 ISSN: 2167-1435
v31 n3071

Exploring the Implications of Technology Acceptance Models for Sensor-based Global Health Technologies

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Abstract

Health Technologies including sensor based- and Health Information- technologies have great implications as decision support systems in global health and security. They hold creative promises for addressing modern day threats to global health including infection, terrorism, the environment and socioeconomic security, yet these are promises that are undeliverable except new technologies are first understood and accepted by potential users. Concerns are no longer limited to the gap between research, commercialization and cost consideration, but now include complex technical and human factors: including form factor, ergonomics, deployment, data communication, aesthetic, knowledge management, and energy efficiency amongst others. These factors have been known to cause users' rejection. In order to mitigate these effects, studies in human factor are devoted toward understanding the interaction between humans and equipment. Technology Acceptance Model (TAM) and its pertinent constructs including perceived ease of use, perceived usefulness have been used to determine human behavioral intention toward invention mock-ups, prototypes and fully developed tools. However, emerging technologies in the global health field have specific domains, hence constructs that may not yield to traditional TAM. This paper attempts to review studies in TAM and their implication for sensor-based global health technologies.

Keywords: TAM, Health Information technology, sensor, global health, public health, security

1. INTRODUCTION

Emerging technologies such as the planned Hewlett Packard (HP) Central Nervous System for the Earth (CeNSE), sensor-integrated systems, Electronic Health Records, Computerized Provider Order Entry, Bar Coding, RFID, Clinical Decision Support Systems and other Environmental Information Systems hold creative promises for addressing modern day threats to global health and socio-economic systems; however, such promises are undeliverable except these technologies are first understood and accepted. The reasons are complex and they include technical and human factors that are critical to the advances and commercialization of sensor networks: manufacturing cost, form factor, deployment, data communication, energy efficiency; and inadequate experience in deployment and experience sharing (Lau, Chang, Hu, Huang, Shyu, Chiu and Huang, 2006).

The threat of rejection of new innovations can be mitigated if at the early stage, the attitudes of potential users and decision-makers are understood. According to Fishbein (1975) attitude as a concept, is important in understanding and predicting the reaction of people to an entity or change and how *behavior*s can be influenced. Drake (2002) while quoting the Center for Devices and Radiological Health's Division of Device User Programs and Systems Analysis wrote that, "the study of human factors is a science devoted to understanding the interaction of people and equipment" (p. 8).

As a result of the complexity of the issue of public, industrial and environmental security, the prohibitive cost of developing new technologies and the socio-economic ramifications of the emerging systems that have been proposed or described for widespread deployment, the complex nature of proposed systems emphasizes the need for circumspection in design and implementation to safeguard such systems from failure that may arise as a result of users' rejection. One of the ways to avert failure or minimize complications that may lead to failure is to understand users' attitude, perception or perceived usefulness of technology (Jain, 2006; Davis and Venkatesh 2004; Venkatesh, Morris, Davis, and Davis, 2003). However, developing instruments for measuring factors often can be time consuming and prohibitive. Yet time is often of essence to determine the prospects of a new technology before enormous resources are invested research and development.

Technology Acceptance Models (TAM) have traditionally been used to study users' behavioral intentions and perceptions toward the usability and ease of use of technology. According to Venkatesh et al. (2003), TAM posits that perceived usefulness and perceived ease of use determine an individual's intention to use a system, intention to use being the mediator of actual system use. This study examines secondary documents in order to understand the implications of TAM for Global Health technologies with emphasis on those that are sensor-based and have potentials to impact socioeconomic security. This includes those that have been designed for use in public health bio-environmental monitoring including bioterrorism; pollution; and vehicle tracking amongst others.

2. A REVIEW OF LITERATURE

Global Health and Security Issues

The threats of bioterrorism, pollution and natural and industrial disasters affecting socio-economic systems are increasingly becoming more complex and complicated; as a result, human security and health concerns can no longer be isolated from socioeconomic security and environmental health. There is a paradigm shift in the way the public views security. Sensing devices are increasingly having implication and significance for national security, public health and environmental monitoring. In several applications such as vehicle tracking, battle field, pollution detection and patients' health monitoring, the primary function of sensors is to sense the environment in which they are embedded and transmit acquired data to a base station for further processing (Hong and Prasanna, 2005).

