VOL. 8, NO. 6, JUNE 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

CONCEPTUAL FRAMEWORK FOR COMPLEXITY MODELING OF SOCIETAL STRESS AND BIOPHYSICAL RESILIENCE

Satish C. Boregowda[1] and Rodney G. Handy[2]
[1]Sandia National Laboratories, Albuquerque, NM, U.S.A
[2]University of North Carolina, Charlotte, NC, U.S.A
E-Mail: rhandy@uncc.edu

ABSTRACT

The present study proposes the development of a complexity science-based analytical model of an integrated societal stress response to a disruptive event or a disaster. The methodology is based on the biological premise that individual human beings respond to stressors or any stimuli in variety of different ways. This individual human stress response is characterized by *General Adaptation Syndrome (GAS)*, which forms the basis for model development. This individual human stress response depends on the event (internal or external) and the level of resilience in each individual. The individual human stress responses are combined to form an aggregate stress response in different cohort groups, which provides a quantitative measure of emergent behavior within that group. The aggregate or collection of these cohort group stress responses is termed as Societal Stress Response (SSR). The emergent behavior at the societal level is modeled using two kinds of conceptual modeling approaches namely *Constructal-Tree Approach* and *Agent-Based Method*. These conceptual models could be implemented to predict how the aggregated stress responses translate into a mass socio-economic behavior (or buyer behavior) with the help of an appropriate modeling approach such as System Dynamics. The transient nature of the American society and the geographical diversity is addressed using the concept of biophysical resiliency with the aid of entropy and exergy concepts from thermodynamics. The United Nations and non-governmental organizations would greatly benefit from this conceptual framework to develop a multi-dimensional strategy to deal with the maladaptive behavior in different population groups during both man-made and natural disasters.

Keywords: constructal theory, general adaptation syndrome, societal stress response, agent-based method, system dynamics.

1. INTRODUCTION

Numerous studies have been conducted in the past to examine the impact of stressors or disruptive harmful events on individual human beings. All of these studies examine the psychological and physiological aspects at the individual or the agent level. The stress concept was first introduced to the scientific community by Hans Selye [1], the father of stress research. Stress is part of our daily human experience and is associated with a great variety of essentially dissimilar problems. Such problems might include medical trauma, emotional disorders, physical effort, fatigue, pain, fear, or major lifestyle changes. Stress is present in a businessman under constant pressure; a soldier in combat; in the athlete straining to win a race; and in the air-traffic controller who bears continuous responsibility for hundreds of lives. All are essentially involved in coping with any type of increased demand upon vital activity, particularly adaptation to new situations. All endogenous and exogenous agents that make such demands are called stressors. According to Hans Selye [1], stress is considered as a multiple or single physiological non-specific response of the body to any demand. It could be either acute (short-term) as in terrorist-driven mall shooting or chronic (long-term) as in prolonged effects of a traumatic event such as post-traumatic stress disorder. Through various biochemical or neural pathways, the body responds to stressful situations resulting in altered physiological functioning leading to diseases of adaptation.

An individual under distress (negative stress) or *eustress* (positive stress) tends to affect other members of the society via a phenomenon called Emotional Contagion [2, 3]. A depressed society is one in which people feel powerless, unhappy, sad - as we have all heard the common phrases - "you can feel it in the air"… the sadness or hopelessness in the war-torn zones of the world. However, during a catastrophic event, there is an acute stress that becomes a chronic stress over a period of time due to memory at the individual or societal level. In this study, an effort is made to develop a system dynamic model with causal loop diagrams to predict the emergent human behavior at societal level during a man-made disaster. Various scenarios could be created in the models to demonstrate the effects of different variables and parameters on emergent behavior.

Using similar logic, the biophysical resilience is related to the societal stress response in some sense. However, it is dependent on the biological, ecological, and physical infrastructure of societies. In other words, the biophysical resilience pertains to the physical aspects of human survival such as food, water, energy, and related supply connections. A conceptual framework using *Entropy* and *Exergy* concepts from thermodynamics are developed to formulate analytical expressions for defining biophysical resilience. The biophysical resiliency of cohort urban and rural social groups in continental US are expressed in terms of entropy and exergy measures.

