COMPUTATIONAL ANALYSIS AND EVALUATION FOR AN AGENT-BASED MODEL OF STRESS AMONG FLOOD VICTIMS

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Abstract

One of the serious negative psychological ramifications that leads to one's life destruction during natural disaster (e.g., flood or earthquake) is stress. Stress has been widely studied to know its mechanism but little work has been conducted to understand its dynamic impacts on natural disaster victims. This paper intends to present evaluation results made on an agent model that was developed previously. The designed model simulates the dynamics of stress effect in natural disaster victims and its evaluation processes show its correctness. Of importance to mention that two evaluation approaches were implemented to prove the validity of the model and ensure the model is adhere to psychological and cognitive literature. The evaluated model can be used as a basis in designing intelligent agents that have reasoning and analytical capability in providing intelligent, social, and proactive support to natural disaster victims suffering of stress negative impacts.

Keywords-- Mathematical Analysis; Cognitive Modelling; Agent-based Modelling; Intelligent Software Agent.

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INTRODUCTION

The last decades have seen a rapid growth of developing cognitive (behavioural or neural) models as a method to understand human mental state. These models have been used to understand the dynamic of human-functioning process such as stress, fatigue, and unipolar depression (Aziz, Ahmad, and Hintaya 2012; Both et al. 2008; Mohammed et al. 2016). Then, this obtained knowledge can be used to create intelligent software agents that possess human-like understanding. As a first step to achieve this, the correctness of these models must be ensured. These models’ correctness is of crucial importance as these models give clear understanding on how reasoning properties can be attained to create intelligent support systems that own reasoning ability while providing support. This paper shows the undertaken activities that prove the correctness of a computational model that was developed earlier.

In the domain of natural disasters, a large number of people will be influenced with its negative impacts through an extension number of potential adverse effects, for example causalities, displacement, and property damage, which can destroy people life. Furthermore, negative psychological effects resulted from natural disaster effects have been examined and shown victims always suffer from stress symptoms, which normally occur when individuals are not able to cope with their losses. Several studies were carried out to study stress antecedents, impacts, and symptoms on victims during natural crisis. However, the dynamics of the interplay among stress factors is not computationally investigated thus a computational model of stress reaction on victims was made. The model was designed to include seven main groups, namely; predisposed factors, resilience, resources, individual attributes, coping, appraisal, and stress reaction. Additional information and discussions related to the developmental processes of the computational model can be found in (Mohammed et al. 2016).

Computational model evaluation refers to a range of activities carried out to prove that the process of developing a model and its expectations are correct, error-free and credible in a significant manner (Antoniadou, Bar thorpe, and Worden 2014). Two well-studied mechanism to prove the validity of the developed computational agent model of stress reaction are introduced in this research work. These approaches are used in the literature to evaluate computational agent models for dynamic behaviours, called; mathematical analysis and automated analysis (Aziz, Ahmad, and Hintaya 2012; Bosse et al. 2009; Both et al. 2008; Mohammed et al. 2016; Sharpanskykh and Treur 2010). This paper is written in different sections as follows: Section 2 elaborates in a brief way the formation of the previously developed agent model of victims’ stress reaction. Section 3 introduces the main concepts of mathematical analysis and automated analysis that have been largely used as computational techniques in checking agent-based models’ correctness. After that, in Section 4 mathematical analysis is conducted to determine the equilibrium states of the model. Section 5 presents logical or automated analysis based on a number of selected cases/conditions identified from related psychological and cognitive empirical literatures. At last, the paper is concluded in Section 6.

AGENT BASED MODEL

Figure 1 gives a conceptual overview of the model developed in (Mohammed et al. 2016), which is based on the major theories in stress response among natural disasters victims. In this model, twelve different inter-related factors were established to construct the conceptual model of victims’ stress. Once the constructional interplays of the model have been determined and depicted, the model was mathematically designed using a set of differential equations. This stage is done by following the Network Oriented Modelling Approach. Note here, all the interconnected nodes were linked to carry values varying from low (0) to high (1).
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Figure 1. A Graphical Representation of the Interplay among Victims’ Stress Factors

FORMAL SPECIFICATIONS
The interplays between the aforementioned factors (as in Figure 1) were grouped into two types based on their relationships; 1) instantaneous and 2) temporal factors. Instantaneous factors refer to the instant contribution, direct contribution to the entire behaviour, while temporal relationships are the accumulative effects (as depicted by Δt) of particular elements. Figure 2 presents all the model’s equations, instantaneous and temporal relations that related to the computational agent model of victims’ stress. More discussion of the model’s equations can be seen in (Mohammed et al. 2016).

