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Sensitivity analysis of a cognitive architecture for the cultural geography model

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THESIS

SENSTIVITY ANALYSIS OF A COGNITIVE ARCHITECTURE FOR THE CULTURAL GEOGRAPHY MODEL

by

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December 2011

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This thesis conducted a thorough sensitivity analysis on the Cognitive Architecture module in the CG model, using experimental design and statistical data analysis techniques, to obtain an assessment of its impact on the civilian population responses, in terms of their stances on key IW issues of concern. Significant single and pairwise interaction factors in the Cognitive Architecture that contribute to the civilians' issue stances were identified. The analysis revealed demographic stereotypes of population groups notably affected by the Cognitive Architecture.

The results will help to streamline data collection efforts, and provide a useful methodology and dataset, to support verification and validation of the Cognitive Architecture. Future research will adapt the Cognitive Architecture across different scenarios, as it evolves with more features.

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SENSITIVITY ANALYSIS OF A COGNITIVE ARCHITECTURE FOR THE CULTURAL GEOGRAPHY MODEL

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LIST OF ACRONYMS AND ABBREVIATIONS

ANA	Afghan National Army
ANP	Afghan National Police
BBN	Bayesian Belief Networks
BVI	Beliefs, Values and Interests
CA	Civil Affairs
CART	Classification and Regression Trees
CF	Coalition Forces
CG	Cultural Geography
COA	Course of Action
COIN	Counterinsurgency
DoD	Department of Defense
DOE	Design of Experiment
IED	Improvised Explosive Devices
IID	Independent and Identically Distributed
IW	Irregular Warfare
LH	Latin Hypercube
LOE	Lines of Effort
LTS	Long-Term Store
M&S	Modeling and Simulation
MIP	Mixed Integer Programming
MORS	Military Operations Research Society
MSCO	Modeling and Simulation Coordination Office
NONBMD	Nearly Orthogonal Nearly Balanced Mixed Design
NOLH	Nearly Orthogonal Latin Hypercube
OSD	Office of the Secretary of Defense
RPD	Recognition-primed Decision Making
SME	Subject Matter Expert
STS	Short-Term Store
TPB	Theory of Planned Behavior
TRAC	Training and Doctrine Command Analysis Center Monterey

TRAC-MTRY	Training and Doctrine Command Analysis Center Monterey
TWG	Tactical Wargame
V&V	Verification and Validation

EXECUTIVE SUMMARY

The complexities of Irregular Warfare (IW) and Counterinsurgency Operations (COIN) have vexed many incumbent governments and coalition forces, with extravagant resources expended in terms of manpower, time and costs, and with military victories achieved within a relatively shorter space of time, yet the outcomes often did not yield the desired level of support from the civilian populace in the areas of interest. The root of the problem deals with understanding not just uniformed adversaries and insurgent forces but also the role of other actors such as non-government organizations and the needs of the civilian populace, which typically consist of peoples with many different social and cultural backgrounds.

Acquiring knowledge of the civilian population is a laborious undertaking that incurs substantial investments in manpower and costs over a long period of time, to research, extract and compile the information into a suitable form for use by IW commanders and decision makers. Modeling offers a potential means of storing this invaluable information in a manner that allows IW operational planners to gain insights on the effects of IW plans via simulation experiments and analysis of the outcomes, without the burden of starting a data collection and analysis effort from scratch. However, most Department of Defense (DoD) modeling and simulation (M&S) solutions are built on the foundations of kinetic military engagements, and are lacking in the capability to adequately model social human behaviors reacting to non-kinetic actions (e.g., setting up and conducting checkpoint search, providing humanitarian aid).

The Cultural Geography model is one of efforts by the Training and Doctrine Command Analysis Center - Monterey (TRAC-MTRY) towards providing a suitable M&S tool for evaluating the outcomes of IW tactical operations on the behavioral responses of civilian populations. The representation of human cognition is a critical aspect of determining the civilian responses, so a prototype Cognitive Architecture module was implemented in the CG model to improve the realism and fidelity of the CG

model for eliciting useful insights on outcomes of IW operations that more closely account for the IW environment in terms of the various actors and civilian population groups.

The Cognitive Architecture is a recent implementation that has not yet been subject to adequate verification or validation. This thesis conducted a thorough sensitivity analysis study on the Cognitive Architecture, to examine its impact on the behavioral responses of civilians affected by IW tactical operations in the form of stances toward keys issues of concern for the operations. Results of the study will drive research efforts on focused areas of improvement in the Cognitive Architecture that yield richer insights. They will channel data collection efforts on the key factors of interest identified from the analysis. Concurrently, they also serve as useful dataset for TRAC-MTRY's verification and validation (V&V) process on the Cognitive Architecture.

The Sensitive Analysis study involved the use of a Nearly Orthogonal Nearly Balanced Mixed Design (NONBMD) to explore a list of nine critical discrete and continuous factors in the Cognitive Architecture, over appropriate level or value ranges within 35 design points, to assess their influence on civilian behavioral stances with respective to six issues of concern in counterinsurgency efforts. The design factors are Working Memory Capacity, Selective Attention Threshold, Expected Communcation, Expected Communcation Time Units, Temperature, Initial Temperature, Lambda (Discount Factor), Experience Threshold and Link Update Interval, while the issues are Civil Control, Civil Security, Economic and Infrastructure Development, Governance, Restoration of Essential Services, and Support for Host Nation Security Forces. The representative CG scenario for the Sensitivity Analysis, involving 62 civilian stereotypes and spanning over 400 days, was derived and modified from both a previous study on the Afghan population in Helmand province, and an IW Tactical Wargame in 2010. For the analysis, 30 replications of simulation runs were conducted for each design point.

After post-processing of the data to associate design factors with the issue stances generated from the experimental runs to facilitate analysis, graphical plots were generated and statistical techniques based on Multiple Linear Regression and Classification and Regression Trees (CART) techniques were applied to derive the sensitivity results.

Results indicated that the overall sensitivity of the Cognitive Architecture as a whole has a low magnitude order of influence of less than one percent, and two outliers design points are found to have the lowest Temperature factors, which represents the volatility of selecting among a list of motivation drivers for influencing decisions made by civilians.

Temperature is identified as the most important significant factor influencing all of the issues, followed by Working Memory Capacity, which controls the amount of events perceived at a time for the formation of situational pictures towards decision making and action selection. Experience Threshold is the third major factor. It defines the number of instances each type of action has to be performed before a civilian switches from Exploratory Learning mode to Recognition-Primed Decision Making (RPD) mode. Action choices tend be more volatile or randomized in Exploratory Learning mode, before selections stabilize to those which the yield highest utility in RPD mode.

Four quadratic factors are observed, with diminishing influences on the issue stances: Temperature, Link Weight Update Interval, Selective Attention Threshold and Experience Threshold. The Link Weight Update Interval represents how often the social network of a civilian agent is updated, which affects the number of agents he can communicate to on the network for affecting issue stances. Selective Attention Threshold refers to the maximum age of messages to be accepted for influencing issue stances and decision making.

A total of 14 pairwise interactions were uncovered and key ones which affect three issues each are: Temperature and Link Weight Update Interval, Working Memory Capacity and Experience Threshold, and Selective Attention Threshold and Temperature. Another notable two-factor interaction affecting two of the issues is the Working Memory Capacity and Temperature. The interactions mentioned are brought about by a combination of possible events that originate from one factor and affecting those from the other factor, leading to a wider variation in the changes to issue stances, as opposed to a single factor acting alone.

Analysis of cognitive architecture effects from the viewpoint of individual civilian stereotypes (in terms of demographic characteristics for age, family status, tribe, rural /urban disposition and political affiliation), was performed across both time and design points. Across scenario time, the trends indicate that in almost all of the issues, many of stereotypes are either positively or negatively influenced. In the remaining issue, stereotypes having mixed effects, with some being positively affected and others negatively affected. The top five and lowest five variances across both time and design points were used a measure to identify notable stereotypes whose issue stances are greatly influenced and those that are hardly affected. Many of these stereotypes with similar extremes in variance (either high or low) share common demographic characteristics, mainly in terms of age, family status, and tribes. Comparing the gaps between the variance extremes for those across time and those across design points, it was the timeline that led to larger variation in effects on issue stances of civilians than design points. There were also a number of stereotypes who are not affected at all by the Cognitive Architecture throughout the simulation, whether across time or design points.

Based on the study outcomes, TRAC-MTRY will continue to improve the Cognitive Architecture implementation and conduct subsequent V&V on the module, towards evolving the CG mode into a more representative IW decision support tool that enables IW operational planners to draw useful insights on the impact of their plans and make better–informed decisions to increase the success of IW operations.

A number of potential ideas, gaps and insights on high yield research focus areas were identified in the course of working on the Sensitivity Analysis study. They include examining the Cognitive Architecture over different scenario contexts to improve its usability over different geographical regions and situational environments on populations of interests, analyzing the Cognitive Architecture in more detail at an event-specific level instead of a whole-of-scenario level, performing sensitivity analysis with enhancements in the Cognitive Architecture such as adding the role of self-esteem, emotion, and mental simulation, incorporating an element of trust for determining communication among civilians and finally adding a mechanism that takes into account both past and current events in affecting issues stance.

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I. INTRODUCTION

A. BACKGROUND

The U.S. military involvement in Iraq and Afghanistan has spanned nearly a decade and exceeded USD 1.2 trillion (Belasco, 2011), with the bulk of it expended on counterinsurgencies (COIN) and irregular warfare (IW) efforts, in “a violent struggle among state and non-state actors for legitimacy and influence over the relevant populations.” With U.S. Department of Defense’s (DoD) stance on IW being strategically as important as traditional combat, it is crucial to invest resources to build up the U.S. capability to effectively conduct IW operations (DoD, 2008).

Towards this aim, the U.S. Training and Doctrine Command Analysis Center in Monterey (TRAC-MTRY) has developed the Cultural Geography (CG) model to evaluate the impact of tactical operational outcomes on the civilian population in an IW environment. Because the success of IW hinges on understanding the social and cultural dynamics of human behaviors and their perceptions towards external influences, it is essential to develop a realistic behavior representation and decision making framework to reflect the effectiveness of outcomes for IW operations. Previous versions of the CG model (version 0.8.4 and below) utilize a set of Bayesian conditional probabilities and scripted actions for representing behaviors. However, this data-driven implementation does not include many cognitive processes involved in human thinking and decision making, such as attention, memory, motivation, and learning. A prototype Cognitive Architecture module was added to the CG model to close this gap. As a new implementation, sensitivity studies would need to be conducted to assess the impact of the Cognitive Architecture on influencing population behaviors in response to tactical IW operations, so as to improve the quality of insights attainable from the CG model to better inform military commanders and decision makers on considerations in IW operations planning.

B. RESEARCH QUESTIONS

This study is targeted at understanding the impact and sensitivity of the new Cognitive Architecture in influencing the population stances on issues of interests, based on a tactical IW wargame scenario in a province of Afghanistan. The elements of the Cognitive Architecture to be studied include selective attention, working memory, and motivation as well as exploratory and recognition-primed decision making (RPD). The relevant issues identified for the study are Civil Security, Civil Control, Governance, Economic and Infrastructure Development, Restoration of Essential Services, and Support for Host Nation Forces, based on TRAC IW Tactical Wargame requirements. Specifically, through experimental design, the author has addressed the following questions in the study:

- How sensitive is the Cognitive Architecture as a whole in affecting the population stances on each of the issues?
- Which factors or interactions among factors in the Cognitive Architecture are more significant in determining the outcome of the issue stances for the population?
- Which are the interesting stereotypes (e.g., by age, tribe, family status) among the population that are more notably affected by the Cognitive Architecture factors, and which of them are hardly affected, in terms of their issue stances?

C. BENEFITS OF THE STUDY

This study forms part of a series of efforts to support TRAC-MTRY in the verification and validation (V&V) of the Cognitive Architecture module in the CG model. The results will offer more supporting data for V&V, at a multi-city provincial population level. Identifying the significant factors in the Cognitive Architecture for the CG model will also facilitate the CG data development process by reducing the dependence on extensive surveys, interviews and literature research currently required to gather social and cultural data on the relevant IW populations. Consequently, with sufficient verification, validation and accreditation of the CG model and the Cognitive Architecture, an understanding of the data obtained from the study can provide valuable insights to guide commanders and decision makers in adjusting their tactical/operational IW plans based on the cognitive nature of various civilian population stereotypes to meet the desired goals of the U.S. government, coalition forces and/or host nation. An example could be to target IW efforts at influencing a majority tribe whose motivations for communication among tribal members can help propagate perceptions of beneficial actions by the U.S. or coalition forces.

D. METHODOLOGY

Experimental design techniques will be employed across a number of simulation replications to explore an indicative range of values for the Cognitive Architecture factors, including any potential interactions among them in affecting the population stances on each of the issues of interest.

To reduce the timeline required for the study, the scenario was based on existing data from the TRAC IW Tactical Wargame, executed in 2010, with some modifications to account for both a smaller subset of entities representing the population stereotypes, and a list of pre-defined sequence of actions normally driven by human players taking on the roles of coalition, host nation and insurgent forces. The cultural geographical context drawn from available literature or narratives and translated into a suitable form for the model, is the Helmand Province in Afghanistan, comprising 62 distinct stereotypes (grouped by family status, tribe, urban-rural disposition, political affiliation and age) representing a population of approximately 600,000 across five Helmand districts.

Regression analysis was conducted on the simulation outputs to determine the sensitivity and significance of the Cognitive Architecture design factors in terms of population stances on issues of concern. Population stereotypes of interest (e.g., pro-insurgent groups and coalition force supporters) were singled out for deeper analysis via separate sets of regression with the design factors.

E. STRUCTURE OF DOCUMENT

Chapter II provides an overview of the social dimension in IW modeling, and a discussion of some cognitive mechanisms from social science theories that can be adapted for IW models. The Cultural Geography Model is described in Chapter III, along with an explanation of the Cognitive Architecture and how it fits into the CG model. The scenario and data selected for the CG model are also included here. Chapter IV delves into the experimentation methodology for the Cognitive Architecture in the CG model, from sensitivity measures and design factors to the application of experimental design techniques in simulation runs. Analysis of the simulation results and key findings for the sensitivity analysis in terms of the Cognitive Architecture as a whole, the significance of individual factors, and the effects on specific population stereotypes, are covered in Chapter V. Finally, Chapter VI concludes with a summary of the experimentation study, and potential future research directions leading from this effort. A list of research references accompanies the last chapter of the document.

II. LITERATURE REVIEW

A. IMPORTANCE OF THE SOCIAL DIMENSION IN IRREGULAR WARFARE

Taking reference from brilliant military strategist Sun Tzu's famous stratagem on "knowing your enemy" before going into battle, it would be wise to consider that the "enemy" in IW is fundamentally different from conventional warfare, where the focus now is on influencing the relevant populations, rather than a kinetic battle against uniformed adversaries. Despite the U.S. having won military victories in Iraq and Afghanistan to oust the incumbent regimes, opinion polls vary on the progress made in "winning the peace." Based on 2007 surveys of the local population in both countries, 70% of Iraqis polled believed the surge of U.S. forces in their homeland will have no effect or will worsen the security situation (BBC News, 2007), while in Afghanistan, 71% of the respondents support the presence of U.S. forces (British Broadcasting Corporation, 2009). This merits a deeper understanding of the social and cultural backgrounds of the population, host government and insurgent groups. One way to achieve this is to collect data on the social and cultural aspects of the various groups and organizations, and frame it into a representative model that can be employed to study the possible effects and implications of IW operations on the population.

B. REPRESENTING THE SOCIAL DIMENSION IN IRREGULAR WARFARE

Gathering the desired information on the local population requires massive investments of resources over a long gestation period, to perform research, conduct interviews, get inputs from Subject Matter Experts (SME), filter out the relevant information and compile it in an accessible form. It would be useful if such information could be captured in a knowledge database to help military commanders plan for effective IW operations. Modeling and Simulation (M&S), as proposed by U.S. DoD's Directive in IW, have the potential to offer an effective means to evaluate tactical and operational IW plans with the social and cultural database compiled from SME and intelligence personnel (DoD, 2008). However, traditional M&S applications were developed for conventional warfare involving force-on-force or combat engagements, and ignored two critical elements of power in IW: host government and local population groups, both of which play a critical role in the battle against insurgents. Most traditional M&S do not represent civilians at all, much less represent civilian perceptions in response to military operations. The Office of the Secretary of Defense (OSD) conducted a proof of principal IW wargame from 2007 to 2009, linking several IW M&S prototypical components. However, this effort failed to produce analytical insights that could inform program decisions (Lukens, 2010), as its huge scope in the modeling of economic and political forces introduced too much error, and the systems dynamics model used was not a robust warfare modeling tool.

The U.S. Army is currently working on enhancing IW M&S, focusing more on gathering data on social science interactions with populations and insurgents groups, as well as information on cultural, ethnic, religious and government groups, to formulate processes for improving the utility of the simulations and models used by U.S. Army professionals (Army Modeling and Simulation Office, 2009). Both the U.S. Army and OSD sponsored a Military Operations Research Society (MORS) workshop on IW Analysis in Feb 2009, inviting special operators, analysts and problem-solvers to help define IW analysis problems, explore techniques to deal with them and recommend ways ahead (Carlucci, 2009). Presenters identified the lack of population-centric behaviors and adequate V&V techniques for existing IW methods, models and tools. Scientists in the Defense Department's Modeling and Simulation Coordination Office (MSCO) are also playing their part by switching from conventional warfare simulations on kinetic behaviors to improving IW techniques through studying and incorporating social and cultural behaviors in M&S, a critical national technology (Cragg, 2009). The development of the CG model is one of TRAC-MTRY's contributions in this area. The CG model is a government-owned open-source agent-based simulation tool for studying population behavioral responses in conflict environments to support the evaluation of tactical and operational IW plans (Alt, Jackson, Hudak, & Lieberman, 2009).

C. COGNITIVE MECHANISMS IN IRREGULAR WARFARE MODELING

Modeling of human behaviors involves an understanding of cognitive science, an interdisciplinary field employing research in psychology, linguistics, neuroscience, computer science, anthropology and philosophy to study how humans store, process and apply knowledge (Miller, 2003). A discussion of potential cognitive mechanisms that can be applied to agent-based simulations such as the CG Model for representing human behaviors influenced by IW operations are covered here.

1. Memory

Atkinson and Shiffrin (1968) categorize memory under three structural components: Sensory Register, Short-Term Store (STS) and Long-Term Store (LTS). The sensory register captures information when stimulus associated with the appropriate sensory dimensions is presented. It decays or disappears from storage within a period of 30 seconds. During this interval, the individual makes a selective scan to attempt to match the sensory input stored with information in the Long-Term Store (LTS), which may be encoded in a different form (for example, a visual image of a person wearing camouflage uniform and carrying a gun could be associated with the verbal term "soldier" in LTS). The resulting match is then transferred to the STS, in the encoding format of the LTS. The research also indicates possible transfer of information from the sensory register to the LTS. As for the STS, it functions like a fixed-size buffer with the decay of the items stored being dependent on the selective rehearsal or repeated recalls of items by the individual. Continual rehearsal allows items to be retained in the STS indefinitely, but this will limit the amount of information to be drawn from the LTS into the STS. When the STS is full, any match made from the LTS with the inputs in the sensory register will not be transferred to the STS. Miller (1956) specifies the limit as 7±2 chunks of items, where chunks are defined based on the relationship among the items (e.g., a string of numbers 09112001 may be difficult to remember, but treating them as three separate chunks: 09, 11, and 2001, creates a recognizable mnemonic for easier recall). While these chunks of information are still available in STS during rehearsal, control processes determined by the individual enables the information to be transferred into LTS. These processes could be "encoding"—associating the chunks with related information in the LTS, or "memorizing"—having more rehearsals on the same chunks. There is, however, wide variance in the amount of information transferred from STS to LTS, and this is due to the encoding strategy adopted (which could be association based on verbal constructs or association with visual images) as well as information search characteristics of individuals (examples are temporal-based or associated-based). Two factors play a part in the LTS item shelf life and retrieval: interference and search control. Interference is a structural mechanism whereby new information can overwrite existing information, whereas search control is tied to an individual's attempt to match the desired piece of information in LTS, which decreases in efficacy as the number of related items in the LTS increases.

2. Attention

Attention involves the selection of relevant information for an individual to process, due to brain's limited capacity to manage complex streams of multiple stimuli. In some cases, the selection of information is voluntary, and is tied to individual beliefs, while in others it is driven by attention-seeking items (e.g., a loud noise or bright colors) in the perceptual field (Mole, 2009). Sensory information arrives in parallel across multiple dimensions such as shapes, colors, motions, smells and sounds. Each of these dimensions contains a number of possible representative features (e.g., "square," "circle," and "rectangle" for shapes, "red," "blue," and "green" for colors). However, the human mind can only relate to one object for a given location, at each time instance. By binding the features across the various dimensions for an object, in a particular location and time, the object can be identified. The window associated with a given place and time can correspond to a group of objects as well, if meaning can be attributed to the group via the combination of the features. Movement of this window constitutes the scope of attention given to perceptual inputs. This is known as the Feature Integration Theory (Treisman & Gelade, 1980). Another theory proposed by Desimone and Duncan (1995) involves bias-competition for achieving selectivity, where a struggle exists among the relevant dimensions of perceptual inputs, to determine a winner based on the highest value attributed across the dimensions. These values are driven by top-down attention-specific signals, which direct the limited channel capacity for human information processing to specific locations or objects of interest. In contrast, the Reflexive Attention theory refers to a bottom-up mechanism where attention is directed in a rapid and involuntary fashion, by an object or location that has undergone a salient change. The downside is that such a focus dissipates more quickly compared to voluntary attention (Gazzaniga, 2004).

3. Perception

Pomerantz (2003) defines perception as a complex sequence of processes for accepting, organizing and interpreting information obtained via our senses. It allows us to associate meanings and perform recognition of objects or events based on our existing knowledge and beliefs. According to (Siegel 2010), the interpretation can lead to perceptions that differ from reality, as we could be misled by our experiences (for example, a white wall bathed in neon yellow light could appear yellow, plain water can taste mildly sweet to someone who had just eaten something bitter). These experiential errors could stem from our sensory limitations or individual judgment. For the case of the latter, it could be that the chunk information presented to our senses does not represent a total reality, so perceptions cannot be validated (e.g., seeing John and Sally, who are both married to different partners, holding hands at a restaurant, may lead to one's perception of them having a tryst), until a full understanding of the circumstances has been made available to us (Travis, 2004). Experiences from perception are also identified with the formation of beliefs over time (Pitcher, 1971). The types of contents derived from these perceptual experiences are in turn determined by attitudes or "intentional modes," which is the mind's direction upon its objects to be perceived (Crane, 2003). A few theories exist on the structures for the various types of contents. They can be Russellian—in the form of an object with properties, Fregean—objects with different modes of presentation, Indexical—associating spatial objects with a dimension relative to the subject (e.g., in location, direction or time), or a combination of the above forms (Siegel, 2010).

4. Learning and Development

Ormrod (1995) states that learning is a long-term change in mental representation or associations as a result of experiences. This change could be in the form of not just skills and knowledge, but also values, attitudes and emotional reactions. Learning theories are classified into three general frameworks: Behaviorism, Cognitivism and Constructivism. In behaviorism, the focus is on learning via association with external observations. One form is classical conditioning, where a neutral stimulus can be tied to a reflex response normally associated with another stimulus (Pavlov, 1927). As an example, dogs which salivate at the sight of food can respond in the same manner to a ringing bell, if a bell is rung whenever food is served to the dogs. Another form is operant conditioning, which emphasizes reinforcement of behaviors through rewards or punishments (Skinner, 1953). Cognitivism goes beyond the acquisition of behaviors and explains learning by identifiable mental functions, which manipulate mental states via a set of rules into skills and knowledge, such as the case of acquiring a language (Bode, 1929). Situated Cognition argues that such learning is contextually dependent on the social, cultural and physical environments, instead of being independent mental processes (Greeno & More, 1993). Finally, in Constructivism, learning is an active process where new knowledge is successively built upon a growing repository of past experiences (Piaget, 1973).

5. Metacognition and Motivation

Metacognition is "knowing about knowing," or, more specifically, an appreciation of what one already knows, together with a correct apprehension of the learning task and what knowledge and skills it requires, combined with the agility to make correct inferences about how to apply one's strategic knowledge to a particular situation, and to do so efficiently and reliably (Taylor, 1999). Four aspects of metacognition, tied to a cognitive enterprise or undertaking, are described by Flavell (1999): (1) Metacognitive knowledge—understanding or beliefs about what, how, when and why various factors (persons, tasks or strategies) affect the course and evaluation of the enterprise, (2) Metacognitive experiences—conscious thoughts, feelings and judgements on the enterprise at hand, (3) Goals—objectives of the enterprise, and (4) Actions (or Strategies)—cognitions or behaviors employed to achieve it. Efklides (2006) goes further to define: (5) Metacognitive skills—application of strategies as cognitive process control functions involved in the enterprise, such as planning, resource allocation and monitoring of task requirements. Motivation is linked to metacognition, since an individual may perform a mental causal search to explain the results of a cognitive enterprise (such as failing an exam), and if the outcome is attributed to lack of ability, this may affect the individual's ability to summon his or her full set of mental intellectual or emotional faculties for future undertaking of a similar cognitive nature, as opposed to putting the blame on an external factor outside of the individual's control (Pierce, 2003).

6. Decision Making

Decision making deals with the process of choosing a preferred option from among a set of alternatives based on some given criteria or strategies. These strategies can be (1) Intuitive—by tendency or familiarity, (2) Empirical—by trial and error, (3) Heuristic—by rule of thumb or philosophical belief, or (4) Rational—by logical reasoning to maximize benefits and utility, while minimizing costs and risks (Wang & Ruhe, 2007). Among the four, rational theory is most widely studied, and is similar to decision theory (Hansson, 2005), which performs choice evaluation on expected utilities, and employs Bayesian networks by assigning conditional probability values when dealing with uncertainties. When rational decision making takes into account the anticipated decisions or actions of more than one individual (e.g., where there is competition or cooperation), it is known as game theory (Ross, 2010). Traditional rational decision methods usually assume that there is adequate time and a composed state of mind in the evaluation of choices. In time-stressed environments, such as civil emergencies and military conflict scenarios, intuitive decision making tends to perform better than analytical methods, for individuals with the requisite knowledge, training, and experience. Cohen, Freeman and Wolf (1996) describe such a situation when both a Naval officer and a Captain, onboard a U.S. AEGIS cruiser in the Gulf of Sidra, see a gunboat emerging from a Libyan port and need to decide whether to engage it or not. It follows on with an explanation of how metacognitive skills of critique (evaluation) and correction (regulation), as well as the ability to differentiate between when they are worth performing and when a current solution suffices, can be applied for time-stressed decision making. Here, an expert with more experience tends to make better-quality decisions compared to a novice. Klein, Orasanu, Calderwood and Zsambok (1993) term such a rapid decision making methodology as Recognition-Primed Decision Making (RPD), which employs experience to overcome the limitation of analytical strategies. RPD has been gaining popularity with the military, with its benefit of significantly increasing the operational tempo, when faster and generally better quality decisions are made by commanders (Ross, Klein, Thunholm, Schmitt & Baxter, 2004). Another decision making paradigm is illustrated by the multi-arm bandit (slot machine), where initially a gambler having no information about the levers on the slot machine is neutral to attempting any one of them, but when some measure of the payoffs from the levers is available, decision has to be made on whether to keep using (or exploiting) the levers with an already high payoff level, or to continue to explore other levers. This exploration versus exploitation dilemma exists in situations when environments are unfamiliar (Berry & Fristedt, 1985).

7. Cognitive Architecture

A cognitive architecture provides a structural framework to represent how the various components of the cognitive mechanisms and processes function together, to achieve human cognition. Alt, Baez and Darken (2011) proposed a situation-based cognitive architecture that can support agent-based simulations such as the Cultural Geography model (Figure 1). It encompasses the cognitive functions of perception (involving selective attention, working memory, situation formation), meta-cognition (involving motivation, emotions, expectations and goals), long-term memory (stores rewards and situations) and action-selection (involving situation and action(s) identification, exploratory versus exploitative (RPD) decision making and mental simulation).