Attacks on global security are no longer restricted to nation states but entities that are difficult to define or pinpoint to a geographical location. The terrorist attack of September 11, 2001 amplified the concern for public safety. Subsequent anthrax attacks in the fall of 2001 at a New Jersey United States postal offices created enormous interests in systems that could be used for environmental monitoring, bio-surveillance, detection and diagnosis in the public, military and private sectors. Most recent man-made disasters – including 2010 British Petroleum oil leakage off the Gulf of Mexico; and natural disasters- such as earthquake in several countries including Haiti in 2010 and the 2005 South East Asia tsunami, as well as the tsunami induced nuclear reactor system failure in Japan - that destroyed untold lives and properties all underlie a need for technologies and practices that can assist key decision makers in forecasting and/or determining the most probable cause of a problem and facilitate methods to solve such problems most accurately. As a result of the 2001 events, military and security agencies have focused on using biosensors to detect biological and chemical agents, a move that has been described as a reversal of the classic migration of military technology to the private domain because traditionally, bio-sensing is done in the pharmaceutical, medical and environmental fields (MarketResearch.com, 2002).

According to Bravata, McDonald and Owens (2002), the United States' capacity to respond to bioterrorism depends in part on the ability of public health officials and clinicians to detect, manage and communicate during a bio-terror event. This is also applicable to other environmental disasters because they impact socioeconomic systems. Information technologies and decision support systems (IT/DSSs) are critical aids to health professionals. Bravata et al. (2002) noted that clinicians and public health officials require diagnostic, management, prevention and reporting decisions as necessary information required in responding to bio-terror attacks. Kornguth (2005) suggested the use of advanced sensor systems as integral components of bio-detection technologies designed for warning, detection and surveillance of bio-terror and agents of biological warfare. While discussing a strategy that is needed to be fully prepared for biological threat detection, prevention and management, Kornguth (2005) suggested multiplexed, multi-array sensor systems as a component of a network needed for rapid detection and identification of biological threats. According to Kornguth (2005), this sensor system will be capable of recognizing all bacterial or viral genomic materials that determine bio-agents' virulent nature, pathogenicity and antigenic characteristics. Previously, one of the difficult aspects of a detection system is the development of multiplexed sensor-based systems capable of detecting several toxic agents.

Direct or indirect interaction of sensor networks or sensor integrated systems with humans and the environment is inevitable. In health, medical and national security applications, one must be able to detect threat agents quickly. Public Health and Information technologists or Information Systems (IS) practitioners (if they have not) will increasingly experience sensor applications once widely deployed. According to Ligler (2009), improved approach to biosensor system integration – amongst other factors- will accelerate the movement of new concepts from the laboratory to the point of use and dramatically increase awareness in the potential applications of sensor technology to improve public health and environmental monitoring. While its benefit is obvious, it is not yet understood what inherent risks it carries, yet its acceptance or otherwise can be mitigated by the views and attitude of those who as 'first responders' in the population, are most likely to encounter it and the consequence of its usage in their education, profession and decision making processes. This will include public health practitioners and Information Systems (IS) managers.

Sensor Based Technologies and their Public Health Impact

Sensors and biosensors are increasingly having implication and significance for national security, public health and environmental monitoring. Public Health practitioners are interested in entities that could impact our lives. Information System professionals collect data and process to enhance decision making. There is a need for public and decision makers' awareness on sensing devices/systems. New technologies require preparation and awareness of those who will benefit from using such technologies in their public health and organizational decision making processes. Information technologies and decisions support systems (IT/DSSs) are critical aid to civil defense organizations and health professionals. As a result of the complexity of the issue of public, industrial and environmental security, the prohibitive cost of developing new technologies and the socio-economic ramifications of the emerging systems that have been proposed or described for widespread deployment, the complex nature of proposed systems emphasizes the need for circumspection in design and implementation to safeguard such systems from failure that may arise as a result of users' rejection.

