

# *DETERMINING THE ROLE OF GEOSPATIAL TECHNOLOGIES FOR STIGMERGIC COORDINATION IN SITUATION MANAGEMENT: IMPLICATIONS OF THE WIRELESS GRID*

## (Poster)

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**Abstract**—Geospatial technologies in conjunction with wireless grids will offer a context for locating and coordinating team activities in such a way that the nature of each team member's effort may be known and understood by other members. This constructed group knowledge enables teams to respond to unforeseen and emergent contingencies and act in concert through the active interpretation of shared artifacts alone without prior planning and coordination. Stigmergic or sematectonic coordination refers to how an individual behaves as part of a collaborative team engaged in a complex task, such as emergency response (i.e. where the task is of such complexity that a coordinated team effort is required to accomplish it). Human stigmergic coordination emerges on the basis of how tasks and goals are structured and understood between the members of the team. Geographically coded information, generated and shared dynamically, gives teams maps of each others' activities, plus remotely sensed data. The major function of the geospatial technology repository and interface is to provide dynamic knowledge of group activities in real time. Environmental changes reveal new dependencies for adaptive collaboration as conditions on the ground evolve, enabling participants to track the evolution of each other's work and mutually adjust to it in a timely manner.

**Index Terms** — geospatial technology, virtual collaboration, wireless grids, complex systems, situation management.

### I. INTRODUCTION

**S**ITUATION management is an example of an iterative planning activity that calls for a high level of coordination between multiple stakeholders: citizens, subject matter experts, scientists, technicians, first responders and managers, i.e. participants with different yet equally important responsibilities, knowledge and experience. Traditional decision support systems and supporting infrastructure that can provide necessary information and resources in a timely fashion are difficult and expensive to develop, with a high rate of unsuccessful implementations. This is due in large part to

the kinds of situations that must be anticipated for systems to be effective.

Existing systems' coverage is geographically limited, and often hampered by fragmented and incompatible telecommunications technologies. The unpredictability of the situations that will arise and will need to be handled make the task of predicting what information will be needed, when and where virtually impossible. Traditional systems architectures are static rather than dynamic, and therefore difficult and time consuming to expand or update as new events change our understanding of what is needed. Many situations are characterized by initial and ongoing uncertainty with regard to scale, location, direction and magnitude.

For effective management, information is needed quickly, at multiple locations, both remote and local. How can we address these challenges? What would a next generation situation management system look like?

Designing and building systems based on new mobile technologies make it unnecessary to try to anticipate all information needs and implement cumbersome infrastructures. Instead, the approach can become one of creating direct communication channels between remote coordinators and local 'boots on the ground', by creating structures for adhoc, situation-based remotely sensed information capture and broadcast. Flexible, dynamically scalable networked systems are configured using simple COTS applications, existing web technology and emerging SDR (software defined radio) and wireless grid technology.

As complex, dynamic information management systems become more common for managing and sustaining critical energy production and distribution, traffic flows, stormwater, hydrology, and food safety and security; geospatial and mobile technologies are increasingly needed to ensure the performance of these systems.

### II. CREATING CONTEXT WITH REMOTE SENSING

*“cooperative work is constituted by the interdependence of multiple actors who, in their individual activities, in changing the state of their individual field of work, also change*

*the state of the field of work of others and who thus interact through changing the state of a common field of work” [22, p. 158].*

Disasters such as the British Petroleum oil spill in the Gulf of Mexico and the fiasco of inadequate emergency planning and response for Hurricane Katrina are large-scale examples of the need to find better ways to educate, communicate and collaborate on the basis of scientific knowledge and risk analysis both in advance of and during emergencies. However, the time to build and use effective systems for situation management is before the incident occurs. Designing and implementing effective systems in advance that can adequately anticipate information and other resource needs at the time of an unforeseen incident is a great challenge. Access to information that is timely, effective and useful is needed.

The research purpose is to investigate the use of geospatial technologies to create contextualized virtual collaborative environments for problem solving, decision support and situation management. Better collaboration and problem-solving is increasingly important as natural and man-made disasters compel us to find ways to manage large-scale situations through action at the local level and coordination at a local, regional, national, or even international level.

In his study of architects, Christensen observed that “in addition to relying on second order coordinative efforts (at meetings, over the phone, in emails, in schedules, etc.), actors coordinate and integrate their cooperative efforts by acting directly on the physical traces of work previously accomplished by themselves or others.” [2] In terms of the challenges of coordinating actions of multiple actors over large and/or distant geographic areas, geospatial technologies provide the necessary context for effective virtual collaboration. Through the use of mobile technologies, the actions of remote actors producing changes in the environment can be seen and understood by other actors in real time. Actors may also respond to the changes they see, or provide a trigger for other actors to respond to their actions. The results of an individual’s activities, if observable by other actors, act as a dynamic source of direction and information for others’. Formal coordination, planning and procedural communications cannot provide the contextualized knowledge in a way that is as timely or effective.