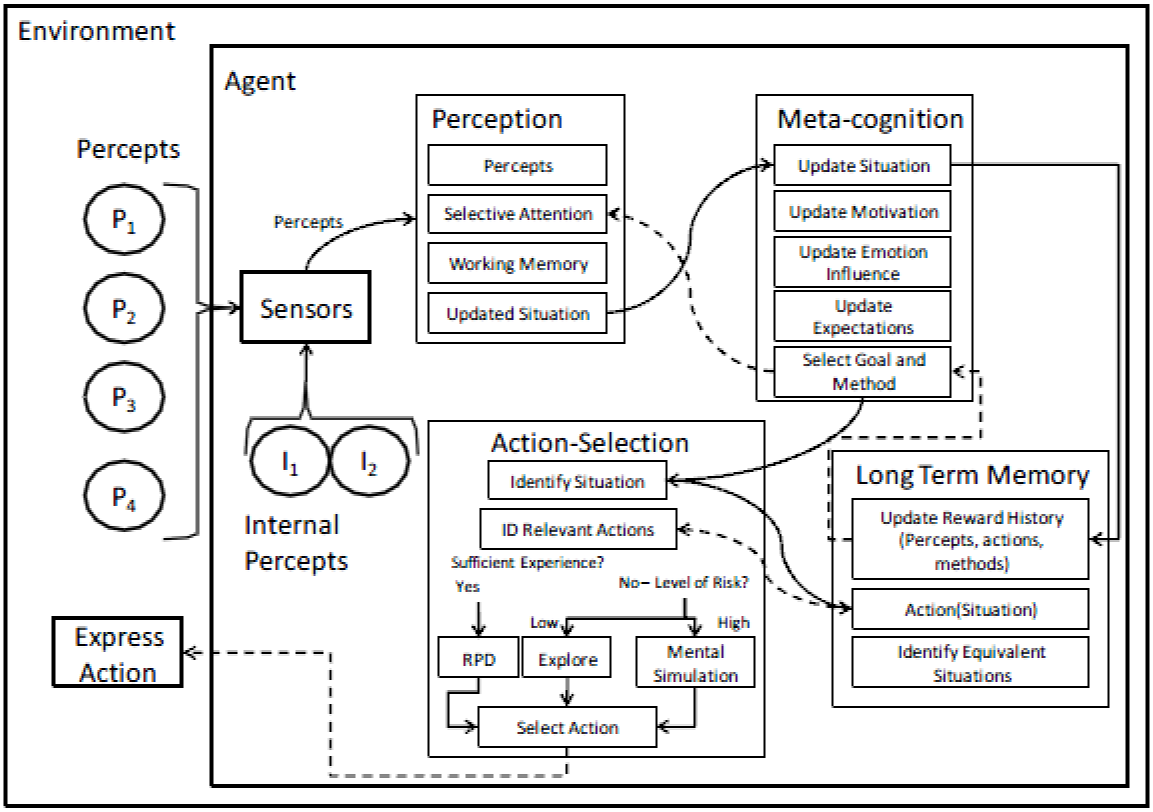

Figure 1. Situation-Based Cognitive Architecture (From Alt et al., 2011)

D. PREVIOUS IMPLEMENTATIONS OF COGNITION IN THE CULTURAL GEOGRAPHY MODEL

1. Theory of Planned Behavior

In the initial versions of the CG model (Alt et al., 2009), cognitive processes that have been implemented are perception and decision making, represented by the use of multi-layer Bayesian Belief Networks (BBN). The underlying social science foundation is based on the Theory of Planned Behavior (TPB) proposed by Ajzen (1991). TPB postulates three key factors that determine an individual's intention, leading to a behavioral response. These are (1) Attitudes, (2) Norms, and (3) Control. *Attitude*s refer to an individual's preference or degree of favor towards a given behavior, while *Norms* are social pressures imposed on an individual to adopt the behavior, and *Control* is the perceived ability of the individual to actually perform the behavior. Within the CG model, the TPB concept takes the form of a BBN, taking in belief inputs of individual agents affecting the attitudes, norms and control. These beliefs are in turn influenced by events from the environment or the agent himself. The reception of events triggers changes in beliefs, and through the TPB, translates into an intention, which manifests in the form of behavioral actions. The relationships between the events, beliefs, attitudes, norms, control and intentions are defined by conditional probabilities determining their likelihood of occurrence. Figure 2 illustrates an instance of this concept.

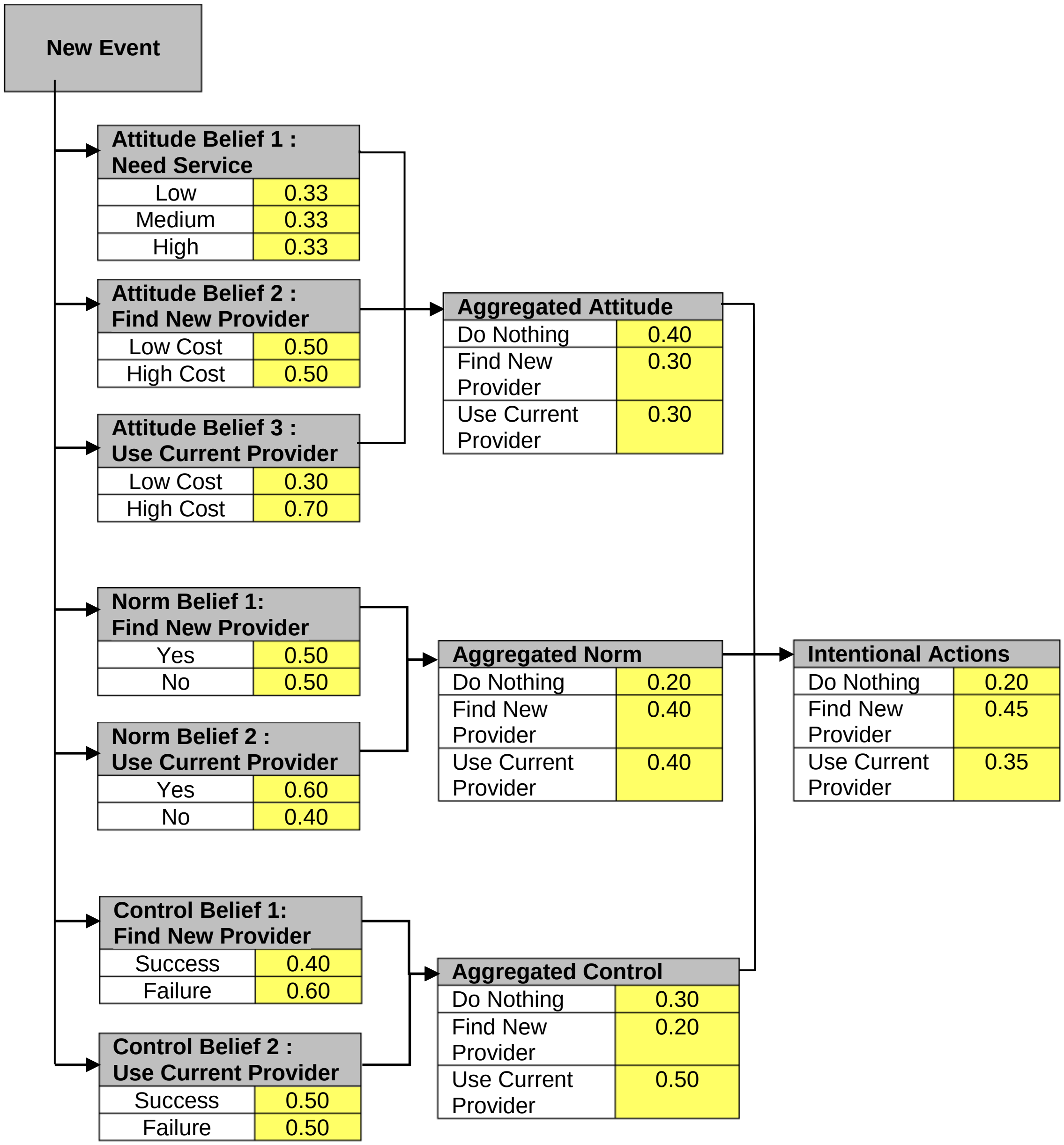

Figure 2. Theory of Planned Behavior implemented as a Bayesian Belief Network (After Yamauchi, 2011)

2. Reinforcement Learning

A recent version of the CG model (Papadopoulos, 2010) attempts to model operant conditioning or reinforcement learning, as well as decision making for insurgents, based on rewards and expected utilities for actions to be taken. A reward score is associated with the execution of each action, with higher scores awarded for outcomes in closer alignment to an agent's goals or objectives. Reinforcement is achieved through weighted aggregation of these rewards. The weights reflect the relative importance between recent and much older events. It is a time-exponential function of the discount factor, with a factor of 1 indicating that both recent and dated actions are equally weighted, while a factor close to 0 means that recent actions matter more. The utility computation for each action is represented by the following equation:

$$U(\tau_j) = \sum_{i=1}^{k} r_i \lambda^{t_i - \tau_j}$$

where U is the total utility for an action that was executed at time τ_j, k is the number of subsequent actions that resulted between time τ_j and the current simulation time, r_i and t_i are the rewards and execution times associated with those resultant actions, and λ is the discount factor. Actions of the same type are then grouped together to determine the expected utility for each action type. The equation that achieves this is :

$$E = \frac{1}{n}\sum_{j=1}^{n} U(\tau_j)$$

where E is the expected utility for a given action type, n is the number times the action was performed and U refers to the utility for each instance of the action type that was executed at time τ_j. Given the computed expected utilities, probabilities are assigned to all candidate actions based on the Boltzmann distribution. A random draw from these probabilities will determine the specific action to be selected in the process of decision making. The Boltzmann distribution is specified by the following :

$$P_i = \frac{e^{E_i/temp}}{\sum_{j=1}^{m} e^{E_j/temp}}$$

where P_i are the probabilities assigned to each action for selection, m refers to number of actions available for selection, E_i and E_j are the expected utilities for action i and j respectively, and *temp* denotes the temperature affecting the variation of choices made. A larger temperature value will render E_i and E_j to be inconsequential, resulting in all actions having similar probabilities of being selected, whereas a low temperature will force higher selection probabilities to be assigned for actions with high expected utilities. The temperature is a fixed value that can be adjusted for different scenarios.

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III. THE CULTURAL GEOGRAPHY MODEL

A. OVERVIEW

The CG model is an open-source, U.S. government-owned, agent-based simulation tool, based on U.S. Army doctrine and social theory, and developed by TRAC-MTRY to support military commanders in their evaluation of tactical operational outcomes on the civilian population in an IW environment. The CG model provides the responses of civilian populations based on their beliefs, values and interests, and through their reactions to the complex set of actions, both kinetic and non-kinetic, that can be performed within IW. Being a discrete-event based model focusing on the effects of operations, as opposed to a time-step driven model which covers both the operational executions and their effects, it enables simulation runs to be completed rapidly, allowing for a multitude of experimentation trials to be conducted over a diverse range of scenario conditions and tactical IW courses of actions (COA), resulting in a more comprehensive assessment of IW strategies for commanders. The CG framework is data-driven and modular in design, to account for population-specific demographic, ethnic and cultural characteristics in different areas of operations, and to support plug-and-play of evolving cognitive and behavioral modules from on-going and future research, experimentation and validation efforts. The outcome is aimed at providing more realistic depictions of population responses to support decision making in IW operations.

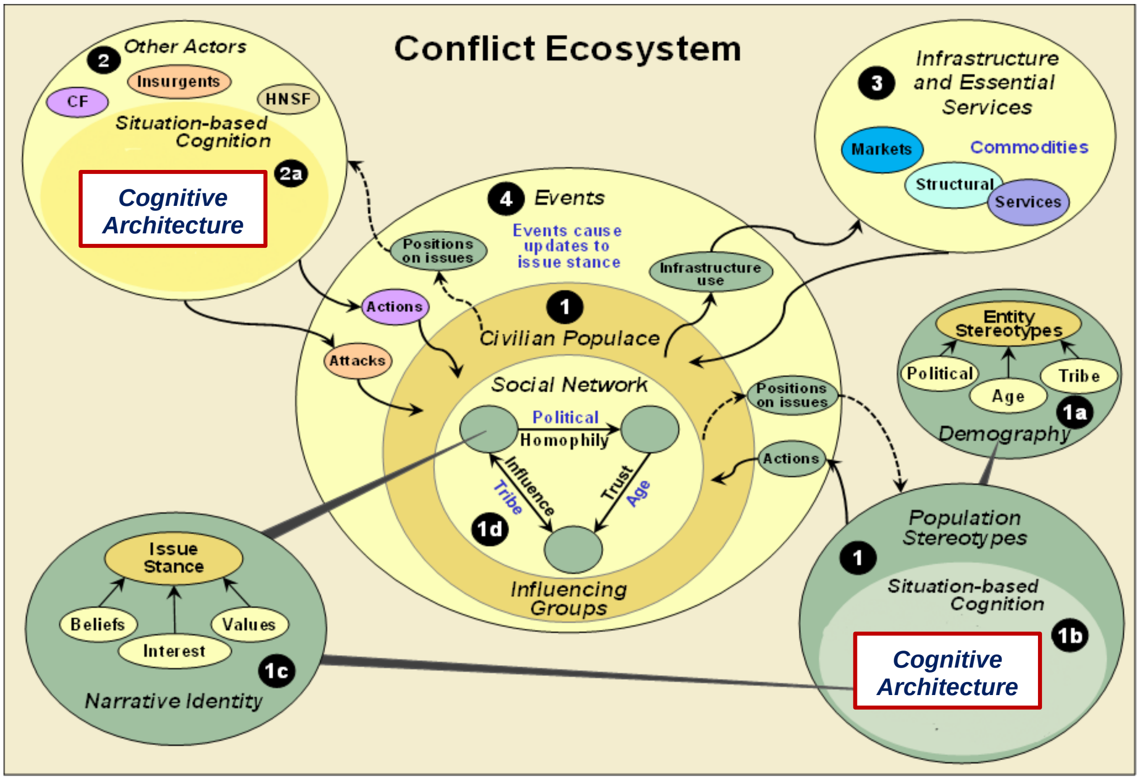

Figure 3. Cultural Geography Model (After Baez, 2011)

The CG model is structured based on the conflict eco-system proposed by Kilcullen (2007) for COIN operations, where each agent wants to maximize his own survivability and advantage, and the objective of the COIN force is to create or restore a stable environment. This structure comprises four main components (see Figure 3): Civilian Populace, Actors, Infrastructure and Events.

1. Civilian Populace

The civilian population is the center of gravity in the CG model. Their behaviors and stances on issues are influenced by events originating from population itself, external actors, and infrastructure/service needs. The civilians are not homogenous and their behavioral characteristics are described by population stereotypes. These stereotypes are defined according to demographic dimensions such as age, gender, education, family status, tribal affiliation (with different community/ethnic/religious groups), political affiliation, and disposition. These demographic dimensions determine the narrative identity and social network of individual agents with assigned stereotypes. All population stereotypes will employ a common Cognitive Architecture to reflect how they will respond to events, in terms of changing their stances on issues via the narrative identity, and in terms of appropriate actions to be taken.

a. Narrative Identity

The identity of a population stereotype is adapted from the narrative paradigm theory proposed by Fisher (1987). This theory claims that culture and life experiences shape an individual's belief and interpretation of the world and events that happen around them. Unlike the traditional paradigm of human rationality, where decisions are made based on only logical arguments, Fisher expands on such a notion, framing humans as essentially storytellers whose decisions are influenced by "good reasons," which can appear in both argumentative and narrative forms. In a narrative form, experiences are related as stories to individuals, whereby their acceptance and meaning is tied to their identification, rather than rational deliberation, with the individuals' personal experiences, values, and cultural backgrounds.

In the CG model, an individual's beliefs, values and interests (BVI) collectively form a belief system that reacts with the events perceived from the Cognitive Architecture to result in a change of stances on issues of concern. The collective beliefs of an individual are based on the demographic dimensions inherent in their stereotypes, with initial stances for these beliefs drawn from SME data. The data exists in the form of entries representing occurrences of stances for each belief column. For each belief, the proportion of stance occurrences indicates the position of the stance for that belief, which can range from 0% to 100%. Aggregation of the belief stances results in a change to related issue stances. The contribution of each belief stance on the affected issue stances is dependent on the conditional probabilities or weights defined by Bayesian Belief Network (BBN) case files. Table 1 shows an example of the data for the initial beliefs stances associated with a civilian stereotype, while Figure 4 represents the initial stance positions for each belief, and the corresponding changes in security issue stances. Events perceived by civilian agents during simulation result in changes to stance positions for related beliefs, which subsequently affects the issue stances.

Table 1. Example of Data for Initial Belief Stances associated with a Population Stereotype

Beliefs	Legitimacy of Security Forces	Legitimacy of the Government	Perception of the Level of Violence	Perception of Coalition Forces
Stance Occurrences	Legitimate	Illegitimate	Unacceptable	Positive
	Legitimate	Illegitimate	Acceptable	Negative
	Illegitimate	Illegitimate	Unacceptable	Positive
	Legitimate	Illegitimate	Acceptable	Positive
	Illegitimate	Illegitimate	Unacceptable	Negative
	Illegitimate	Illegitimate	Acceptable	Negative
	Illegitimate	Legitimate	Unacceptable	Negative
	Legitimate	Illegitimate	Unacceptable	Negative
	Illegitimate	Illegitimate	Acceptable	Positive
	Illegitimate	Legitimate	Unacceptable	Negative

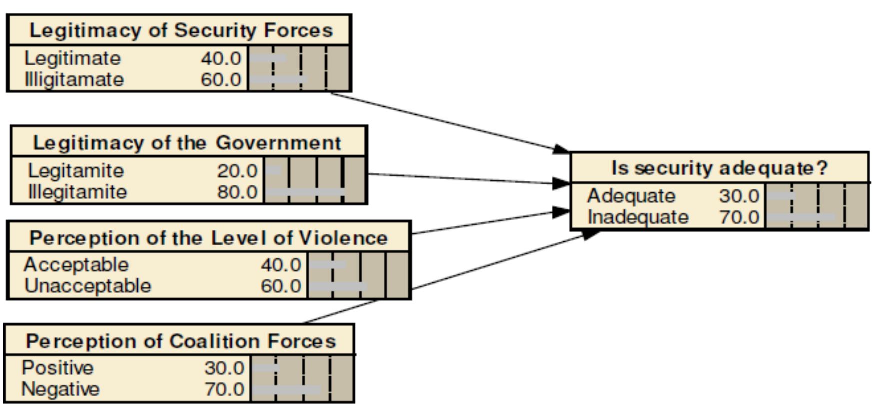

Figure 4. Bayesian Belief Network relating Beliefs to Issue Stances

b. Social Network

Civilians tend to communicate their experiences to those in the surrounding social network wherein they reside, and these shared experiences often have the most impact on recipient agents with similar characteristic traits. This idea is drawn from the concepts of homophily and propinquity. Homophily refers to the degree of likeness among individuals and is a function of the differences in the demographic dimensions (McPherson, Smith-Lovin & Cook, 2001). Propinquity relates to the physical proximity among individuals. Homophily is applied in the CG model to determine the social distance and corresponding link weight between civilian agents, for identifying who are in the same social network for communicating of events. The equation for computing the social distance and link weights between individuals is given by the following:

$$s_{ij} = \sqrt{\left(\frac{k_{1_{ij}}}{\max k_1}\right)^2 + \left(\frac{k_{2_{ij}}}{\max k_2}\right)^2 + \cdots + \left(\frac{k_{d_{ij}}}{\max k_d}\right)^2},\ w_{ij} = 1 - \frac{s_{ij}}{d}$$

where s_{ij} is the social distance between civilian agents i and j, k_{dij} is the distance in terms of dimension d between agents i and j, max k_d is the maximum dimensional distance for d among all agent pairs, and w_{ij} is the link weight for representing how close agents i and j are socially in a network. Link weights are normalized between 0 and 1. There are currently two categories of dimensions affecting the social distance: demographic and issue stances. Agents will communicate events to a maximum of N-nearest neighbors, in terms of the closest social distance or highest link weight, where N is a static number predefined by the scenario. To represent propinquity in terms of geographical reach for communication, only agents within a predefined physical radius are added to the N-neighbor list.

2. Actors

These refer to individuals, groups or organizations outside of the civilian population, but having the ability to influence the population via actions (e.g., attacking the civilians with improvised explosive devices (IEDs), or conducting security patrols). Actors can include coalition forces, insurgents, host nation security forces, non-governmental organizations, or any combinations of these types that fit the desired scenario. Their behaviors can be achieved in two ways: scripted actions at pre-defined times or actions generated using the Cognitive Architecture.

3. Infrastructure and Essential Services

The civilian population consumes services and utilizes infrastructure. Provision of these needs is implemented by multi-server queues, with each queue offering one type of service or commodity. Some examples of the commodities and services are: food, water, electricity, medical treatment, education and jobs. Individual agents rely on the Cognitive Architecture to address when consumption of these services or commodities should take place, and whether to search for a new service provider or use the previous one. The outcome of provider seeking actions will be evaluated based on the availability of service at the time of need, quantity of commodities or level of service that can be acquired, queue capacity, and waiting time before obtaining service.

4. Events

Events can be interpreted as actions performed by civilian or actor agents. For the purpose of observing the behavior of civilians, only events which affect the civilians' issue stances and influence decisions made in the context of IW operations are represented. Such events can be kinetic (e.g., insurgent raids on population), non-kinetic (e.g., manning a checkpoint), community-based (e.g., providing social services), communication-based (e.g., running an information campaign), or changes in political structures (e.g., a host nation leader has died).

B. COGNITIVE ARCHITECTURE MODULE

The Cognitive Architecture provides a structural framework for cognitive processes involving the human mind. A working version of the Cognitive Architecture has been implemented in the CG model based on the proposed situation-based agent architecture from Alt et al (2011), though not all components are available yet. The diagram in Figure 5 depicts the current set of components that make up the architecture.

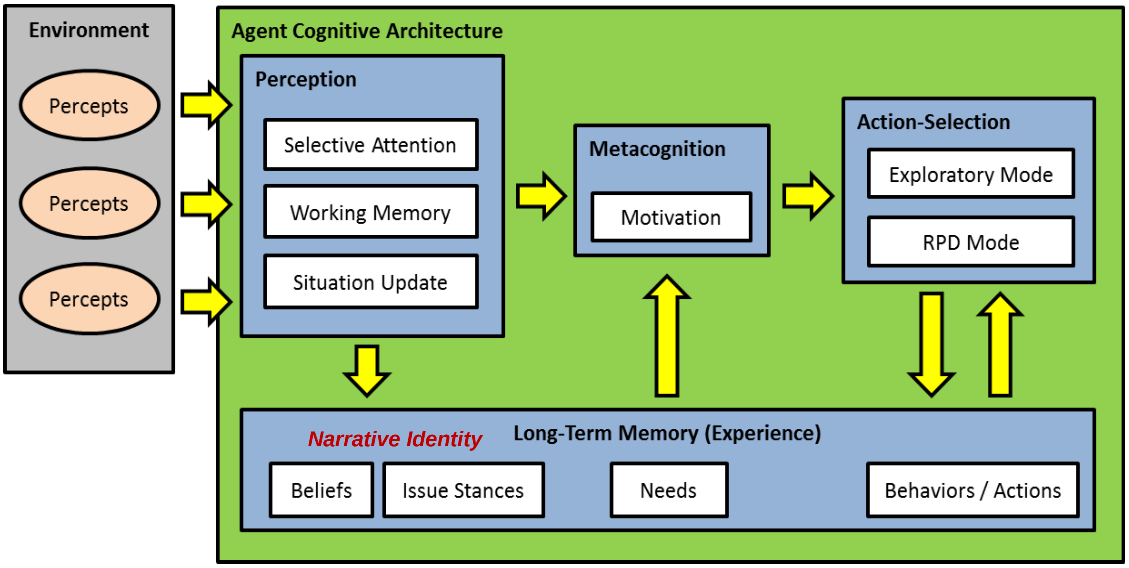

Figure 5. Cognitive Architecture Module for the CG Model

Structurally, the Cognitive Architecture module for each agent stereotype or other actor comprises four components: perception, meta-cognition, action-selection, and long-term memory. The module responds to events or percepts from the environment in two ways: (1) it changes stances on issues, and (2) it triggers a decision for an action to be taken. In the CG model, percepts contain information about the environment and are usually associated with actions performed by civilian or actor agents. Percepts from actions can also be received by the agent who performed the action (e.g., a civilian who is looking for a job will receive information on whether the job is found). Only percepts which are relevant and are within geographical reach for an agent will be received by the Perception component, which updates issues stances in the Long-Term Memory component of the agent according to his narrative identity. The output from Perception will also be compared with agent's needs in the Long-Term Memory, to determine which of the needs are fulfilled and which are still lacking. This outcome will provide a source of motivation in the Metacognition component to determine an available set of behavioral actions associated with the motivational driver. These set of actions will be evaluated in the Action-Selection component, together with previous reinforced behaviors or actions drawn from the Long-Term Memory, to obtain the most appropriate action to be performed by the agent in response to the percepts received. The outcome of the agent's actions will result in events that impact himself or other agents, and thus generating percepts that once again trigger the Cognitive Architecture processes of the impacted agents. The components of the Cognitive Architecture are described in more details below:

1. Perception

Percepts relevant to the perception component for an agent are first entered into the Selective Attention filter, which discards percepts older than a threshold age since the associated action last occurred. This could be because the message for the percept was communicated by agents much further away in geographical reach or it could be that those agents chose to communicate it at a much later time, depending on how their Cognitive Architectures interpret it. The percepts which are retained will be queued for processing by the Working Memory. It operates as a buffer mechanism which can process only a limited number of percepts at each time instance. Each set of precepts in the working memory will form a situational picture of the environment. Therefore, the size of the working memory will result in the formation of different situational pictures, with a few comprehensive pictures if the working memory size is large, and many subset pictures of the entire situational environment for a small working memory. Information from the situational pictures will contribute to changes in the issue stances, via the Bayesian Belief Network probabilities associated with the agent's narrative identity. Situation updates also inform the agent of the status of his needs, in determining the motivation categories and motivational goals within the metacognition component to drive decision making during action-selection. For example, an agent who needs medical service once every two months will receive a status update indicating medical attention is required when two months are up, and result in him responding with an appropriate action to visit the local pharmacy or seek consultation from a doctor). Another area impacted by the situational picture is the Control aspect of the Theory of Planned Behavior. This will reflect the degree of success for previous actions performed by the agent, based on the situational outcomes perceived.

2. Metacognition

Motivational goals are the current drivers for decision making in the metacognition component. The role of emotion has a significant impact too, but it has not yet been incorporated into the Cognitive Architecture. For the CG model, four primary motivation categories are identified: (1) Physiological—which refers to the need for consumption of services or utilization of infrastructure, (2) Self-Protection—which pertains to the need to defend the interests of the agent, (3) Affiliation—representing the agent's propensity to behave in a manner similar to those in the same social network, and (4) Self-Esteem—which can be understood as a desire to achieve wealth, fame or recognition among social peers. Currently, for the CG model, only actor agents have the Self-Protection motivation category, and Self-Esteem has not been included for both civilian and actor agents yet. Upon receipt of a situation update, the metacognition component will compare it with the existing needs of the agent and determine which one of the motivation categories are more important at that point in time. The evaluation will be based on the lack of fulfillment in the particular motivation category and the weights associated with the category. The result will be a motivation score from 0 to 1 for each category, with a higher value indicating a greater unmet need. As the scores in all categories sum to 1, this allows a motivation category to be selected using the Boltzmann distribution. From the category chosen, a set of motivations related to the category will be evaluated in the same manner, to determine the final motivational goal for action selection. A temperature setting is used in Boltzmann distribution, to indicate the degree of randomness in the motivation category and motivational goal selection, and the value is fixed throughout the simulation. This process is illustrated in Figure 6.

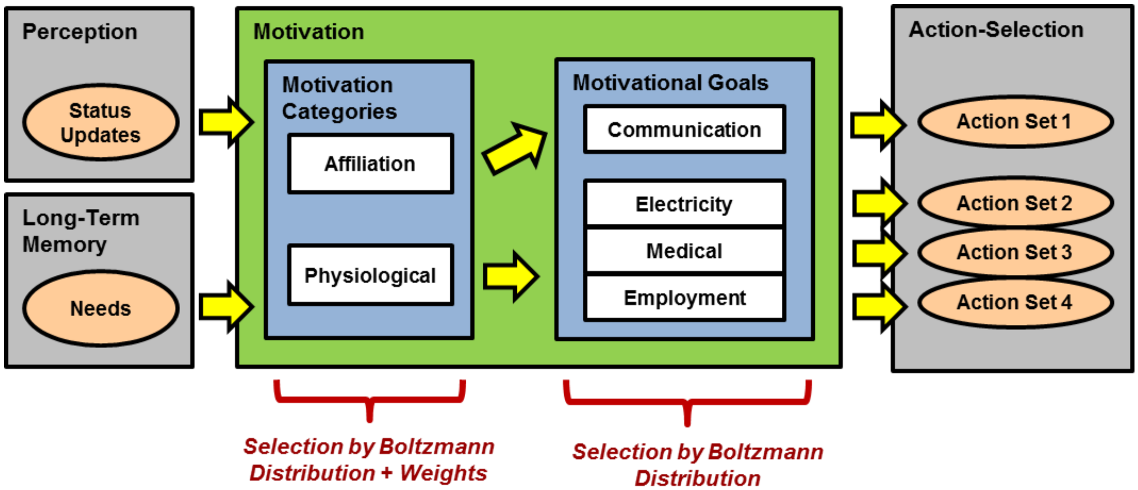

Figure 6. Selection of a Motivational Goal in the Metacognition Component

3. Action-Selection

Once a set of potential behavioral actions has been derived from the motivation goal chosen, the next step will be to select an appropriate action from the set. There two methods that can be employed: Exploratory Learning and Recognition-Primed Decision Making (RPD). The action-selection component first starts out in the Exploratory Learning mode, where the agent tends to make choices in a more random manner, as opposed to a more utility-driven manner. Reinforcement learning is implemented the CG model to support action-selection. The effect is to increase the expected utilities for actions that are repeatedly performed, but utility contributions from past actions are exponential degraded by a discount factor (λ), with each unit of age since they were last performed. Again, the Boltzmann distribution is used here, but the temperature is initially set at a high value to represent more randomness, with each action having an almost equal likelihood of being selected. As the agent gains more experience through performing more actions, this temperature setting will decrease, leading to a higher selection probability to be associated with actions having higher expected utilities. This will happen until sufficient experience has been acquired to transit to the RPD mode, indicating the agent can now rely on prior knowledge and past experiences to make decisions on actions. This mode transition is tied to an experience threshold representing the number times each action must first be performed. The agent enters the RPD mode only after all actions have been performed the appropriate number of times specified by their respective thresholds. In the RPD mode, where the agent will remain for the rest of the simulation, the temperature remains constant, and by that time, it would have fallen to a low level to indicate a tendency for the agent to select higher utility actions. The gradual temperature decrease is modeled using the following equation :

$$new\ temperature = \frac{previous\ temperature}{1+\left(\frac{min(N)}{experience\ threshold}\right)}$$

where min(N) represents the minimum number of times an action has been performed, among all possible N candidate actions. For the CG model implementation, once an action is been scheduled, the agent will execute it to completion, meaning there will be no disruptions to perform other actions in the interim period.