VOL. 8, NO. 6, JUNE 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

2. THEORY AND BACKGROUND

2.1. Societal stress model

The level of Societal Stress Response (SSR) on a global scale depends on the extent to which people share their feelings and emotions. In this case, the Social Neuroscience basis of Emotional Contagion and Empathy-Based Motivation is established by Singer [2, 3]. Social neuroscience provides insights into the neural mechanism underlying our capacity to represent others' intentions, beliefs, and desires, referred to as "Theory of Mind (TOM)" or “mentalizing", and the capacity to share the feelings of others, referred to as "empathy". Tania Singer [2, 3] has translated the above social neuroscience model into analysis of neuroeconomic behavior that might be of interest in this study. The most fundamental solution concepts in Game Theory - Nash equilibrium, backward induction, and iterated elimination of dominated strategies - are based on the assumption that people are capable of predicting others' actions. These concepts require people to be able to view the game from the other players’ perspectives, i.e., to understand others’ motives and beliefs. Economists still know little about what enables people to put themselves into others’ shoes and how this ability interacts with their own preferences and beliefs.

In the area of social and health psychology, Matthews *et al*., [4] have shown that low socioeconomic status (SES) populations show disproportionate rates of cardiovascular disease (CVD) morbidity and mortality. These health disparities data could provide a quantitative framework to predict the proposed Societal Stress Response (SSR). They have also used the Reserve Capacity Model [5] as a conceptual framework through which to examine the roles of stress, psychosocial resources, and emotional factors in SES and ethnic CVD disparities, in a community-based random sample of middle-aged, Mexican-American and non-Latino White women with relatively low and high SES (N=300). The Reserve Capacity Model (RCM) posits that individuals with lower social status (low SES, minority ethnicity) may suffer negative emotional and physical health consequences due to stress experienced across multiple domains. Stress may exert direct effects on behavioral and physiological risk processes, or it may influence emotional variables, which themselves are putative CVD risk factors. In addition, persons with low social status may maintain a smaller bank of resilient psychosocial resources with which to manage stress, making them especially vulnerable to concomitant physical and emotional wear and tear. These types of studies might indirectly provide with substantial information about how people respond during critical times like terrorist attacks.

2.2. Biophysical resiliency model

Numerous studies have been conducted by scholars to examine rise and fall of great civilizations. Among these studies, it has become clear through recent works of Diamond [6, 7] and Tainter [8] that complex societies do face major challenges in meeting the needs of the population during a catastrophic event. These disasters tend to expose inherent weakness in the design of our critical infrastructures and thus could lead to catastrophic outcomes. The present study introduces a novel concept called Biophysical Resilience (BPR), which is defined by the interaction between biological and physical constraints of the human-environment interaction. The dynamics of population growth coupled with physical limits of natural and man-made human ecological systems are taken into consideration in developing a model. These concepts include entropy and exergy that define the physical and biological flows in the complex web of life.

3. SOCIETAL STRESS MODEL

The proposed model of collective human stress response behavior in extreme conditions is based on a biological concept of homeostasis, which drives our basic instinct to survive. All living organisms, including humans, have a tendency maintain an internal state of constancy that is termed as “milieu intérieur” [9] or “Homeostasis” [10]. This tendency in humans is assumed to be a strong force behind our behavior patterns and become more evident during stressful events. The Bio-Psycho-Socio-Economic Model flows from individual biological survival to psychological well-being to social acceptance to economic survival are depicted in Figure-1.

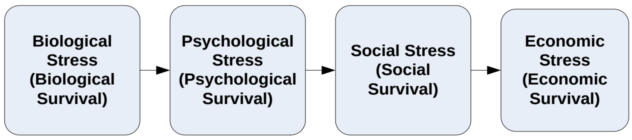

Figure-1. Biology to Economics.