#### A. Wireless Grid Technology

Syracuse University, Virginia Tech and others have created the first international Wireless Grid Innovation Testbed (WiGiT). WiGiT provides students, faculty, firms and representatives of government a forum to learn from and an opportunity to participate in this new market, which is growing in part from a prior National Science Foundation (NSF) Partnerships for Innovation Project (PFI) [24]. The WiGiT project involves participants globally with easy access to its main findings and activities on the internet. Programmers, individuals, researchers and companies, including media worldwide in both developed and developing countries, have access to and benefit from this activity. The intent is to spur further innovation and economic growth extending from these NSF-sponsored technologies. WiGiT will help define transformative technologies by bridging the

gap between wireless network middleware and grid application layers, creating new markets and realigning existing ones. WiGiT will serve industry needs for intra-system or crossover work bridging grid or cloud computing on one platform, and wireless Internet on another, contributing to open standards and application programming interfaces for wireless grids. The WiGiT testbed and related courses, seminars, and workforce training will accelerate commercialization of novel products and services, while accelerating partner community economic development [17, 24].

The wireless grids technology invented by this NSF funded project transforms disparate devices into a shared and interactive grid of accessible resources. Wireless grids “edgware” technology sits at the outermost limits of existing networks, allowing all facets of a user’s environment: printers, mp3, documents, photos, cell phone, PC and new plasma TV, etc. to be interoperated and shared easily. This creates a revolutionary new class of social software for ad hoc distributed resource collaboration and allows for coordination of devices and content on a new scale. The NSF PFI has led to the successful commercialization of an edgware software platform that allows diverse electronic devices in offices, homes, dorms, malls, industrial complexes and mobile settings to virtually communicate and interact. The WiGiT project demonstrates transformative collaboration and working through wireless grids enabled environments and sets out standards for international adoption in this new area. [17, 24]

#### B. Expected Impacts and Outcomes

The broader impact of wireless grid connectivity specifications developed with WiGiT support will be determined ultimately by their utility to user and device communities. Open source developers interested in wireless grids distributed collaboration and network mash-up features will be significant early users. A wide range of new applications is expected across industry sectors and social communities. Businesses, government agencies and private individuals will have new options for interacting within and across regions.

Through identification and creation of standards for device sharing in a dynamic environment, seamless sharing of many types of devices becomes possible. For example, mobile phones, mobile Internet devices, printers, displays, remote sensing and telemetry devices, local weather sensors, medical and emergency responder systems, nanotechnologies, wireless sensor networks, etc. Software, hardware, policy and social aspects and requirements for sharing wireless sensor networks through remote experiments with the wireless grid environment are underway.

Localization in wireless ad hoc networks is efficient. There is no central control unit to identify the location of a node in a wireless ad hoc network. Location of a node is identified relative to a node or nodes whose location is/are known. Recent WiGiT localization research used signal strength to identify node location successfully. Power conservation is achieved through mobile wireless network grids. The wireless grid itself is a green/clean technology, because of its theoretical high energy efficiency/low energy use. Routing

protocols for wireless grid networks with power constraints have been developed and tested. The signal strength of a transmission depends on the power of the transmitter; these two standing problems are naturally tied together and resolved in a wireless grid environment.

The impact of this project for situation management lies in its combination of new technologies for ‘edgware’, i.e. for grid or cloud computing applications across edge devices with wireless networking; and the implications of this technology for situation management implementation and adoption. Businesses, government agencies and private individuals will have new options for interacting, conducting business and sharing. The WiGiT platform development effort has had and will have influence on standards for wireless connectivity. Projects to investigate wireless grids’ utility in working and collaborating in virtual distributed, mobile fashion are planned.

### III. VIRTUAL COORDINATION AND GEOSPATIAL TECHNOLOGIES

Cogburn et al [4] propose a socio-technical model of virtual organizations based on a detailed multi-disciplinary literature review. The ten factor model, based on Cummings’ definition of virtual organizations [5] combines social and technical elements based on empirical research results to guide the development of effective virtual organizations: "a group of individuals whose members and resources may be dispersed geographically and institutionally, yet who function as a coherent unit through the use of cyberinfrastructure (CI)." Cogburn et al [4] point to two key characteristics of virtual organizations. First, virtual organizations “maintain their structure without sharing a physical space” and second, “they use technology-mediated communication to function”. [4, p.1)

Olson’s theory of remote scientific collaboration, derived from National Science Foundation (NSF) studies in the fields of collaborative communication and the sociology of science as well as from the science of laboratories project identifies five major clusters of socio-technical components that are important for successful remote collaboration [22]. These are (1) The nature of work, (2) level of common ground, (3) collaboration readiness, (4) management, planning and decision-making and (5) technology readiness.