There is a Mental Simulation mode to which the agent in RPD mode can switch when situations are more volatile, or risky in terms of the variation in expected utilities, but this feature will only be incorporated in a future version of the CG Cognitive Architecture module.

Utility Computation for Reinforcement Learning in Action-Selection

When an infrastructure or service-related action is performed, such as seeking a service provider or obtaining services from the current provider, the utility computation includes the Theory of Planned Behavior (TPB) as well. Here, the Attitudes, Control and Norms for a behavior or action under the TPB contributes to the utility associated with the outcome for that action. The Attitude component looks at a set of issues that are considered to be pertinent for the behavior. For each issue, the difference between the strength of the previous issue stance position minus the current issue stance position is obtained. These differences are weighted and summed to determine the utility for attitude. The utility for the Control component is the ratio of the consumption amount from the service or infrastructure to the required service level based on the agent’s needs. As for the social Norms component, the proportion of agents within the same social network (in terms of N nearest neighbors within a physical proximity radius) who behave in the same manner or take the same action is a measure of utility. Together the Attitude, Control and Norms are weighted and summed to derive the final utility score for the outcome of the behavior or action taken.

In the case of an agent deciding whether to communicate with another agent on the outcomes of actions perceived, the utility is simply 1.0 if the selected action is to communicate, and 0.0 if the agent chose not to communicate.

4. Long-Term Memory (Experiences)

The long-term memory contains the state of the agent for purposes of cognition. It covers the current belief and issues stances, level of need in each of the motivational goals, as well as the expected utilities computed from past actions taken. Situational updates are received from the perception component to effect changes in beliefs and issue stances. Need levels defined at the start of the simulation are stored and used for comparison by the motivation component whenever a situation update reflects how much of each need has been fulfilled. This comparison on the lack of fulfillment will generate motivation scores for the selection of motivation categories and motivational goals. The long term memory also tracks the outcomes of actions performed after being chosen by the action-selection component, to compute the expected utilities for each action, which will be retrieved for future evaluation in action selection.

C. CG DATA AND SCENARIO

Data collection and scenario development for CG model is a laborious effort, extending over a long period of literature research, surveys with locals, interviews with IW military personnel and consultations with SMEs. As the focus of this study was on sensitivity analysis for the CG Cognitive Architecture, and not scenario-specific analysis of the population behavioral response for IW operations planning, a large part of the study is devoted to the sensitivity experimental design, with most of the CG data and scenario elements reused from two sources: (1) a previous Helmand study to support the Pakistan-Afghanistan Strategic Multi-layered Assessment (Hudak, Baez, Jones, et al., 2010), and (2) an IW tactical wargame (TWG) conducted in 2010 with the help of the CG model (Hudak, Vargas, Brown, et al., 2010).

1. CG Data

The data in the CG model consists primarily of demographic groups, population stereotypes, beliefs and their relation to issue stances, as well as infrastructure and essential services.

a. Population Demographic Groups and Stereotypes

Social-demographic narratives and statistics are drawn from the civilian population of 600,000 across six districts in the Helmand Province of Afghanistan (i.e., Kajaki, Sangin, Gereshk, Lashkar Gah, Nawa-i-Barakzai, and Garmsir). The information is compiled from polling or census data and open source literature. Advice from anthropologists are sought to help partition the civilians into distinctive demographic dimensions and groups based on predominant social-demographic characteristics, while minimizing the number of stereotypes needed to keep it manageable for the CG. Table 2 indicates the five demographic dimensions and possible stereotypes derived from the Helmand study.

Table 2. Demographic Dimensions, Groups and Stereotypes for Helmand Province

Dimension	Family Status	Tribe	Disposition	Political Affiliation	Age
Population Groups	Inherited ("Son of")	Pro-Government (Alizai)	Rural	Fundamentalists	Military Age Male
	Achieved (Politics/Wealth)	Marginalized / Violent (Noorzai / Ishaqzai)	Urban	Moderates (Traditionalists)	Spin Giri ("White Beards"/ Elders)
	Poor/ Unemployed	Passive (Barakzai / Alakozai)		Progressive / Secular	
Stereotype Codes	I, A, Un	P, V, Pa	R, U	F, M, S	Ma, Sp

A civilian population stereotype is a combination of groups along the 5 demographic dimensions and identified by the codes. For example, an unemployed military age male, who is aligned with a passive tribe, living in a rural area, and supports the fundamentalist Taliban party, can be identified by Un-Pa-R-F-Ma. A brief description of these dimensions and groups are given.

(1) Family Status.

Family cohesiveness provides a support system for the Afghan groups, and can be classified into three main status groups:

- Inherited—Being the family son of an elder who is regarded with respect or holds religious titles, and belonging to an elite landed family who became rich through poppy trade.
- Achieved—Holding positions of influence such as a military commander, government officials, or having links with influential people at the district or provincial level. Wealth is often through business ventures (including narcotics trade) and property purchase.
- Poor / Unemployed—Illiterate tribal people, young seminarians, and low-educated jobless youths living in poverty. Many of those who joined the Taliban insurgents come from this group.

(2) Tribe.

There is sufficient coherence and strength in tribal structures to significantly play a role in peace-building process, and these tribes can be categorized under three groups:

- Pro-Government (Alizai)—Many of the key governmental positions at district levels and above come from the Alizai tribe and Alizais prefer do things their way with a fusion of tribal and federal government (rather than tribal and Taliban) leadership.

- Marginalized / Violent (Noorzai / Ishaqzai)—Many Noorzai are pro-Taliban and deeply associated with the narcotics industry. Ishaqzai were severely marginalized in the post-Taliban governments by various Jihadi commanders, and took to joining warlords and Taliban rebels.

- Passive (Barakzai / Alakozai)—The Barakzais seems to benefit disproportionately in power and patronage from the Karzai government, thus having more education, government positions, land ownership, tribal unity and businesses. They are relatively peaceful but are viewed by other tribes with envy and distrust. Alikozais have a live-and-let-live policy with the Taliban. They allow the Taliban free passage through tribal areas, but forbid the Taliban from mounting any operations there.

(3) Disposition.

Disposition in the Helmand Province is modeled based on rural and urban groups, where access to employment opportunities, services and infrastructure differs.

- Rural—Most occupations in this group are agricultural and tied to poppy cultivation (include growing, transportation, and security). The rural populace is often stereotyped as backward, conservative, naive, but trustworthy by Afghan urbanites.

- Urban—Many of the urban population occupations revolve around the grand bazaars and support to the larger market places. City dwellers are considered corrupt and untrustworthy by people in rural areas.

(4) Political Affiliation.

Afghanistan has a fragmented multi-party system, requiring parties to form coalition alliances to achieve political gain. The affiliation groupings are based on their trust in Islamic versus secular government rule:

- Fundamentalists—Generally believes in a strict Islamic state and a literal interpretation of the Islamic Law (Shari'ah). They are pro-Taliban and are against having foreigners in Afghanistan.

- Moderates (Traditionalists)—Generally believes in a strict Islamic state and most believe in the implementation of Islamic Law (Shari'ah). However, their religious views are less extreme as the Taliban and they hold mixed positions on the Afghan government.

- Progressive / Secular—Believes in secular Afghan governance and opposes radical Islam, treating it as separate from the government. Many of them are well-educated and are generally pro-democratic.

(5) Age.

With the average male life expectancy in Afghanistan to be 44 years, a breakpoint of 40 is used to delineate between military age youth and elders.

- Military Age Male—Every year, only 150,000 out of 500,000 Afghanistan youths find lawful employment opportunities (e.g., opium-free farming or with the army and police units). Many others join the insurgents.

- Spin Giri (“White Beards” / Elders)—They are traditional leaders holding jurisdiction within tribal territories, with titles often inherited. They are influential in terms of family background and economic power (especially land ownership), with good negotiation skills and linkages to the government.

b. Population Beliefs and Issues of Concern

In the TWG in 2010, the question of concern was on how changes in the task organization of Civil Affairs (CA) teams enable tactical commanders to meet their IW objectives. Specifically, the TWG examined how CA teams assigned at the Battalion Staff level influenced tactical decision making compared to CA teams assigned at the Brigade level. To understand how these decisions might impact population, the TWG scenario derives population issue stances related to six Counterinsurgency Lines of Effort (COIN LOE). These LOE include:

(1) Civil Security—An assessment of whether the population perceives security to be adequate (or inadequate) in Helmand. The goal is to protect areas, resources, and the populace from both external and internal threats.

(2) Civil Control—An assessment of whether the population perceives that adequate (or inadequate) civil control exists in Helmand. The goal is to regulate selected behavior and activities of individuals and groups to reduce risk to individuals or groups and promote security.

(3) Governance—An assessment of whether the population perceives existing government structures and services to be adequate (or inadequate) in Helmand. Measures of adequate governance include providing essential government services such as infrastructure and legal services, with sufficient transparency. The goal is to apply offensive operations in a manner to help strengthen local government.

(4) Economic and Infrastructure Development—An assessment of whether the population perceives the economy and infrastructure as adequate (or inadequate) in Helmand. The goal is for tactical units conducting COIN to consider how offensive operations can assist in stimulating the economy of their local area.

(5) Restoration of Essential Services—An assessment of whether the population perceives existing essential services as adequate (or inadequate) in Helmand. The goal is for tactical units to consider how to incorporate essential service projects as a complementary portion of their offensive operations.

(6) Support to Host Nation Security Forces—An assessment of whether the population perceives host nation security forces as adequate (or inadequate) in Helmand. The goal is to conduct combined operations with host nation security forces to improve their tactical and technical competence and develop professionalism.

The concept of narrative identity was then applied to extract beliefs from the population stereotypes that maps to these six LOE issues with regards to changes in stances, when influenced by events around them. Stances for both the beliefs and issues are "Adequate" and "Inadequate." A total of 13 beliefs were identified and listed in Table 3, along with their descriptions. The issue stances of the six LOEs affected by these beliefs are based on the Bayesian Belief Network shown in Figure 7.

Table 3. List of Beliefs for Population Stereotypes in the Sensitivity Analysis Scenario

#	Beliefs	Description
1	Security	This belief addresses the perception of how safe and protected the population feels within the area it habitually does its daily business.
2	Freedom of Movement	This belief addresses the ability of people to move about their area without impediment or fear of violence. Can be a woman going to the market, a farmer going to neighboring village, or someone traveling to another province.
3	Local Power and Authority to Govern Self	This belief addresses the perception of the community as to its power and authority base. For some it's the ability to govern or defend itself, for others it is respect to local authority figures or former Mujahidin, and others it is poppy/opium. It is likely that people will value several of these items.
4	Negligible Corruption Levels	This belief addresses the perception of exploitation within the community. Most society has some level of corruption, but some abuse of power is simply intolerable compared to others.
5	Dispute Resolution	This belief addresses the process for the community to solve arguments over issues that aren't covered under the rule of law such as ownership and control of property or addressing real and perceived wrongs and offenses between people.
6	Value of Outside Influences	This belief addresses the perception on the value of outsiders providing resources, security, essential services, etc. This doesn't address the population's view of outsiders, simply the view of the assistance and influence provided.
7	Legitimacy of the Government	The belief addresses the perception that the government asserts appropriate level of force, transparency, taxes/other payments, and represents the people. Also that it provides protection to its people.
8	Decision Making Involvement	The belief addresses the perception that the person has some say, impact, or control on and within the current governing body. Also addresses the participatory nature of the governing body.
9	Modernization of Essential Services	The belief addresses the perception on whether essential services are modernized enough to increase the capacity and capability of meeting the population's need for basic necessities such as food and water.

10	Living Conditions and Basic Needs	The belief addresses the perception of whether or not the community is able to meet its basic needs such as food, water, and shelter.
11	Educational Opportunities	The belief addresses the perception on the importance and value of education for both males and females.
12	Employment Opportunities	This belief addresses the perception on the impact that development in their area is having on employment opportunities for its people.
13	Technology	This belief addresses the perception on whether infrastructures are modernized enough to improve the standard of living in measures such as having electricity, cell phones and televisions.

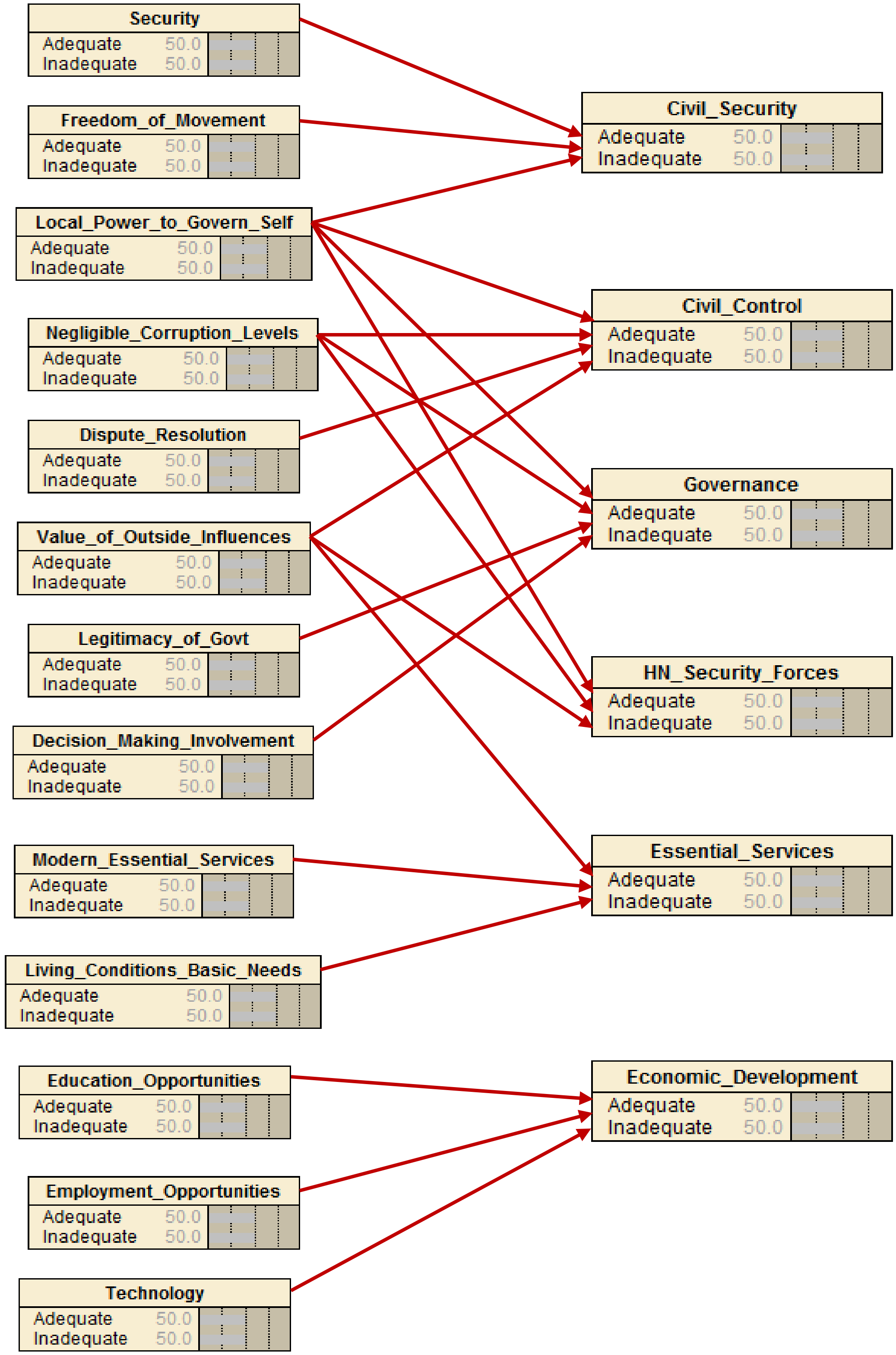

Figure 7. Mapping of Belief Stances to Issue Stances for the Sensitivity Analysis Scenario

c. Infrastructure and Essential Services

Based on study research, interviews with provincial reconstruction personnel in Helmand as well as a TRAC analyst, the essential services and providers were identified. The provider has affiliations with government, insurgent or non-governmental organization groups, so accepting a service from a provider may affect the issue stances (e.g., if an entity acquired medical services from a provider that supports the host government, the entity's change in issue stance regarding governance may be more positive than had the entity received medical service from another civilian agent who supports the Taliban). To keep the scope of sensitivity analysis manageable, only the Electricity service will be available and it will be within reach of the population agents. The provider is a civilian agent associated with the Government of the Islamic Republic of Afghanistan.

2. CG Scenario

Scenario-specific information deals with behaviors of the population, as well as other actors and their potential actions that influence the population issue stances and behavioral response actions. The nature and degree of impact for events and actions on the population response are elicited from SMEs. Another aspect of the scenario is the distribution of civilian agents, actors and infrastructure services across the Helmand province.

a. Population Behaviors

Behaviors for the population from the TWG 2010 revolve around seeking and consumption of essential goods and services, and the communication of the events experienced through other actors or outcomes of service-related actions to other agents. The choice of actions will depend on the decision made by the Cognitive Architecture for each agent stereotype. Access to service providers will be restricted to a proximity radius for civilian agents. Success or failure of acquiring the service is also dependent on server parameters that include capacities, transfer rates and operating times, as well as agent's tolerance for long queues and waiting times. The outcome of an attempt to acquire the service will affect each agent's beliefs and issue stances, and agents may be motivated to communicate the outcome to other civilian agents within the same social network. The impact of actions by other actors is determined through Bayesian Belief Networks to effect both a change in belief and related issue stances, with the data based on questionnaires completed by SMEs representing academia, Afghan citizens, and the U.S. military.

b. Other Actors

For the sensitivity analysis, the subset of actors from the TWG 2010 that are identified to be of significant influence to the population in terms of affecting beliefs and issue stances are: Afghan National Army (ANA), Afghan National Police (ANP), Coalition Forces (CF) and Criminals. The list of 62 scripted actions or events associated with these actors in the scenario can be found in Table 4.

Table 4. Actions / Events for Other Actors

Event #	Action / Event
1	ANA attacks Taliban or criminal
2	Civilians assist ANA's actions
3	Civilians resist ANA's actions
4	ANA conducts checkpoint
5	ANA cooperates with locals
6	ANA fails to cooperate with locals
7	ANA funds a key leader
8	ANA holds a Shura (consensual conflict resolution with localized leaders)
9	ANA kills civilians
10	ANA meets a key leader
11	ANA operates in the area
12	ANA receives information from locals
13	ANA searches house
14	ANA searches village
15	ANA threatens key leader
16	ANP attacks Taliban or criminal
17	Civilians assist ANP's actions
18	Civilians resist ANP's actions

19	ANP conducts checkpoint
20	ANP cooperates with locals
21	ANP extorts from locals
22	ANP extorts from locals at checkpoints
23	ANP fails to cooperate with locals
24	ANP funds a key leader
25	ANP holds a Shura (consensual conflict resolution with localized leaders)
26	ANP kills civilians
27	ANP meets a key leader
28	ANP operates in the area
29	ANP meets a key leader
30	ANP receives information from locals
31	CF abandons outpost
32	CF asks for a place in the Jirga (a traditional Afghanistan- wide council for conflict resolution by consensus)
33	CF attacks Taliban or Criminals
34	Civilians assist CF's actions
35	Civilians resist CF's actions
36	CF conducts checkpoint
37	CF conducts Irrigation Project
38	CF conducts Medical Civil Action Program
39	CF conducts Potable Water Project
40	CF conducts show of force
41	CF cooperates with locals
42	CF establishes outpost
43	CF fails to cooperate with locals
44	CF funds a key leader
45	CF holds a Shura (consensual conflict resolution with localized leaders)
46	CF improves infrastructure
47	CF Irrigation Project fails
48	CF kills civilians
49	CF makes payment to locals
50	CF Medical Civil Action Program fails
51	CF meets a key leader
52	CF observes population
53	CF operates in the area
54	CF Potable Water Project fails
55	CF receives information from locals

56	CF searches house
57	CF surveys population
58	CF threatens a key leader
59	CF conducts Unmanned Aerial Surveillance on population
60	Criminal attempts opium sale
61	Criminal attempts to kidnap civilians
62	Criminal civilians assist actions

c. Distribution of Agents and Infrastructure

In the TWG 2010 scenario, a total of 500 civilian agents were modeled in the scenario, but for the sensitivity analysis, 62 of them will be picked as representative of different population stereotypes spread across the Helmand Provincial districts, supported by the electricity infrastructure provider. Table 5 provides the distribution of demographic groups and population stereotypes in the scenario.

Table 5. Distribution of Demographic Groups for Sensitivity Analysis

Dimension	Demographic Group	Code	Percentage
Family Status	Inherited ("son of")	I	10%
	Achieved (Politics / Wealth)	A	35%
	Poor / Unemployed	Un	55%
Tribe	Pro-Government (Alizai)	P	34%
	Marginalized / Violent (Noorzai / Ishaqzai)	V	26%
	Passive (Barakzai / Alakozai)	Pa	40%
Disposition	Rural	R	61%
	Urban	U	39%
Political Affiliation	Fundamentalists	F	31%
	Moderates (Traditionalists)	M	40%
	Progressive / Secular	S	29%
Age	Military Age Male	Ma	55%
	Spin Giri ("White Beards"/Elders)	Sp	45%

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IV. EXPERIMENTATION METHODOLOGY

A. MEASURES OF SENSITIVITY

As behavioral response of civilians to IW operations was the key focus of the CG Model, it would be appropriate to track the sensitivity impact of the Cognitive Architecture on civilian issue stances that change according to events they perceived from actions perpetuated by other actors as well as other civilians in the population. Due to the intensive efforts on research and gathering of population-related data from SMEs, six issues of concern drawn from TWG 2010 study were reused for the sensitivity measure. They were originally meant to study the impact of organizational structures in civil affairs programs on IW operational objectives for tactical commanders. Table 6 provides the list of issues and their associated stances. The stances can take values from 0 to 1. Descriptions of the issue stances are covered in Chapter III, Part C, Section 1, under "Population Beliefs and Issues of Concern."

Table 6. Measures of Sensitivity

Sensitivity Issue for the Population	Stances
Civil Security	Adequate (0 to 1), Inadequate (0 to 1)
Civil Control	Adequate (0 to 1), Inadequate (0 to 1)
Governance	Adequate (0 to 1), Inadequate (0 to 1)
Economic and Infrastructure Development	Adequate (0 to 1), Inadequate (0 to 1)
Restoration of Essential Services	Adequate (0 to 1), Inadequate (0 to 1)
Support to Host Nation Forces	Adequate (0 to 1), Inadequate (0 to 1)

B. EXPERIMENT DESIGN

The objective of sensitivity analysis is to estimate the change in a system on the outputs of interest as a result of changes in experimental factors (Kleijnen, 2009). It will be useful to discover which of the factors have the greatest influence on the system's measures of interest. In real-world systems, it is impractical to observe effects from the different variations in the experimental factors, since the outcome of an experimentation trial will affect the elements in the system, such as the perception of civilian populations, for the next trial. Simulations can be employed to study input factor changes in a controlled environment. It can also introduce randomness in a stochastic scenario to mitigate against biased results from experimentation runs. However, due to the computationally large number of permutations for the input factors and their ranges, it would be feasible to explore only a limited subset of the desired sensitivity space. Moreover, higher order regression effects (e.g., quadratic forms of the inputs) and interactions are difficult to be perceived, especially if traditional experimentation trials involving the variation of one input while keeping the rest constant are employed, since it is the combination of inputs that leads to interaction effects on the outputs of interest. Therefore, good design of experiment (DOE) techniques are crucial to manage these considerations (Kleijnen, Sanchez, Lucas & Cioppa, 2005).

1. Design Factors

For sensitivity analysis, the focus is not on numerical prediction, but rather estimating tendencies of effects, so identification of a shorter list of more influential design factors and variation levels from the full range of inputs for the Cognitive Architecture will allow a for a more thorough investigation of the sensitivity effects. This is preferable to spreading the limited number of computational design combinations or points over the entire list of inputs and ranges, some of which may be less relevant in the CG model, with regard to changing the issue stances. Based on a fundamental understanding of the Cognitive Architecture, in consultation with the Cognitive Architecture framework designer, Alt J.K., and model developer, Yamauchi H., a total of nine design factors for the Cognitive Architecture were finalized and listed in Table 7, along with their descriptions.

Table 7. Cognitive Architecture Sensitivity Analysis Design Factors and Levels

#	Design Factor	Level Type	Level Range	Description
1	Working Memory Capacity	Discrete, Integers	3 to 10	Number of percepts an agent can process in each time unit.
2	Selective Attention Threshold	Continuous, Decimal Places (0)	1 to 90	Age of percepts to be discarded, in time units.
3	Expected Communication	Continuous, Decimal Places (0)	1 to 90	Number of times an agent is motivated to communicate with other agents within each communication period.
4	Expected Communication Time Units	Continuous, Decimal Places (0)	1 to 90	Defines the number of time units for a communication period.
5	Temperature	Continuous, Decimal Places (2)	0.1 to 10	Fixed setting for randomness in Boltzmann selection of Motivation Categories and Motivational Goals. A lower temperature indicates a tendency towards higher utility choices, while a higher temperature represents more distributed and randomized choices.
6	Initial Temperature	Continuous, Decimal Places (2)	0.1 to 10	Initial setting for randomness in the Boltzmann selection of actions, during exploratory action-selection mode. Actual temperature decreases as a wider spread of actions are performed, until RPD mode is achieved, upon which it will remain unchanged. A lower temperature indicates a tendency towards higher utility choices, while a higher temperature represents more distributed and randomized choices.
7	Lambda (Discount Factor)	Continuous, Decimal Places (2)	0.1 to 1	Degradation of utility associated with outcomes of past actions in reinforcement learning. A value of 1 implies no degradation, while 0 indicates that past actions have no effect on computation of utility.
8	Experience Threshold	Discrete, Integers	1 to 10	Threshold for the number times each type of action needs to be performed before an agent switches from exploratory to RPD action-selection mode.
9	Link Weight Update Interval	Continuous, Decimal Places (0)	1 to 30	Frequency of update in time units to determine current social network for communications and social norms contribution in infrastructure or service-related action-selection (Theory of Planned Behavior).

2. Nearly Orthogonal, Nearly Balanced, Mixed Design

Given the limited budget of design points, or the combinations of factor levels among the design factors, it is beneficial to have an efficient and balanced spread of points to cover the sensitivity space. At the same time, it is important to reduce the amount of correlation that exists in the spread of multi-factor design points, so that for each point, the effects on the issue stances can be more independently measured from undesired coupling between design factors. Orthogonality is another goal in the distribution of design points, which provides a structure for identifying the weight of each factor in influencing issue stances. A full-factorial design of the nine factors, with just 10 levels each (which is already less than the variations required for the design factors), will result in 10^9 design points, each resulting in a simulation execution or run. Latin Hypercube (LH) sampling provides efficient space-filling features for quantitative factors, with a much lower number of points compared to factorial designs. It uses permutations for the levels in each design factor column, and for each row or design point, factor levels for each design factor is sampled such that they do not repeat along the columns. Table 8 shows an LH example of a three-factor design, each with three levels.

Table 8. Latin Hypercube Design Example

Design Point	Factor 1	Factor 2	Factor 3
1	3	1	2
2	2	3	1
3	1	2	3

The nearly orthogonal Latin Hypercube (NOLH) proposed by Cioppa and Lucas (2007) further extends upon the LH, which has poor orthogonality properties for smaller designs, achieving maximum pairwise correlations between factors of less than 0.03. However, for a mixed design involving both continuous and discrete factors, the effects of rounding continuous factor levels for NOLH application can destroy its near-orthogonality feature. Vieira, Sanchez, Kienitz & Belderrain (2011) presented a mixed integer programming (MIP) approach termed as the Nearly Orthogonal, Nearly Balanced Mixed Design (NONBMD) that relaxes the balance constraint of having an equal number of instances for each level of each factor (which is the case for LH), and tries to optimize the combinations of factor levels to achieve near orthogonal designs with maximum pairwise correlations of less than 0.05, while achieving efficiency in terms of design points. This approach has been adopted for the Cognitive Architecture sensitivity analysis study in this paper, resulting in an efficient and nearly orthogonal design with only 35 design points from the nine design factors, and a maximum pairwise correlation of 0.0125. Table 9 provides the design point combinations while Figure 8 shows the pairwise correlation values.