<table>
<thead>
<tr>
<th>No</th>
<th>Concept</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Challenge</td>
<td>( Ch(t) = \lambda_{ch}.P_{s}(t) + (1-\lambda_{ch}).[1-(S_{e}(t).\left(1 - Pr(t)\right))] .P_{s}(t) )</td>
</tr>
<tr>
<td>2</td>
<td>Harm</td>
<td>( Hm(t) = \left[1- (\beta_{hm}.P_{s}(t) + (1 - \beta_{hm}).Pr(t))\right] \cdot \left[\beta_{hm}.S_{e}(t) + (1- \beta_{hm}).Ih(t)\right] )</td>
</tr>
<tr>
<td>3</td>
<td>Threat</td>
<td>( Th(t) = \left[\omega_{th}.S_{e}(t) + (1-\omega_{th}).(1 - Pr(t)).S_{e}(t)\right] .(1 - P_{s}(t)) )</td>
</tr>
<tr>
<td>4</td>
<td>Imminence of Harm</td>
<td>( Ih(t) = Ph(t).(1 - C_{s}(t)) )</td>
</tr>
<tr>
<td>5</td>
<td>Acceptance</td>
<td>( Ap(t) = Ch(t).\left(1 - Hm(t)\right) )</td>
</tr>
</tbody>
</table>

| 6  | Short-term Stress           | \( S_{s}(t) = \delta_{ss}.[S_{e}(t) \cdot (1 - C_{s}(t))] + (1 - \delta_{ss}).[E_{x}(t).(1 - H_{d}(t))] \) |
| 7  | Exhaustion                  | \( E_{x}(t).\Delta t = E_{x}(t) + \mu_{ex}.(1 - E_{x}(t)).\left[E_{f}(t) - E_{x}(t)\right].E_{x}(t).\Delta t \) |
| 8  | Coping Skills               | \( C_{s}(t).\Delta t = C_{s}(t) + \beta_{cs}(1 - C_{s}(t)).\) |
| 9  | Long-term Stress            | \( L_{s}(t).\Delta t = L_{s}(t) + \zeta_{ls}.(1 - L_{s}(t)).\left[S_{ss}(t) - L_{s}(t)\right].L_{s}(\Delta t) \) |
| 10 | Ability to Cope             | \( A_{c}(t) + \left[\omega_{uc1}.P_{f}(t) + \omega_{uc2}.E_{f}(t).\right][1 - E_{x}(t)] \) |
| 11 | Problem-focus Coping       | \( P_{f}(t) = (1 - H_{b}(t)).[\beta_{pf}.A_{p}(t) + (1 - \beta_{pf}).H_{d}(t)] \) |
| 12 | Emotional-focus Coping     | \( E_{f}(t) = H_{b}(t).\left[1 - \alpha_{ef}.A_{p}(t) + (1 - \alpha_{ef}).H_{d}(t)\right]\) |
| 13 | Commitment                  | \( C_{m}(t) = \alpha_{cm}.P_{s}(t) + (1 - \alpha_{cm}).Pr(t) \) |
| 14 | Holdback                    | \( H_{b}(t) = \mu_{hb}.Th(t) + (1 - \mu_{hb}).I_{hm}(t) \) |
| 15 | Hardiness                   | \( H_{d}(t) = \omega_{h1}.S_{e}(t) + \omega_{h2}.C_{m}(t) + \omega_{h3}.C_{l}(t) + \omega_{h4}.C_{l}(t) \) |
| 16 | Control                     | \( C_{l}(t) = \beta_{cl}.P_{s}(t) + (1 - \beta_{cl}).E_{p}(t) \) |
| 17 | Experiences                 | \( E_{p}(t) = \lambda_{ep}.E_{p_{norm}}(t) + (1 - \lambda_{ep}).R_{s}(t) \) |

