U.S. Air Force

Human Performance Cognitive Model for Air Force Information Operations

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Background

The Air Force Research Laboratory/HEP directorate requested that SAIC conduct a study to determine the feasibility of integrating the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model into a software system for information operations (IO) that would also include the effects of stress and other human performance variables. To accomplish this task, SAIC gathered information on existing and planned work to support customer requirements, identified human performance modeling concepts related to these requirements, assessed the feasibility of applying the SAFTE model to the IO domain, and analyzed the software effort necessary to integrate SAFTE with existing or planned software systems. It was determined, in consultation with the technical point of contact, that the most useful approach to this problem was to build on prior work conducted for the Army Research Institute under sponsorship of the Defense Advanced Research Projects Agency that focused on the development of a simulated command entity that could control simulated forces within a distributed interactive simulation.

The main goal of the ARI project was to develop a command entity that demonstrated realistic human capabilities and limitations in order to improve the realism of simulated forces. In 1997, Science Applications International Corporation developed a human performance model to serve as the central driver of a simulated command entity within a force on force simulation. This initial model incorporated the effects of sleep deprivation and fatigue, stress, confidence, time pressure and a simple representation of training and experience. In developing this initial model, a deliberate decision was made to limit the scope of the model so that its performance could be tested in relation to a set of simple parameters. This model was sufficiently promising in its performance that a follow-on effort continued in 1998 to add additional realism and complexity to the human performance model. **The 1998 effort resulted in a stand alone Human Performance Cognitive Model that integrated the effects of fatigue, stress, positive motivation, training, experience, and personality on human decision-making and decision response time.**

This report reviews the literature that supports the basic ingredients of the model and describes the extensions and improvements to the model that have been developed for the Air Force. This new model runs on a PC and is written in Borland C++. The model reads inputs from a scenario file that defines the timing of stress events, confidence building events, and sleep periods. The model creates an output file that is a minute-by-minute status table of effectiveness, decision type, reaction time changes and other status information. This model could be integrated into a larger model of information operations to modulate decision accuracy and speed.

General Model of Stress Effects on Performance

Several recent and extensive reviews of the stress literature are available and form the empirical basis of the report. Driskell, et al. (Driskell, Mullen, Johnson, Hughes, and Batchelor, 1992; Driskell, Hughes Guy, Willis, Cannon-Bowers, and Salas, 1991), has conducted two exhaustive meta-analsysis reviews of the stress literature. These were conducted specifically to support the Air Force and Navy in preparing for studies to simulate the stressful environment for training. These reports were supplemented by material from three recent collections of reviews edited by Driskell and Salas (1996), Klein, Orasanu, Calderwood, and Zsambok (1993), and Flin, Salas, Strub, and Martin (1997). All together, these reviews summarize the results of over 1,350 studies of stress, many sponsored by branches of the Armed Forces. These reviews considered a variety of factors which have been found to degrade performance and have been defined as stressors. Figure 1 is a diagram of a general model of the effects of stressors on performance. Factors included in the simulation model are shown in bold. On the left is a listing of stressor conditions. These are divided into two general categories: the physical environment and the conditions of the task itself. Physical stressors include noise, extremes of temperature, vibration, physical isolation, and threat of failure or injury, including the use of chemical or biological agents. Stressful conditions of the task include time pressure, multiple task demands, and sustained performance that lead to sleep deprivation and fatigue. The effects of these stressors are not uniform across individuals. In the center of the diagram are modulating conditions of the individual and social setting that can moderate the effects of these stressors on performance. They include individual factors such as training, experience, personality factors, and motivation, as well as social factors such as unit cohesion, leadership, group pressure, and social supports. The effects of these stressors can be manifest in a variety of performance and physiological effects: speed of responding, accuracy, physiological responses (cardiovascular and neuroendocrine changes) and psychological effects such as altered mood, motivation and psychiatric illness.

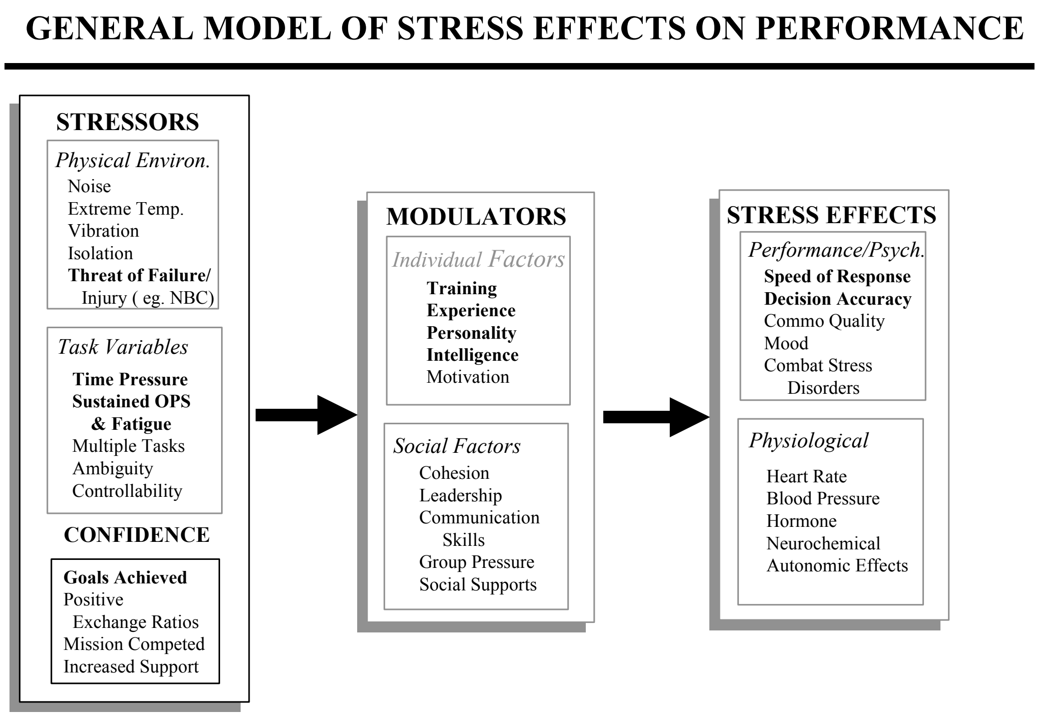


Figure 1. General model of stress effects on performance.stress effects on performance.

Not all stressors alter performance in the same way. For example, sleep deprivation and group pressure reduce both performance speed and accuracy. Time pressure and extreme cold, on the other hand, increase speed and reduce accuracy (Driskell, et. al., 1992, pp 165). In addition, the size of these changes is dependent on the type and magnitude of the stressor. Heat and noise have significant but small effects on performance, while fatigue and group pressure have relatively large effects on performance. The size of the effect will depend on the magnitude of the stressor. The effects of noise are nearly linear with the sound pressure level; the effect of fatigue increases with hours of sleep deprivation and is modulated by the physiological circadian rhythm. Hence, it is not reasonable to speak of the effects of stress on performance as a single hypothetical construct; rather, there are a variety of identifiable environmental and task conditions that alter the capacity of individuals to perform in ways that are, in part, specific to the nature of the conditions and, in part, dependent on individual factors. To simulate the conditions will require a model that has components specific to the conditions being emulated.