Table 9. Nearly Orthogonal, Nearly Balanced Mixed Design Points

Design Point #	Working Memory Capacity	Selective Attention Threshold	Expected Communication	Expected Communication Time Units	Temperature	Initial Temperature	Lambda (Discount Factor)	Experience Threshold	Link Weight Update Interval
1	9	85	26	44	6.04	6.04	0.49	7	8
2	6	34	80	87	6.32	6.32	0.31	6	1
3	8	44	42	59	1.8	1.51	0.56	6	7
4	8	47	62	65	2.08	0.67	0.72	4	13
5	7	14	34	42	2.93	2.65	0.25	4	8
6	4	80	47	77	3.49	7.17	0.13	4	18
7	6	72	29	37	7.17	2.36	0.33	4	3
8	6	75	11	9	8.3	7.74	0.59	5	4
9	5	42	1	11	2.36	1.23	0.9	3	20
10	8	9	39	21	3.21	1.8	0.28	3	9
11	4	65	87	24	0.95	6.89	0.97	3	6
12	7	57	77	1	0.67	3.49	0.64	10	15
13	9	87	75	16	6.61	0.38	0.51	3	21
14	6	37	52	19	5.76	4.06	0.18	2	10
15	5	39	9	29	9.43	8.3	0.85	2	11
16	7	70	14	80	4.06	4.91	0.15	2	14
17	3	16	85	4	5.47	9.15	0.38	10	24
18	10	77	65	62	7.45	8.87	0.36	9	17
19	4	11	67	47	4.63	7.45	0.23	2	16
20	5	54	82	57	0.38	4.63	0.67	1	25
21	5	67	49	14	5.19	5.19	0.2	7	22
22	3	26	37	34	8.59	2.93	0.43	8	19
23	10	6	44	32	8.02	8.59	0.77	8	5
24	9	59	32	6	4.34	8.02	0.74	1	26
25	9	4	24	82	3.78	9.43	0.46	1	28
26	8	1	72	39	9.72	4.34	0.87	1	23
27	4	52	70	85	9.15	5.47	0.95	5	13
28	10	62	21	49	0.1	9.72	0.54	8	29
29	10	32	59	70	7.74	0.1	0.69	7	18
30	7	21	6	52	1.23	5.76	0.92	9	2
31	4	49	54	75	1.51	6.61	0.79	5	3

32	3	82	19	72	8.87	2.08	0.82	6	28
33	3	19	4	67	2.65	3.21	0.61	10	27
34	8	29	57	54	6.89	0.95	0.41	9	23
35	5	24	16	26	4.91	3.78	0.1	5	12

Correlations

	WorkMemCap	SelAttnThres	ExpComm	ExpCommTU	Temp	InitTemp	Lambda	ExpThres	LinkWtUpdInt
WorkMemCap	1.0000	0.0013	-0.0017	-0.0002	-0.0011	0.0001	0.0021	-0.0006	-0.0125
SelAttnThres	0.0013	1.0000	-0.0017	0.0028	-0.0034	-0.0034	-0.0008	-0.0020	0.0012
ExpComm	-0.0017	-0.0017	1.0000	0.0019	0.0055	-0.0027	0.0019	-0.0024	0.0064
ExpCommTU	-0.0002	0.0028	0.0019	1.0000	-0.0009	0.0013	0.0046	0.0015	0.0040
Temp	-0.0011	-0.0034	0.0055	-0.0009	1.0000	-0.0007	0.0004	0.0010	-0.0011
InitTemp	0.0001	-0.0034	-0.0027	0.0013	-0.0007	1.0000	0.0024	0.0001	0.0028
Lambda	0.0021	-0.0008	0.0019	0.0046	0.0004	0.0024	1.0000	-0.0018	0.0054
ExpThres	-0.0006	-0.0020	-0.0024	0.0015	0.0010	0.0001	-0.0018	1.0000	-0.0017
LinkWtUpdInt	-0.0125	0.0012	0.0064	0.0040	-0.0011	0.0028	0.0054	-0.0017	1.0000

Figure 8. Pairwise Correlation Matrix

C. SCENARIO EXECUTION

For each experimentation run, the simulation is executed for 400 time units, each representing a day in the real world, allowing sufficient time for the various scripted events from other actors to take place, thereby contributing to the 62 civilian agents' behavioral responses and corresponding changes in issue stances. Actual time for each run takes about 30 seconds to a minute, depending on whether the Cognitive Architecture design factor levels lead to more events occurring (e.g., if expected communications is set to a high level, there is a tendency for more communication events to take place). To obtain independent and identically distributed random variables (IID) in the simulation for reducing bias and achieving more normalized distributions, 30 replications are run for each design point, with a different random seed used in each of the replications but retaining the seed for similar replications across design points.

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V. DATA ANALYSIS

A. METHODOLOGY, TECHNIQUES AND TOOLS

1. Data Output and Post-Processing

The simulation is configured to output the desired measures of sensitivity, which are the six issue stances indicating the response of the civilian population to the actions of the actor agents (coalition forces, host government security forces and criminals) in the sensitivity analysis scenario. As the stance positions can be measured based on being “adequate” or “inadequate,” and since they are complementary to each other, only the “adequate” stance position from 0 to 1.0 is logged in the simulation. The adequate issue stance positions are individually captured for each of the 62 agents in the scenario, 401 time units or days (from day 0 to day 400), and this is done for the 30 replication runs associated with each of the 35 design points. The output is generated in the form of comma-delimited files with a .“csv” extension, to facilitate processing by JMP, an interactive statistical data analysis tool with a wide range of graphical display formats such as distribution and regression plots. With a total of over 26 million rows of data for each issue stance, post-processing is done by JMP to collapse the issue stance data in terms of their mean values by design points, for the sensitivity and significant factor identification, and by civilian stereotypes, for obtaining insights on stereotypes of interest. As the CG model does not have the capability to output the design factor levels, Ruby script programming is employed to append the factor levels to each of the issue stance position output rows. It is also used to merge the different .”csv” files into a single .”csv” file for collapsing by JMP. As the simulation is time-dependent in terms of action effects on civilian issues stances, it will have a serial correlation on the data which leads to an initial bias before steady-state is reached on the mean issue stance positions. For a terminating simulation in this case, this issue can be overcome by replication / deletion method, where the non-steady-state values of the issue stance positions are removed in each replication via inspection of the graphical display of changing issue stance positions across time (Sanchez, 2007). The issue stance positions for the remaining time instances which are less biased, will then be collapsed by both design points and stereotypes, to derive their mean values,. For the sensitivity analysis scenario, the time interval or warmed-up time gauged for removal of values spanned from day 0 to day 99, as can be seen from the Figure 9 of the mean issue stance position for each of the issue stances plotted across time in days. The cut-off point of 100 days was chosen so that steady-state mean values can be observed across issues stances.

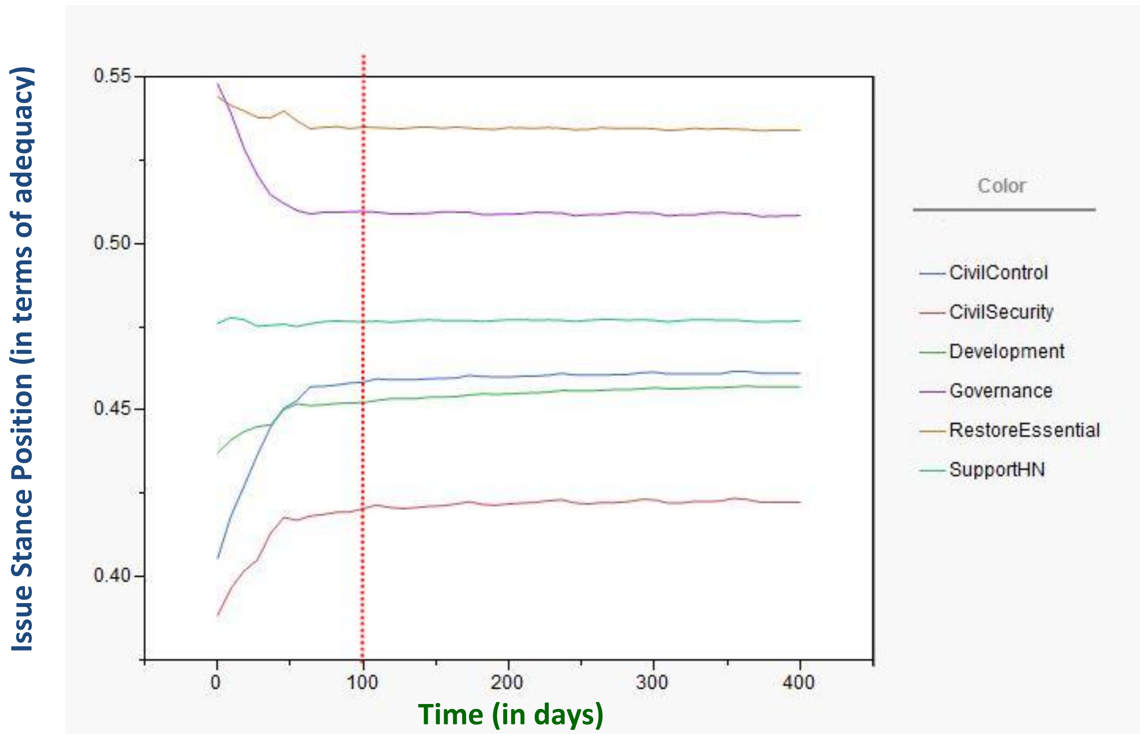


Figure 9. Warmed-Up Time and Mean Issue Stance Position across Time in Days

2. Analysis

JMP is used to perform statistical analysis on the sensitivity, significant factors and stereotype observations. The distributions of the issue stance positions are first plotted to check for normality and outliers across replications and across design points. These histograms and graphical plots provide an indication of the overall sensitivity of the cognitive architecture in terms of replications and design points. Multiple linear regression are then applied to fit a suitable model using the nine cognitive architecture design factors for each of the six issue stances, based on the 35 post-processed mean issue stance positions with respect to the design points. Using hypothesis testing, the models fitted can help to identify which significant design factors in the cognitive architecture have higher confidence levels (or lower p-values) in contributing to the civilian stance positions on the issues. Another analysis technique, Classification and Regression Trees, which partitions the level ranges of key factors into hierarchical binary trees, is employed to help determine the significant design factors affecting each of the issue stance positions.

As with all regression models, assumptions should be checked before inferences are drawn. For the fitted models of the issue stance positions with the cognitive architecture factors, the assumptions checked are: (1) Equal variances of the residuals, (2) Little or no bias in the expected values of the output, with the mean of residuals close to zero, (3) Independence between design points and between replications, and (4) Normality of the residual values.

B. OVERALL SENSITIVITY ANALYSIS RESULTS

For the overall sensitivity analysis, the objective is to provide an indication of the extent of changes on the issue stance positions due to changes in the levels of cognitive architecture factors, represented by design points. It also reveals whether there are design point outliers that influence the stance positions by a larger degree compared to other design points.

The effect of replications on the issue stance positions is first checked to determine if bias exists, before sensitivity analysis is done on the design points. For each issue stance and replication, the mean stance position across all 35 design points are taken and plotted with the replication indexes from 1 to 30, with the results shown in Figure 10. The minimal variations in the issue stance positions indicate that none of randomly seeded replications are biased towards all issue stances.

The next step involves looking at the overall effect of the design points on the issue stance, based the on collapsed mean issue stance positions by design points, for each issue. Figure 11 shows the result, which reveals that there is minimal impact (less than 0.01 or 1% difference in magnitude on a scale of 0 to 1) on the issue stances across all design points.

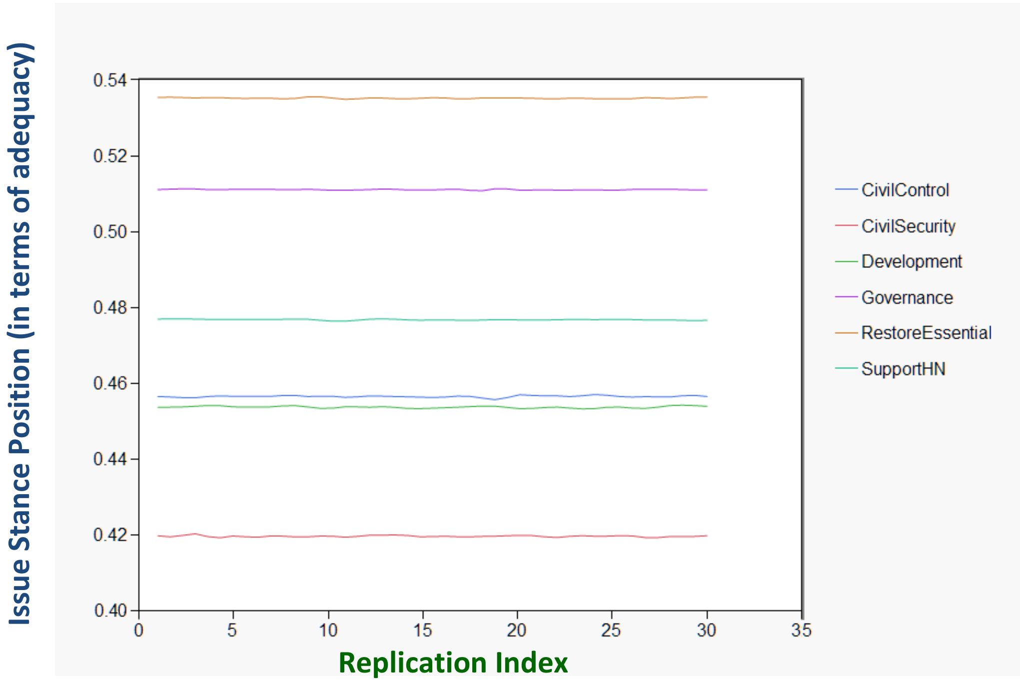


Figure 10. Issue Stance Positions by Replications.

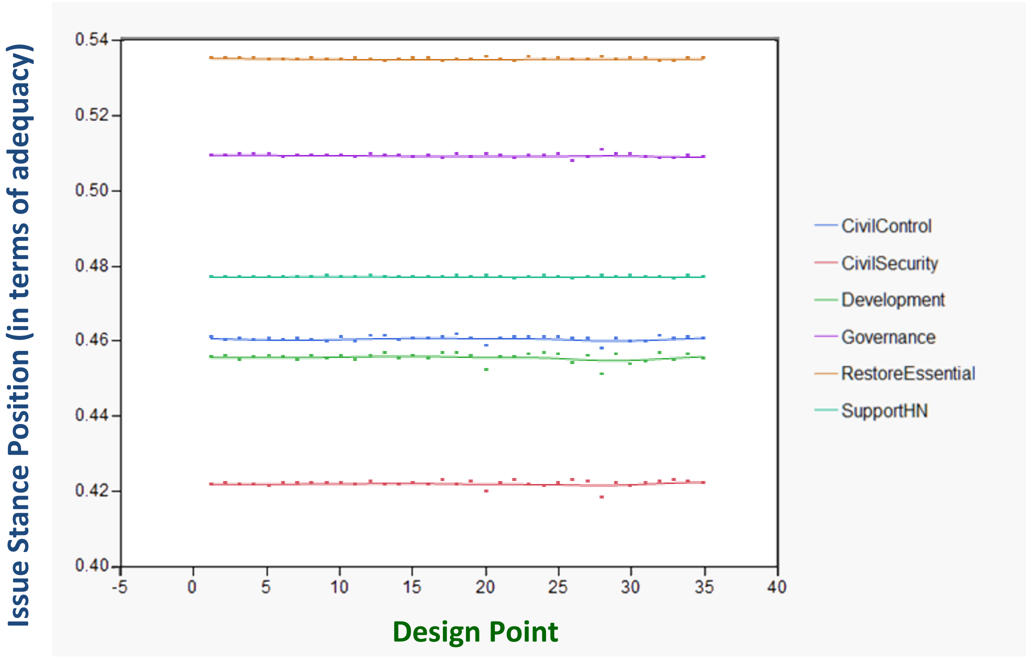


Figure 11. Issue Stance Positions by Design Points

Although the overall effect may not be significant, by looking at the different design point distributions on the individual issue stances, more insights can be observed. The histograms of the distributions are shown in Figures 12 and 13, along with their statistical mean, maximum, minimum and standard deviation values.

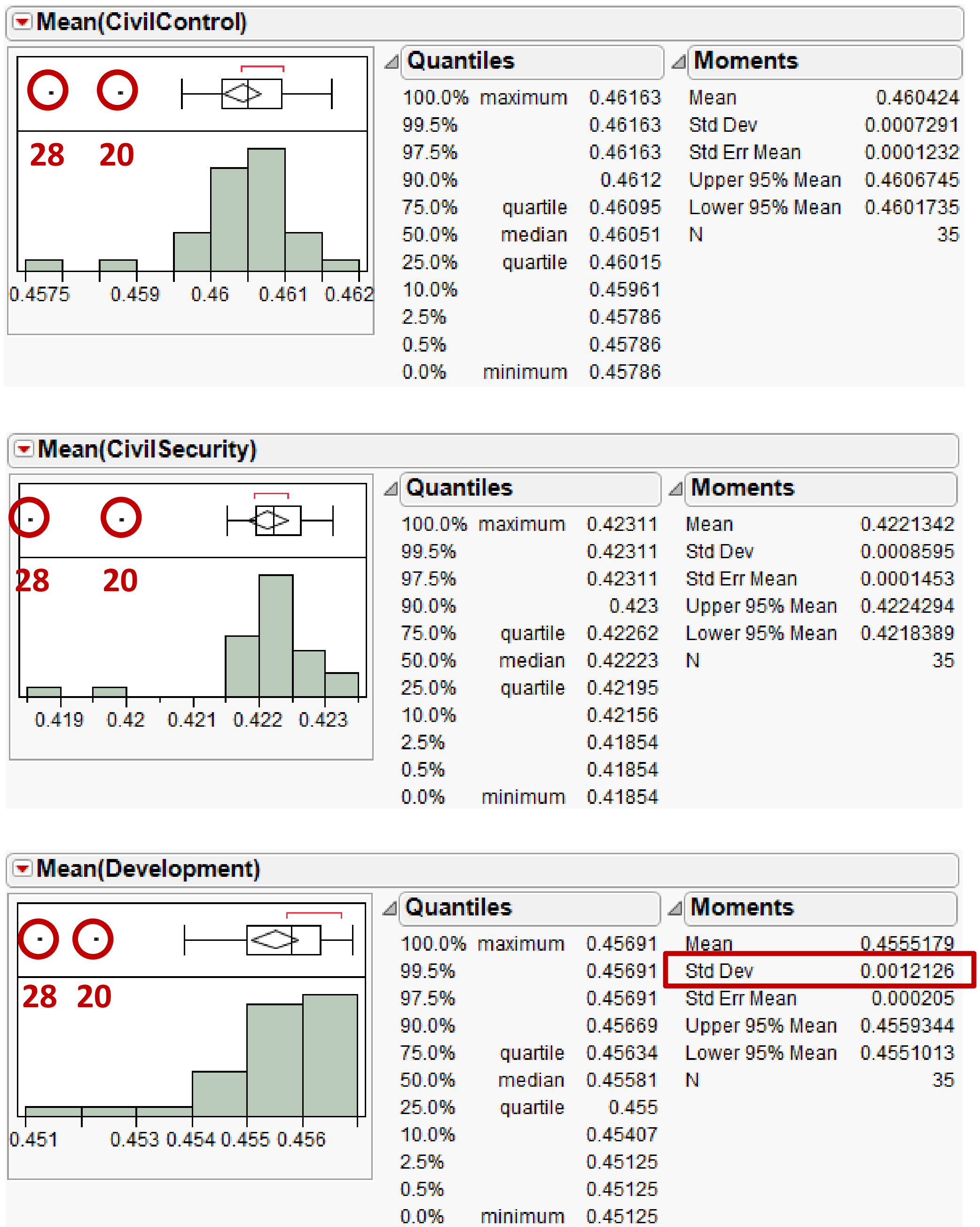
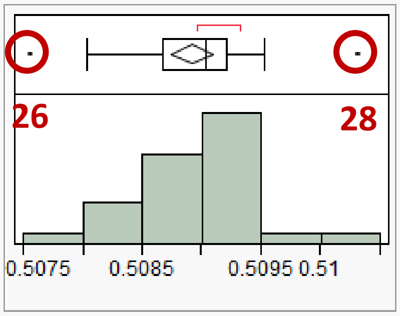


Figure 12. Histogram of Civil Control, Civil Security, and Economic and Infrastructure Development Issue Stance Positions by Design Points

Mean(Governance)



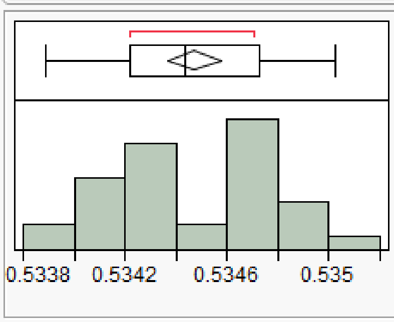
Quantiles

100.0%	maximum	0.51032
99.5%		0.51032
97.5%		0.51032
90.0%		0.50933
75.0%	quartile	0.50922
50.0%	median	0.50904
25.0%	quartile	0.50867
10.0%		0.50817
2.5%		0.50756
0.5%		0.50756
0.0%	minimum	0.50756

Moments

Mean	0.5089224
Std Dev	0.0004997
Std Err Mean	8.4471e-5
Upper 95% Mean	0.5090941
Lower 95% Mean	0.5087507
N	35

Mean(RestoreEssential)



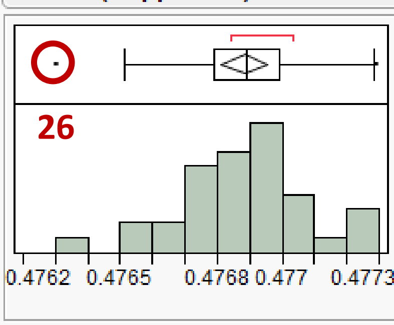
Quantiles

100.0%	maximum	0.53503
99.5%		0.53503
97.5%		0.53503
90.0%		0.53488
75.0%	quartile	0.53472
50.0%	median	0.53443
25.0%	quartile	0.53422
10.0%		0.53406
2.5%		0.53389
0.5%		0.53389
0.0%	minimum	0.53389

Moments

Mean	0.5344721
Std Dev	0.0003096
Std Err Mean	5.2336e-5
Upper 95% Mean	0.5345785
Lower 95% Mean	0.5343658
N	35

Mean(SupportHN)



Quantiles

100.0%	maximum	0.47729
99.5%		0.47729
97.5%		0.47729
90.0%		0.47717
75.0%	quartile	0.47699
50.0%	median	0.47689
25.0%	quartile	0.47679
10.0%		0.47661
2.5%		0.4763
0.5%		0.4763
0.0%	minimum	0.4763

Moments

Mean	0.4768845
Std Dev	0.0002064
Std Err Mean	3.4884e-5
Upper 95% Mean	0.4769554
Lower 95% Mean	0.4768136
N	35

Figure 13. Histogram of Governance, Restoration of Essential Services, and Support to Host Nation Security Forces Issue Stance Positions by Design Points

From the histogram plots, the effects of the cognitive architecture design points in terms of variation or standard deviation are the greatest for the Economic and Infrastructure Development Issue and least for the Support to Host Nation Security Forces Issue. Although each issue has different mean stance position values, these are scenario-dependent on the actions being performed and locations of the civilian agents, both of which affect the perception and resultant change in issue stance positions. Therefore, differences in the mean values cannot be attributed to the cognitive architecture design factors alone.

On the other hand, the outlier design points are able to provide more information since the same few points (20, 26 and 28) exists across a number of issues. These outlier points are circled and numbered in red. From the factor levels of the design points in Table 9, design points 28 and 20 have the lowest Temperature factor levels of 0.1 and 0.38 respectively, in the level range from 0.1 to 10. The Temperature factor represents the volatility in selection of a range of motivational categories (e.g., physiological or social affiliation) and motivational goals within the categories (e.g. to communicate or not in the case of social affiliation). A low Temperature value for a civilian agent means that it will be more likely to select the same motivational categories and goals, which will in turn constrain the agent to the same set of actions driven by the motivational choices. So if these actions have a positive outcome on the adequacy of an issue (e.g., Governance), the related issue stance position will tend to increase more than the issue stance positions of agents in other design points with higher temperature values. However, if these actions lead to negative outcomes for some issues (e.g., Civil Control, Civil Security, and Economic and Infrastructure Development), the reverse will happen, leading to lower issue stance positions on adequacy. Therefore, the observations on the issue stance positions for the low Temperature outlier design points 20 and 28 are reasonable. As for design point 26, it has the highest Temperature factor level of 9.72, but the lowest Selection Attention Threshold factor level of 1, in the level range from 1 to 90. Having a high Temperature means the motivation and resultant associated actions chosen will be more volatile and randomly determined, making it difficult to estimate the effects on the issue stances. Selection Attention Threshold defines which events perceived by the civilian agent are to be discarded based on the age (in time units) of the events which are communicated to it by another agent. Since each time unit in the simulation represents one day, a Selection Attention Threshold of 1 for the civilian agent means all messages passed on to it that are more than a day old will be discarded. As agents need time to pass messages across geographical distances, it is likely that the civilian agents in design point 26 are affected by only events that they perceive personally and events shared by agents near them. So if actions by actors and other civilians around an agent's location have a negative effect on the adequacy of an issue stance (e.g., Governance, and Support to Host Nation Security Forces), these issue stance positions will tend be lower compared to other design points where agents have higher Selective Attention Thresholds.

Instead of plotting histograms, the distribution of design points across each issue stance can also be plotted as dots, which provides an indication of how far each design point deviates from the distribution centroid line. These dotted graphical plots are shown in Figures 14 to 19, with the outlier design points indicated in red and likely contributing factors in green text (bracketed values denote the factor level).