The science and research that are very important to the development of sensor innovations are based on materials created from organic and inorganic substances. Smith (2002) stated that "Both inorganic and organic materials are used in the fabrication of sensors. Inorganic materials include single crystals like quartz, silicon, and compound semiconductors; polycrystalline and amorphous materials like ceramics, glasses, and their composites; and metals. Organic materials are mainly polymers; however, recently, lipids, enzymes, and biochemical compounds (e.g., antibodies and DNA molecules) are used in biosensors (p. 16)" According to Dreher (2004), the micro technology developed in the latter half of the 20th century produced a revolution that led to the development of computers and the *Internet* and drove us into the emerging era of nanoscale technology. In theory, nanoparticles can be created from almost every chemical. But most nanoparticles that are in use are made from transition metals, silicon, carbon (single-walled carbon nanotubes; fullerenes), and metal oxides such as zinc dioxide and titanium dioxide (Dreher, 2004). Muray et al. (2000) observed that some nanoparticles are made of a combination of metals and compounds forming nanocrystals or quantum dots (Dreher, 2004). Dreher observed that other authors discussed nanoparticles as materials which display peculiar physico-chemical characteristics that give unique mechanical, thermal, electrical and imaging properties associated with them. The proposed plan for a global deployment of systems based on sensor technologies suggests a widespread installment and presence of nanomaterials in the human environment. According to Dreher (2004) occupational and public exposure to these materials will increase dramatically soon

ISSN: 2167-1435
v31 n3071

because of their utility and sheer ability to improve quality and performance of many consumer products in the public, medical manufacturing and industrial sectors. Yet information is scarce about the public health implications and especially environmental risk assessment of manufactured nanoparticles.

The Role of Information Systems and Communication Technologies in Public Health Safety

David and Jerome (2007) expressed concern about the dual nature of technologies- present or future - applied to address environmental issues and terrorism while noting the potentials of new technologies in the fight against terrorism including the convergence of genomics, robotics, information technologies and nanotechnology. Furthermore, David and Jerome (2007) indicated that each of these developing technologies offers a mixture of benefits and risks. An integrated system might cause unintended problems, the most important being "the possible contribution to terrorists' motives" (David and Jerome, 2007, p.1). Bravata, McDonald, and Owens (2002) prepared a report that details the methodology, results and conclusions of a systematic and extensive search for published materials on the use of IT/DSSs to serve the information needs of health practitioners in the event of a bio-terror attack. Bravata and his team of researchers (2002) developed a conceptual model to specify the decisions and tasks involved in the diagnosis, management, prevention, surveillance and communication by health workers and concluded that survey of Public Health officials could be used to better describe the information needs in preparing for bio-terror attack.

The early detection of disease outbreaks by a medical bio-surveillance system depends on two major components: 1) the contribution of early and reliable data sources and 2) the specificity, sensitivity, and timeliness of bio-surveillance detection algorithms (Siegrist and Pavlin, 2004). In a Siegrist and Pavlin (2004) study designed to determine whether automated detection algorithms can reliably and quickly identify the onset of natural disease outbreaks that are surrogates for possible terrorist pathogen releases, historic data were collected from five metropolitan areas over 23 months Collected data included International Classification of Diseases, Ninth Revision (ICD-9) codes related to respiratory and gastrointestinal illness syndromes. Considering the minimal availability of data for an actual biologic attack, the authors concluded that it might be difficult to determine how quickly an algorithm might detect an attack and suggested that research is needed to assess the value of electronic data sources for predictive detection.

Advances in diverse academic fields have enhanced the prospect of the development of better detection systems. Kornguth (2005) discussed a new strategy that is needed to be fully prepared for biological threat detection, prevention and management. Kornguth (2005) also suggested multiplexed, multi-array sensor systems as a component of a network needed for rapid detection and identification of biological threats. According to Kornguth (2005), this sensor system will be capable of recognizing all bacterial or viral genomic materials that determine bio-agents' virulent nature, pathogenicity and antigenic characteristics. One of the most difficult aspects of a detection system is the development of multiplexed sensor based system capable of detecting several toxic agents.