Figure 2. Concepts and Mathematical Specifications
All the defined formal specifications were programmed using
numerical programming language (i.e., Matlab) and a set of
reasonable simulation traces were generated for evaluation
purpose. The simulated traces were generated to explain the
important patterns that give an answer to why victims develop a
level of stress (or does not develop stress) during stressful event
like natural disaster. Figure 3 depicts the example of some
simulation traces generated from the experiments. Later, these
simulated traces were compared with the findings from the
literature and were analyzed using mathematical analysis and
automated logical verification.

Figure 3. Example of Simulation Traces for (a) Long-term Stress
and Resilience and (b) Coping Skills and Exhaustion

AGENT MODEL EVALUATION
The primary purpose in testing a numerical model is to ensure
that the conceptual explanations and the model solutions are
accurate. In other words, the validation stage is a method of
ensuring that the concept is being appropriately developed and
applied. This process will also give clear understandings of the
behavior of the system and improve the computational models as
well. Moreover, the evaluated model should reflect the real world
to make sure that the model is correct and validated. In this paper,
two well-known approaches will be used to verify the accuracy of
the model, namely; mathematical analysis and logical
verification. Mathematical analysis is carried out to test the
model’s conceptual and theoretical validity. Equilibrium analysis
was performed to address the stability of solutions of
differential equations and trajectories of temporal dynamic
systems under a number of perturbations of initial conditions. It
means equilibrium points hold long time behavior of real-world
models. Solutions in particular frequently reach (or remain
similar to) stable points of equilibrium as time gets large. For
example, if given the difference equation;

\[ y_{t+1} = A y_t + B \]

then an equilibrium point of y is given by,

\[ y^* = B/(1-A), \text{ if } A \neq 1 \]

and \( y^* \) is stable if and only if \(-1 < A < 1\), unless \( y_0 \) is constant.

Therefore, a movement from the equilibrium value is equal to a
new solution with different starting conditions, and thus a stable
equilibrium can be defined as one for which any displacement from
equilibrium is followed by a sequence of values of y which
again converge to equilibrium.

Second approach is the logical verification which used as an
alternative for manual proof as it is only feasible for formal
specification of small systems. The Temporal Trace Language
(TTL) is used as an automated verification approach where
this proof-checking tool uses the presence of a set of generated traces
and TTL proof checker implemented on a computer (Boase et al.
2009). It can provide an answer in a few minutes or even seconds
for many models as the search always terminates (due to the
finite search space). TTL provides method for scientists to
evaluate qualitative and quantitative specifications of given
domains. Fundamentally, this formal language is based on a set of
atoms to represent three main concepts, namely; 1) states of
the world and its environment (world action), 2) time points
(temporality), and 3) simulation traces. The interplay between
these three concepts can be formalized as

\[ \text{state } (y,t) = p \]

which means that state property \( p \) is true in the state of trace \( y \) at
time point \( t \). TTL has a high expressive power. For example, the
possibility of explicit reference to time points and time durations
enables modeling of the dynamics of continuous real-time
phenomena, such as cognitive behavioral analysis and neural
models. If the verification results do not meet expected
outcomes, the model was then revised. Otherwise, the model can
be regarded as a model that can simulate the respected domain.
The implementation of these two approaches will be covered in
Section 4 and 5.

