresponds to how you feel right now. The numbers vary between 0, not at all, and 10, to a very high degree.

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<th>To a very high degree</th>
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**Fatigue Questionnaire II, Yoshitake, 1971**

**Directions:** Please circle just one answer. Answer spontaneously on how you feel prior to the simulation.

**Type 1: Physical Fatigue**

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<td>Become weary of talking</td>
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<td>3.</td>
<td>Unable to concentrate</td>
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<td>Become apt to forget things</td>
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<td>7.</td>
<td>Become nervous</td>
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<td>9.</td>
<td>Feeling sad</td>
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<td>10.</td>
<td>Feeling anger</td>
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<td>11.</td>
<td>Feeling stressed</td>
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<td>12.</td>
<td>Feeling sleepy</td>
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**Type 2: Mental Fatigue**

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<td>6.</td>
<td>Feel dizzy</td>
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<td>7.</td>
<td>Have a tremor in the limbs</td>
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<td>8.</td>
<td>Feel warm in the body</td>
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Job Satisfaction Survey

The following 15 questions address how satisfied you are in your current position. Please only select one letter by circling that letter.

1. I am satisfied with how often I analyze data.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree

2. I am satisfied with how often I learn new information.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree

3. In my job, I am satisfied with how often I take part in problem solving.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree

4. In my job, I am satisfied with how often I perform detailed tasks.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree

5. There are several ways to advance or make lateral moves in my organization.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree

6. I am satisfied with the amount of resources I have to do my job.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree
7. There are opportunities to develop new skills that are interest to me.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree

8. My management is fair and reasonable.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree

9. My job is important to the organization.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree

10. I am comfortable with how much direction I receive from my boss.
    a. Strongly disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly agree

11. I am able to improve my work skills because of the feedback I get on the job.
    a. Strongly disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly agree

12. My coworkers respect each other’s opinions and values.
    a. Strongly disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly agree

13. I understand how my work affects the work of others and the success of the organization.
    a. Strongly disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly agree
14. I get a sense of satisfaction from the work I do.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree

15. I like the level of responsibility I am given in my work.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree
Post-test Questionnaire

1. After the test, my eyes were irritated. _____Yes _____No
   The irritation is caused by: ____________________________
2. I have blurred vision after completing the testing. _____ Yes _____No
3. My eyes have a dry burring sensation. _____ Yes _____No
4. Do you have a headache now that was not present prior to testing.
   _____ Yes _____No
   My headache was most likely caused by: ____________________________
5. On a scale 1 to 10, with 1 been not realistic and 10 being realistic, how would you
describe the problems you received during the simulation? ______________
6. On a scale 1 to 10, with 1 been not realistic and 10 being realistic, how would you
describe the overall simulation? ______________________________
APPENDIX C: ORIGINAL DATA
## Original Data

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<th>Physical Demand</th>
<th>Temporal Demand</th>
<th>Performance</th>
<th>Effort</th>
<th>Frustration</th>
<th>Lack of Motivation</th>
<th>systolic</th>
<th># problems/hr</th>
<th>Completion time in min</th>
<th>Heart Rate</th>
<th>Hrs on Console</th>
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<td>56</td>
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<th>Sensitivity</th>
<th>Specificity</th>
<th>Accuracy</th>
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<tbody>
<tr>
<td>G/S people with fatigue</td>
<td>0.8933333333</td>
<td>0.886792453</td>
<td>0.890625</td>
</tr>
<tr>
<td>G/S people w/o fatigue</td>
<td>0.9090909090</td>
<td>0.882352941</td>
<td>0.899280576</td>
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Sensitivity 0.518518519   Sensitivity 0.591836735   Sensitivity 0.444444444
Specificity 0.7           Specificity 0.777777778   Specificity 0.862745098
Accuracy 0.614035088     Accuracy 0.777777778     Accuracy 0.862745098

Sensitivity 0.8933333333   Sensitivity 0.909090909   Sensitivity 0.928571429
Specificity 0.886792453   Specificity 0.882352941   Specificity 0.949152542
Accuracy 0.890625        Accuracy 0.899280576     Accuracy 0.937984496


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