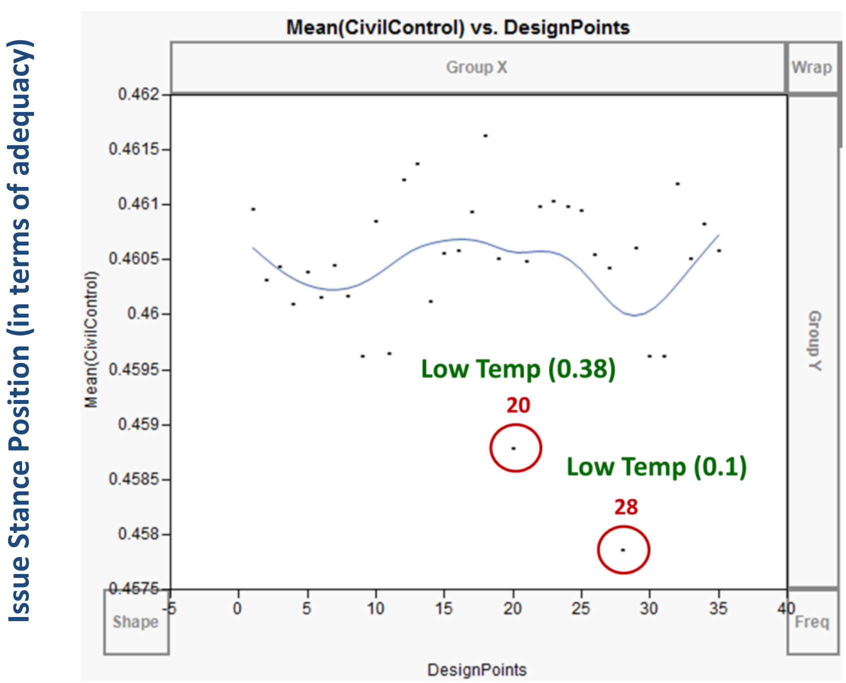


Figure 14. Plots of Civil Control Issue Stance Positions by Design Points

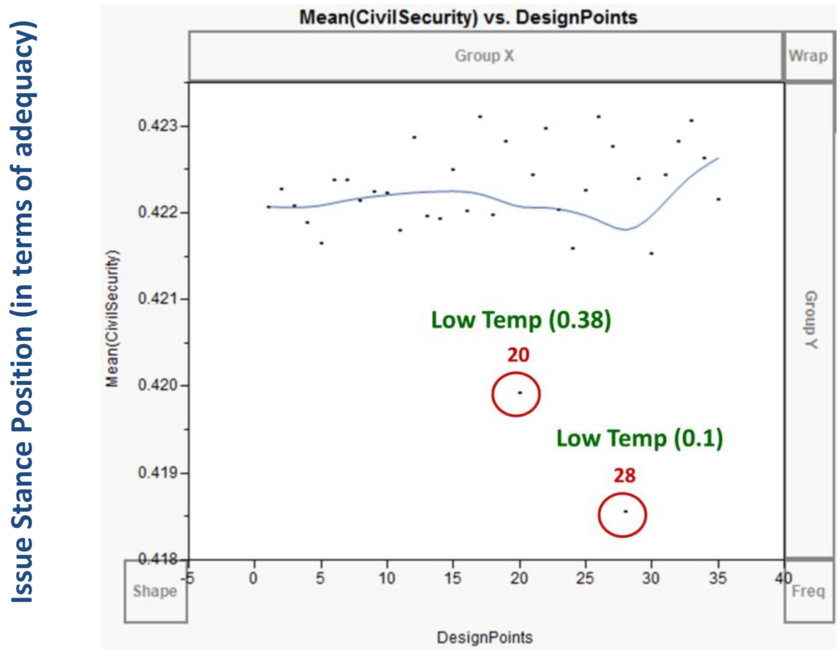


Figure 15. Plots of Civil Security Issue Stance Positions by Design Points

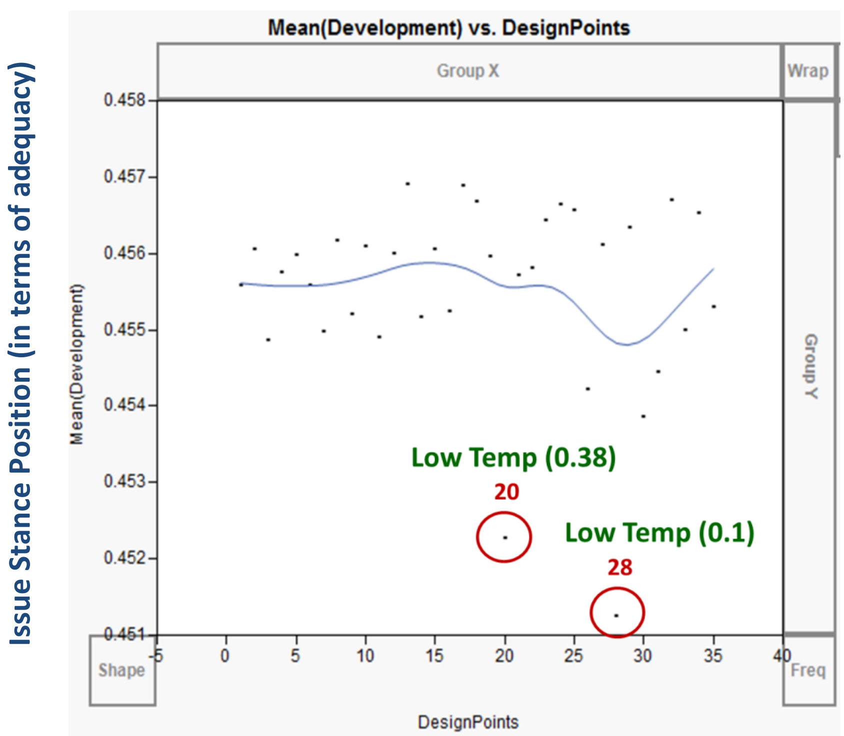


Figure 16. Plots of Economic and Infrastructure Development Issue Stance Positions by Design Points

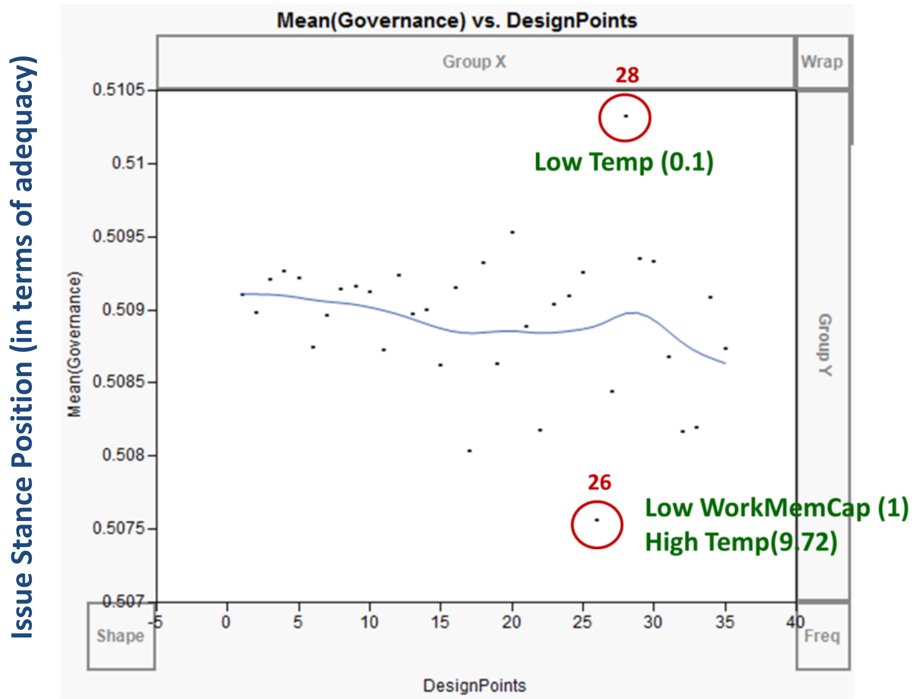


Figure 17. Plots of Governance Issue Stance Positions by Design Points

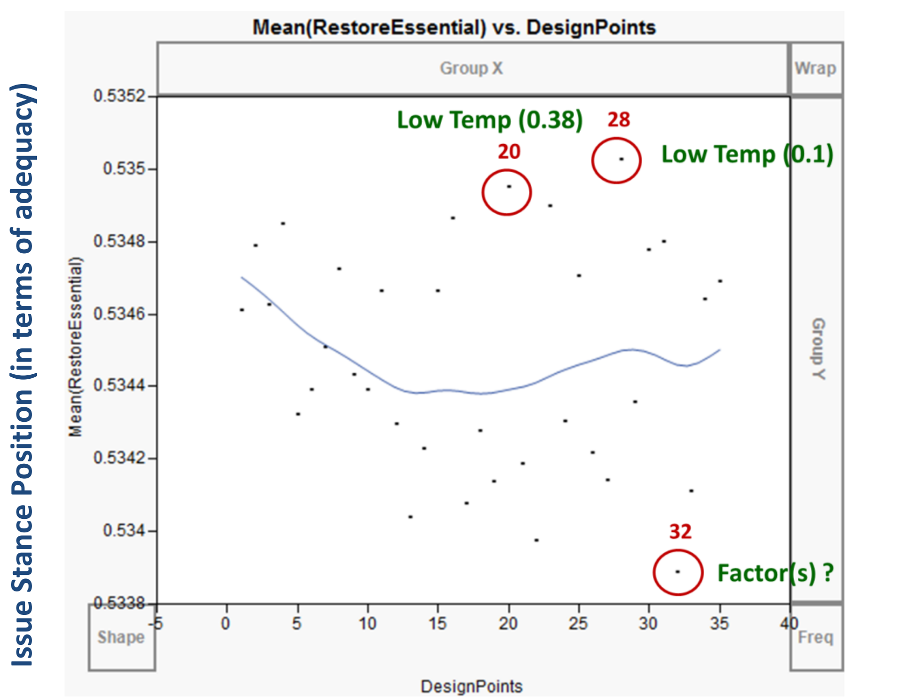


Figure 18. Plots of Restoration of Essential Services Issue Stance Positions by Design Points

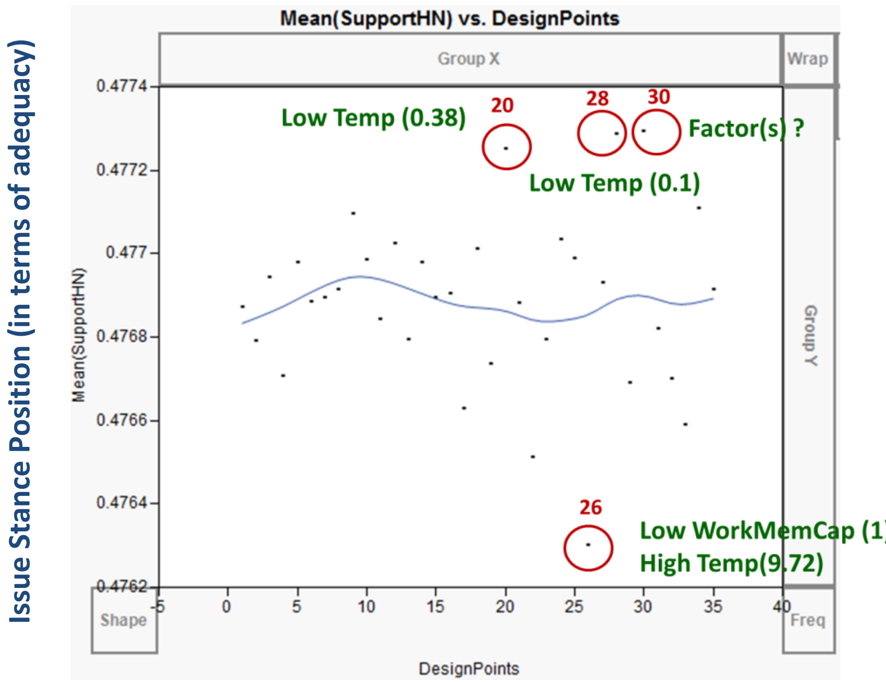


Figure 19. Plots of Support to Host Nation Security Forces Issue Stance Positions by Design Points

The plot results are similar with the histogram distribution, for outlier design points 20, 26 and 28. However, two additional outlier design points were obtained from the dotted plots, which are 30 and 32. Based on the factor levels for these two design points, there wasn't a single factor that borders on the extremes of the level ranges to explain for notably higher (design point 30) or lower (design point 32) issue stance positions compared to other design points. This could very likely be due to the interaction of multiple factors leading to the salient differences in the stance positions. The next section will delve into analysis results with respect to individual factors and their interactions.

C. SIGNIFICANT FACTORS IDENTIFICATION

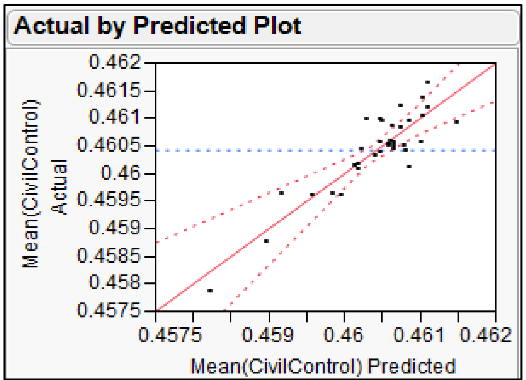
In significant factors identification, the objective is identify which of the cognitive architecture factors contribute more significantly to each of the six issue stance positions, in terms of the degree of adequacy. Contributions which result from interactions between two of the factors are also elicited from the analysis of the simulation.

There are two methods employed for significant factors identification in this study. The first method uses a multiple linear regression model which fits a straight line equation that outputs the expected issue stance position, based on the line intercept and linear coefficient terms of the cognitive architecture factor levels. Additional linear coefficients are used for representing factors in a quadratic form, and interactions between two factors. Using hypothesis testing, a p-value can be derived for the factor terms in the equation to assess the likelihood or significance that each of these factors contributes to the output issue stance positions. The other method is Classification and Regression Trees (CART), which partitions the output space of values into hierarchical binary groups, each of which is associated with a factor level range that contributes to it. This method provides an easy way to see which are the significant contributing factors, by locating them in the upper branches of the hierarchical tree structure.

1. Multiple Linear Regression Analysis Results

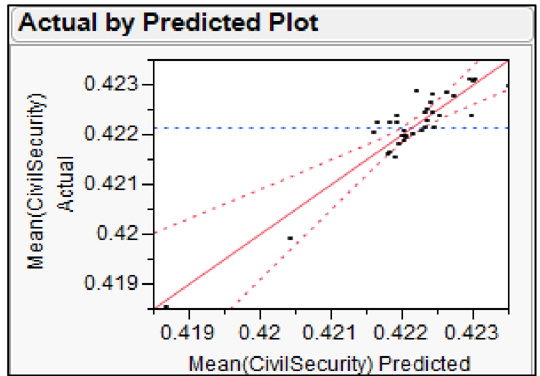
For each issue of interest, a multiple linear regression model was fitted. From the fit, corresponding R-squared and Adjusted R-squared values obtained. The R-squared value, ranging from 0 to 1, indicates degree to which the output issue stance positions can be computed by all the cognitive architecture regression factors in the fitted equation or model. A value of 1 means that factors are a perfect fit, and they can determine the exact output issue stance position, given the input factor levels. Increasing the number of regression factor terms will tend to provide a better fit, but it also leads to over fitting, which will result in a less effectively matched model if new issue stance positions are introduced (e.g., a different set of random seeds are used in the simulation runs). The Adjusted R-squared term provides a penalty for every additional factor added to the regression model. Therefore, a high R-Squared with a low Adjusted R-squared value indicates that they are too many unnecessary variables in the fit, compared to a result with both high R-Squared and Adjusted R-squared values.

Figure 20 shows the plots of the multiple linear regression models fitted for each of the six issue stances and their positions, along with the R-squared and Adjusted R-squared values displayed before the plots. The fitted lines are in solid red, with black dots representing the actual issue stance positions.



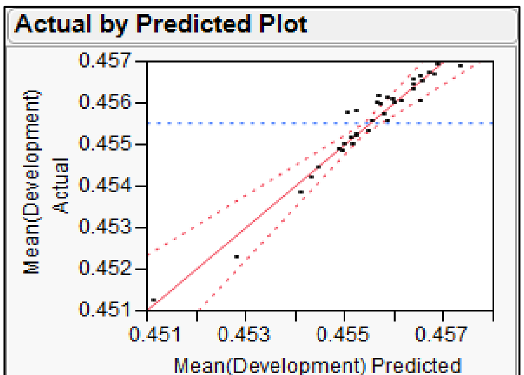
Summary of Fit

RSquare	0.798539
RSquare Adj	0.73655



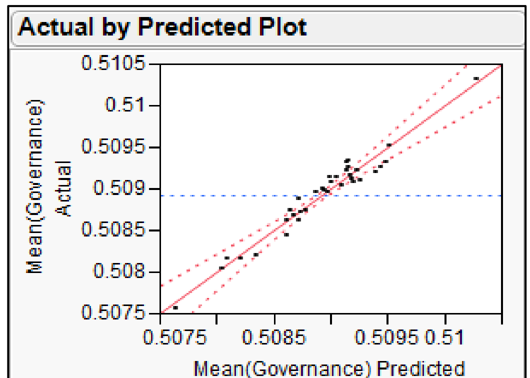
Summary of Fit

RSquare	0.873806
RSquare Adj	0.804973



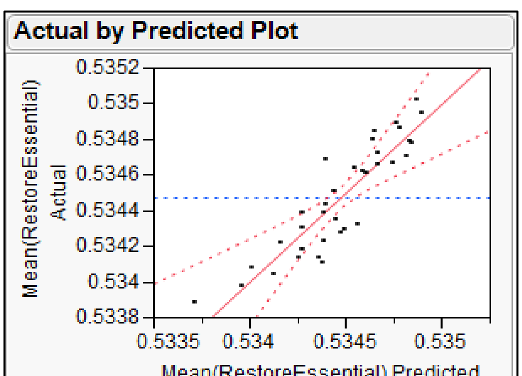
Summary of Fit

RSquare	0.95322
RSquare Adj	0.916288



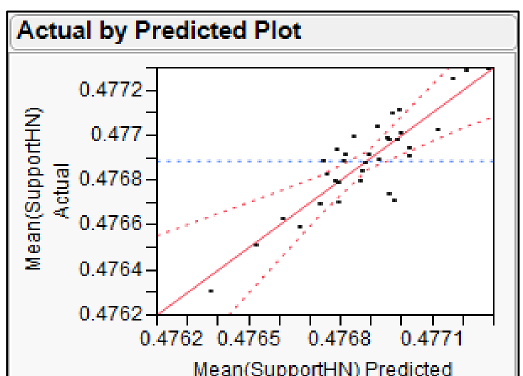
Summary of Fit

RSquare	0.952113
RSquare Adj	0.929211



Summary of Fit

RSquare	0.810506
RSquare Adj	0.719878



Summary of Fit

RSquare	0.781098
RSquare Adj	0.689889

Figure 20. Linear Regression Model Fit of Issue Stance Positions by Design Points

To select the appropriate factors for the fitting, Forward Stepwise regression is used to increasingly add factor terms and compare the fits to get the minimum Akiaiki's Information Criterion (AIC) value. AIC checks the likelihood of the fit and adds a penalty for each factor term added. Compared to Backward Stepwise Regression, which starts with all possible terms and drops them in a decremental manner for fit checking, Forward Stepwise Regression uses less factor terms and avoids over fitting. The latter technique is chosen since the focus of this study is to identify the significant factors and not all factors.

The resultant plots in Figure 20 indicate that best fit is obtained for the Economic and Infrastructure Development Issue, and the Governance Issue, with both having R-Squared values of over 0.95 and Adjusted R-Squared values of over 0.91. The worst fit in terms of the variation of the dots from the fitted line, was for the Support to Host Nation Security Forces Issue, which manages an R-Squared value of 0.78 and a much lower Adjusted R-Squared value of 0.69, an almost 10% drop from its R-Squared value.

For each fitted model associated with their issue stances, hypothesis or inference testing is done using the t-statistic to determine the p-value, or the probability that the factor does not contribute to the issue stance. The standard error deviations from the output issue stance positions will be used to derive the t-statistic for checking the p-value of each factor. As there are more than a few cognitive architecture factor terms contributing to the issue stances, only terms with p-values of 0.01 and below (or contribution likelihood of at least 99% and above) are considered significant in this study. Interaction plots generated using JMP are also used to analyze the significant factor interactions derived from the inference tests. The results are categorized by issue stances.

a. Civil Control Issue

Figure 21 shows the list of factor terms in the fitted multiple linear regression model, in descending order of significance to the Civil Control issue stance. The highlighted red box refers to the significant factor terms. The p-values are in the "Prob > |t|" column.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
temp	0.0001589	2.279e-5	6.97	<.0001*
(expComm-44.2286)*(expCommTU-44.2286)	-4.699e-7	9.7e-8	-4.84	<.0001*
(temp-4.90857)*(temp-4.90857)	-0.000037	8.872e-6	-4.17	0.0003*
(temp-4.90857)*(initTemp-4.90857)	3.273e-5	8.549e-6	3.83	0.0007*
(expCommTU-44.2286)*(temp-4.90857)	2.585e-6	1.015e-6	2.55	0.0171*
initTemp	-2.485e-5	2.282e-5	-1.09	0.2860
expCommTU	1.0301e-6	2.575e-6	0.40	0.6924
expComm	5.9914e-7	2.595e-6	0.23	0.8192

Figure 21. Multiple Linear Regression Factor Terms for Civil Control Issue Stance

(1) Significant Single Factors.

- **Temperature.** There is only one significant single factor, which is the Temperature, with a p-value less than 0.0001 or contribution likelihood of more than 99.99%. The Temperature factor represents the volatility of selecting among motivation categories and motivational goals, which lead to a corresponding set of actions related to the motivational choices that can be performed by individual civilian agents. The actions chosen and their corresponding events generated will likely be different for every decision made, if Temperature level is high or more volatile, while a low Temperature means the same set of actions are likely to be performed as they result from a stable and less often changing choice of motivation categories and motivational goals. So it seems reasonable that different actions possibilities for low and high Temperature levels will have different effects on the Civil Control issue stance position.

(2) Significant Quadratic Factors.

- **Temperature.** Temperature is also a quadratic term for the Civil Control issue. Since Temperature level is an exponential input for determining the volatility of selecting motivation categories and motivational goals. (Chapter II, Part D, Section 2), it will have diminishing effects on the changes in motivational choices and resultant actions performed, for affecting the Civil Control issue stance positions.

Figure 22 shows the two-factor interaction plots for the multiple linear regression model of the Civil Control issue stance. The vertical axes on the left refer to the mean civilians' adequacy on the issue, while the horizontal axes at the bottom refer to the level ranges of factors in their respective columns. Values within the plots correspond to levels for the factors in each row. They interact with the vertical factor levels via the blue and red lines to produce different issue stance positions in terms of its adequacy. Significant interaction terms derived from Figure 21 are circled in red.

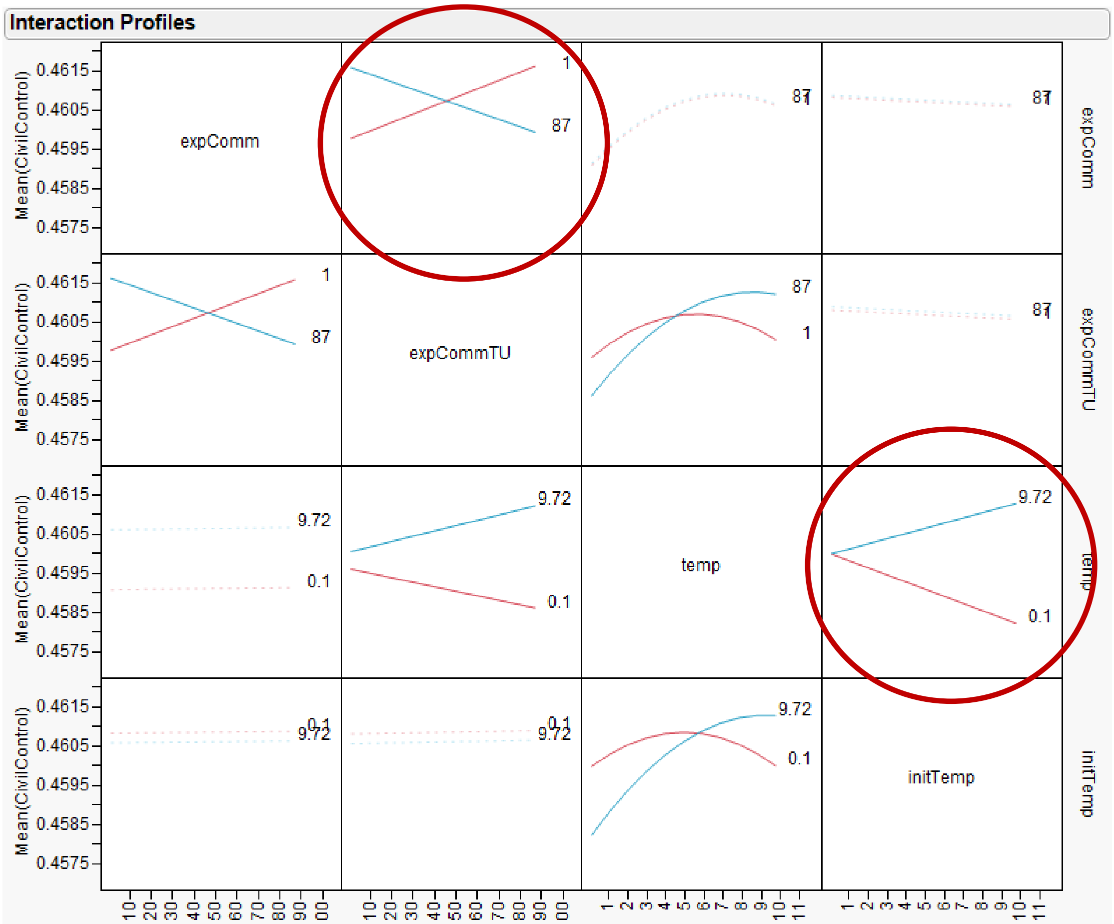


Figure 22. Multiple Linear Regression Interaction Plots for Civil Control Issue Stance

(3) Significant Interaction Factors.

- **Expected Communication and Expected Communication Time Units.** Civilian agents have a motivation to communicate with other agents in the same social network on perceived events. More communication messages passed will lead to more changes in the issue stances from new events perceived in those messages. The number of times each agent is motivated to communicate is given by the Expected Communication factor level, and the time interval for meeting this number of communication instances is specified by the Expected Communication

Time Units. Therefore, there is an inherent relationship between the Expected Communication factor and Expected Communication Time Units factor. A higher Expected Communication factor level will lead to increase communications performed, while a longer Expected Communication Time Units factor level leads to a drop in the number of communication messages passed among agents. Both factor levels result in different numbers of potential communication events and since events communicated affects the issue stances of individuals, the final issue stance positions are likely to differ.

- **Temperature and Initial Temperature.** Temperatures refers to volatility of making choices for motivation categories and motivational goals, while Initial Temperature refers to the volatility of selecting among a set of actions associated with the motivation categories and motivational goals selected. For a low Temperature, there is less volatility and a higher tendency to select the same motivation categories and motivation goals, which constraints the range of actions to be selected to those tied to the motivation choices. In this case, the different levels for Initial Temperature will only lead to effects on issue stances brought about by the limited range of actions for selection, so volatility of choices is kept within those actions. If the Temperature is high, the different levels of Initial Temperature will have a larger range of actions to select from, thus increasing the volatility scope and effects on issue stances.

b. Civil Security Issue

Figure 23 shows the list of factor terms in the fitted multiple linear regression model, in descending order of significance to the Civil Security issue stance. The highlighted red box refers to the significant factor terms. The p-values are in the "Prob > |t|" column.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
temp	0.0001268	2.316e-5	5.47	<.0001*
(workMemCap-6.42857)*(expThresh-5.14286)	-5.731e-5	1.174e-5	-4.88	<.0001*
(expThresh-5.14286)*(initTemp-4.90857)	-3.131e-5	8.437e-6	-3.71	0.0012*
linkWtUpdInt	-0.000034	9.836e-6	-3.46	0.0023*
(linkWtUpdInt-15.0857)*(linkWtUpdInt-15.0857)	-3.802e-6	1.234e-6	-3.08	0.0055*
expThresh	6.9478e-5	2.374e-5	2.93	0.0078*
(lambda-0.53714)*(initTemp-4.90857)	-0.000377	0.000132	-2.85	0.0093*
(workMemCap-6.42857)*(temp-4.90857)	2.637e-5	1.016e-5	2.59	0.0165*
(temp-4.90857)*(linkWtUpdInt-15.0857)	6.8199e-6	2.927e-6	2.33	0.0294*
workMemCap	-0.000066	0.000032	-2.07	0.0508
initTemp	1.218e-5	2.552e-5	0.48	0.6378
lambda	0.0000309	0.000269	0.11	0.9096

Figure 23. Multiple Linear Regression Factor Terms for Civil Security Issue Stance

(1) Significant Single Factors.

- **Temperature.** Temperature is the primary significant single factor, with a p-value less than 0.0001 or contribution likelihood of more than 99.99%. The Temperature factor represents the volatility of selecting among motivation categories and motivational goals, which lead to a corresponding set of actions related to the motivational choices that can be performed by individual civilian agents. The actions chosen and their corresponding events generated will likely be different for every decision made, if Temperature level is high or more volatile, while a low Temperature means the same set of actions are likely to be performed as they result from a stable and less often changing choice of motivation categories and motivational goals. So it seems reasonable that different actions possibilities for low and high Temperature levels will have different effects on the Civil Security issue stance position.

- **Link Weight Update Interval.** The Link Weight Update Interval factor determines the periodic interval in time units (or days in this scenario) for the social network of civilian agents to be updated, as issue stances changes to draw agents closer together due to their similarities, or to set them further apart when the differences among them are large. This social network affects whom the agent will communicate messages to and determines the social norms to be adopted for choosing among different actions based on their expected utility or reward (as covered in the Theory of Planned Behavior for action selection in Chapter III, Part B, Section 3). Changes in frequency of updates will result in different messages sent and received for each civilian agent as their issue stance changes during the simulation to affect their social network, and these in turn lead to subsequent changes in issue stance positions if messages passed involved events related to the issue stance concerned.

- **Experience Threshold.** The Experience Threshold factor determines the number of times each type of action must be performed before a civilian agent gains enough experience to switch from an Exploratory Learning mode to the Recognition-Primed Decision-making (RPD) mode for action selection. An agent in Exploratory Learning mode tends to be volatile or random in the selection of actions to be performed. This volatility increases the opportunity for decision choices to be spread across a wider range of actions in order to meet the Experience Threshold for performing each type of action. In the RPD mode, action choices will stabilize to those with better utilities or rewards. For a given set of actions taken, a high Experience Threshold means an agent takes a much longer time to exit Exploratory Learning mode and stabilize his action choices. The differences in actions chosen as a result of the time spent in Exploration Learning mode during the Experience Threshold levels will lead to varying events generated and perceived, and in turn carry different effects on the issue stance position.

(2) Significant Quadratic Factors.

- **Link Weight Update Interval.** The update frequency for determination of social networks is given by the Link Weight Update Interval factor, with a higher level indicating longer time periods between updates. However, the rate of update has an effect on communication or comparing of social norms in action selection only if there are sufficiently large changes in the civilian issue stance social dimension during the interval to cause a change in the social network. In cases where changes in the issue stance dimension is minimal, having a low Link Weight Update Interval level or high frequency of update has little effect on the changes in communication or action selection, which in turn leads to little effect on issue stances, compared to having updates which are slower or equal to the rate where changes in the issue stance dimension are more influential. This diminishing effect on the issue stance provides some explanation for the quadratic term.