The Decision Simulation and the Effects of Stress

A Decision Simulation could simulate a variety of functions:

- Movement of forces and aircraft
- Target selection and firing
- Survivability and risk to force

- Communication from higher headquarters and to subordinate units
- Cognitive Characteristics
  - ⇒ Environmental and task specific stress factors
  - ⇒ Modulating antecedent conditions
- Mission analysis
- Situation analysis
- Determination and selection of courses of action
- Revision and execution of orders

The primary performance that is simulated is the determination and selection of courses of action. In other words, the simulated entity is a decision maker. The effects of stress will be manifest in the quality and speed of decision-making. As a consequence, the primary literature that is relevant to this simulation is that which describes the effects of stressors on decision-making. The picture that is emerging from the variety of studies of stress on decision-making is that the effects are strongly dependent on training and experience. When confronted with time pressure and work overload, the less experienced decision maker is subject to a variety of errors that can degrade the quality of decisions in a variety of ways, as summarized by Orasanu and Backer (1996): "decision makers use a small number of heuristics (rules) in making their decisions (Tversky & Kahneman, 1973), fail to consider all possible decisions and outcome options (Slovic, Fischhoff, & Lichtenstein, 1977), are inconsistent in dealing with risk (Lopes, 1983), ...[are] likely to display premature closure - terminating the decisional dilemma without generating all the alternatives and without seeking all available information about the outcomes (Janis, 1983)."

Klein (1996), on the other hand, proposes that these errors are primarily relevant to "prescriptive decision strategies" that use some form of multi-attribute utility analysis. This decision-making strategy is best suited to cases in which there is "less time pressure, more carefully collected data, multiple stakeholders, or generally lower levels of experience (Klein, 1996)." Studies of experienced decision makers under stress suggest that a more streamlined decision strategy is used which is called Naturalistic Decision Making (Klein, Orasanu, Calderwood, and Zsambok, 1993; Orasanu & Connolly, 1993; Klein, 1989, in press; Klein & Crandall, 1995). This strategy is best suited for settings where the decision task is unclear, the available information is incomplete, unreliable, or continuously changing, and stressors such as time pressure and high stakes are present (Orasanu & Connolly, 1993). Under such situations, it is impractical to adopt an exhaustive prescriptive decision strategy that requires complete data and is time-consuming. Klein (1996, 1989, in press) has proposed that experienced decision makers faced with this situation use the Recognition-Primed Decision (RPD) model. According to this model (Klein, 1989), the experienced decision maker can make rapid but effective decisions by using experience to size up the situation and to generate and evaluate courses of action one at a time (as opposed to comparatively). In the simple case, the situation is recognized as typical of ones encountered before and a typical course of action can be immediately applied. More complex situations that are not typical lead to more diagnosis and require a more deliberate analysis of course of action. The diagnosis strategy may involve the construction of a series of hypotheses or stories to explain the available information. That story that accounts for most or all of the data and is not contradicted by the data is adopted. Once the situation is diagnosed - a plausible story is constructed to account for the data - the appropriate course of action is usually obvious. When multiple courses of action are open to the decision maker, then each is evaluated for likely outcome (Klein & Crandall, 1995). Those courses of action that lead to difficulties or unacceptable outcomes are rejected, often leaving only one acceptable action, under this specific set of conditions. The product of naturalistic decision making is a decision that is adequate and resistant to time pressure, if not absolutely optimal. Alternative, more exhaustive strategies are disrupted by time pressure and, consequently, yield decisions that are flawed or not timely. The studies of naturalistic decision making "show that experienced decision makers are able to generate reasonable options as the first ones they consider, and select these options to carry out when performing a stressful task such as flying a complex mission in a simulator (Klein, 1996, 1997; Klein, Wolf, Militello, & Zsambok, 1995; Stokes, Kemper, & Marsh, 1992; Yates, 1990; and Wichens, 1987)." However, naturalistic decision-making critically depends on a high level of experience.

Effects of Time Pressure

For this initial decision simulation, not all stressors can be modeled and not all modulators will be considered. Based on the reviews by Driskell and colleagues (Driskell, Mullen, Johnson, Hughes, and Batchelor, 1992; Driskell, Hughes Guy, Willis, Cannon-Bowers, and Salas, 1991), the two most salient stressors that are also likely to apply to the command entity are time pressure and fatigue brought on by continuous operations. Based on the review of decision making under stress, the most important modulator variable of these stress effects is training and experience, which greatly mitigates the effects of time pressure.

The important implication from the review of decision-making under time pressure is that much larger effects should be expected with inexperienced personnel as compared to experienced personnel. For inexperienced decision makers who cannot rely on a recognition-primed decision strategy or who attempt to use an exhaustive prescriptive strategy, the effects of time pressure will be to seriously degrade decision making (Crego & Spinks, 1997). Driskell, et al., 1992, have summarized the literature on time pressure and have found that a relatively simple linear equation relates the magnitude of time pressure to the size of the stress effect. The magnitude of time pressure (MAG) is defined as:

MAG = longer time period/(longer period + shorter period).

Hence, a task that normally is performed with high accuracy in 60 seconds that is required in 42 seconds would have a MAG value of .587 and would predict a correlation coefficient with accuracy (r) of -.3. For this simulation we may define three *a priori* levels of potential time pressure of low (.481), moderate (.587) and high (.707) with corresponding changes in accuracy of low (r = -.1), moderate (r = -.3), and high (r = -.5).

Driskell does not consider the modulating effects of experience on the magnitude of the time pressure effect (Driskell, et. al., 1992). Based on the review of naturalistic decision making (Klein, 1996, 1997), time pressure will tend to increase the likelihood that the model will attempt to make a situation primed decision. The likelihood of a situation primed decision will depend on the level of experience.

Fatigue and Sleep Deprivation Effects

Modern combat augmented by night vision devices and electronic means of navigation and communication is not constrained by time of day and the cloak of darkness. The flow of battle may be relatively continuous with few breaks for sleep and recuperation. Under these conditions of continuous or sustained operations, sleep deprivation and fatigue may be a natural human hazard. Moreover, studies of sleep patterns in simulated combat at the National Training Center indicate that commanders (Lieutenant Colonels and Colonels) in force on force operations average just over four hours of sleep per day, about half the normal requirement for fully effective performance (Belenky, Balkin, Thomas, Redmond, Kant, Thorne, Sing, Wesensten, & Bliese, 1993). Furthermore, laboratory studies of sleep deprivation indicate that the most sensitive indicators of sleep deprivation are cognitive operations, such as logical reasoning, mathematical operations, short term memory, and decision making (Thorne, Genser, Sing & Hegge, 1983; Banderet, Stokes, Francesconi, Kowal, & Naitoh, 1981; Horne, 1988; Angus & Heslegrave, 1985). Hence, fatigue can be a strong disrupter of command level performance.

Science Applications International Corporation (SAIC) has developed a Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) Model for the Air Force Research Laboratory**.** The SAFTE model builds on prior work by SAIC. The first conception of a sleep and performance model was derived from the **A**rmy **U**nit **R**esiliency **A**nalysis (**AURA**) sleep and performance module (Klopcic, 1989). A stand-alone model was developed by SAIC that could then be modified to better reflect current psychophysiological and performance research. The product of that effort was the first version of the **S**leep and **P**erformance **M**odel (**SPM**), written in FORTRAN (Hursh & McNally, 1993).

In a subsequent effort (Belenky, Balkin, Redmond, Sing, Thomas, Thorne, Wesenten, & Hursh, 1996), the SPM was refined and served as an integral element of the actigraph-based **S**leep and **A**ctivity **M**onitor (**SAM**). This wrist worn device was designed to provide real-time assessment of cognitive-performance potential based on sleep and wakefulness patterns derived from activity records. To support this effort, the inventor added major new capabilities to the sleep and performance model. User inputs were replaced with actual data, new SPM algorithms were developed that were based on several long-term sleep deprivation studies conducted by the Walter Reed Army Institute of Research, and the model was adjusted to better reflect more recent observations on the recuperative value of sleep. This new, homeostatic model was implemented in two forms: a Windows-environment spreadsheet with imbedded graphics that was designed to be a development and demonstration tool and a Visual Basic program designed for SAM development that used, as input to the SPM model, sleep estimates derived from large actigraph data files.