MATHMATICAL ANALYSIS
In this section, the possible equilibrium points are analysed.
There ought to be one essential assumption; all the exogenous
variables have a constant value. Provided the assumption that all
parameters are non-zero, this leads to the following equations
where an equilibrium state is characterized by:

\[
\begin{align*}
    dR(t)/dt &= \kappa [1 - R(t)] (H_d - R(t), R_s) \\
    dE(t)/dt &= \mu [1 - E(t)] (E_f - E(t), Ex) \\
    dC(t)/dt &= \beta [1 - C(t)] (A_C - C(t), Cs) \\
    dL(t)/dt &= \zeta [1 - L(t)] (S_s - L_s, L_s) \\
\end{align*}
\]

Equation 27 later provides possible combinations of equilibria
points to be further analyzed. This expression can be
elaborated using Law of Distributivity as \((A \land B) \lor (A \land C) \lor (B \lor C) \land (D \lor E \lor F)\) expression
can be formed:

\[ (S_s-L_s) \lor (L_s=0) \lor (L_s=1) \land \quad (A_c-C_s) \lor (C_s=0) \lor (C_s=1) \land \quad (H_d-R_d) \lor (R_s=0) \lor (R_s=1) \land \quad (E_f-E_x) \lor (E_x=0) \lor (E_x=1) \]

This equation 27 later provides possible combinations of equilibria
points to be further analyzed. This leads to the difficulties to have
a full analysis of complete equilibrium cases due to the large
number of combinations that occurred (in this case \( 3^4 = 81 \)
probabilities). There are only five equilibria cases are discussed in
this paper.

Case #1: \( Ex = 1 \land Cs=0 \)

In this case, from equation (10), this case equivalent to:

\[ Ac = w_{ae} Pf \]

If \( w_{ae}=1 \), this case equivalent to \( Ac = Pf \)

Moreover, from equation (6) it follows that:

\[ S_s = \delta_{ss} Se + [1 - \delta_{ss}] [1 - H_d] \]

Assuming \( \delta_{ss}=1 \), this case equivalent to \( S_s = Se + [1 - H_d] \)
Finally, from deeper analysis for equation (4), this case can be
summarized to \( Ih = Ph \)

Case #2: \( Rs=1 \)

In this case, equation (17) will provide:

\[ Ep = \lambda E p \Delta_{norm} \]

If \( \lambda Ep=1 \), \( \neg Ep = E_{norm} \)
Case #3: \( \text{Ex}=\text{Ef} ^ \wedge \text{Cs}=1 \)

Equation (6) provides a set of equilibrium points through:

\[ S_1 = (1 - \text{Ef}) [\text{Ef} + (1 - \text{Ef})] \]

and if \( S_2 = 1 \) then therefore \( S_3 = 0 \)

In addition, from equation (14), the equilibria can be found

\[ A = w_{\text{tr}} \text{Pf} + w_{\text{pl}} \text{Ef} [1 - \text{Ef}] \]

Assuming \( w_{\text{tr}} = 1 \), this case is equivalent to:

\[ A = \text{Pf} + \text{Ef} [1 + \text{Ef}] \]

Finally, from equation (4), this case is equivalent to \( \text{Ep}=0 \)

Case #4: \( \text{Rs}=\text{Hd} \)

Consider equation (10), therefore this is equivalent to:

\[ \text{Ep}=\lambda_{\text{tr}} \text{Pf} \text{norm} + (1 + \lambda_{\text{tr}}) \text{Hd} \]

Assuming \( \lambda_{\text{tr}}=1 \) and \( \text{Ep}_{\text{norm}}=1 \), this is equivalent to \( \text{Ep}=\text{Ep}_{\text{norm}} \) and \( \text{Ep}=\text{Hd} \)

Case #5: \( \text{Ap}=0 \)

From equation (5), it leads to:

\[ \text{Ch} (1 - \text{Hm}) = 0 \], this leads to \( \text{Ch}=0 \) or \( \text{Hm}=1 \)

Automated Logical Analysis

A number of experimental results from the simulation traces have been used as a foundation to evaluate the identified cases obtained from the literatures and were successfully confirmed. Following are some of the evaluated cases.