Figure 24 shows the two-factor interaction plots for the multiple linear regression model of the Civil Security issue stance. The vertical axes on the left refer to the mean civilians' adequacy on the issue, while the horizontal axes at the bottom refer to the level ranges of factors in their respective columns. Values within the plots correspond to levels for the factors in each row. They interact with the vertical factor levels via the blue and red lines to produce different issue stance positions in terms of its adequacy. Significant interaction terms derived from Figure 23 are circled in red.

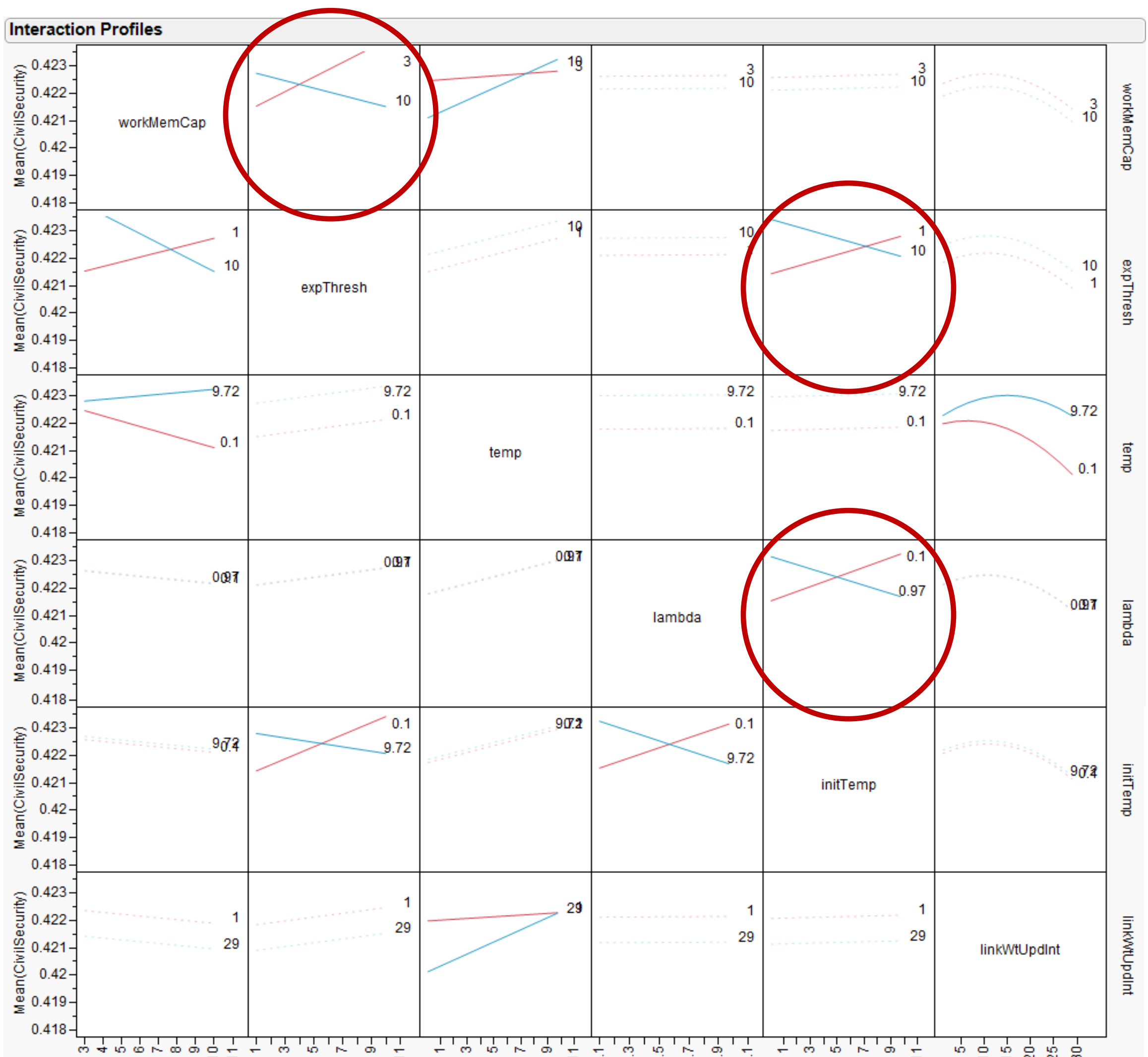


Figure 24. Multiple Linear Regression Interaction Plots for Civil Security Issue Stance

(3) Significant Interaction Factors.

- **Working Memory Capacity and Experience Threshold.** The Working Memory Capacity factor indicates how many events can be processed for each time instance. For a low Working Memory Capacity, even if a large number of events are perceived by a civilian agent at a time, these events have to be queued for gradual processing. The result will be multiple instances of motivation and action selection decisions, each based on the contents in the working memory. But for a high Working Memory Capacity, only one decision needs to be made, based the entire set of events perceived. The varying number of decisions and corresponding actions chosen will lead to different number of events generated to influence issue stances. On the other hand, for a given set of actions taken, the Experience Threshold is an indication of the time spent in the more volatile or random Exploratory Learning mode for action-selection, before switching to the Recognition-Primed Decision Making (RPD) mode where action choices tend to fall back to those with high utilities. The differences in actions chosen will thus affect issue stances differently when comparing both modes. Therefore, the number of decisions made and actions selected due to the Working Memory Capacity will interact with the Experience Threshold in affecting the time to switch from Exploratory Learning to RPD mode, which in turn affects the issue stances.

- **Experience Threshold and Initial Temperature.** The Initial Temperature factor level sets the initial volatility level for action-selection in Exploratory Learning mode. As more types of actions are being performed and Experience Threshold for each action type is not crossed yet, the volatility of action-selection will be gradually lowered until RPD mode is reached, where the volatility is stabilized to those actions with higher utilities. However, if the Initial Temperature is high, the final volatility reached in RPD mode will still be fairly high, so action choices are not the same compared to a lower Initial Temperature in RPD mode. The mix of action choices for both the time spent in Exploratory Learning mode vs RPD mode due the Experience Threshold, and volatility level due to the Initial Temperature, results in different effects on issue stances.

- **Lambda and Initial Temperature.** The Lambda factor, which ranges from 0 to 1, refers to the discount rate for computing utilities with actions that were performed in the past. A Lambda factor of 0 means all previous actions do not contribute to utility computation for making action choices, while a factor of 1 means the full extent of previous actions are used to assess the utility of actions to be selected. Therefore, different Lambda values will have likely lead to different actions selected since the utilities for selection are not the same. Coupled with volatility of actions chosen due the Initial Temperature levels, the final effect on issue stances can vary widely.

c. Economic and Infrastructure Development Issue

Figure 25 shows the list of factor terms in the fitted multiple linear regression model, in descending order of significance to the Economic and Infrastructure Development issue stance. The highlighted red box refers to the significant factor terms. The p-values are in the "Prob > |t|" column.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
(temp-4.90857)*(temp-4.90857)	-0.000115	0.000015	-7.68	<.0001*
temp	0.0001595	2.955e-5	5.40	<.0001*
lambda	0.0016548	0.000354	4.68	0.0002*
(temp-4.90857)*(lambda-0.53714)	0.0005816	0.000135	4.30	0.0004*
(expComm-44.2286)*(temp-4.90857)	-3.727e-6	9.188e-7	-4.06	0.0007*
expComm	1.1684e-5	2.892e-6	4.04	0.0007*
(expThresh-5.14286)*(expComm-44.2286)	3.4159e-6	8.817e-7	3.87	0.0010*
(selAttThresh-44.2286)*(temp-4.90857)	5.2328e-6	1.368e-6	3.83	0.0011*
(expCommTU-44.2286)*(lambda-0.53714)	-0.000042	1.154e-5	-3.63	0.0018*
expThresh	8.6112e-5	2.446e-5	3.52	0.0023*
(selAttThresh-44.2286)*(expComm-44.2286)	3.9041e-7	1.113e-7	3.51	0.0023*
(temp-4.90857)*(linkWtUpdInt-15.0857)	8.5361e-6	2.567e-6	3.33	0.0036*
selAttThresh	-6.603e-6	2.829e-6	-2.33	0.0307*
expCommTU	-4.213e-6	2.629e-6	-1.60	0.1256
linkWtUpdInt	5.0686e-6	7.56e-6	0.67	0.5106

Figure 25. Multiple Linear Regression Factor Terms for Economic and Infrastructure Development Issue Stance

(1) Significant Single Factors.

- **Temperature.** Temperature is the primary significant single factor, with a p-value less than 0.0001 or contribution likelihood of more than 99.99%. The Temperature factor represents the volatility of selecting among motivation categories and motivational goals, which lead to a corresponding set of actions related to the motivational choices that can be performed by individual civilian agents. The actions chosen and their corresponding events generated will likely be different for every decision made, if Temperature level is high or more volatile, while a low Temperature means the same set of actions are likely to be performed as they result from a stable and less often changing choice of motivation categories and motivational goals. So it seems reasonable that different actions possibilities for low and high Temperature levels will have different effects on the Economic and Infrastructure Development issue stance position.

- **Lambda.** The Lambda factor, which ranges from 0 to 1, refers to the discount rate for computing utilities with actions that were performed in the past. A Lambda factor of 0 means all previous actions do not contribute to utility computation for making action choices, while a factor of 1 means the full extent of previous actions are used to assess the utility of actions to be selected. Therefore, different Lambda values will have likely lead to different actions selected since the utilities for selection are not the same. It is reasonable to say that the outcomes of the actions affect the issue stances differently if Lambda values differ.
- **Expected Communication.** The Expected Communication factor determines the number of times each civilian agent is motivated to communicate with other agents in the same social network for each time interval specified by the Expected Communication Time Units factor. For a given time interval specified by the Expected Communication Time Units factor, the higher the Expected Communication level, the larger the tendency is for agents to communicate with each other, leading to more changes in issue stances, compared to lower Expected Communication levels.
- **Experience Threshold.** The levels in the Experience Threshold factor determines the number of times each type of action must be performed before a civilian agent gains enough experience to switch from an Exploratory Learning mode to the Recognition-Primed Decision Making (RPD) mode for action selection. An agent in Exploratory

Learning mode tends to be volatile or random in the selection of actions to be performed. This volatility increases the opportunity for decision choices to be spread across a wider range of actions in order to meet the Experience Threshold for performing each type of action. In the RPD mode, action choices will stabilize to those with better utilities or rewards. For a given set of actions taken, a high Experience Threshold means an agent takes a much longer time to exit Exploratory Learning mode and stabilizes his action choices. The differences in actions chosen as a result of the time spent in Exploration Learning mode during the Experience Threshold levels will lead to varying events generated and perceived, and in turn carry different effects on the issue stance position.

(2) Significant Quadratic Factors.

- **Temperature.** Temperature is also a quadratic term for the Economic and Infrastructure Development issue. Since Temperature level is an exponential input for determining the volatility of selecting motivation categories and motivational goals. (Chapter II, Part D, Section 2), it will have diminishing effects on the changes in motivational choices and resultant actions performed, for affecting the Economic and Infrastructure Development issue stance positions.

Figure 26 shows the two-factor interaction plots for the multiple linear regression model of the Economic and Infrastructure Development issue stance. The vertical axes on the left refer to the mean civilians' adequacy on the issue, while the horizontal axes at the bottom refer to the level ranges of factors in their respective columns. Values within the plots correspond to levels for the factors in each row. They interact with the vertical factor levels via the blue and red lines to produce different issue stance positions in terms of its adequacy. Significant interaction terms derived from Figure 25 are circled in red.

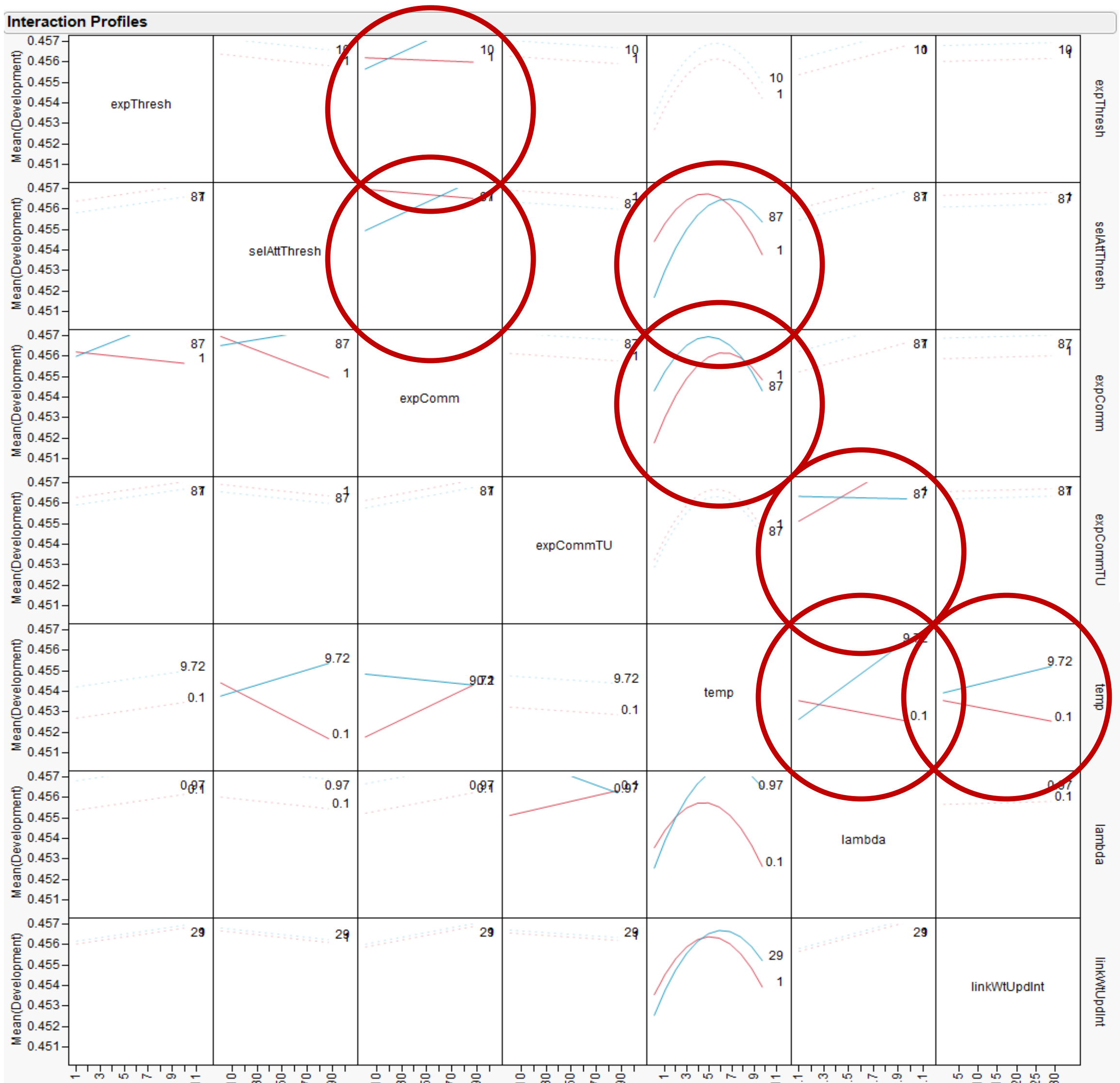


Figure 26. Multiple Linear Regression Interaction Plots for Economic and Infrastructure Development Issue Stance

(3) Significant Interaction Factors.

- **Temperature and Lambda.** The Temperature factor determines the volatility of selecting motivation categories and motivation goals, which constraints the range of actions to be selected to those tied to the motivation choices. The Lambda factor refers to the discounted rate for computing utilities with actions that were performed in the past. Therefore, different Lambda values will have likely lead to different actions selected since the utilities for selection are not the same. However, the action choices affected by Lambda factor is different if the Temperature factor leads to a constraint on the range of action choices. So the final effect on issue stances will vary with both Lambda and Temperature.

- **Expected Communication and Temperature.** As indicated in significant Expected Communication single factor, a higher Expected Communication level leads to more changes in issue stances. Coupled with the different types of action choices affecting the issue stances due to the volatility of motivational choices derived from the Temperature factor, the final effect from both factors can be significant.

- **Experience Threshold and Expected Communication.** Experience Threshold is an indication of the time spent in the more volatile or random Exploratory Learning mode for action-selection, before switching to the Recognition-Primed Decision Making (RPD) mode where action choices tend to fall back to those with high utilities. The differences in actions chosen will thus affect issue stances differently when comparing both modes. As indicated in the significant Expected Communication single factor, a higher Expected Communication level leads to more changes in issue stances. Both of these factors working together seem to contribute to a wider variation in the issue stances.

- **Selective Attention Threshold and Temperature.** The Selective Attention Threshold factor provides the age in time units (or days) of events received which are to be discarded. A lower Selective Attention Threshold means only recent events matter to the issue stances, while a higher Selective Attention Threshold takes in many events which happen in the past to account for their effects on issue stances. The Temperature factor determines the volatility of selecting motivation categories and motivation goals, which constraints the range of actions to be selected to those tied to the motivation choices. Both the range of actions for selection due the Temperature factor and the number of events affecting the issue stances due to the Selective Attention Threshold factor can combine to produce varying effects on issue stances.
- **Expected Communication Time Units and Lambda.** The Expected Communication Time Units factor constraints the communication of events among civilian agents to be completed within a given time interval. A shorter Expected Communication Time Units will thus lead to more communication events affecting the changes in issue stances. The Lambda factor refers to the discounted rate for computing utilities with actions that were performed in the past. Therefore, different Lambda values will have likely

lead to different actions selected since the utilities for selection are not the same. Together, both factors seem to provide a wider variation in the effects on the issue stances from both the communication events and action choices.

- **Selective Attention Threshold and Expected Communication.** The Selective Attention Threshold factor determines the age of events and thus number of events received for influencing the issues stances, while Expected Communication is tied to the amount of communication events affecting the issue stances. Both factors work together to determine different sets of events for affecting the issue stances.
- **Temperature and Link Weight Update Interval.** The Temperature factor affects the list of action choices selected and corresponding events generated for influencing issue stances, due to the volatility of the Temperature factor in determining the motivation categories and motivational goals for deriving available action choices. Link Weight Update Interval factor levels indicate the update frequency of social networks for civilian agents, affecting the communication links among agents who share similar issue stances within the simulation, and the social norms criteria for computation of utilities used in action selection. Events passed among agents due to changes in communication links and events generated due to the affected social norms criteria will thus be different. Together the range of events from both the Temperature and Link Weight Update Interval factors lead to more significant contributions in the issue stances.

d. Governance Issue

Figure 27 shows the list of factor terms in the fitted multiple linear regression model, in descending order of significance to the Governance issue stance. The highlighted red box refers to the significant factor terms. The p-values are in the "Prob > |t|" column.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
workMemCap	0.000124	1.149e-5	10.80	<.0001*
temp	-7.636e-5	8.472e-6	-9.01	<.0001*
(temp-4.90857)*(linkWtUpdInt-15.0857)	-5.059e-6	9.377e-7	-5.40	<.0001*
(workMemCap-6.42857)*(expThresh-5.14286)	1.9917e-5	4.195e-6	4.75	<.0001*
(selAttThresh-44.2286)*(temp-4.90857)	1.6144e-6	3.982e-7	4.05	0.0005*
(selAttThresh-44.2286)*(selAttThresh-44.2286)	-1.418e-7	4.675e-8	-3.03	0.0059*
(workMemCap-6.42857)*(temp-4.90857)	-1.161e-5	3.934e-6	-2.95	0.0071*
(expThresh-5.14286)*(temp-4.90857)	7.4076e-6	2.949e-6	2.51	0.0195*
selAttThresh	1.0271e-6	9.899e-7	1.04	0.3102
linkWtUpdInt	-1.491e-6	3.124e-6	-0.48	0.6377
expThresh	-2.394e-6	8.171e-6	-0.29	0.7721

Figure 27. Multiple Linear Regression Factor Terms for Governance Issue Stance

(1) Significant Single Factors.

- **Working Memory Capacity.** The Working Memory Capacity factor one of the primary significant single factors, with a p-value less than 0.0001 or contribution likelihood of more than 99.99%. It indicates how many events can be processed for each time instance. For a low Working Memory Capacity, even if a large number of events are perceived by a civilian agent at a time, these events have to be queued for gradual processing. The result will be multiple instances of motivation and action selection decisions, each based on the contents in the working memory. But for a high Working Memory Capacity, only one decision and action selection needs to be made, based the entire set of events perceived. The varying number of decisions and corresponding actions chosen will lead to different number of events generated to influence issue stances.

- **Temperature.** Temperature is the other primary significant single factor, with a similar p-value with the Working Memory Capacity factor, which is less than 0.0001 or having a contribution likelihood of more than 99.99%. The Temperature factor represents the volatility of selecting among motivation categories and motivational goals, which lead to a corresponding set of actions related to the motivational choices that can be performed by individual civilian agents. The actions chosen and their corresponding events generated will likely be different for every decision made, if Temperature level is high or more volatile, while a low Temperature means the same set of actions are likely to be performed as they result from a stable and less often changing choice of motivation categories and motivational goals. So it seems reasonable that different actions possibilities for low and high Temperature levels will have different effects on the Governance issue stance position.

(2) Significant Quadratic Factors.

- **Selective Attention Threshold.** The Selective Attention Threshold factor provides the age in time units (or days) of events received which are to be discarded. A lower Selective Attention Threshold means only recent events matter to the issue stances, while a higher Selective Attention Threshold takes in many events which happen in the past to account for their effects on issue stances. As the scenario may involve many agents whom are not located too far away from one another, it will not take too long for messages to reach another agent. Therefore, Selective Attention Threshold level with a discarding age that is longer than the time taken to pass the messages around will have little or no effect on the number of events accepted for influencing the issue stances.

Figure 28 shows the two-factor interaction plots for the multiple linear regression model of the Governance issue stance. The vertical axes on the left refer to the mean civilians' adequacy on the issue, while the horizontal axes at the bottom refer to the level ranges of factors in their respective columns. Values within the plots correspond to levels for the factors in each row. They interact with the vertical factor levels via the blue and red lines to produce different issue stance positions in terms of its adequacy. Significant interaction terms derived from Figure 27 are circled in red.

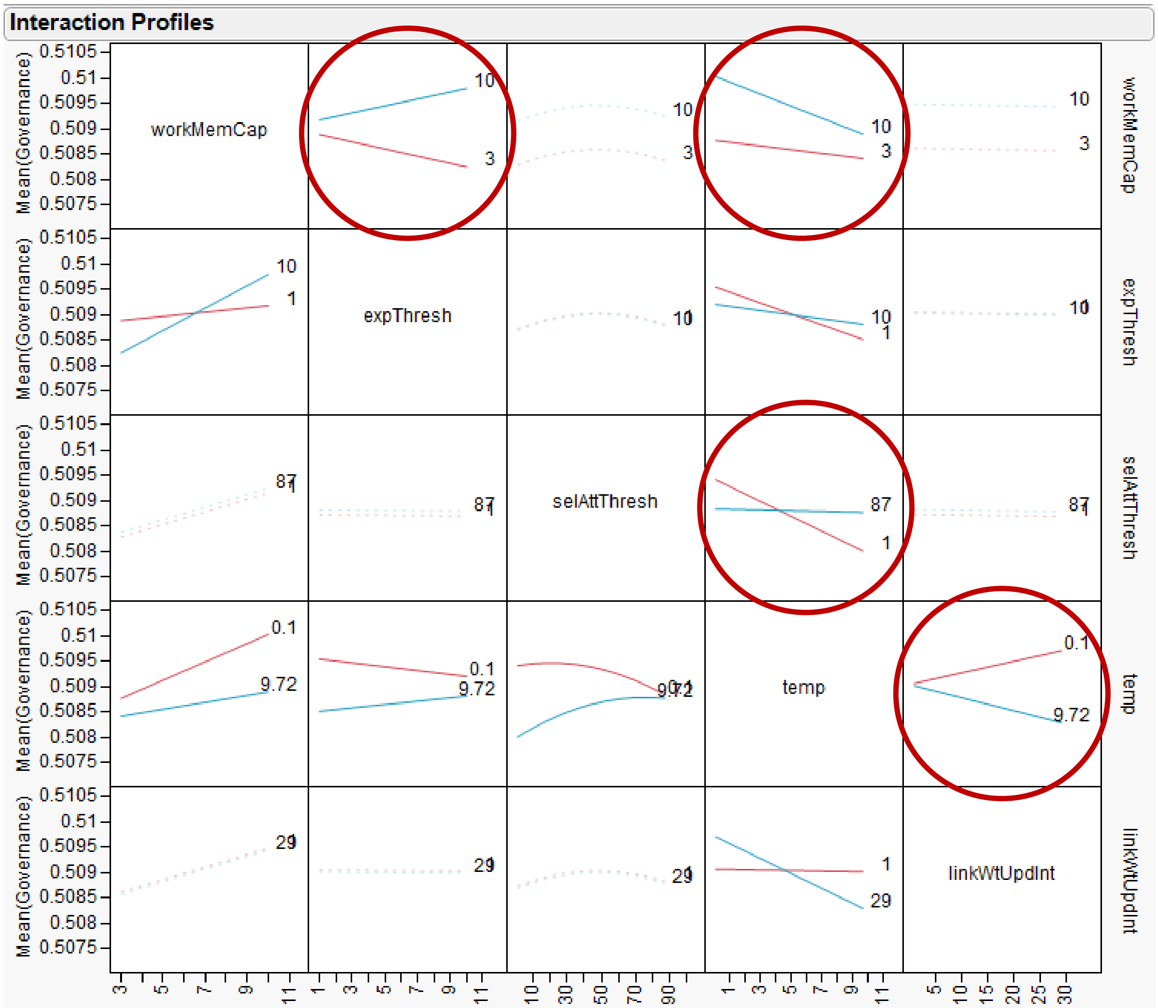


Figure 28. Multiple Linear Regression Interaction Plots for Governance Issue Stance

(3) Significant Interaction Factors.

- **Temperature and Link Weight Update Interval.** The Temperature factor affects the list of action choices selected and corresponding events generated for influencing issue stances, due to the volatility of the Temperature factor in determining the motivation categories and motivational goals for deriving available action choices. Link Weight Update Interval factor levels indicate the update frequency of social networks for civilian agents, affecting the communication links among agents who share similar issue stances within the simulation, and the social norms criteria for computation of utilities used in action selection. Events passed among agents due to changes in communication links and events generated due to the affected social norms criteria will thus be different. Together the range of events from both the Temperature and Link Weight Update Interval factors lead to more significant contributions in the issue stances.

- **Working Memory Capacity and Experience Threshold.** The Working Memory Capacity factor indicates how many events can be processed for each time instance. For a low Working Memory Capacity, even if a large number of events are perceived by a civilian agent at a time, these events have to be queued for gradual processing. The result will be multiple instances of motivation and action selection decisions, each based on the contents in the working memory. But for a high Working Memory Capacity, only one decision needs to be made, based the entire set of events perceived. The varying number of decisions and corresponding actions chosen will lead to different number of events generated to influence issue stances. On the other hand, for a given set of actions taken, the Experience Threshold is an indication of the time spent in the more volatile or random Exploratory Learning mode for action-selection, before switching to the Recognition-Primed Decision Making (RPD) mode where action choices tend to fall back to those with high utilities. The differences in actions chosen will thus affect issue stances differently when comparing both modes. Therefore, the number of decisions made and actions selected due to the Working Memory Capacity will interact with the Experience Threshold in affecting the time to switch from Exploratory Learning to RPD mode, which in turn affects the issue stances.

- **Selective Attention Threshold and Temperature.** The Selective Attention Threshold factor provides the age in time units (or days) of events received which are to be discarded. A lower Selective Attention Threshold means only recent events matter to the issue stances, while a higher Selective Attention Threshold takes in many events which happen in the past to account for their effects on issue stances. The Temperature factor determines the volatility of selecting motivation categories and motivation goals, which constraints the range of actions to be selected to those tied to the motivation choices. Both the range of actions for selection due the Temperature factor and the number of events affecting the issue stances due to the Selective Attention Threshold factor can combine to produce varying effects on issue stances.