In FY97, the Army Natick Research, Development, and Engineering Center awarded funding to further develop the model. This effort was undertaken to give the model the capability to predict performance based on a schedule of sleep and activity. New features added by the inventor included a more sophisticated circadian rhythm function, a circadian sleep propensity function, and a method to extend the predictions of the model to task effectiveness, as well as cognitive capability (Hursh, 1998). The model was named the **S**leep, **A**ctivity, **F**atigue, and **T**ask **E**ffectiveness (**SAFTE**) Model. In FY98, the Air Force Research Laboratory at Brooks AFB contracted to have the SAFTE model extended to comply with Air Force requirements and to incorporate the results of an ongoing pilot sleep deprivation study. The next version of the model developed by SAIC incorporated revisions to predict variations among cognitive tasks and changes in pilot task effectiveness. Cognitive capacity is the fundamental ability to perform mental operations as measured by specialized functional tests and task effectiveness is the ability to performance components of military tasks within the limits allowed by the system, as measured by a flight simulator or during a training exercise. During Phases I and II of an AF SBIR project (SAIC was subcontractor to the small business NTI, Inc.), the SAFTE model was enhanced further by SAIC and the current version was delivered to the Air Force in 2001.

The major components of the model are diagrammed in Figure 2, bottom portion. At the heart of the model is the *cognitive reservoir* that maintains a balance of effective performance units. During sleep, units are added to the *cognitive reservoir* according to the *sleep accumulation function*, which specifies how many units of effective performance are credited for each minute of sleep. The rate of accumulation is responsive to the *sleep deficit*, the difference between the current level of the *cognitive reservoir* and its maximum capacity. During time awake, units are subtracted from the *cognitive reservoir* according to the *performance use function,* which specifies a linear decrease in the *cognitive reservoir* with each minute awake. *Potential performance effectiveness* is sum of three terms, *the level of the cognitive reservoir*, expressed as a percent of its maximum capacity, the *performance circadian rhythm,* and the general *stress effects*, discussed below. Finally, the model stipulates a delay between the start of sleep and the beginning of sleep accumulation. This factor introduces a penalty for interruptions in sleep, or sleep fragmentation.

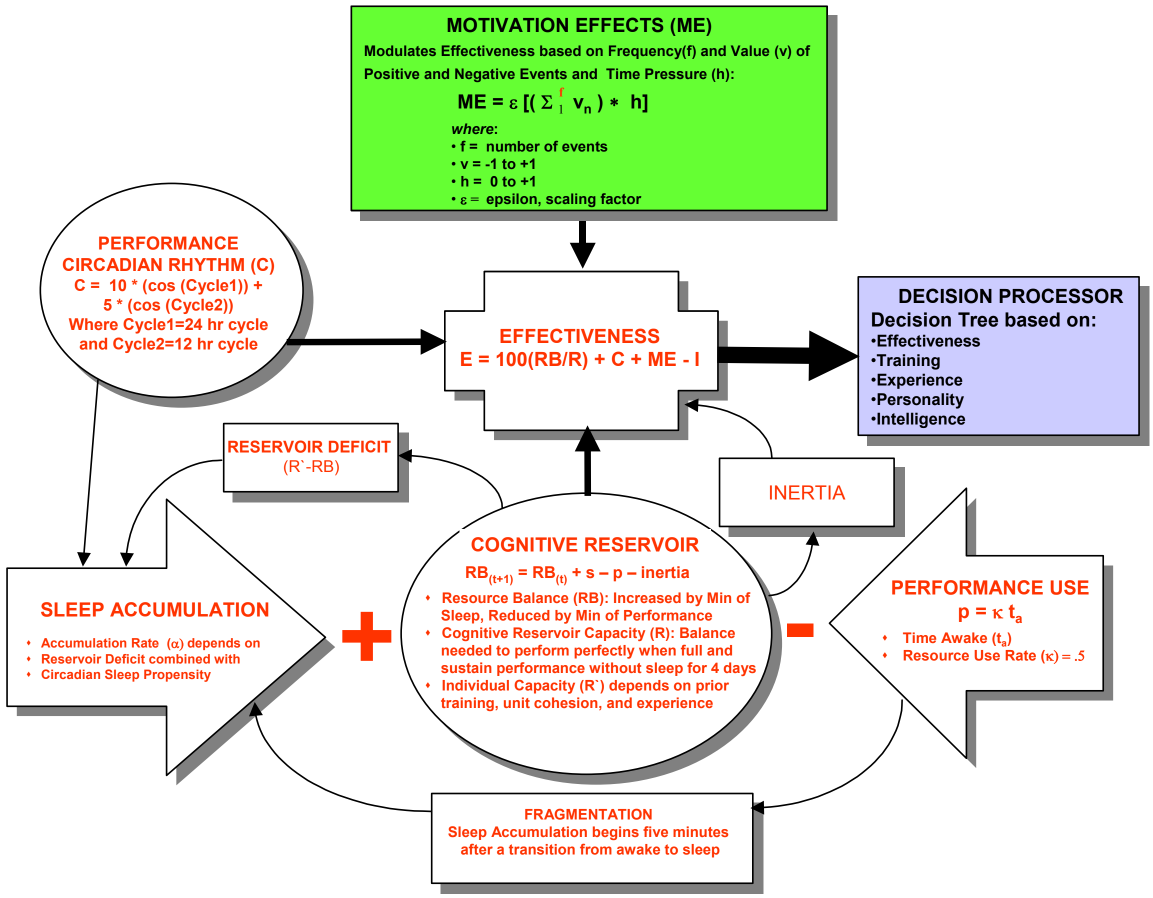


Figure 2. Model of sleep deprivation and circadian effects on performance.

The overall model is homeostatic because of the feedback loop between sleep deficit and the rate of sleep accumulation. Within specified limits, the model will increase the rate of accumulation to partially offset the accumulation of a sleep debt. In other words, when a person becomes fatigued, the model specifies that a deeper, more restorative sleep state is achieved for each minute of sleep. As the deficit is reduced, the depth of sleep and the contribution to the sleep reservoir also decreases back to the baseline level. As a result, a person that obtains only four hours of sleep per day for an extended period will accumulate a sleep debt for the first two or three days, with a resulting loss in effectiveness. After that point, the person will achieve an equilibrium state in which no additional deficit occurs and the level of performance degradation when awake remains relatively constant. For the purposes of the current command simulation, the duration of the scenario is short relative to the effects of sleep deprivation which accumulate over days. In addition, during the scenario it is presumed that the command entity will not have an opportunity to sleep. As a consequence, the effects of sleep deprivation will be based upon an accumulation of sleep debt that has occurred prior to the start of the simulation and the computation of sleep accumulation during the simulation will not be necessary. The model has been applied off-line to compute starting values of the *cognitive reservoir* (*resource balance*, RB) that reflect preexisting levels of sleep deprivation. These values are shown in Table 2 for fully rested (eight hours of sleep per day for prior five days) and seven levels of fatigue representing the effects of average amounts of sleep per day for the preceding five days, ranging from seven hours to one hour per day. These values are the level of RB at midnight prior to the day of the scenario. Since the sleep model assumes that all sleep periods start at midnight, the initial RB reflects the effects of a full day awake without the usual sleep on the following night. For example, the initial RB for the eight hour case is 2400 units which is the full capacity less the effects of a full day of performance for 16 hours (960 minutes x .5 = 480 units) and without the benefits of the next eight hours of sleep that restores 480 reservoir units.

Table 1: Initial values of the Resource Balance (RB) of the Cognitive Reservoir after five days of sleep averaging the duration shown in the table.

Starting Value of Resource Balance (RB) at Midnight of Scenario Day							
Average Hours of Sleep per Day for Prior 5 Days							
8	7	6	5	4	3	2	1
2400	2361	2308	2239	2129	1844	754	0

During the scenario, the RB will deplete and *potential cognitive effectiveness* degrades with hours awake according to formulas described below. The computation of Effectiveness (E) includes consideration of the usual circadian rhythm in performance (C). This factor varies from +10 percent to -10 percent, depending on the time of day and peaks at the nominal value of 2000 hours. This factor combines additively with the percent resource balance at the time of the performance (T).