The new paradigm involves the development of nanotechnology based sensors capable of detecting all threat agents simultaneously. This can be coupled seamlessly with an integrated communication software capable of converting large scale data to actionable information (Kornguth, 2005). Berndt, Fisher, Craighead, Hevner, Luther, and Studnicki (2007) explained that the development of a formidable bioterrorism surveillance system requires effective solutions to many critical challenges. According to the researchers, such a system must be able to support multi-dimensional historical data provide a real time surveillance of sensor data and must possess the capability for recognition of patterns that enables it for quick identification of aberrant situations. Furthermore, Berndt et al. (2007) wrote that such a system must be able to lend itself as an analytic environment that accelerates investigations by health responders. Stark (2007) gave a summary of the sensing systems and the technologies that could lead to bio-agent detection and for use by responders in the field.

A Review of Relevant Models and Theories

Models exist for examining users' technology acceptance and the explanation of the various dynamics and factors that contribute to a successful adoption or otherwise of new innovations (Venkatesh, Morris, Davis, and Davis, 2003). The Technology Acceptance Model (TAM) specifies that the usage of information technology is determined by beliefs a user holds about the perceived usefulness (PU) and perceived ease-of-use of the technology (PEU) (Davis, 1989). According to Lanseng and Andreassen (2007), TAM posits that the actual use of information technology is determined by usage intention and attitudes. These factors in turn are determined by two key constructs including PU and PEU. Based on Ajzen and Fishbein's (1980) Theory of Reasoned Action (TRA), TAM explains the determinants of user acceptance of a broad range of end-user computing technologies (Davis, 1986). Perceived Usefulness, one of the primary determinants of system use is defined as the prospective user's subjective probability that his or her job performance within an organizational context will be improved by using a specific application system (Davis et al., 1989). Jarrett (2003) described the TRA as an attitudinal theory used to predict the behavior or intent regarding adoption or non-adoption of innovations based on attitudinal behavior and subjective norm.

Technology acceptance models have been tested on post-prototype technology (Davis and Venkatesh, 2004). Jain (2006) identified the inadequacies of these models for testing pre-prototype technologies, and as a result modified existing models for use in testing pre-prototype technologies. One reason for the development of models is the importance of technology to development. According to Jain (2006), such research findings have consequences for the development of costly or risky IT, because it allows for an early estimation of IT acceptance before too many limited or costly resources are expended toward new IT development; and allows for ample time where applicable, to modify key aspects related to the IT appeal.

Venkatesh et al. (2003) proposed a unified view on users' acceptance resulting in the Unified Theory of Acceptance and Use of Technology (UTAUT) and compared the variables of the most commonly cited users' acceptance models. UTAUT was developed from eight of existing models and validated in a longitudinal study across four organizations. According to Neufeld, Dong, & Higgins (2007), the UTAUT model synthesizes and rationalizes user acceptance literature to provide an easily consumable model to explain behavioral intention and use.

Information Systems researchers are interested in users' knowledge of IS/IT/ICT tools, their conception and even preconception. For individuals, the process of acceptance commences even before individuals have interacted with the technology. For instance, the success or failure of a new technology depends on users' acceptance which depends on the preconceived knowledge of the technology, its perceived usefulness and the users' behavioral intention toward the IT (Jain, 2006; Davis and Venkatesh, 2004; Davis, Bagozzi, & Warshaw, 1989). Pre-prototype user acceptance testing (PUAT) may be significant for the success of new IS/IT/ICT tools.

According to Davis and Venkatesh (2004), the failure rate for newly developed IS remains unacceptably high, especially for large and complex systems. This observation is corroborated by the Standish Group "CHAOS Summary 2009" report which showed a marked decrease in project success rates, with only 32% of all projects delivered on time, on budget, and with required features and functions. A statement attributed to Jim Johnson -the chairman of The Standish Group- indicated that 24% of all projects failed while 44% were challenged, delivered late, went over budget, and/or with less than the required features and functions (The Standish Group, 2009). Davis and Venkatesh (2004) employed the TAM model to investigate the implications of PUAT for software project management. The authors' approach was to recreate mock-ups of an existing system with features that approximate what would have been available during the early development stages of the system. They exposed 106 users to the recreated mock-up and observed their reactions at multiple points in time. Through the use of functionality descriptions, story boards, and screen designs from the early stages of system design, the researchers were able to simulate the progression from a pre-prototype to a post-prototype (working version) of the software product. The authors observed that pre-prototype measurement of behavioral intention (BI) was highly correlated with one and three-month's post-prototype BI measurement.