- **Working Memory Capacity and Temperature.** The Working Memory Capacity factor indicates how many events can be processed for each time instance. For a low Working Memory Capacity, even if a large number of events are perceived by a civilian agent at a time, these events have to be queued for gradual processing. The result will be multiple instances of motivation and action selection decisions, each based on the contents in the working memory. But for a high Working Memory Capacity, only one decision needs to be made, based the entire set of events perceived. The varying number of decisions and corresponding actions chosen will lead to different number of events generated to influence issue stances. The Temperature factor affects the list of action choices selected and corresponding events generated for influencing issue stances, due to the volatility of the Temperature factor in determining the motivation categories and motivational goals for deriving available action choices. Both the number of events available for processing and corresponding number of actions made due to the Working Memory Capacity, and the different action choices available due to the Temperature factor work together to provide a larger variation in changes to the issue stance.

e. ***Restoration of Essential Services Issue***

Figure 29 shows the list of factor terms in the fitted multiple linear regression model, in descending order of significance to the Restoration of Essential Services issue stance. The highlighted red box refers to the significant factor terms. The p-values are in the "Prob > |t|" column.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio		Prob>|t|
temp	-4.762e-5	0.000011	-4.32		0.0003*
expCommTU	5.0557e-6	1.201e-6	4.21		0.0003*
(temp-4.90857)*(linkWtUpdInt-15.0857)	-4.303e-6	1.229e-6	-3.50		0.0019*
(workMemCap-6.42857)*(expCommTU-44.2286)	1.8333e-6	5.761e-7	3.18		0.0041*
workMemCap	4.1377e-5	1.336e-5	3.10		0.0051*
(lambda-0.53714)*(initTemp-4.90857)	0.0001465	6.024e-5	2.43		0.0232*
(workMemCap-6.42857)*(workMemCap-6.42857)	-0.000019	7.908e-6	-2.40		0.0250*
(initTemp-4.90857)*(linkWtUpdInt-15.0857)	-3.739e-6	1.593e-6	-2.35		0.0278*
initTemp	2.5223e-5	1.17e-5	2.16		0.0418*
lambda	0.0001846	0.00012	1.53		0.1386
linkWtUpdInt	-4.152e-6	4.43e-6	-0.94		0.3584

Figure 29. Multiple Linear Regression Factor Terms for Restoration of Essential Services Issue Stance

(1) Significant Single Factors.

- **Temperature.** Temperature is one of the primary significant single factors, with a p-value of 0.0003 or a contribution likelihood of 99.97%. The Temperature factor represents the volatility of selecting among motivation categories and motivational goals, which lead to a corresponding set of actions related to the motivational choices that can be performed by individual civilian agents. The actions chosen and their corresponding events generated will likely be different for every decision made, if Temperature level is high or more volatile, while a low Temperature means the same set of actions are likely to be performed as they result from a stable and less often changing choice of motivation categories and motivational goals. So it seems reasonable that different actions possibilities for low and high Temperature levels will have different effects on the Restoration of Essential Services issue stance position.

- **Expected Communication Time Units.** The Expected Communication Time Units factor is the other primary significant single factor, with a similar p-value to the Temperature factor of 0.0003 or a contribution likelihood of 99.97%. This factor constraints the communication of events among civilian agents to be completed within a given time interval. A shorter Expected Communication Time Units will thus lead to more communication events affecting the changes in issue stances compared to a longer Expected Communication Time Units.

- **Working Memory Capacity.** The Working Memory Capacity factor indicates how many events can be processed for each time instance. For a low Working Memory Capacity, even if a large number of events are perceived by a civilian agent at a time, these events have to be queued for gradual processing. The result will be multiple instances of motivation and action selection decisions, each based on the contents in the working memory. But for a high Working Memory Capacity, only one decision needs to be made, based the entire set of events perceived. The varying number of decisions and corresponding actions chosen will lead to different number of events generated to influence issue stances.

(2) Significant Quadratic Factors.

There are no significant quadratic factors in the multiple linear regression model for the Restoration of Essential Services issue stance.

Figure 30 shows the two-factor interaction plots for the multiple linear regression model of the Restoration of Essential Services issue stance. The vertical axes on the left refer to the mean civilians' adequacy on the issue, while the horizontal axes at the bottom refer to the level ranges of factors in their respective columns. Values within the plots correspond to levels for the factors in each row. They interact with the vertical factor levels via the blue and red lines to produce different issue stance positions in terms of its adequacy. Significant interaction terms derived from Figure 29 are circled in red.

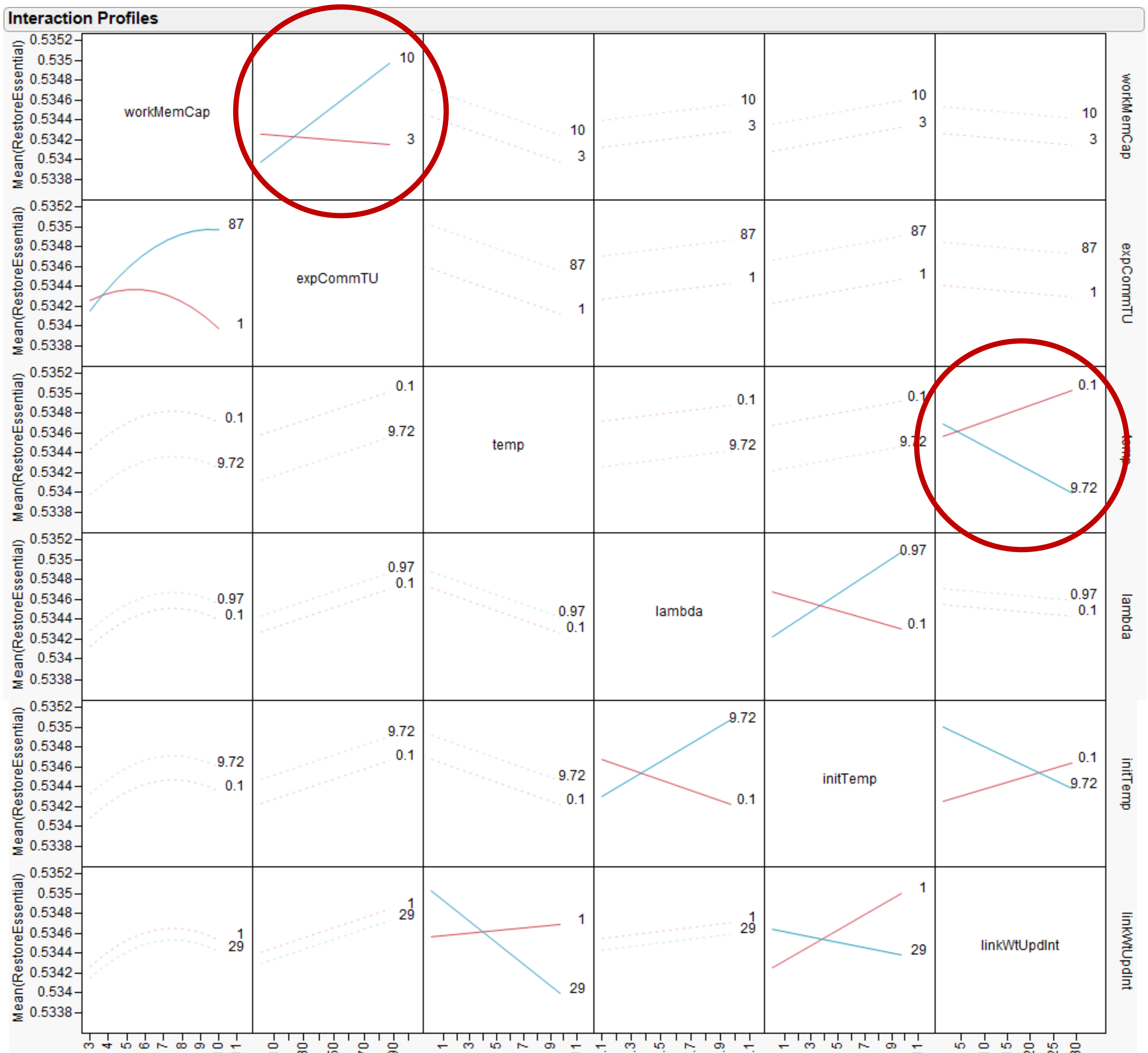


Figure 30. Multiple Linear Regression Interaction Plots for Restoration of Essential Services Issue Stance

(3) Significant Interaction Factors.

- **Temperature and Link Weight Update Interval.** The Temperature factor affects the list of action choices selected and corresponding events generated for influencing issue stances, due to the volatility of the Temperature factor in determining the motivation categories and motivational goals for deriving available action choices. Link Weight Update Interval factor levels indicate the update frequency of social networks for civilian agents, affecting the communication links among agents who share similar issue stances within the simulation, and the social norms criteria for computation of utilities used in action selection. Events passed among agents due to changes in communication links and events generated due to the affected social norms criteria will thus be different. Together the range of events from both the Temperature and Link Weight Update Interval factors lead to more significant contributions in the issue stances.

- **Working Memory Capacity and Expected Communication Time Units.** The Working Memory Capacity factor indicates how many events can be processed for each time instance. For a low Working Memory Capacity, even if a large number of events are perceived by a civilian agent at a time, these events have to be queued for gradual processing. The result will be multiple instances of motivation and action selection decisions, each based on the contents in the working memory. But for a high Working Memory Capacity, only one decision needs to be made, based the entire set of events perceived. The varying number of decisions and corresponding actions chosen will lead to different number of events generated to influence issue stances. The Expected Communication Time Units factor constraints the communication of events among civilian agents to be completed within a given time interval. A shorter Expected Communication Time Units will thus lead to more communication events affecting the changes in issue stances. The Working Memory Capacity factor's contribution on the number of events to be processed and number of actions made interacts with the Expected Communication Time Units factor's determination of the number of communications events, so the varying events generated will have a significant effect on the issue stance.

f. Support to Host Nation Security Forces Issue

Figure 31 shows the list of factor terms in the fitted multiple linear regression model, in descending order of significance to the Support to Host Nation Security Forces issue stance. The highlighted red box refers to the significant factor terms. The p-values are in the "Prob > |t|" column.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
(workMemCap-6.42857)*(expThresh-5.14286)	1.8675e-5	3.646e-6	5.12	<.0001*
temp	-2.78e-5	7.193e-6	-3.86	0.0007*
(selAttThresh-44.2286)*(temp-4.90857)	1.1221e-6	3.27e-7	3.43	0.0022*
(workMemCap-6.42857)*(temp-4.90857)	-1.013e-5	3.203e-6	-3.16	0.0042*
(expThresh-5.14286)*(expThresh-5.14286)	9.2636e-6	3.223e-6	2.87	0.0083*
(expThresh-5.14286)*(selAttThresh-44.2286)	-7.272e-7	3.054e-7	-2.38	0.0256*
workMemCap	1.9569e-5	9.603e-6	2.04	0.0527
(workMemCap-6.42857)*(workMemCap-6.42857)	-9.68e-6	5.04e-6	-1.92	0.0667
expThresh	-1.131e-5	8.418e-6	-1.34	0.1918
selAttThresh	4.1923e-8	8.75e-7	0.05	0.9622

Figure 31. Multiple Linear Regression Factor Terms for Support to Host Nation Security Forces Issue Stance

(1) Significant Single Factors.

- **Temperature.** Temperature is only significant single factors, with a p-value of 0.0007 or a contribution likelihood of 99.93%. The Temperature factor represents the volatility of selecting among motivation categories and motivational goals, which lead to a corresponding set of actions related to the motivational choices that can be performed by individual civilian agents. The actions chosen and their corresponding events generated will likely be different for every decision made, if Temperature level is high or more volatile, while a low Temperature means the same set of actions are likely to be performed as they result from a stable and less often changing choice of motivation categories and motivational goals. So it seems reasonable that different actions possibilities for low and high Temperature levels will have different effects on the Support to Host Nation Security Forces issue stance position.

(2) Significant Quadratic Factors.

- **Experience Threshold.** The levels in the Experience Threshold factor determine the number of times each type of action must be performed before a civilian agent gains enough experience to switch from an Exploratory Learning mode to the Recognition-Primed Decision Making (RPD) mode for action selection. An agent in Exploratory Learning mode tends to be volatile or random in the selection of actions to be performed. This volatility increases the opportunity for decision choices to be spread across a wider range of actions in order to meet the Experience Threshold for performing each type of action. In the RPD mode, action choices will stabilize to those with better utilities or rewards. For a given set of actions taken, a high Experience Threshold means an agent takes a much longer time to exit Exploratory Learning mode and stabilize his action choices. The differences in actions chosen as a result of the time spent in Exploration Learning mode during the Experience Threshold levels will lead to varying events generated and perceived, and in turn carry different effects on the issue stance position. However, there are some actions which are required to be performed only after long periodic intervals (e.g., legal services). In this case, the agent with even a moderate Experience Threshold level may not be able to exit the Exploratory Learning mode and thus higher Experience Thresholds will have diminishing effects on the differences in action choices, which leads to a quadratic effect on the issue stance.

Figure 32 shows the two-factor interaction plots for the multiple linear regression model of the Support to Host Nation Security Forces issue stance. The vertical axes on the left refer to the mean civilians' adequacy on the issue, while the horizontal axes at the bottom refer to the level ranges of factors in their respective columns. Values within the plots correspond to levels for the factors in each row. They interact with the vertical factor levels via the blue and red lines to produce different issue stance positions in terms of its adequacy. Significant interaction terms derived from Figure 31 are circled in red.

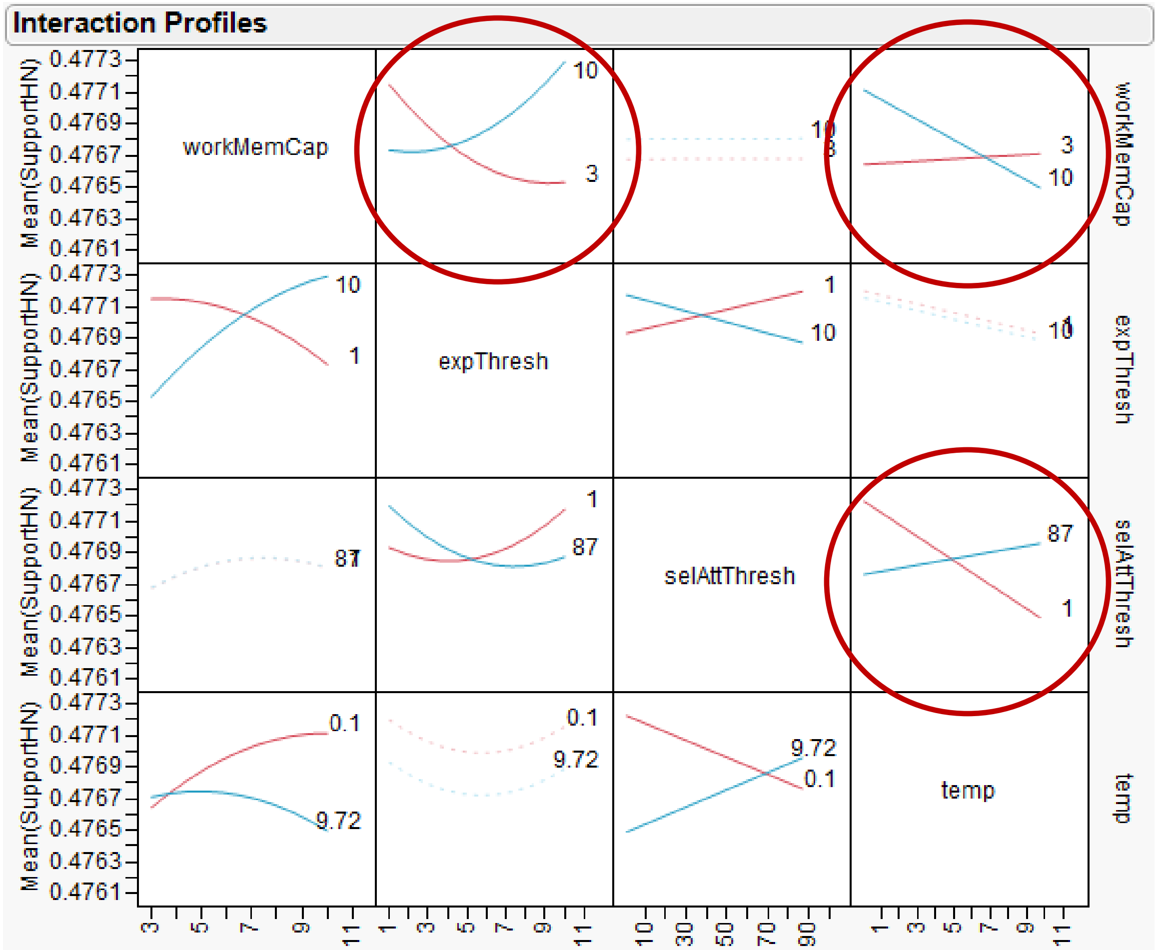


Figure 32. Multiple Linear Regression Interaction Plots for Support to Host Nation Security Forces Issue Stance

(3) Significant Interaction Factors.

- **Working Memory Capacity and Experience Threshold.** The Working Memory Capacity factor indicates how many events can be processed for each time instance. For a low Working Memory Capacity, even if a large number of events are perceived by a civilian agent at a time, these events have to be queued for gradual processing. The result will be multiple instances of motivation and action selection decisions, each based on the contents in the working memory. But for a high Working Memory Capacity, only one decision needs to be made, based the entire set of events perceived. The varying number of decisions and corresponding actions chosen will lead to different number of events generated to influence issue stances. On the other hand, for a given set of actions, the Experience Threshold is an indication of the time spent in the more volatile or random Exploratory Learning mode for action-selection, before switching to the Recognition-Primed Decision Making (RPD) mode where action choices tend to fall back to those with high utilities. The differences in actions chosen will thus affect issue stances differently when comparing both modes. Therefore, the number of decisions made and actions selected due to the Working Memory Capacity will interact with the Experience Threshold in affecting the time to switch from Exploratory Learning to RPD mode, which in turn affects the issue stances.

- **Selective Attention Threshold and Temperature.** The Selective Attention Threshold factor provides the age in time units (or days) of events received which are to be discarded. A lower Selective Attention Threshold means only recent events matter to the issue stances, while a higher Selective Attention Threshold takes in many events which happen in the past to account for their effects on issue stances. The Temperature factor determines the volatility of selecting motivation categories and motivation goals, which constraints the range of actions to be selected to those tied to the motivation choices. Both the range of actions for selection due the Temperature factor and the number of events affecting the issue stances due to the Selective Attention Threshold factor can combine to produce varying effects on issue stances.

- **Working Memory Capacity and Temperature.** The Working Memory Capacity factor indicates how many events can be processed for each time instance. For a low Working Memory Capacity, even if a large number of events are perceived by a civilian agent at a time, these events have to be queued for gradual processing. The result will be multiple instances of motivation and action selection decisions, each based on the contents in the working memory. But for a high Working Memory Capacity, only one decision needs to be made, based the entire set of events perceived. The varying number of decisions and corresponding actions chosen will lead to different number of events generated to influence issue stances. The Temperature factor affects the list of action choices selected and corresponding events generated for influencing issue stances, due to the volatility of the Temperature factor in determining the motivation categories and motivational goals for deriving available action choices. Both the number of events available for processing and the corresponding number of actions performed due to the Working Memory Capacity, and the different action choices available due to the Temperature factor work together to provide a larger variation in changes to the issue stance.

2. Classification and Regression Tree (CART) Analysis Results

Using JMP, the range of each issue stance positions in terms of their adequacy between 0 to 1 are partitioned into chunks under a hierarchical binary tree, based on the cognitive architecture design factors contributing to the specific chunk in the tree branches.

Table 10 lists the R-Squared values and number of splits obtained from the CART analysis for each issue.

Table 10. R-Squared Values and Split Counts for CART Analysis of Issues

Issue	R-Squared Value	Number of Branch Splits
Civil Control	0.513	4
Civil Security	0.459	4
Economic and Infrastructure Development	0.576	4
Governance	0.637	4
Restoration of Essential Services	0.673	4
Support to Host Nation Security Forces	0.573	6

The R-Squared values, ranging from 0.459 to a maximum of 0.673, are generally lower than those obtain from multiple linear regression models, which ranged from 0.781 to 0.953, and had Adjusted R-Squared values ranging from 0.690 to 0.929. One reason could be due to the limited number of 35 design points, and corresponding issue stance position spaces, which restricts the coverage space of the splits in determining the stance positions. Since the R-Squared values from the CART analysis are lower and the focus here is not predicting the stance positions from the factor ranges associated with each branch of the tree, but rather on the significant factors contributing to the issue stances, only the factors associated with the top two branch levels will be treated as significant. The resultant list of significant factors obtained from the CART analysis for each issue is shown in Table 11, in descending order of contributions to the issue stance, from left to right.

Table 11. Top Two Significant Factors for Issue Stances from CART Analysis

Issue	Top Significant (or Branch) Factor	2nd Top Significant (or Branch) Factor
Civil Control	Temperature	Working Memory Capacity
Civil Security	Temperature	Working Memory Capacity
Economic and Infrastructure Development	Temperature	Initial Temperature
Governance	Working Memory Capacity	Expected Communication Time Units
Restoration of Essential Services	Temperature	Working Memory Capacity
Support to Host Nation Security Forces	Temperature	Temperature

The results indicated that the Temperature factor is appears as the largest significant factor (top branch) for all of the issues, except for the Governance issue. The Temperature factor indicates the volatility of selecting motivation categories and motivation goals, leading to different associated sets of actions, which in turn causes events to influence the issue stances. Therefore, with different Temperature factors, variations in the action sets and resultant actions performed can be large, leading it to be a major contributor for most of the issue stances. In fact Temperature also accounts for the top two significant factors in the Support to Host Nation Security Forces issue.

The next largest significant factor (2nd Branch) appears mostly to be Working Memory Capacity for three of the six issues, with it being the largest significant factor for the Governance issue. The Working Memory Capacity factor indicates how many events can be processed for each time instance. For a low Working Memory Capacity, even if a large number of events are perceived by a civilian agent at a time, these events have to be queued for gradual processing. The result will be multiple instances of motivation and action selection decisions, each based on the contents in the working memory. But for a high Working Memory Capacity, only one decision needs to be made, based the entire set of events perceived. The varying number of decisions and corresponding actions chosen will lead to different number of events generated to influence issue stances.

The other two significant factors are Initial Temperature and Expected Communication Time Units. Initial Temperature levels determine the initial volatility of actions to be selected when the civilian is in Exploratory Learning mode, and affect the final volatility reached when Recognition-Primed Decision Making (RPD) mode is reached after sufficient experience is gained by performing each action type a number of times, as specified by the Experience Threshold factor level. Low Initial Temperatures means more stabilized action choices initially and after entering RPD mode, while higher Initial Temperatures would lead to more volatility initially but gradually stabilizing but maintaining some level of volatility when RPD mode is entered. Differing volatility levels in action selection leads to different events resulting from the actions chosen, which in turn affects how issue stances are changed. Expected Communication Time Units constraints the communication of events among civilian agents to be completed within a given time interval. A shorter Expected Communication Time Units will thus lead to more communication events affecting the changes in issue stances compared to a longer Expected Communication Time Units.

D. OBSERVATIONS ON STEREOTYPES

In the Sensitivity Analysis results, the overall effects on the issue stances are examined in terms of design points. For the Significant Factor Identification results, the individual effects of factors are examined on the issue stances. The next step is to go a level deeper and examine the effects on issue stances from the point of view of civilian agents, each with a different stereotype. The trends on changes in issue stances for civilian stereotypes can be framed based on the scenario timeline or based on the design points.

1. Effects on Issue Stances of Stereotypes across Time

Figures 33 to 38 shows the effect of changes in the issue stance positions (in terms of adequacy from 0 to 1) by stereotypes (each represented in a different color), plotted across the scenario timeline from day 0 to day 400, with the mean issue stance positions taken across all design points.

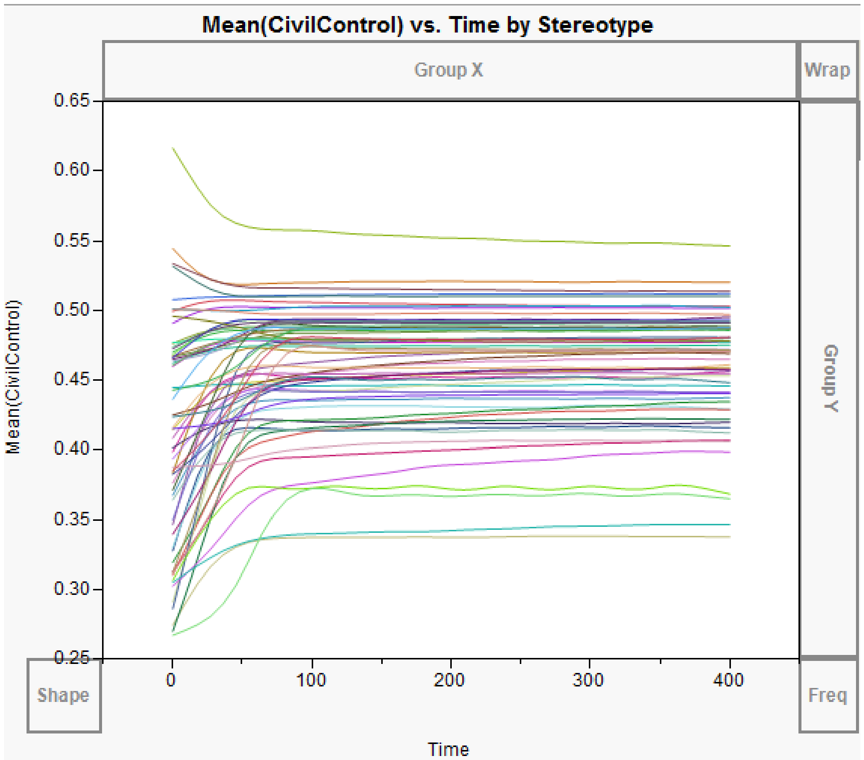


Figure 33. Line Plots of Effects on Civil Control Issue Stance by Stereotypes across Time

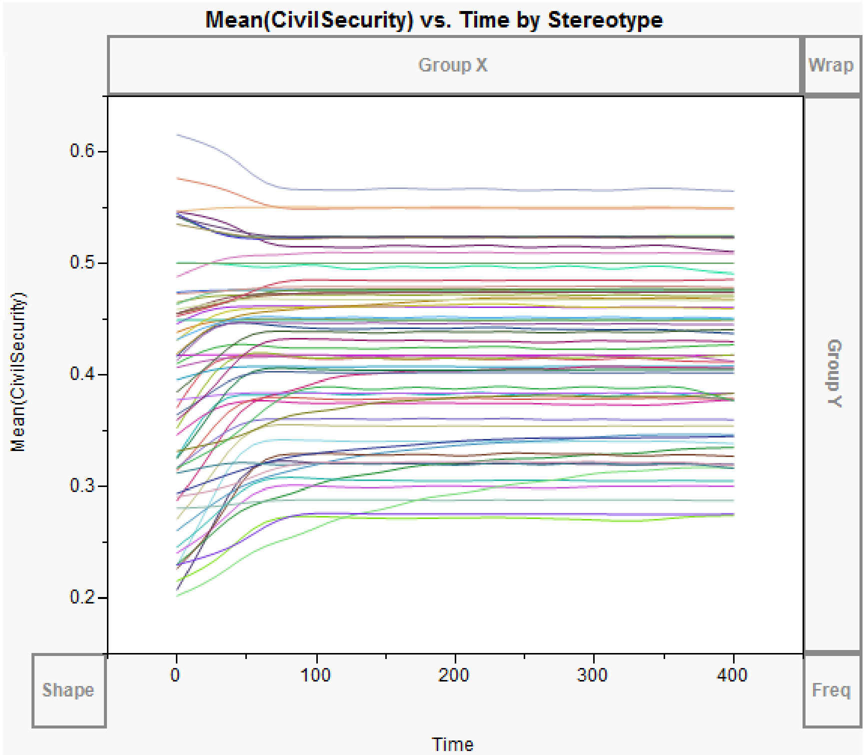


Figure 34. Line Plots of Effects on Civil Security Issue Stance by Stereotypes across Time

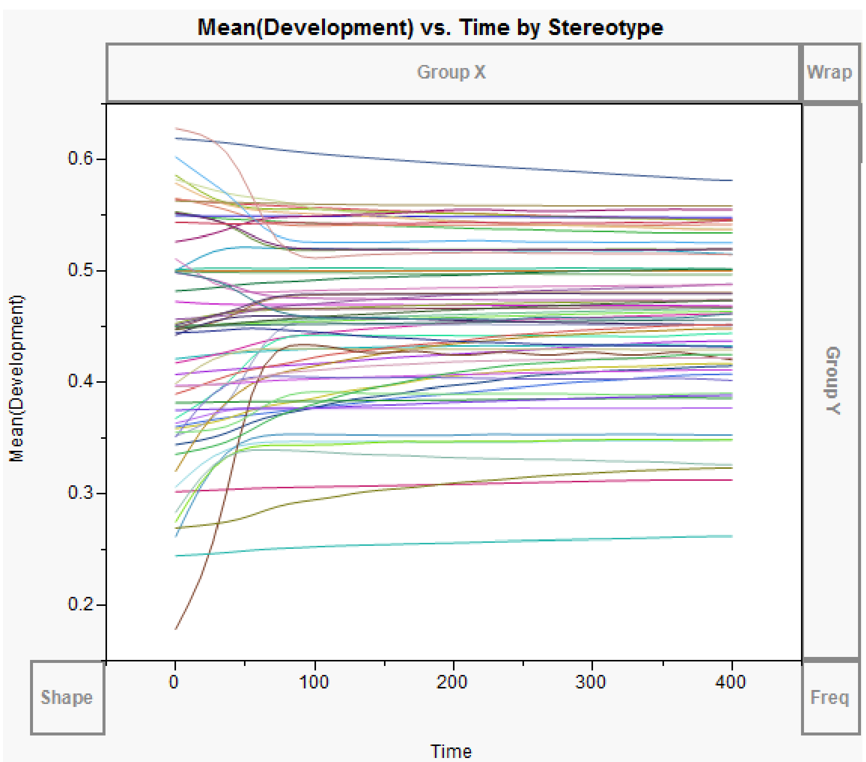


Figure 35. Line Plots of Effects on Economic and Infrastructure Development Issue Stance by Stereotypes across Time