General Stress Effect

The effects of stress can degrade cognitive performance as represented in the computation of Effectiveness (E) in Figure 2. The stress effect (SE), as represented in this simplified model, is designed to reflect the influence of stressful events and time pressure on effectiveness in making decisions. One key factor in this model of stress is the occurrence of significant events in the battle scenario that may either advance the mission (positive or confidence building events) or hinder the mission (negative or stressful events). The computation of the stress effect (SE) depends, in part, on the frequency of those events (f) and their value or severity. Mission advancing or confidence building events can range in value from 0 to +1; hindering or stressful events can range in value from 0 to -1. The overall stress effect at any moment in time considers the sum of these values over the preceding time interval.

The ability to process and react to events is modulated by the time available. During a slowly developing operation with events occurring infrequently in time there is plenty of time to react to events and take appropriate action. This tends to diminish the effects of stressful events. Hence, the value of battle events is multiplied by a factor that represents time pressure (h). Since it is not possible at present to actually measure the magnitude of time pressure in an actual scenario, the model may be exercised with a binary time pressure variable (h) with a value of 0 or 1 that represent a multiple of the stress effect of 1 or 2, respectively.

The overall value of the stress effect is subject to the decay of memory over time. As time elapses since an event, the value of that event in contributing to the total value of SE declines according to the double exponential shown below, based on classic memory experiments (Ebbinghaus, 1913; van Ormer, 1932). The initial term of the expression represents short-term memory and the second term represents long-term memory:

$$CurrentValue = 136.5e^{-10t} + 31e^{-0.195t} + 19.44$$

given that *Current Value* is the percent of the original value at time *t* since the original value, and time is in hours.

Naturalistic Decision Making

The effects of stress on performance are strongly conditioned by individual factors such as level of training and experience, personality and experience. The importance of these individual traits is strongly dependent on the level of stress, fatigue, and time pressure. As introduced above, we model the way these factors combine to control the selection of a course of action according to a decision theory called naturalistic decision making (Klein, 1996, 1997). The structure of this process is diagrammed in Figures 3 and 4. The overall level of effectiveness, E, resulting from the sleep and fatigue model and the stress process, determines the first level of control. Based on detailed studies of decision-making in stressful emergency situations, it is clear that the nature of decision making is phasic, depending on time pressure at each stage of the event or battle (Crego & Spinks, 1997). Periods of time-constrained decision pressure are interspersed with periods of time-rich decision opportunity. The first level of the structure in Figure 3 represents the oscillation between these two general states. The outcome of this first branch is based on the level of E and is probabilistic; as E varies based on changes in time pressure, stress, and fatigue, the likelihood of branching to the left or right varies continuously. The left hand branch is selected most often when E is high based on low time pressure, stress and fatigue. This is a time rich decision opportunity and the greater the level of training, experience and intelligence, the more likely the command entity will select the optimal or correct course of action. As training, experience, and intelligence decline, the greater the likelihood that the decision will simply be a random selection from those courses of action that are reasonable for this situation. Note, however, that this is a probabilistic process and only under the most extreme condition of no experience and training will course of action selection actually be random. In practice, given the normal requirements for command, no command entity would ever approach this extreme case.

The right hand branch is selected most often when E is low based on high time pressure, stress and fatigue. This represents time constrained decision pressure and results in what we call situation primed decision making after the concept of "recognition primed decision making" described by Klein (1996, 1997). We call it situation primed because it is variations in the situation that call forth different decision types based on prior experience with similar situations. According to this mode of decision-making, the experienced commander, when confronted with extreme time pressure or stress, does not attempt an exhaustive utility analysis of all available options. Rather, the commander

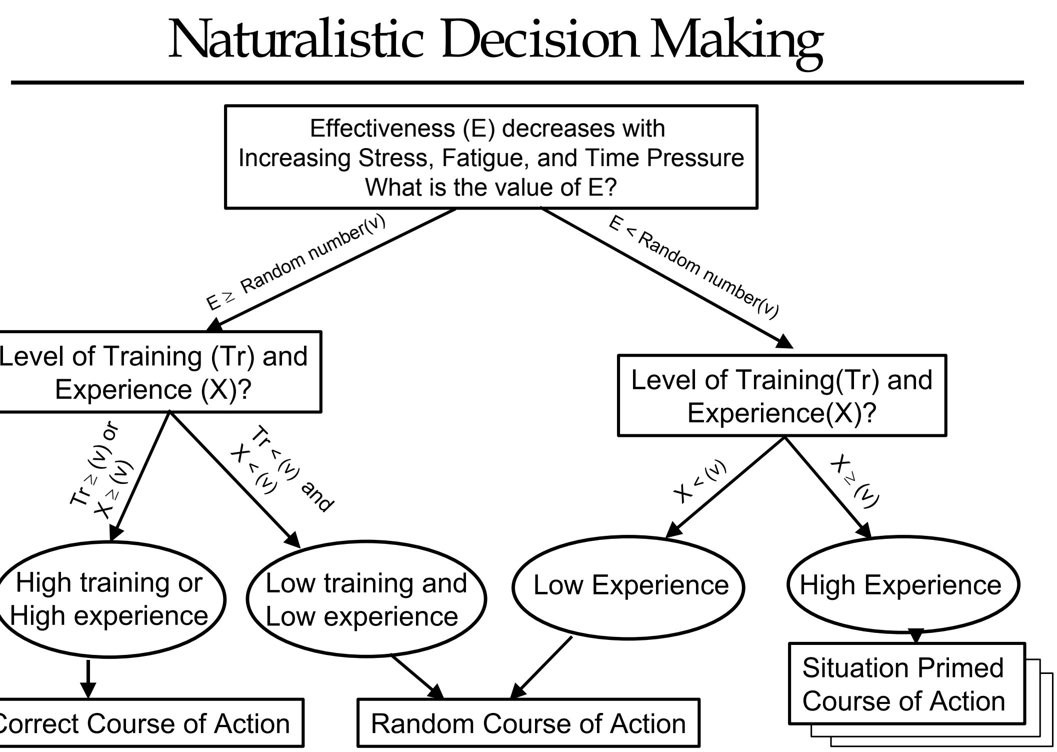


Figure 3. Naturalistic decision making under stress: decision tree showing effects of stress, fatigue, time pressure, training and experience.

looks for features of the situation that resemble prior experiences and recalls successful decisions from those prior occasions. Once the situation is "type identified", the commander can apply a "typical" course of action. Obviously, the likelihood of engaging in situation primed decision making will strongly depend on the level of prior experience required to build this catalog of typical courses of action. Again, the branching process is stochastic and varies continuously with the level of the continuous variable level of experience.

Based on the previous discussion of naturalistic decision-making, it is clear that training and experience play a major role in determining the effects of stressful events and time pressure on performance. A highly experienced commander can effectively deal with stressful events under time pressure by relying on the recognition of typical situations that immediately suggest corrective actions. Only unusual situations with unclear solutions require time consuming diagnosis and analysis to reach an effective course of action. This experience factor can greatly reduce the performance degrading effects of stressful events. This factor is represented by the experience factor (x) that varies from 0 to 1 (low to high experience).