The pattern of individual stress responses is derived from the medical concept of Hans Selye [1] called General Adaptation Syndrome (GAS). Hans Selye is a renowned stress researcher and is well-known in the medical literature for his pioneering work in experimental stress biology. The Figure-2 depicts the concept of GAS applied to an individual human agent. The GAS exhibited in each individual (or agent) is extended to various socio-economic groups, whose buying behavior could be predicted. The study applies the biological concept of GAS to examine the Societal Stress Response (SSR) to disruptive events. Although it could be argued that there are individual differences in the stress response, the pattern of response of group of individual who form a social group will be exhibit pattern to similar to that of GAS. The schematic of GAS is provided in the Figure-2.

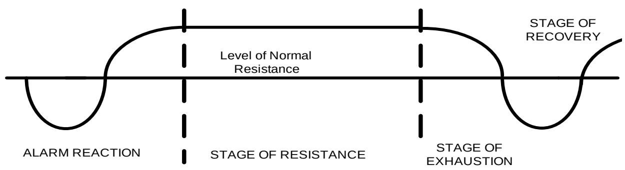

Figure-2. General adaptation syndrome.

VOL. 8, NO. 6, JUNE 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

The First Question - How does the individual human stress response translate into a group behavior? This is answered via framework for Societal Stress Response Model depicted in Figure-3. Furthermore, the studies conducted by Sapolsky [11] establish the fact that socioeconomic status (SES) plays a major role in health and eventually determine how low SES individuals respond to stressors. In this regard, the health data (obesity, body weight, cardiovascular health, diabetes, etc…) could provide an indication how the community or a social group as a whole would respond to a stressful event such as a terrorist attack (man-made) or natural disaster. It is clear from the studies that the low social rank with no control over work and lack of social support creates vulnerability and becomes evident during disruptive events.

The Second Question - How do we quantify this bio-psycho-socio-economic stress response of a social group or an urban inner city or a suburb or a rural county? The information entropy measure is developed for each one of the variables, biological, psychological, social, and economic. The resulting entropy measure provides an indication of how a particular group might respond to a crisis. An axiom is proposed to provide a quantified measure of stress response in a community or a social group of interest.

Axiom-1: The societal stress response is an aggregate of individual human stress responses to a disruptive event and is measured as change in two identifiable states on time scale. It is quantified as follows:

Societal Stress Response = f {Biological, Psychological, Social, and Economic Variables}

Where

Biological variables include physical health status, obesity and diabetes, CVD data, substance abuse, crime, HIV, and other fitness-related information.
Psychological variables include mental health status, obesity, tobacco and alcohol usage, drugs, crime, HIV, and other fitness-related information.
Social variables include SES, social networks, social support groups, religious and/or spiritual resources, pro-social activities, etc…
Economic variables might include both macro and micro-economic variables -employment, commodity prices, consumer confidence, etc…

3.1. Agent-based approach

The agent-based approach is dynamic and functional nature. A system dynamic model of Figure-3 is developed for an individual (agent) and extended to represent a social group with various archetypes. These archetypes represent various factions of American society and the interaction among the subgroups leads to a subgroup emergent behavior. It is the interaction among these subgroups that leads to an emergent behavior at the societal level. When there is a stressful event, the individual human beings respond to this event emotionally. These emotions continue to spread among the members of the society leading to an emergent behavior that needs to be predicted. The basic framework for spreading of emotions (or emotional contagion - see Figure-3) is provided in Figure-4 using agent-based modeling approach, which could also be modeled using system dynamics [12].