Since PEU is more useful in post-prototype measurement, the implication is that PU which also has been determined to be useful in predicting users' post-prototype PU up to six month, is a more important determinant of intention when compared to PEU.

ISSN: 2167-1435
v31 n3071

Jain (2006) noted the limitations of Davis and Venkatesh's model and the UTAUT for pre-prototype measurements. According to Jain (2006), the limited number of models for PU determinants were developed and tested at the post-prototype stage that is, after IT has been tested and used by prospective users. Therefore, Jain (2006) incorporated components that were drawn from earlier models of determinants of PU because: 1) the UTAUT contains variables that are not applicable at the pre-prototype technology stage, and 2) they neglect a lack of variables that may be specifically relevant to pre-prototype technologies. Jain's (2006) study involved a total of 128 respondents and measured 10 constructs using 7-point likert scale anchored between "strongly disagree" and "strongly agree" endpoints and observed that users' preconceptions regarding an IT can have a lasting impact on their usage behavior with regard to the IT. Through this research, Jain was able to provide determinants of PU. It is noteworthy that Jain's pre-prototype measurement involved a wireless network, a technology that had been used elsewhere and was assumed as a pre-prototype for Jain's study because of the fact that the technology was the first introduction of its kind in the municipality where Jain conducted his study. This is at variance with Davis and Venkatesh's (2004) definition of "pre-prototype" as the stage of the IT development process before a working prototype has been tested or used by prospective users. It is not impossible that some of the subjects surveyed in Jain's study had previous knowledge and experience of the wireless network technology elsewhere before relocating to the studied municipality. Jain's report did not provide any indication that this potential bias was addressed. Any prior exposure of any of the participants in Jain's study could bias its assumption as a pre-prototype study.

Davis and Venkatesh (2004) used a mock-up description approach. They described such pre-prototype method as simple text descriptions that do not give much detail as to the specifics of a software product and that can be the simplest form of mock-ups produced in early design and developmental stages. Similar to Jain's (2006) concern about the failure of technology due to users' preconception, Davis and Venkatesh (2004) observed that the errors in requirements specifications are major contributor to costly software project failures hence it is very helpful if Information Systems developers verify requirements by predicting users' acceptance of a new system based on users' evaluations of its specifications. Furthermore, Davis and Venkatesh (2004) opined that system specifications should be available for users' evaluation during the earliest stages of the system development, ideally before building a working prototype, noting that predictive and stable measures of PU can be captured from system users who have received information about the functionality of a system and have not had a direct hands-on usage experience.

Concern for the success of new innovations is well placed. For an emerging technology like the sensor network system, pre-implementation knowledge and attitude is important because of potential ramifications that may not yet be obvious. As individual units, these devices exist for various needs and in diverse fields. But as a worldwide network system, they remain innovations whose importance, impact, significance and research is still a mystery and not well known as suggested by a paucity of literature in the field. Previous studies cited above helped to generate discussions and hence, served in educating and creating awareness for experts and the public alike, thereby fulfilling the social awareness and knowledge components of Rogers' (1995) Innovation of Diffusion theory.

Furthermore, it is known that societal knowledge about an innovation is a great instrument for engineering positive opinion or attitude toward a novel technology. A theoretical framework developed by Attewell (1992) to study the diffusion of complex technologies in organizations revealed that knowledge including lack of technical skills were important barriers to diffusion; as a result, organizations tend to delay the adoption of complex technologies until employees acquire sufficient technical know-how to implement and operate new innovations successfully.