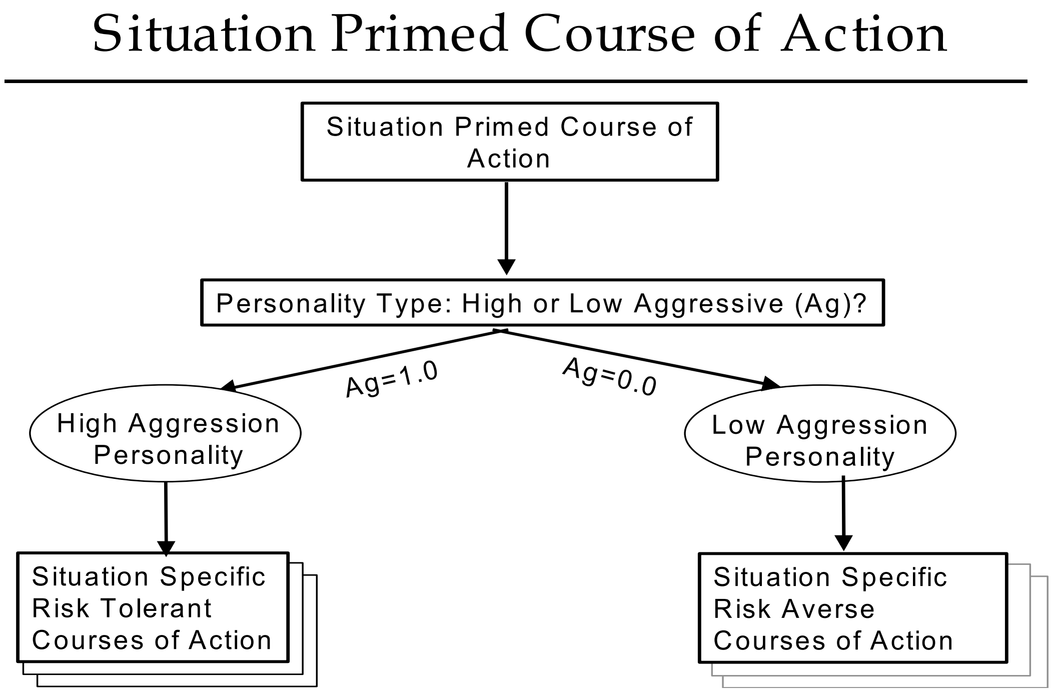


Figure 4. Decision tree showing effect of aggressive personality trait on situation primed decisions.

Experience is not computed, per se. We can only presume that some commanders have low experience and others have high experience. We represent these levels with various values of "x", ranging from 0 to 1 for low to high experience. Note that an experience level of "1" causes the left hand branch to always select the doctrinally correct course of action and the right hand branch to always select a situation primed course of action. Obviously, it is unlikely that anyone would actually achieve an experience level of "1" - everyone can learn and improve their skills - but a level of "1" is the doctrinally perfect commander. Hence, both of these branches are probabilistic, depending on the level of experience.

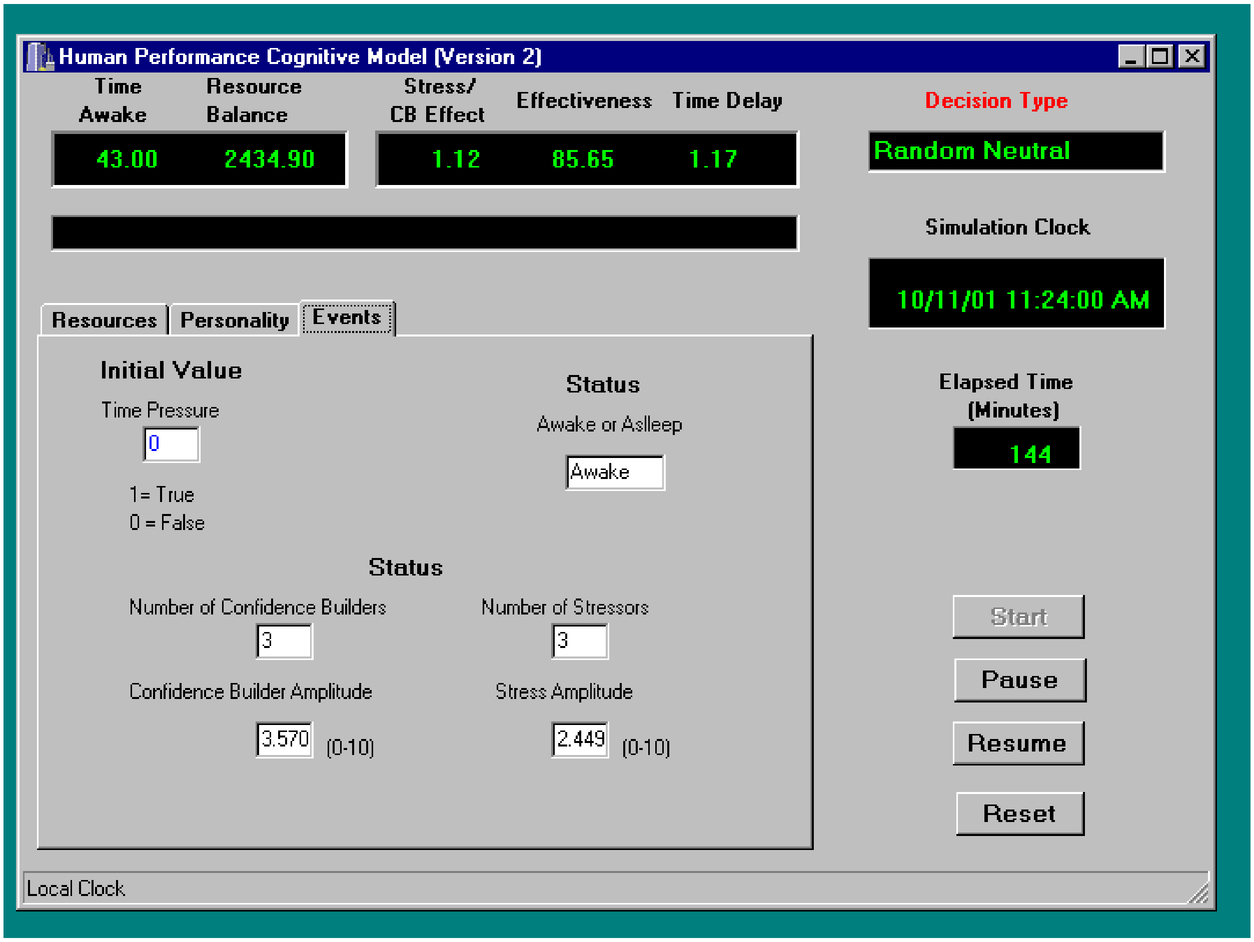
Training is also an important modulating factor. When time pressure, fatigue and stress are low, the decision model will attempt to arrive at a correct decision based on exhaustive analysis. Success will depend on the level of training and experience. If either training or experience is high, there is a high likelihood that a correct decision will result. As training and experience move toward zero, the likelihood that the decision will be an uninformed random selection from the available courses of action increases.

Personality

Once the model has determined that a situation-primed course of action should be selected, the decision model considers the personality of the command entity, see Figure 4. Research suggests that as stress and time pressure increase, personality traits become more dominant in the selection of a course of action (Sanbonmatsu & Fazio, 1990). In this model, a single dimension of personality is represented that varies from highly aggressive, risk tolerant (Ag=1.0) to non-aggressive, risk averse (Ag=0.0). The higher the level of the aggressive personality trait the higher the likelihood that the situation primed decision will be an aggressive decision. The decision library includes examples of situation primed-aggressive decisions, situation primed-neutral decisions, and situation primed-risk adverse decisions to represent high, medium, and low levels of the aggressive trait.

Human Performance Cognitive Model

All of the concepts described above have been incorporated into a software simulation called the Human Performance Cognitive Model (HPCM). The HPCM is a computer program that provides information on the effectiveness and type of decision anticipated from a decision maker under a variety of simulated conditions. Simulated conditions include rested or sleep deprived states, decision makers with various personality types, experience, and training; the effect of the time of day, and the effects of time pressure, stressful and/or confidence building events. The HPCM is a tool that was originally developed for the US Army and has been subsequently modified to include updates and added functionality for US Air Force applications.