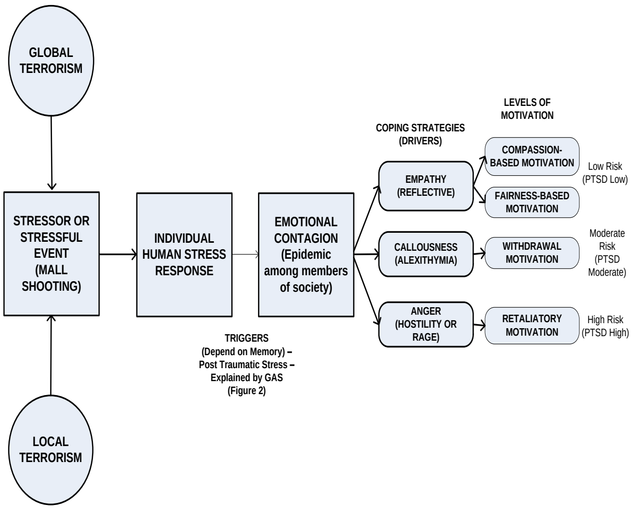

Figure-3. Framework for societal stress response model.

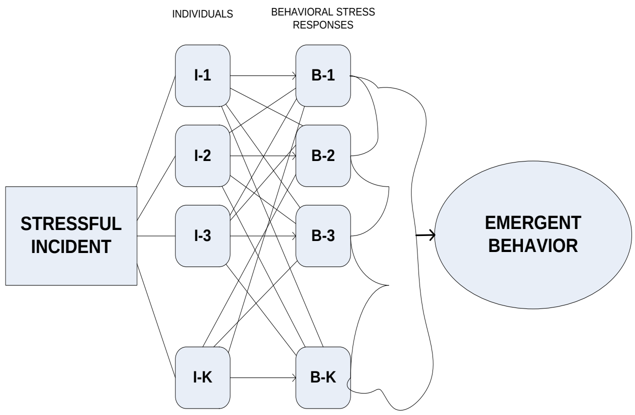

Figure-4. Agent-based modeling of emotional contagion.

3.2. Constructal approach

The constructal-based approach is more geometric or structural in nature [13]. The resulting structure is takes the shape of an asymmetric tree in which the outcomes bifurcate depending on the impact of media and other external factors. The diffusion of emotions takes the path of a tree in the most optimal manner. This means that the emotions can spread from one individual to a few and from a few to a many or vice versa. It mimics the flow of heat energy from a point (individual) to a volume (group of individuals) and vice versa. While building this type of model, it is apparent that the features of high-stressed societies or social groups are reflected in steep economic disparities and social segregation. They are also

ARPN Journal of Engineering and Applied Sciences

characterized by higher (or lower) IDV, higher MAS, higher UAI, and lower LTO index scores [14].

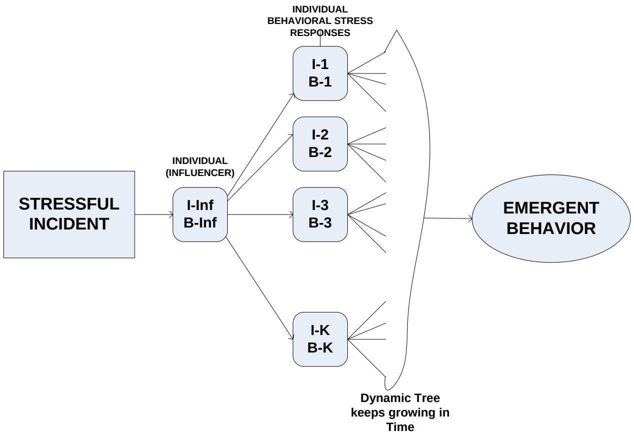

Figure-5. Constructal-tree modeling of emotional contagion.

4. BIOPHYSICAL RESILIENCY

4.1. Definition of biophysical resiliency

The present section involves development of an axiomatic approach to definition and measurement of biophysical resilience of societies and their response to both natural and man-made disasters. This complex system thermodynamics-based approach is based on concepts such as entropy and exergy. The entropy and exergy are both defined as extensive variables that depend on the mass, density, and volume. While entropy refers to the level of disorder or chaos or activeness in a system, the exergy pertains to the available potential within the system to produce maximum possible work. As entropy increases, the exergy decreases thereby reducing the available potential of the system. The biophysical resiliency of cohort urban and rural social groups in continental US are expressed in terms of entropy and exergy measures. These expressions in turn are embedded within an appropriate complex systems model. The interplay between entropy and exergy are simulated and the aggregate emergent behavior of the cohort groups is obtained. The simulation results would become available for comparison with the real world data to make policy decisions.