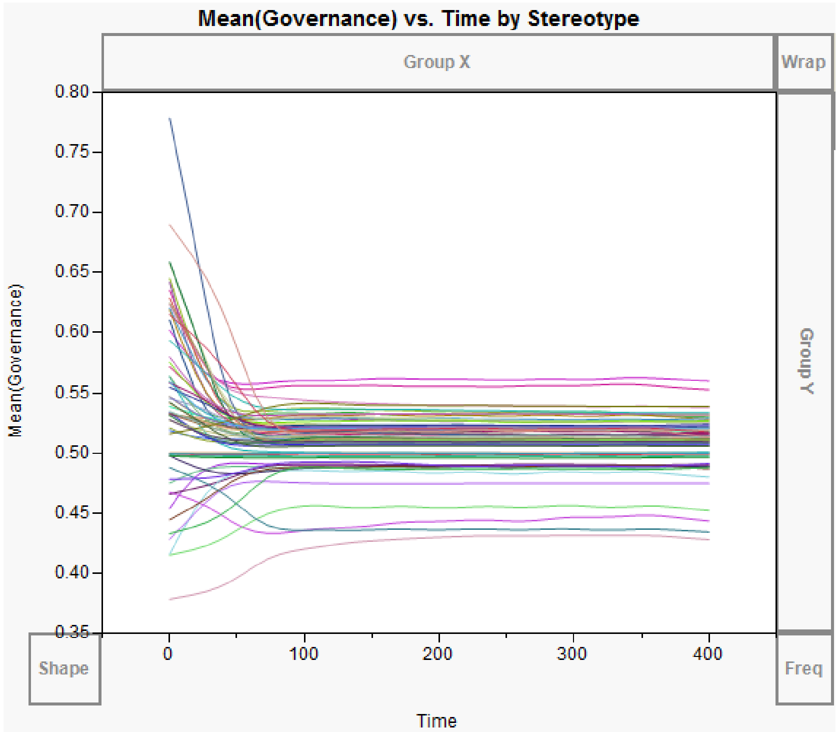


Figure 36. Line Plots of Effects on Governance Issue Stance by Stereotypes across Time

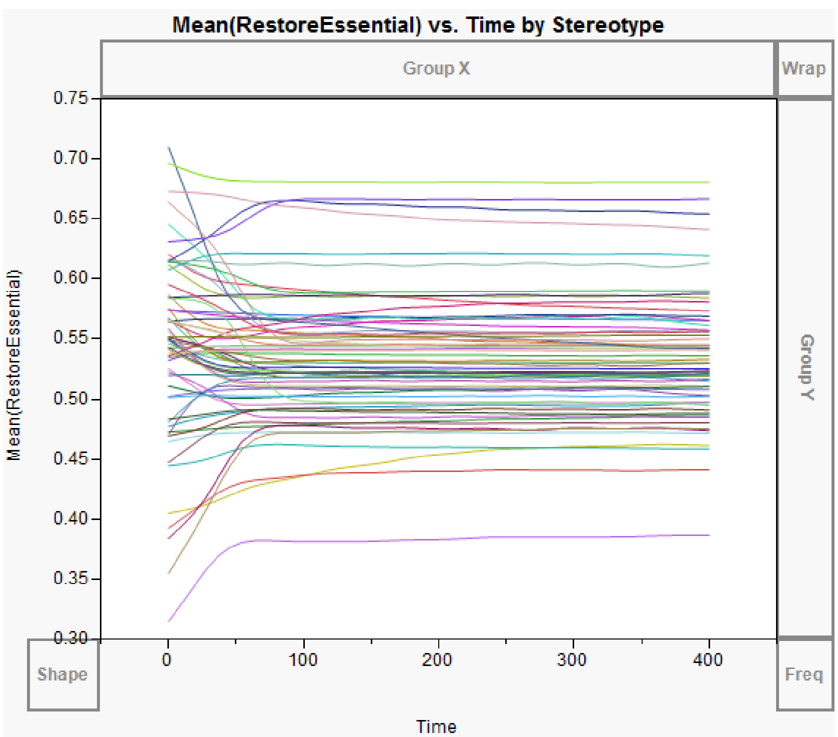


Figure 37. Line Plots of Effects on Restoration of Essential Services Issue Stance by Stereotypes across Time

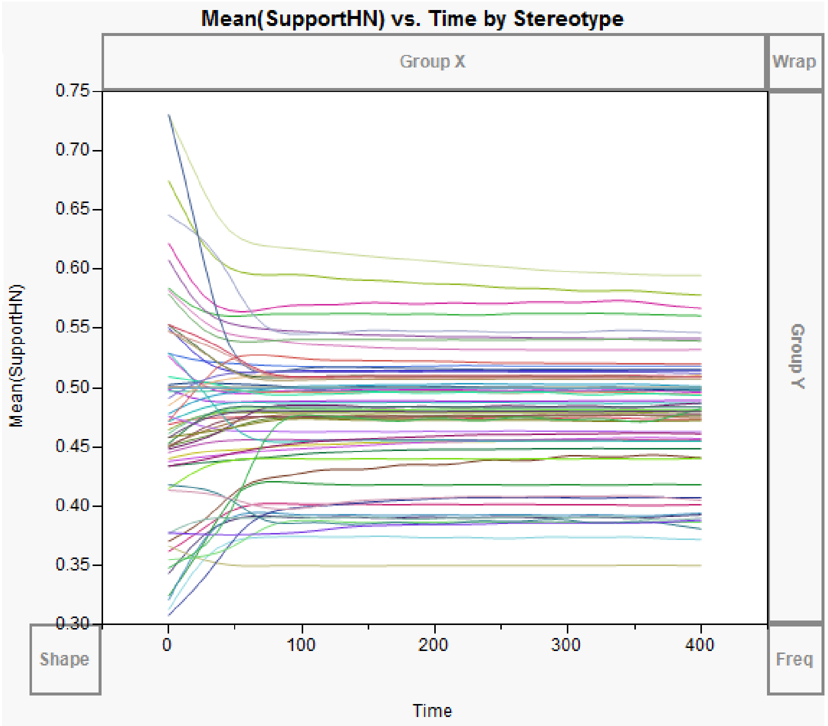


Figure 38. Line Plots of Effects on Support to Host Nation Security Forces Issue Stance by Stereotypes across Time

From the line plots for the issue stances by stereotypes across time, it can be observed that many stereotypes are affected more positively or optimistically (an increase in stance from time 0 to the time 400) towards the Civil Control and Civil Security issue stance, whereas many are negatively or pessimistically (a decrease in stance from time 0 to the time 400) affected in terms of the Governance, Restoration of Essential Services, and Support to Host Nation Security Forces issue stance. For the remaining Economic and Infrastructure Development issue, most of the stereotypes are having mixed feelings over being positively and negatively affected.

The extent to which each stereotype is affected in terms of the issue stances can be measured by taking the variance of the issue stances across each day in the scenario timeline. However, to avoid any bias results before reaching steady-state mean values of the issue stances, only the periods from day 100 to 400 (after the simulation has warmed up) is used for the variance computation. The resulting top five largest variances and bottom five lowest variances of the stereotypes for each issue stance are indicated in Tables 12 and 13.

Table 12. Top 5 and Lowest 5 Variances for Civil Control, Civil Security, and Economic and Infrastructure Development Issue Stance by Stereotypes across Time

Issue	Civil Control	Stance Variance	Civil Security	Stance Variance	Economic and Infrastructure Development	Stance Variance
Stereotypes (5 Largest Variances)	Un_V_U_S_Sp	0.00177	Un_V_R_F_Ma	0.00108	Un_Pa_R_F_Sp	0.0042156
	Un_P_U_S_Sp	0.00166	Un_P_R_M_Ma	0.00074	Un_V_U_S_Sp	0.0012693
	Un_Pa_U_S_Sp	0.00126	Un_P_R_S_Ma	0.00064	A_V_R_M_Sp	0.0008706
	Un_P_U_M_Sp	0.00105	Un_Pa_R_F_Sp	0.0006	I_Pa_R_M_Ma	0.0007826
	Un_P_U_S_Ma	0.00104	Un_P_R_F_Sp	0.00059	Un_V_R_S_Sp	0.0007538
Stereotypes (5 Lowest Variances)	A_P_R_F_Ma	1.11E-06	I_Pa_U_M_Ma	0	A_P_R_S_Sp	0
	A_V_R_M_Ma	1.17E-06	A_P_U_F_Ma	6.87E-08	I_P_U_S_Sp	2.18E-07
	A_V_R_F_Ma	1.18E-06	A_Pa_R_F_Ma	8.92E-08	A_P_U_F_Ma	4.80E-07
	A_Pa_R_M_Ma	1.37E-06	A_P_R_F_Ma	4.93E-07	A_Pa_R_F_Ma	5.13E-07
	A_Pa_R_S_Sp	1.80E-06	Un_Pa_U_F_Ma	6.19E-07	I_Pa_U_M_Ma	5.84E-07

Table 13. Top 5 and Lowest 5 Variances for Governance, Restoration of Essential Services, and Support to Host Nation Security Forces Issue Stance by Stereotypes across Time

Issue	Governance	Stance Variance	Restoration of Essential Services	Stance Variance	Support to Host Nation Security Forces	Stance Variance
Stereotypes (5 Largest Variances)	Un_P_U_S_Sp	0.003056	Un_P_U_S_Sp	0.001193	Un_P_U_S_Sp	0.002034
	Un_V_U_S_Sp	0.002122	Un_V_U_S_Sp	0.000956	Un_V_R_S_Sp	0.001448
	Un_P_U_S_Ma	0.000953	Un_V_R_F_Ma	0.000877	Un_P_U_M_Sp	0.000752
	Un_P_U_M_Sp	0.000698	Un_Pa_U_S_Sp	0.000728	A_V_R_M_Sp	0.000751
	Un_Pa_U_S_Sp	0.000616	Un_Pa_U_S_Ma	0.000533	Un_Pa_R_S_Ma	0.000574
Stereotypes (5 Lowest Variances)	A_P_R_S_Sp	0	I_Pa_U_M_Ma	1.61E-07	Un_V_U_M_Ma	0
	A_Pa_R_S_Sp	1.01E-07	Un_Pa_U_F_Ma	2.98E-07	I_Pa_R_M_Ma	0
	Un_P_R_S_Ma	3.84E-07	Un_V_R_S_Ma	4.91E-07	A_P_R_S_Sp	0
	A_P_R_M_Ma	6.78E-07	A_P_R_M_Sp	1.15E-06	A_P_U_F_Ma	7.70E-07
	A_P_U_F_Ma	1.02E-06	Un_Pa_U_M_Sp	2.13E-06	A_V_R_F_Ma	3.30E-06

From Tables 12 and 13, the differences in the five largest and five lowest variances can be in many orders of magnitude, with some of the lowest variances being 0, meaning those stereotypes are not affected at all by on some issues throughout the scenario. It could be that their locations are too far away from actions or messages related to those issue stances.

The results for the five largest variances in the issue stances seem to come from Unemployed (Un) population groups and are usually more Elderly (Sp). Those who are living in Urban areas (U) and more Secular (S) in political association (rather than fundamentalist or traditionalists) tend to be affected more in terms of the Civil Control, Governance, and Restoration of Essential Services issues, whereas those in Rural Areas (R) are affected more by the issues of Civil Security, Economic and Infrastructure Development, and Support to Host Nation Security Forces.

For the five lowest variances, most of the stereotypes are more influential and wealthy, being in the Achieved (A) status group, and they tend to younger military age males (Ma). Most of them are aligned with the Pro-Government (P) and Passive (Pa) tribes, rather than the Marginalized / Violent (V) tribes. Those living in the Rural Areas (R) tend to be less affected by the issues of Civil Control and Governance.

2. Effects on Issue Stances of Stereotypes across Design Points

Across Design Points, the effects on issue stances should assessed based on the period after the warmed-up time, i.e., from day 100 to 400. Again the variance computation can be used to determine the extent of the effects on the stereotypes. The five largest and five lowest variances across the design points, with the mean of the issue stance positions taken over the warmed-up period for each design point, are listed in Tables 14 and 15.

Table 14. Top 5 and Lowest 5 Variances for Civil Control, Civil Security, and Economic and Infrastructure Development Issue Stance by Stereotypes across Design Points

Issue	Civil Control	Stance Variance	Civil Security	Stance Variance	Economic and Infrastructure Development	Stance Variance
Stereotypes (5 Largest Variances)	Un_Pa_U_M_Ma	8E-05	Un_P_R_S_Ma	0.00028	A_Pa_U_M_Ma	0.0001142
	Un_Pa_R_F_Ma	5E-05	Un_V_R_F_Ma	0.00027	Un_V_R_S_Sp	0.0001099
	Un_Pa_R_M_Ma	3.1E-05	Un_P_R_S_Sp	0.00012	Un_P_U_S_Sp	9.629E-05
	Un_P_R_S_Ma	2.4E-05	Un_Pa_R_S_Ma	4.5E-05	I_Pa_R_M_Ma	8.406E-05
	Un_P_R_M_Ma	2.1E-05	Un_Pa_R_S_Sp	1.7E-05	A_P_R_F_Ma	8.346E-05
Stereotypes (5 Lowest Variances)	A_Pa_U_F_Ma	4.52E-08	I_Pa_U_M_Ma	0	A_P_R_S_Sp	0
	I_P_U_S_Sp	5.62E-08	A_P_U_F_Ma	4.08E-08	A_V_R_F_Sp	1.01E-07
	Un_V_U_M_Ma	5.81E-08	Un_P_U_F_Ma	4.28E-08	A_V_R_F_Ma	1.29E-07
	A_V_R_M_Sp	6.68E-08	A_Pa_U_F_Sp	5.80E-08	A_V_U_M_Ma	1.62E-07
	I_P_R_M_Ma	7.78E-08	Un_V_U_S_Ma	5.98E-08	A_V_R_S_Ma	2.18E-07

Table 15. Top 5 and Lowest 5 Variances for Governance, Restoration of Essential Services, and Support to Host Nation Security Forces Issue Stance by Stereotypes across Design Points

Issue	Governance	Stance Variance	Restoration of Essential Services	Stance Variance	Support to Host Nation Security Forces	Stance Variance
Stereotypes (5 Largest Variances)	Un_P_R_F_Ma	2.64E-05	A_Pa_R_F_Sp	9.1E-05	Un_P_U_M_Sp	5.15E-05
	Un_Pa_U_M_Ma	2.57E-05	Un_P_U_S_Sp	5.79E-05	A_Pa_R_S_Ma	3.56E-05
	Un_Pa_R_M_Sp	1.26E-05	Un_P_R_S_Sp	4.38E-05	Un_Pa_R_M_Sp	1.44E-05
	Un_Pa_R_F_Ma	1.1E-05	A_P_R_M_Ma	3.34E-05	Un_Pa_R_F_Sp	1.14E-05
	A_P_R_M_Sp	9.27E-06	A_P_R_S_Sp	2.32E-05	Un_Pa_R_F_Ma	8.94E-06
Stereotypes (5 Lowest Variances)	A_P_R_S_Sp	0	I_Pa_U_M_Ma	6.41E-08	Un_V_U_M_Ma	0
	Un_Pa_U_F_Sp	1.60E-08	I_Pa_R_F_Ma	1.17E-07	I_Pa_R_M_Ma	0
	I_P_U_S_Sp	4.87E-08	A_V_R_F_Sp	1.59E-07	A_P_R_S_Sp	0
	I_P_R_M_Sp	5.38E-08	Un_P_U_F_Sp	1.65E-07	Un_Pa_U_S_Sp	3.03E-08
	A_V_R_F_Ma	6.65E-08	A_Pa_U_F_Ma	2.13E-07	Un_Pa_U_F_Sp	5.54E-08

Compared to the much higher variance differences between the five largest and five lowest values across time, the similar set of variance differences across design points yields lower values. This means the stereotypes are less affected by the cognitive architecture parameters than the scenario timeline where actions are performed by civilians and actor agents, within the same warmed-up period from days 100 to 400. There are also a number of civilian stereotypes who are not affected at all by the design points (with variances of 0) and they happen to be the same stereotypes not affected by time too. It could be that their locations are too far away from actions or messages related to those issue stances.

For the five largest variances across design points, the stereotypes are tend to be Unemployed (Un) and reside in mainly the Rural Areas (R). Only a few (two) belong to the Marginalized / Violent (V) tribes, while the rest side with either Pro-Government (P) or Passive (Pa) tribes. The younger military aged males (Ma) are more concerned and affected by the Civil Control issue, while the Elders (Sp) have their concerns and more fluctuations in the Restoration of Essential Services issue.

As for the five lowest variances across design points, the Urban (U) and The younger military aged males (Ma) population stereotypes tend to be less affected by the Civil Security issue, while the Achieved (A) population groups with influential standing and wealth, who tend to be aligned with the Marginalized / Violent (V) tribes and living in the Rural Areas (R), are less likely to be affected by the Economic and Infrastructure Development issue. For the Elderly (Sp), they are minimally affected in terms of the Governance issue and the Fundamentalists (F) are not affected much by the issue of Restoration of Essential Services.

VI. CONCLUSION

A. SUMMARY

The Cultural Geography model is an evolving tool developed by TRAC-MTRY to evaluate the impact of Tactical Operations in Irregular Warfare (IW) on civilian populations of interest. Human cognition plays an important role in the effectiveness of the CG model, by introducing more realism in modeling the behavioral responses of civilians impacted by IW operations, as well as influential actions from other actors such as insurgents, host governments or non-governmental organizations. A prototype implementation of a Cognitive Architecture was added to the CG model to improve the fidelity of human cognition modeling. Building on the foundations of existing social theories, it incorporates the components of perception, metacognition, action-selection and long-term memory. This thesis provides an important foundational step towards the verification and validation of the Cognitive Architecture implementation in the CG model.

In this thesis, a sensitivity study was conducted on the Cognitive Architecture of the CG model, employing a Nearly Orthogonal Nearly Balanced Mixed Design (NONBMD) to explore a list of nine critical discrete and continuous factors in the Cognitive Architecture, over appropriate range of values for each of the 35 design points, to assess their influence on civilian behavioral stances with respect to six issues of concern in counterinsurgency efforts. The design factors are Working Memory Capacity, Selective Attention Threshold, Expected Communcation, Expected Communcation Time Units, Temperature, Initial Temperature, Lambda (Discount Factor), Experience Threshold and Link Update Interval, while the issues are Civil Control, Civil Security, Economic and Infrastructure Development, Governance, Restoration of Essential Services, and Support for Host Nation Security Forces. The representative CG scenario for the Sensitivity Analysis, involving 62 civilian stereotypes and spanning over 400 days, was derived and modified from both a previous study on the Afghan population in Helmand province, and an IW Tactical Wargame in 2010. For the analysis, 30 replications of simulation runs were conducted for each design point.

Results of the analysis for the Cognitive Architecture as a whole indicates the impact on variations in issue stances across all design points is less than one percent. However, previous studies on the CG model using other cognitive representations such as the Theory of Planned Behavior and the Bayesian Belief Networks have also displayed minimal changes in the issue stances after a warmed-up stabilization period when they have stabilized. Outliers in the variation occurs for two of the 35 design points with very low Temperature levels representing the tendency to select only motivational drivers with the highest rewards, for decision making of a suitable response action based on the current situation perceived.

At an individual factor level, results in the use of both Multiple Linear Regression analysis and Classification and Regression Tree (CART) analysis revealed a list of significant factors, based on a p-value of less than 0.01 or the likelihood of contribution of more than 99% for Multiple Linear Regression analysis, and based on the top two levels of hierarchical tree splits for CART analysis. Among the interesting observations are:

- Temperature emerged as the most important significant factor, appearing in all of the issue stances.
- Working Memory Capacity, which controls the amount of events perceived at a time for decision making and action selection, affects the number of action choices made for a given set of events, and accounts for another large significant factor affecting a number of issue stances (i.e., Civil Control, Civil Security, Governance and Restoration of Essential Services for CART analysis, and Governance and Restoration of Essential Services for Multiple Linear Regression analysis).
- The third major factor of significance for a few issues (i.e., Civil Security and Economic and Infrastructure Development for Multiple Linear Regression analysis) is the Experience Threshold, which defines the number of instances each type of action has to be performed before a civilian switches from Exploratory Learning mode to RPD mode. Action

choices tend be more volatile or randomized in Exploratory Learning mode, before selections stabilize to those which the yield highest utility in RPD mode.

- The remaining significant factors, affecting only one issue stance in the Multiple Linear Regression analysis, and ordered in deceasing significance are Lambda, Expected Communication Time Units, Expected Communication, and Link Weight Update Interval. For CART analysis, the other significant factors, appearing only in the lower hierarchical tree branch are Initial Temperature and Expected Communication Time Units.

There some significant factor contributions obtained from the Multiple Linear Regression analysis that exists in a quadratic form with diminishing effects. They are:

- Temperature—which is an exponential term in the computation of motivation selection,
- Link Weight Update Interval—which is more effective when issue stances changes are captured within the interval to result in corresponding changes in the social network
- Selective Attention Threshold—which is limited in impact by the length of time for messages to be passed around due to the scenario geographical size.
- Experience Threshold—which has diminishing influence when opportunities for some actions do not appear frequently enough to cross the threshold between the volatile Exploratory Learning mode and the stabilized Recognition-Primed Decision Making (RPD) mode for action selection.

Pairwise interactions among the Cognitive Architecture factors on the issue stances are discovered through analysis of Interaction Plots obtained from Multiple Linear Regression models. There are total of 14 possible two-factor interaction types, so the more salient ones contributing to two or more issues will be highlighted here. The following three factor combinations each affect three issues:

- Temperature and Link Weight Update Interval—volatility of events generated from motivation and subsequent action selection due to Temperature is expanded with variations in the number of events that can be communicated as the social network changes due to Link Weight Update Intervals, so together the wide range of event combinations can lead to additional effects on relevant issue stances.
- Working Memory Capacity and Experience Threshold—differing situational pictures due to Working Memory Capacity sizes result in a spectrum of different motivation and action selections outcomes, along with corresponding events. For a given set of events, the Working Memory Capacity also affects the number of decisions made due to the size of events it can handle at the time for decision making. As for the Experience Threshold, for a given set of actions taken, it indicates the time spent in the volatile Exploratory Learning mode where actions are chosen more randomly, before switching to a more stable RPD mode where choices tend towards those actions with higher rewards or utilities. Therefore, the number of decisions made and actions selected due to the Working Memory Capacity will interact with the Experience Threshold in affecting the time to switch from Exploratory Learning to RPD mode, which in turn affects the outcome of actions chosen, and the corresponding changes in issue stances based on those actions.
- Selective Attention Threshold and Temperature—differing situational pictures formed as aged events exceeding the Selective Attention Threshold levels are filtered lead to different motivation and action selections outcomes, along with corresponding events. The volatility of events generated from motivation and subsequent action selection due to

due to the Temperature contributes additional variability to the issue stances, when interacting together.

One other less notable pairwise factor interaction, but still significant enough to affect two issues is:

- Working Memory Capacity and Temperature—differing situational pictures due to Working Memory Capacity sizes result in a spectrum of different motivation and action selections outcomes, along with corresponding events. For a given set of events perceived, the number of decisions made is also determined by Working Memory Capacity, with one decision made for events equivalent to the size of the Working Memory Capacity. These decisions are compounded by the volatility of selecting motivation categories and motivational goals, subsequently influencing the actions chosen and issues affected.

From the viewpoints of individual civilian stereotypes, the effects of the Cognitive Architecture on issue stances are plotted across both the scenario time and the design points.

- Across scenario time, the trends indicate that many stereotypes seem to be more positively influenced on issues of Civil Control and Civil Security, while for issues of Governance, Restoration of Essential Services, and Support to Host Nation Security Forces, many stereotypes are negatively influenced. Only for the Economic and Infrastructure Development issue are the stereotypes having mixed effects, with some being positively affected and others negatively affected.
- Based on the top five and lowest five variances for each of the issue stance effects across time, individual stereotypes with some common demographic characteristics can be observed. Generally, the most affected stereotypes in terms of variance tend to be Unemployed and are more Elderly, while the less affected ones are mainly younger military aged

males, belonging to the Achieved (or influential) status group, and are aligned more to the Pro-Government and Passive tribes, rather than the Marginalized / Violent tribes.

- Across design points, the top five and lowest five variances for each of the issue stance effects also led to insights on stereotypes sharing similar demographic characteristics. Most of the stereotypes who are more affected in terms of variance are Unemployed and reside mainly in the Rural Areas, and they usually with either the Pro-Government (P) or Passive (Pa) tribes, with only few siding with the Marginalized / Violent (V) tribes. As for those who are minimally affected, there does not seem to be any common traits that exist among most of the stereotypes.
- Comparing the stereotypes affected based on variances for those across time and those across design points, it was found that the gaps between the largest effects and smallest effects for stereotypes across time is much higher than those for stereotypes across design points. This indicates that the effects of the Cognitive Architecture on stereotype issues seem to be more influential across time than among design points. It was also observed that for those stereotypes which are not affected at all by some issues (with variances of 0), the stereotypes turn out to be the same whether the variance is across time or across design points. This is likely due to the location of the civilian, which may be too far away to receive actions or messages related to those issue stances.

B. SIGNIFICANT CONTRIBUTIONS

This thesis provided an understanding of the potential influence of the prototype Cognitive Architecture module in the CG model, on population responses to IW operations based on various issue stances. At a deeper level, it identified which of the cognitive architecture factors and pairwise factor interactions are more significant in affecting the issue stances, paving the way for laborious data collection efforts to be focused more on those significant factors and interactions, and aligning more research efforts towards improving the realism and fidelity of the Cognitive Architecture module through understanding the significance of each factor and how they might be better modeled. Finally, the suitability of the prototype Cognitive Architecture module for determining the response of the different population stereotypes will drive future research on configuring and improving the Cognitive Architecture based on stereotypes of interest. Together, the methodology from the overall sensitivity analysis, significant factor identification and stereotype level of analysis provide a useful framework for the verification and validation of the Cognitive Architecture implementation, while the results provide insight into the evolution of the CG model into a higher value-added tool for IW military commanders and decision makers to understand their impact of their IW plans and make better- informed decisions to improve the success of IW operations.

C. FUTURE RESEARCH

In the process of working on the sensitivity analysis, some ideas on potential improvements to the Cognitive Architecture emerged, while gaps were identified with respect to more realistic applications of the CG model for IW operations evaluation, and insights are gained on areas of research to focus on for yielding greater returns given budget and time constraints. Here are some of the likely gems that can be carved out from the existing work:

- **Exploring Different Scenarios.** Due to the complex nature of human interactions in different IW environments, the Cognitive Architecture and its associated factors may need to be studied across a wide range of IW scenarios, in terms of timeline, location, population demographics and distribution, actor initiatives for gathering civilian support, and provision of different infrastructure and services, so it can configure them to be more representative of the situations for the evaluation of tactical IW operations in different geographical regions and situational environments on the populations of interests.
- **Relating Events to the Cognitive Architecture Effects.** As the current sensitivity analysis study focuses on understanding the effect boundaries

as well as factors and stereotypes of significance with regard to the Cognitive Architecture, a second level of analysis could be invested to get more outcomes on the direction of factor changes and pattern of changes (e.g., fluctuating up and down, or gradually increasing), by tying factor effects to information on the actual events perceived and processed for decision making. This analysis is targeted at more individual IW operational events for influencing civilians, rather than on a set of fixed-scenarios for studying the effect on the Cognitive Architecture.

- **Analyzing Enhancements on Cognitive Architecture.** The existing implementation of the Cognitive Architecture did not include the motivational drivers for self-esteem, nor the influence of emotions on decision making. There is a mental simulation model that allows some level of exploration even in the RPD action-selection mode, if the volatility of the action in terms of the utility rewards is too high. Further sensitivity analysis can be conducted when these features have been implemented to determine the suitability of the Cognitive Architecture module for supporting IW operational planners.

- **Adding Trust to Social Communication.** There is Trust concept in the CG model that determines whom civilians may communicate with, through the process of building relationships. It is an extension of the current social network based on social distance or link weights and physical proximity. In the current sensitivity study, the Trust filter was turn off as it is also a recent work that needs further validation. However, including it after sufficient verification and validation can provide more realism that supports the sensitivity study of the Cognitive Architecture by ensuring the communication events need not always be transmitted to everyone in the social network, as the current implementation for communication events is such that communication is always preferred (with a utility of 100%) to no communication (which has a utility of 0%). Having more communication taking place than what is realistic in a social environment interferes with the changes in issue stances due to communication, and this impacts analysis of the Cognitive Architecture factors in terms of their effect on issue stances.

- **Applying Reinforced Effects on Event Changes to Issue Stances.** Unlike reinforcement learning in action selection, previous events have no impact in the computation of effects in issue stances for each new situational picture formed by the current set of events perceived. Implementing some reinforcement relationships to account for past events on changing issue stances will be more realistic for the Cognitive Architecture module and improve its V&V status.

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