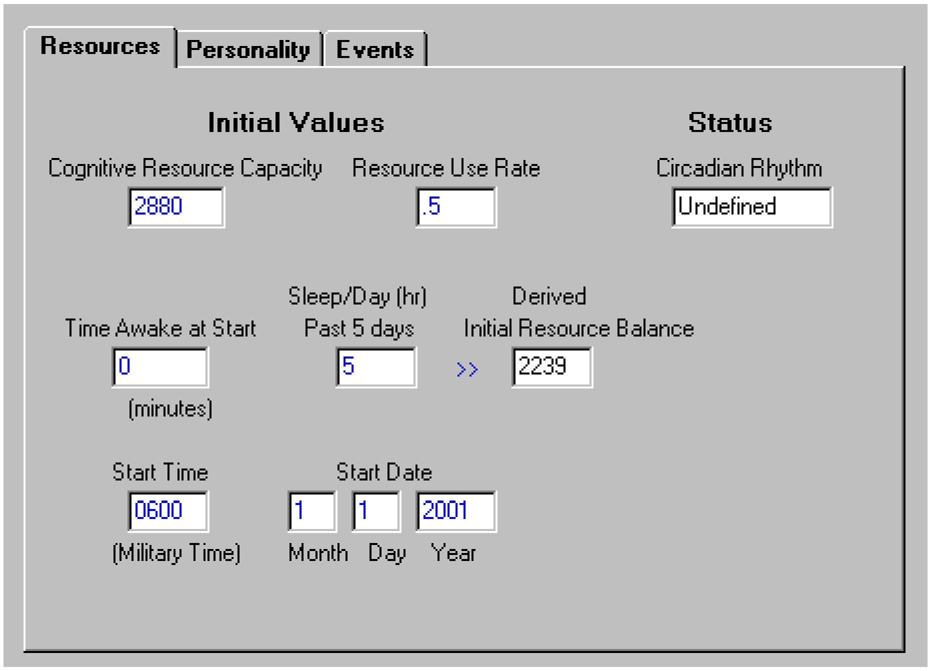
User Inputs

The HPCM user input/ status screen is for entry of initial values that tailor the simulation for a variety of scenarios under which the decision maker's performance can be simulated. Variables that are for user input are coded in blue.

Resources:

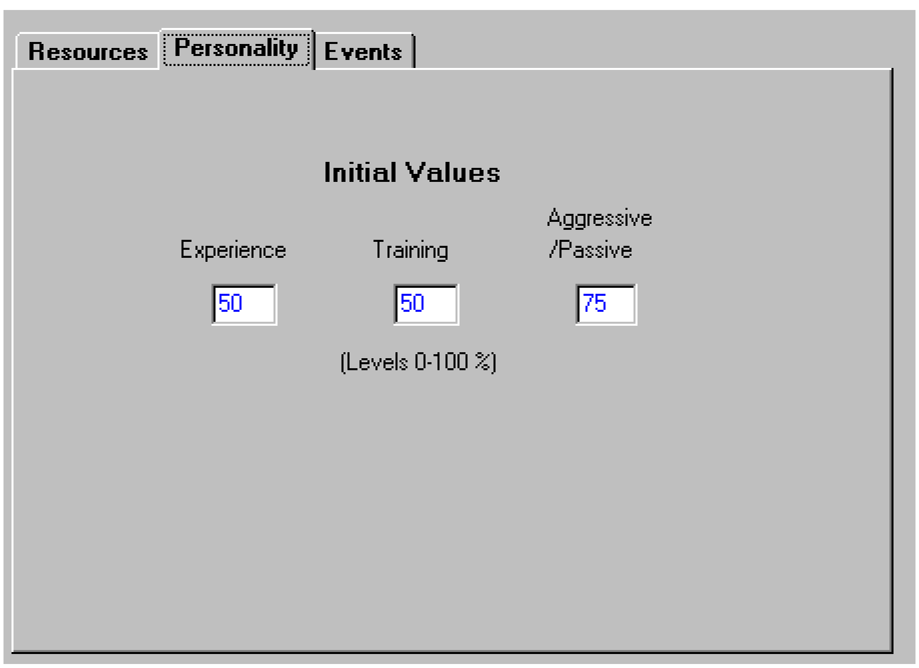
The HPCM user input screen allows the user to provide the cognitive resource capacity of the decision maker, which is a measure of the maximum beneficial effect of past sleep. This has a default value of 2880 units. The user can input the resource use rate, which determines the rate at which the cognitive resource balance is depleted. This has a default value of 0.5 units per minute. The user can specify the number of minutes that the decision maker has been awake since their last period of sleep. The default value is set at 0 minutes. This number is used to subtract units of resource balance at the specified resource use rate from the initial resource balance.

Resource Balance = Resource Balance - (Initial Time Awake) * (Resource Use Rate)

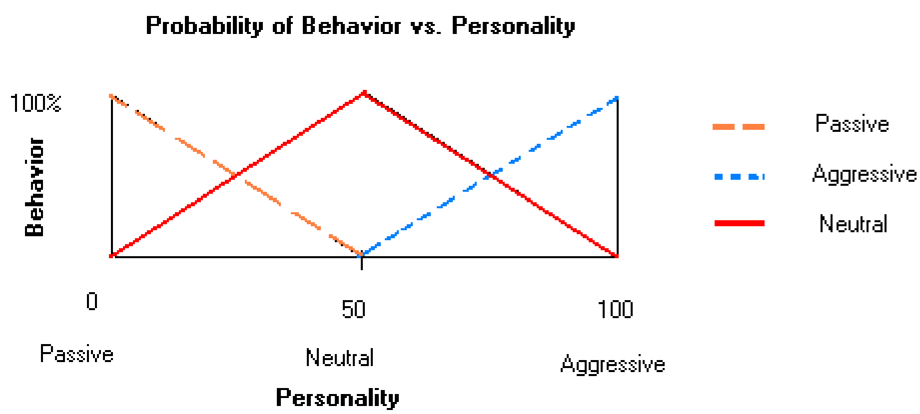


The user can provide the number of hours of sleep that the decision maker has had per day (on average) over the past 5 days. The default is set to 5 hours per day. This number is used to determine the initial resource. The user can provide the start time and date of the simulation. The start time is input in military time.

Personality:

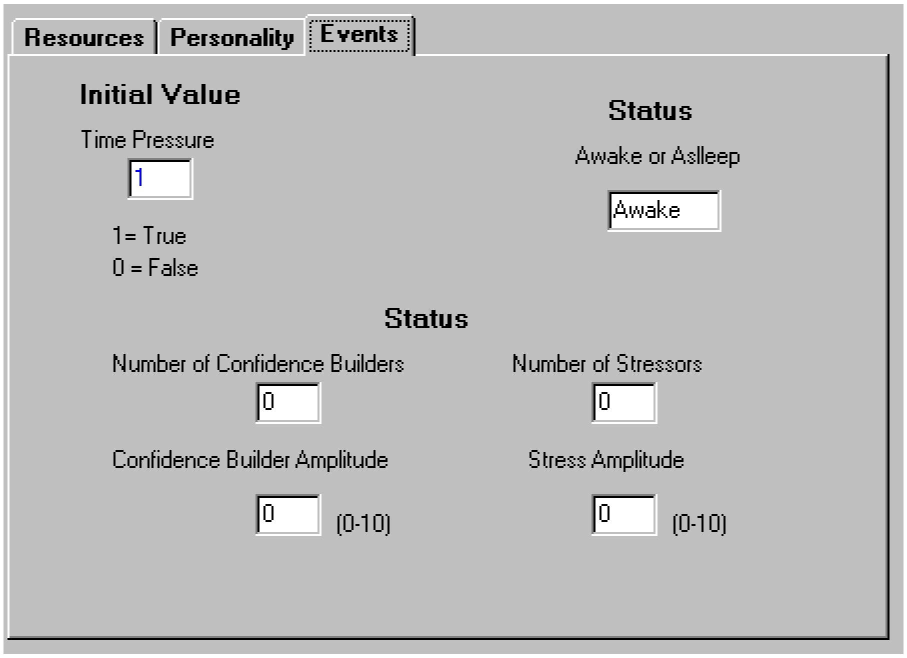


The user can provide information regarding the personality of the decision maker. The experience level of the decision maker is specified from between 0 and 100% of the maximum experience value. The training level of the decision maker is specified from between 0 and 100% of the maximum training value. The tendency toward aggressiveness or passiveness of the decision maker can be specified. A value of 100 corresponds to a decision maker who has a high propensity for making aggressive decisions, a value of 50 corresponds to a person who is neutral, and a value of 0 corresponds to a person who has a high propensity to make passive decisions. Values in between 0, 50, and 100 are allowed and correspond to various degrees of aggressiveness or passivity. The probability of the decision maker choosing an aggressive, neutral, or passive choice of action is determined by the degree of aggressiveness or passivity of decision maker. The probabilities of these options associated with different values of aggressive/passive personality are described below:



The default values are set at experience = 50, training = 50, aggressive/passive = 75.