Situation management calls for a high level of coordination between scientists, technicians, first responders and managers. Traditional decision support systems that can provide necessary information in a timely fashion are difficult and expensive to develop, with a high rate of unsuccessful implementations. This is in large part because of the nature of natural disasters and human catastrophes. The unpredictability of the situations that could arise and will need to be handled make the task of predicting what information will be needed, when and where virtually impossible. Situations are characterized by ongoing uncertainty with regard to scale, location, direction and magnitude, both at their inception and as they unfold. Information and knowledge about situation statuses are local, dynamic and rapidly changing.

### IV. STIGMERGY

Stigmergy refers to a particular type of observed coordination behavior in insects. Individual ants, for example, do not seem to cooperate or communicate explicitly, but they demonstrate complex cooperative behaviors at the group level, such as nest building. Stigmergic coordination in a human context refers to how an individual behaves as part of a collaborative team engaged in a complex task, such as a busy restaurant on a Friday evening. For situation management involving emergency response on a large scale, for example, the task is of such complexity that a coordinated team effort is required to accomplish it, but the effort is greatly complicated by the scale of the effort. Where the restaurant team operates in the limited space of the professional kitchen, situation management is often characterized by activity in multiple locations or jurisdictions, and across broad regions and conditions. Human stigmergic coordination emerges on the basis of how tasks and goals are structured and understood between the members of the team, and how they respond to unique contingencies. Geospatial technologies offer a context for locating and coordinating team activities in such a way that the nature of each team member’s effort may be known and understood by other members. Smart telecommunications applications afford dynamic access, updates and information. This constructed group knowledge enables trained, non-co-located teams to share their statuses, respond to unforeseen and emergent contingencies and act autonomously, but in concert, through the active interpretation of shared artifacts without prior planning and coordination. GPS-enabled smart phones allow geo-tagged photos and video to be sent as emails or voicemails, with either text or voice messages attached, in near or actual real time, supporting dynamic, accurate, up-to-the-minute coordination and information-sharing. The major function of the server-based geospatial technology repository and smart interfaces is providing dynamic understanding in real time to allow dependencies to become clear, for adaptive collaboration as conditions on the ground evolve, enabling participants to track the evolution of each other’s work, and mutually adjust to it.

Many examples exist of community mapping projects and public participation efforts that integrate existing technologies with municipal and regional GIS using citizens’ own smartphones and computers in conjunction with government-supported web-based GIS interfaces. These include an innovative graffiti and vandalism reporting and status update system developed by the City of Boston [30], and the Central New York Interoperable Communication Consortium (CNYICC), an emergency response system being developed as a partnership between five counties in upstate New York [24]. The CNYICC development is based on the WiGiT platform, and will allow five isolated county systems using incompatible technologies to expand and integrate.

Designing and building systems based on new mobile technologies makes it unnecessary to try to anticipate all information needs. Instead, the approach becomes one of creating direct communication channels between coordinators and ‘boots on the ground’. Flexible, adhoc systems that are dynamically scalable can be configured using simple COTS

applications, existing web technology and emerging wireless grid (software defined radio) technology.

Utilization of interfaces based on mobile social networking and geospatial technologies creates visual and audible, real time or near real time information of situations and human response activities as they unfold. Integration of geospatial, wireless telecommunications and social networking applications data to create dynamically updated web-based maps via handheld or smart-phone applications can capture location-based actions and communications. Unlike traditional emergency management systems, this technology is easily deployed and scalable because it requires only leveraging existing infrastructure plus the new edgeware needed to create the seamless interaction of the devices.

## V. THEORETICAL BASIS AND METHODOLOGY

The research investigation will focus on empirical examples of situation management and emergency planning systems that utilize mobile technologies, map-based interfaces, real-time or near real-time dynamic updates, and temporal and physical change management of updates and sequences.