VP1: High resilience results low stress while encountering a stressful event (Tung, Ping, and Kris 2014)

\[ \forall Y \text{: Trace}, Y_1, Y_2 : \text{TIME}, Y_1, Y_2 : \text{REAL}, \forall Y : \text{INDIVIDUAL} \]

\[ \text{state} (Y_1, t_1) = \text{resilience_value} (X, D_1) \]

\[ \text{state} (Y_2, t_2) = \text{long_stress_value} (X, D_2) \]

\[ D_1 \geq 0.8 \text{ & } t_2 = t_1 + d \] \quad \Rightarrow \quad D_2 \leq 0.4

VP2: Hardiness works to control stress level (Abdollahi et al. 2015; Garrosa et al. 2008)

\[ \forall Y : \text{Trace}, Y_1, Y_2 : \text{TIME}, \forall Y_1, Y_2, B_1, B_2 : \text{REAL}, \forall Y : \text{INDIVIDUAL} \]

\[ \text{state} (Y_1, t_1) = \text{hardiness_value} (X, D_1) \]

\[ \text{state} (Y_2, t_2) = \text{high_stress_value} (X, B_2) \]

\[ D_2 \geq 0.8 \text{ & } t_2 \leq t_1 + d \] \quad \Rightarrow \quad B_1 \leq B_2

VP3: Problem-focused coping strategy will help to reduce the level of stress during stressful event (Dimiceli, Steinhardt, and Smith 2010)

\[ \forall Y : \text{Trace}, Y_1, B_1, B_2, D_1, D_2 : \text{REAL}, \forall Y_1, Y_2, B_1, B_2 : \text{REAL}, \forall Y : \text{INDIVIDUAL} \]

\[ \text{state} (Y_1, t_1) = \text{problem_focus_coping} (X, B_1) \]

\[ \text{state} (Y_2, t_2) = \text{problem_focus_coping} (X, B_2) \]

\[ \text{state} (Y_1, t_1) = \text{high_stress_value} (X, D_1) \]

\[ \text{state} (Y_2, t_2) = \text{high_stress_value} (X, D_2) \]

\[ B_1 \geq 1 \text{ & } B_2 \geq 1 \] \quad \Rightarrow \quad D_2 \leq D_1

VP4: Emotion focus strategy leads to exhaustion in coping (Clarke and Goosen 2009)

\[ \forall Y : \text{Trace}, Y_1, B_1, B_2, D_1, D_2 : \text{REAL}, \forall Y_1, Y_2, B_1, B_2 : \text{REAL}, \forall Y : \text{INDIVIDUAL} \]

\[ \text{state} (Y_1, t_1) = \text{emotion_focus_coping} (X, B_1) \]

\[ \text{state} (Y_2, t_2) = \text{emotion_focus_coping} (X, B_2) \]

\[ \text{state} (Y_1, t_1) = \text{high_stress_value} (X, D_1) \]

\[ \text{state} (Y_2, t_2) = \text{high_stress_value} (X, D_2) \]

\[ B_1 \geq 0.6 \text{ & } t_2 = t_1 + d \text{ & } B_2 \geq 1 \] \quad \Rightarrow \quad D_2 \leq D_1

VP5: This condition explains the value when it stays above or below another variable value for a specified interval

\[ \forall Y : \text{Trace}, Y_1, B_1, B_2, \forall t, t_1, t_2 : \text{TIME}, \forall Y : \text{INDIVIDUAL} \]

\[ \text{state} (Y_1, t_1) = \text{has_value} (X, B_1) \]

\[ \text{state} (Y_1, t_1) = \text{has_value} (X, B_2) \]

\[ t_1 \leq t \leq t_2 \] \quad \Rightarrow \quad B_2 \geq B_1

CONCLUSION

A computational agent model of stress reaction of victims' natural crisis was developed earlier as a first step towards developing an intelligent artefact that proactively mitigates natural disaster victims’ stress (Mohammed et al. 2016). Evaluation process of the developed model is conducted in this paper to ensure its correctness and applicability. Accordingly, two approaches were implemented, namely; mathematical analysis and automated analysis. Mathematical analysis was performed to prove the occurrence of equilibria as a basis to describe convergence or stable points of the proposed model while automated analysis was performed to prove the adherence of simulation traces to psychology and cognitive literature. It can be concluded that the proposed model can be used as an analytical tool of a software agent that will support natural disaster victims at the evacuation centres. Future work will focus on the integration of pervasive and ubiquitous sensing technology with the proposed model.

REFERENCES