Events:

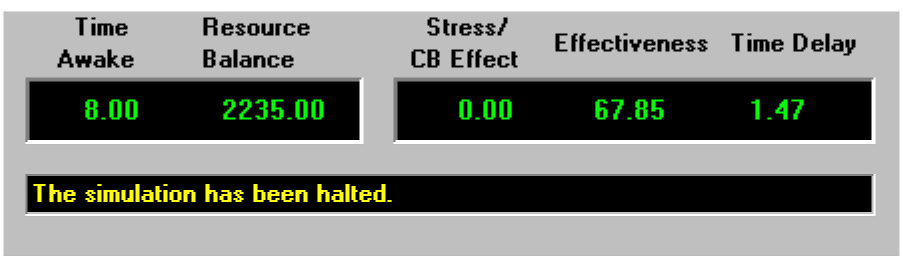


The user can supply whether the decision maker is under time pressure or not during the simulation. Time pressure doubles the negative impact of stressful events. The default value is set to 1, meaning there is time pressure.

Status Variables

The HPCM provides a variety of variables that are displayed during the simulation.

Upper Screen:



The number of minutes that the decision maker has been awake since the last period of sleep is displayed under the heading Time Awake. The resource balance provides a display of how sleep deprived the decision maker is at any given time during the simulation. This value will not go above the Cognitive Resource Capacity. The stress/confidence builder effect is a measure of the combined effect of stress, time pressure, and confidence building events given by:

S/CB Effect = (Confidence Builder Effect) – $(1/(1+e^{-\text{Skewed Experience}}))$(Time Pressure) *(Stress Effect)

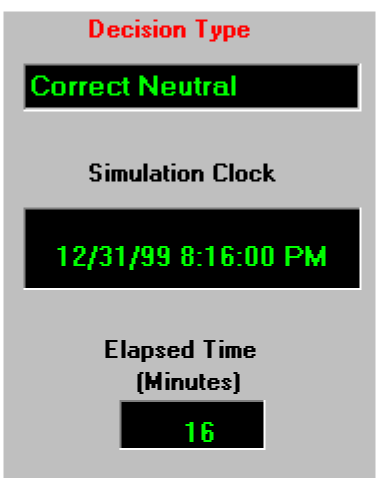
where Skewed Experience = 15 – 0.25*Experience. The multiplicative sigmoid function $(1/(1+e^{-x})$ of the Stress Effect causes the value of experience to mitigate the effects of time pressure and stress. The value of Experience is skewed to account for a learning curve that is necessary before stress mitigation occurs. Time pressure is 1 if there is no time pressure and time pressure is 2 if there is time pressure. Confidence building effects vary from 0 to 10 as do stress effects. The S/CB Effect value changes over time as events occur and as the effects of the events decay with time. The effectiveness and the time delay of the decision maker are displayed as the simulation runs. Effectiveness is calculated as:

Effectiveness = (100*(Resource Balance)/(Resource Capacity)) + (S/CB Effect) + Circadian Rhythm
(Note: The formula for circadian rhythm is given below in the resources section.)

The time delay is calculated as:

Time Delay = 1/[{(100*(Resource Balance)/(Resource Capacity)) + (S/CB Effect)* (1 - 0.9*Experience/100) + Circadian Rhythm}/100]

For the calculation of time delay, experience modulates the stress effect between 100% (low experience) to 10% of the stress effect (high experience). The Message Box provides notice to the user of simulation status (ex. halted), events (ex. decision maker goes to sleep or wakes up or a stress or confidence building event occurs), or error messages (ex. input file has incorrect values).

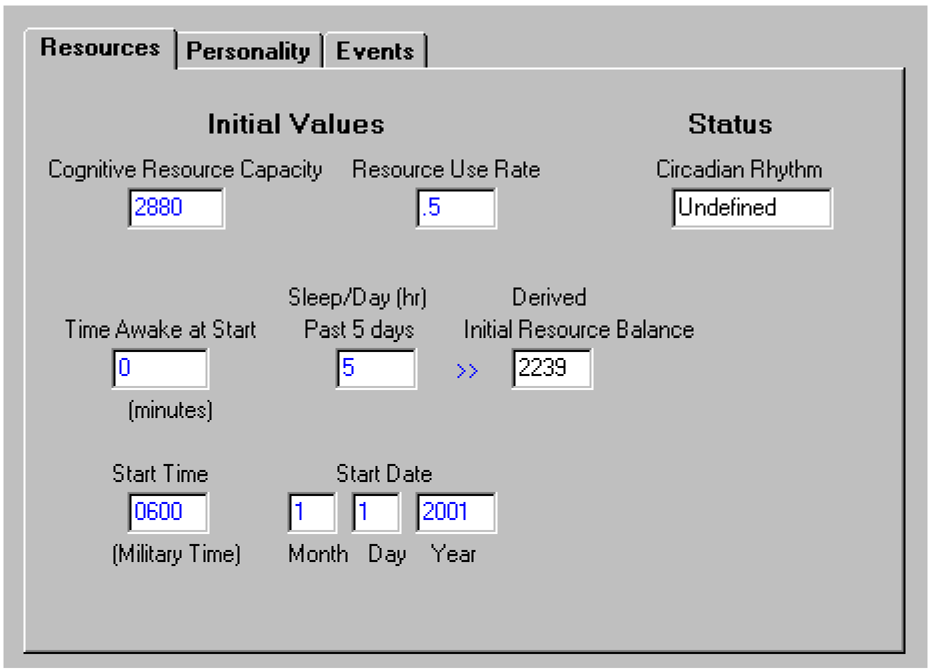


The current decision type is displayed. The possible types of decisions are correct aggressive, correct neutral, correct passive, random aggressive, random neutral, random passive, primed aggressive, primed neutral, and primed passive. A primed decision is considered to be an action taken largely based on prior experience or training without

lengthy consideration of the differences between the present situation and those of the past. The decision status is asleep during sleep periods of the decision maker.
The decision types are based on probabilities of various decision types based on current effectiveness and personality (aggressive/passive nature, training, and experience) of the decision maker.

The Simulation Clock provides the current time during the simulation. It is displayed using time in AM or PM and with Month/Day/Last Two Digits of Year. The Elapsed Time display presents the number of minutes the simulation has been running.