The theoretical foundation for system design is based on activity theory as discussed by Kuutti [16] and Nardi [20]; and further explained by the work on spontaneous and unplanned yet purposeful coordination in biology (sematectonic communication or stigmergy) by Odum and Grasse [13]. Polanyi's theories of tacit and explicit knowledge and how they are created and transmuted internally and externally through learning, experience and collaboration (Dewey, Kolb, Piaget) are the basis for understanding how knowledge is generated through action and how collaborative activity operates as a medium for understanding and collaborative knowledge creation in context. Geospatial technologies provide an interactive visual representation of the dynamic, complex situation environment, thereby becoming the context for virtual collaboration [17]. Social networking and telecommunications media, deployed using the wireless grids technology, enhance intrinsically human coordination skills and attributes to significantly improve team response and effectiveness. Strong digital literacy and spatial thinking skills, an important and necessary component of training, form a significant part of the gateway for comprehension and participation in complex, dynamic situations [29]. Team coordination depends on how an individual behaves as part of a collaborative group engaged in a complex task, such as emergency response. Coordination emerges on the basis of how tasks and goals are structured and understood between the members of the team. Geospatial technologies offer a context for locating and coordinating team activities in such a way that the nature of each team member's effort may be known and understood by other members.

### A. Critical Incident Technique

The critical incident technique (CIT) is a set of procedures used to identify and analyze critical incidents from a behavioral-cognitive perspective. The technique was developed during WWII by Col. John C. Flanagan to better understand effective and ineffective behaviors for aviation

training [9]. The technique is essentially a semi-structured interview or questionnaire which asks the participant to describe a critical incident in detail, defined by Flanagan as "any observable human activity that is sufficiently complete in itself to permit inferences and predictions to be made about the person performing the act" [9, p. 237]. The participant may be an actor in the incident or an observer. In contrast to other research methods that may examine normal practices and procedures, CIT focuses on specific incidents which are unusual or outside of the norm to quickly identify problems or opportunities. According to Butterfield et al, "The CIT started out as a task analysis tool and, although it is still used as such within industrial and organizational psychology, it has expanded its use in counseling psychology, nursing, education, medicine, and elsewhere to also become an investigative and exploratory tool" [1, p.489]. Since Flanagan's original publication in *Psychology Bulletin*, his article has been cited more frequently by organizational and industrial psychologist than any other [1]. CIT has become a standard technique in counseling psychology, and over five decades of use the technique has expanded to measure and improve job performance and professional practice in a wide range of disciplines, including healthcare, education and business [1]. It has proven to be a robust and reliable research method. In the more than 50 years since its development, the technique has been applied hundreds of times in dozens of fields, with relatively few and minor changes to Flanagan's original procedure [1]. In addition to its original application for task analysis and training improvement, today it is also recognized as an effective exploratory and investigative tool [1, p.475].

CIT as a research method that is useful for this study because it was developed to investigate effectiveness as well as points of failure through the retrospective, in-depth analysis of a singular event. In the context of the sort of incidents mentioned as examples, it reveals multiple viewpoints and experiences to build multi-dimensional pictures of how events unfold.

### B. Data Collection

Data will be collected via interviews with first responders, local residents and participating citizens involving various emergency situations. Collection of situation reports, activity logs, news reports, and weather and other governmental data collections pertinent to the interviews. The purpose will be to reveal multiple viewpoints and experiences to build a multi-dimensional picture of how virtual collaboration is effected and enabled by the use of interactive map-based interfaces and real-time interactive information.

### C. Data Analysis

Using Critical Incident Technique (CIT), the research will study the effect of the above-mentioned technologies on work coordination and collaboration, decision support, and response and coordination efforts for situation management. Telephone, online and face-to-face interviews will be conducted with first responders, managers, coordinators, and volunteers. The data analysis will include both qualitative content analysis and

quantitative methods to identify strengths, weaknesses, threats and opportunities inherent in existing systems and practices.

## VI. CONCLUSION

Utilizing interfaces based on the fundamentals of human interaction, collaboration for management and coordinated action is an intuitively meaningful approach to problem-solving across a range of scales. Social networking and geospatial technologies, deployed using wireless grid technology for seamless integration of networked edge devices creates a context for detailed and summarized, visual and audible, real time or near real time understanding of situations and human response activities as they unfold. Integration of geospatial technologies, wireless telecommunications and social networking applications such as web-based maps that can be updated in real time via handheld or smart-phone applications combine remote sensing telemetry with real-time activity updates. These technologies can capture location-based actions and communications for immediate information sharing, dynamic time line construction and active, contingency-based planning. Coordinators in remote coordination centers can see and hear what is happening at multiple locations, while responders on the ground can see and hear what other local and remote teams are doing. Unlike traditional situation management systems, these technologies will be easily deployed and offer unlimited scalability because they will be built on leveraging network infrastructure for internet and telecommunications; compact, modular applications similar to those for smartphones; and mobile, relatively inexpensive equipment.

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