3. DISCUSSSION AND CONCLUSION

Recent world events indicates that threats to global health and socio-economic systems are not abating. In fact if precedence is anything to go by, current events suggest an increase in this trend. Emerging threats to global health are neither traditional nor conventional. Furthermore, population explosion in many parts of the world and persisting poverty continue to indicate needs for innovations to manage worsening health situation. Such needs and threats in the past have raised concerns that spurred disruptive innovations and intrusive technologies to address global health issues. New technologies and innovations have great implication and significance for national security, public health and environmental monitoring. Public Health practitioners are interested in entities that could impact our lives. Information system professionals collect data and process to enhance decision making. The public has an on-going need for education and awareness on public health issues including technologies that may alleviate the impact of natural and man-made perturbations. In fact new technologies require preparation and awareness of those who will benefit from using such technologies in their public health and organizational decision making processes. Information technologies and decision support systems (IT/DSSs) are critical aid to civil defense organizations and health professionals.

As a result of the complexity of the issue of public, industrial and environmental security, the prohibitive cost of developing new technologies and the socio-economic ramifications of the emerging systems that have been proposed or described for widespread deployment, the complex nature of proposed systems emphasizes the need for circumspection in design and implementation to safeguard such systems from failure that may arise as a result of users' rejection. One of the ways to avert failure or minimize complications that may lead to failure is to understand users' attitude, perception or perceived usefulness of technology (Jain, 2006; Davis and Venkatesh 2004; Venkatesh, Morris, Davis, and Davis, 2003). Regarding new innovations, Technology Acceptance Models remain classic techniques essential in developing theoretical foundation for determining users' behavioral intentions, as well as perceived usefulness (PU) and ease of use (PEU). Classic research in TAM as indicated by most of the literature found for this review study, are found in technologies outside the health or global health fields.

The different domains associated with Health based technologies are different from other non-health technologies, and could benefit from models specifically designed to measure PEU and PE, yet health related domain-dependent constructs may not yield to traditional models.

For instance, *Health, Information* and *Technology* are three domains identifiable in Health Information Technology. It is a general knowledge that broad and consistent utilization of HIT have helped to improve health care quality and productivity while preventing medical errors by extending real-time communications of health informatics among health care professionals. Ultimately, it improves access. As in other technologies, safety, quality and efficiency are concerns that may factor into users' behavioral intention toward these types of technologies. In order words, safety, quality and efficiency are important in the three domains of Health Information technologies. Specifically, the behavioral intention of potential users of HIT could hinge on the individual's health status, health beliefs, health insurance and the future assurance of it as well as other health concerns. In the domain of *Information, health data, data safety and integrity, political leaning,* and other subjective norms such as peer pressure could be important to the potential user. To the potential user, the technology as a platform, its broader goals especially its ability to help reduce errors, health cost etc. are important to individuals as well as public health institutions.

Furthermore, we can differentiate between HIT and sensor-based technologies designed for Global Health. While many of the aforementioned may be factors to consider in the development or adaptation of existing TAM, it is pertinent to note that Global Health sensor-based technologies because of their geo-socio-political reach may present larger issues and concerns. This may include domestic and international considerations such as global security, sovereignty, economics and ethics among others (Ajani, 2014). This is a qualitative study in which the author surveyed public health educators for their perception on global sensor networking. According to the author, respondents recognized the benefits of these technologies for the environment, health and safety, but also expressed concerns about the implications for personal freedom, civil liberties, security and privacy of personal information. These are factors which may not be found in constructs of classic TAM hence the requirement for the development of newer models that could take cognizance of these facts.

The unconventional nature of new threats to global health require our collective ability to respond and quickly develop integrative systems from non- or pre- existing multiple technologies.

ISSN: 2167-1435
v31 n3071

But due to its elaborate nature and developmental time for constructs that may be specific to new technologies, TAM may not lend themselves as quick evaluative tools for measuring behavioral intentions. In response to this, other authors developed Emerging Technologies Semantic Differential Scale (ETSDS) (Ajani and Stork, 2013). In a pre-implementation studies that provided a mock-up description of a sensor-based technology designed for environmental monitoring, the authors tested a technique that was demonstrated to be a simple reliable measure for quantifying attitudes as evaluative judgments about objects and concepts. Analysis centered on bipolar adjectives that have relevance to the constructs used in traditional TAM investigations (e.g. usefulness).
According to the authors, social desirability was a limitation of their study. Nevertheless, it is useful in pointing direction for future studies aimed at developing theories and models for emerging technologies such as the Sensor-based global health systems.

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