Resources:



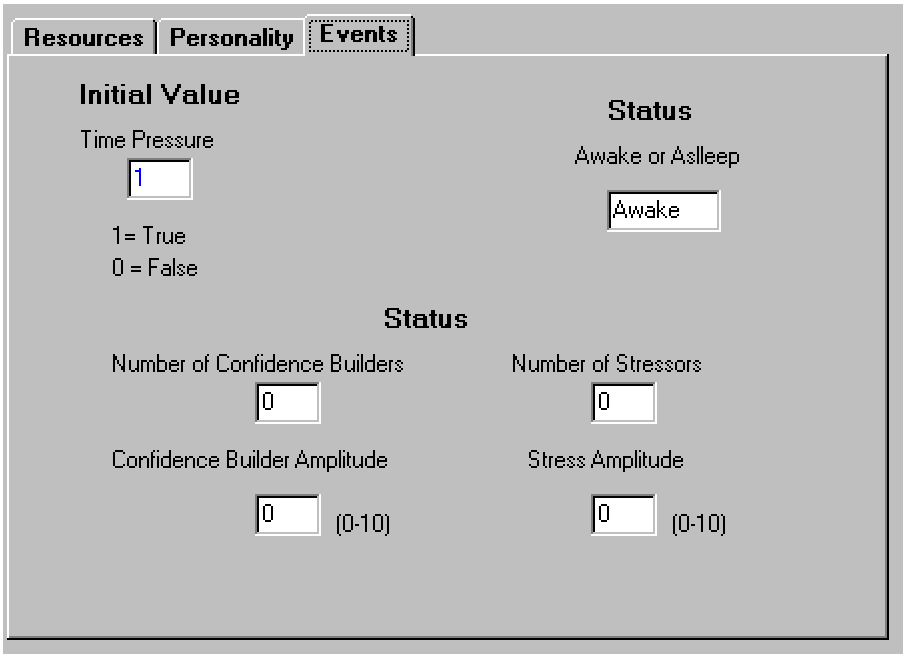
Circadian rhythm is displayed during the simulation. A high negative value corresponds to a greater propensity for sleep at that time and reduces the probability of a correct decision but the decision maker. The Circadian rhythm is calculated as:

$$\text{Circadian Rhythm} = 10 * (\cos(\text{Cycle})) + 5 * (\cos(\text{Cycle2}))$$

where $\text{Cycle} = ((\text{Time of Day}) - 18.0)/24)*2\pi$ and
$\text{Cycle2} = ((\text{Time of Day}) - 18.0 - 3)/12*2\pi$.

The Time of Day is calculated based on user input of start time plus the elapsed time.

Events:



The sleep or wake status of the decision maker is displayed. The decision maker begins the simulation awake but can go to sleep and wake up during the simulation based on the desired scenario that can be input from an external file. During the time at which the decision maker is awake the Resource Balance is decreased by:

Resource Balance = Resource Balance - (Initial Time Awake) * (Resource Use Rate) .

During the time at which the decision maker is asleep the Resource Balance is increased by:
Resource Balance = Resource Balance + Sleep Intensity

The Sleep Intensity is calculated by:

Sleep Intensity = Sleep Propensity + Sleep Debt,

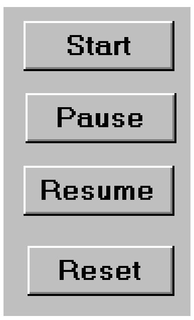
where Sleep Debt = 0.0026243*(Resource Capacity – Resource Balance)
and Sleep Propensity = 0 - (0.55*Circadian Rhythm).

The value of Sleep Intensity is maximally allowed to go to 4.4. The number and amplitude of both stressful and confidence building events are displayed. The number of stress events is the cumulative number of stressful events that have occurred during the simulation. Likewise, the number of confidence builders is the cumulative number of confidence building events that have occurred during the simulation. The amplitude of stressful or confidence building events decays using a double exponential associated with short and long term memory of the events. The decays for confidence building events are calculated by:

LongTermCB = LongTermCB * (exp((0 – TimeChange)/ 532.4))+ cb/2
ShortTermCB = ShortTermCB * (exp((0 - TimeChange)/ 4.311))+ cb/2.

An input Confidence Building Event is divided evenly between the long-term and short-term memory. Thus, a Confidence Building Event with an amplitude of 4 would add 2 to each long term and short term memories. The TimeChange is a minute. The addition and decay for the stress events are calculated similarly.

User Controls



The HPCM provides four buttons for controlling the simulation. The controls are a Start button, Pause button, Resume button, and Reset button. The Start button initiates the simulation that will continue until stopped. The values of input parameters can be set prior to initiation of the simulation. The Pause button halts the simulation after which the simulation can be continued by clicking the Resume button. The Reset button stops the simulation and resets are all user inputs to their default values.

Event Inputs

The simulation program includes the ability to have specified events occur during specified times during the simulation. The events that can be specified include going to sleep, waking up, confidence building events, and stress events. These events are input to the simulation from an external file that is always called "Scenario.txt" and is always read from the same folder that contains the executable file. The inputs are encoded by a series of three integer values for each event. The first number is the number of minutes into the simulation that the event occurs. The second number is the event type. The value of 0 corresponds to a stressful event, 1 corresponds to a confidence building event, 2 corresponds to the decision maker going to sleep, and 3 corresponds to the decision maker waking up. The third number is the amplitude value (from 0 to 10) for a stress event or confidence building event (10 is high and 1 is low). The amplitude value is irrelevant for the events of waking up or going to sleep. Thus, the series 80 2 0 would mean that the decision maker will go to sleep 80 minutes after the simulation starts. Any stressful or confidence building events that occur while the decision maker is asleep are ignored. The file including the events should have the inputs listed in time order. For example, the following list:

100	1	5
150	0	3
800	2	0
1100	3	0
1250	1	2

correctly includes increasing time from the start in the first column with the first event (confidence builder of amplitude 5) occurring 100 minutes after the start of the simulation and the next event (stressor with amplitude of 3) occurring at 150 minutes after the start of the simulation.

Output File

The HPCM provides an output file that stores the results of the simulation run for subsequent usage. The output file is an Excel spreadsheet that is always named "HPCMResults.xls" and is always written to same folder that contains the executable file. Sequential model runs will cause this file to be overwritten.

	A	B	C	D	E	F	G	H	I	J
1	Initial Values									
2	Aggressive=75 Experience=50 Training=50 TimePressure=1									
3	Start_Time=600 Start_Date (Month/Day/Year)=1/1/2001									
4	Initial_Time_Awake=0 Initial_Resource_Balance=2400									
5										
6	Elapsed_Time	Time_Awake	Resource_Balance	Stress	Confidence_Builder	Stress/CB_Effect	Effectiveness	Time_Delay	Decision_Type	
7	1	1	2399.5	0	0	0	73.296	1.36433	8	
8	2	2	2399	0	0	0	73.2828	1.36458	5	
9	3	3	2398.5	0	0	0	73.3112	1.36405	4	
10	4	4	2398	0	0	0	73.3339	1.36363	2	
11	5	5	2397.5	0	0	0	73.3665	1.36302	1	
12	6	6	2397	2	0	0	73.3892	1.3626	1	
13	7	7	2396.5	1.7911	0	-4	69.4118	1.44068	2	
14	8	8	2396	1.62506	0	-3.5822	69.8623	1.43139	1	
15	9	9	2395.5	1.49301	0	-3.25012	70.217	1.42416	5	
16	10	10	2395	1.38791	0	-2.98602	70.5137	1.41816	1	
17	11	11	2394.5	1.30419	3	-2.77583	70.7465	1.4135	5	

The file includes the initial values for personality including: degree of aggressiveness, experience, and training. The initial values for whether there is time pressure, the start time in military time, and the start date (Month/Day/Year) are included. The initial time awake and the initial resource balance are also included. Subsequently, the file includes updates regarding the variables Elapsed Time, Time Awake, Resource Balance, Stress, Confidence Builder, Stress/confidence Builder Effect, Effectiveness, Time Delay, and Decision Type after each minute of the simulation. Elapsed Time is the number of minutes the simulation has been running. The Time Awake variable supplies information regarding the number of minutes that the decision maker has been awake without sleep. The resource balance keeps a measure of how sleep deprived the decision maker is at any given time during the simulation. Stress and Confidence Builder values correspond to the amplitude of the effect on the decision maker of any past events. The Stress/confidence Builder Effect is a measure of the combined effect of stress, time pressure, and confidence building events. Effectiveness is a percentage of the maximum effectiveness. Time delay is determined as 1/(Effectiveness/100). The decision types are encoded as the following: 0=asleep, 1=correct aggressive, 2=correct neutral, 3=correct passive, 4=random aggressive, 5=random neutral, 6=random passive, 7=primed aggressive, 8=primed neutral, and 9=primed passive. The decision types are based on probabilities of various decision types based on current effectiveness and personality variables (Aggressive/passive Personality, Training, and Experience).

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