4.2. Entropy-based model

What is Entropy? Entropy is a measure of a disorder in a system, any system in the universe, which is governed by the laws of thermodynamics. Can we measure or quantify this "disorder" in a society in terms of measurable quantities such a population mass, population density, population volume, land, transportation networks, etc…? The answer is Yes, if we can identify the appropriate physical and/or economic variables such as the price of an essential commodity, the quantity purchased, and the time interval, we could compute the macro-level of entropy in a society. Also, the complex societies comprising of large number of interconnections or interdependencies exhibit high levels of micro-level entropy. For example, the population in Chicago city, its density, access routes to and out of the urban center, resistance to flow of people from a volume to a point or vice versa. These measurable physical variables could be combined using Maxwell (Thermodynamic) relations and Boltzmann expression to compute physical (macro) entropy and information (micro) entropy measure.

Axiom-2: The Physical (macro) entropy change is a system response to a disruptive event in terms of measurable macro physical variables as the system goes from State 1 (before disruption) to State 2 (after disruption).

Biophysical Entropy Change = f {Population Density, Mass, Volume, Land Mass, Location, Access Routes}

Axiom-3: The Information (micro) entropy is a system response to a disruptive event in terms of measurable micro informational variables as the system goes from State 1 to State 2.

Bio-Information Entropy = f {Income, Commodity Prices, Volume of Purchase, Educational Level}

4.3. Exergy-based model

Exergy, on the other hand, is a measure of quality of the system or its potential to produce maximum allowable energy or work. The useful or the maximum energy that a system can produce diminishes over time due to lost work caused by increase in entropy, which destroys exergy. The resiliency of the society depends on the existing design of all infrastructures. This will give an idea how a society or a social group would respond during a catastrophic event. The low entropy and high exergy is an indication that society is stable and has the resources, natural, social, and economic, to counter the negative effects of system disruption.

Axiom-3: The biophysical exergy is a measure of the quality or the maximum potential of the system. This term could be used to provide a quantitative measure of system resiliency (SR) to disruptive events.

Biophysical Exergy = System Resiliency (SR) = f {Fitness Variables}

The fitness variables include SES, health status, social networks, social support groups, religious and/or spiritual resources, local food production systems, distributed energy generation systems, local manufacturing, employment base, and so on. They also include cultural attributes such as IDV, MAS, UAI, LTO, and so on. This implies that higher the entropy (stress), lower the exergy (resilience). One of the features of high-entropy societies is reflected in steep economic disparities and social segregation, which are also characterized by higher (or lower) IDV, higher MAS, higher UAI, and lower LTO index scores.

ARPN Journal of Engineering and Applied Sciences

Entropy and Exergy (System Resilience, SR) are dynamic variables and they vary as a function of time and behave as shown in Figure-6.

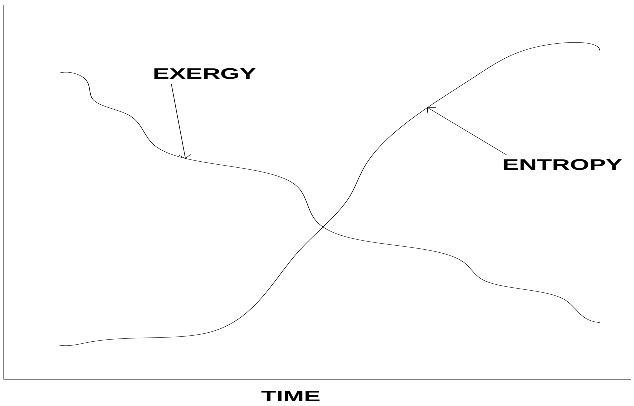

Figure-6. Entropy (stress) versus exergy (resilience).

The high entropy and low exergy (with low System Resilience, SR) societies might require external intervention to mitigate the negative effects of disasters or crises. They also have less resilience at the local level and thus require external help to mitigate the deleterious effects. In other words, the immune system is compromised and the local agents lack the ability to respond to a crisis and thus require a powerful anti-biotic (federal response) to fight the infection. The concepts of entropy and exergy could be used to measure the level of immunity in a system or resilience.

5. CONCLUSIONS

The results from this study offer some preliminary indications suggesting that the OSI may be a valuable index to detect vulnerability of the human body to various levels of stress. The finding of a statistically significant difference in the population mean OSI values between males and females indicates that there is a great potential for use of OSI. It could be a much better measure of stress than single physiological indicators. The Mann-Whitney test results show there is a statistically significant difference between male and female OSI stress responses. The same nonparametric statistical analysis indicates that there is no statistically significant difference between male and female SSI stress responses. As a result of this paradox, it is suggested that the OSI, along with the SSI, could become a robust methodology for measurement and evaluation of stress in work and living environments. The Objective Stress Index (OSI) in combination with Subjective Stress Index (SSI) could be used to provide a measure of stress and predict health risk due to stressful life conditions. This unified stress measure could provide the fields of behavioral medicine, psychology, and public health sciences in general with something which has long been sorely missing - a scientifically sound and clinically useful way of quantifying human stress as a single number.

Nomenclature

BPR	Biophysical resilience
CVD	Cardiovascular disease
IDV	Individualism measure
LTO	Long-term orientation
MAS	Masculinity measure
PDI	Power-distance index
RCM	Reserve capacity model
GAS	General adaptation syndrome
SES	Socio-economic status
SR	System resiliency
SSR	Societal stress response
TOM	Theory of mind
UAI	Uncertainty avoidance index

ACKNOWLEDGEMENTS

The authors wish to thank Munaf Syed Aamir of Sandia National Laboratories for the support.

REFERENCES

[1] Selye H. 1976. Stress in Health and Disease. Boston: Butterworth Publishers Ltd.

[2] Singer T. The Neuronal Basis and Ontogeny of Empathy and Mind Reading: Review of Literature and Implications for Future Research, Neuroscience and Biobehavioral Reviews. 30: 855-863.

[3] Singer T. and Lamm C. 2009. The Social Neuroscience of Empathy. The Year in Cognitive Neuroscience 2009: Annual New York Academy of Sciences. 1156: 81-96.

[4] Matthews K. A. and Gallo L. C. 2011. Psychological Perspectives on pathways linking socioeconomic status and physical health. The Annual Review of Psychology. 62: 501-530.

[5] Gallo L. C. 2009. The Reserve Capacity Model as a framework for understanding psychosocial factors in health disparities. Applied Psychology: Health and Well-Being. 1: 62-72.

[6] Diamond J. 2011. Collapse: How Societies Choose to Fail or Succeed. Penguin, New York, USA.

[7] Diamond J. 2005. Guns, Germs, and Steel: The Fates of Human Societies. W. W Norton and Company, New York, USA.

[8] Tainter J. A. 2005. The Collapse of Complex Societies (New Studies in Archaeology). Cambridge University Press, Cambridge, U.K.

[9] Bernard C. 1957. An Introduction to the Study of Experimental Medicine. Dover Publications, New York, USA.

[10] Cannon W. 1963. Wisdom of the Body. W. W Norton and Company, New York, USA.

[11] Sapolsky R. M. 2004. Why Zebras Don't Get Ulcers. Henry Holt and Company, New York, USA.

[12] Sterman J. D. 2000. Business Dynamics. McGraw-Hill Book Company, New York, USA.

[13] Bejan A. 2000. Shape and Structure, From Engineering to Nature. Cambridge University Press, Cambridge, U.K.

[14] Hofestede G. 2001. Culture's Consequences: Comparing Values, Behaviors, Institutions and Organizations across Nations. Sage Publications, NY, USA.