MASCAL: RFID Tracking of Patients, Staff and Equipment to Enhance Hospital Response to Mass Casualty Events

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Most medical facilities practice managing the large numbers of seriously injured patients expected during catastrophic events. As the demands on the healthcare team increase, however, the challenges faced by managers escalate, workflow bottlenecks develop and system capacity decreases. This paper describes MASCAL, an integrated software–hardware system designed to enhance management of resources at a hospital during a mass casualty situation. MASCAL uses active 802.11b asset tags to track patients, equipment and staff during the response to a disaster. The system integrates tag position information with data from personnel databases, medical information systems, registration applications and the US Navy's TACMEDCS triage application in a custom visual disaster management environment. MASCAL includes interfaces for a hospital command center, local area managers (emergency room, operating suites, radiology, etc.) and registration personnel. MASCAL is an operational system undergoing functional evaluation at the Naval Medical Center, San Diego, CA.

INTRODUCTION AND BACKGROUND

Effective response to natural disasters and catastrophic events requires hospitals be capable of scaling clinical operations in the face of events that would overwhelm normal business processes. Such emergency response capabilities have long been a priority within the military; however, the recent tsunami in East Asia reminds us that adequate disaster preparedness is a universal requirement in all societies.

The resources available to both civilian and military hospitals responding to a disaster are finite. When resources become limited, the continued effectiveness of a response depends on skilled supply and demand management. The term 'situational awareness' is often used to denote a key ingredient in making timely, effective decisions during rapidly evolving events. When situational awareness is lost, supervisors make resource allocation decisions blindly, staff and equipment are sub-optimally utilized, and patient care is negatively impacted.

Tools and techniques that monitor and communicate the state of business processes are essential to preserving situational awareness. Almost all disaster preparedness programs utilize dedicated observers who relay critical information using radios or cell phones to emergency response coordinators. More sophisticated facilities may track patients using bar-coded ID bands or monitor bed occupancy as secondary indicators of the demands being placed on the healthcare delivery system.

Unfortunately, such manual processes are often not part of a hospital's daily routine, and as the degree of chaos escalates, personnel revert back to the familiar. It has been our experience during emergency response drills that the timely execution of manual processes fail and situational awareness is lost precisely when it is needed most.

Air traffic controllers have long used visual dashboards that automatically track aircraft, flight trajectories, and available runways to safely manage commercial air space. Just-in time manufacturing processes face similar issues coordinating supplies, inventory, and logistics. These latter industries are beginning to utilize RFID asset tags to preserve visibility into the state of critical business processes. We theorize that real-time location of medical 'assets' using RFID tags and a visual dashboard would be similarly useful in responding to disasters with numerous injured patients.

Mass casualty workflow description

The management of casualties at military and civilian hospitals is surprisingly similar and follows a predictable series of steps:

1. Stabilization & Transport: Mass casualty workflow starts in the field where emergency personnel triage injured patients, make preliminary assessments and start treatments protocols. These efforts are scrawled on a triage card attached to the victim or even on their forehead. Once sufficiently stabilized, victims are

then transported to a receiving medical facility.

2. Turnover: Upon arrival at the medical center, transport staff must efficiently communicate with receiving staff to identify those needing immediate attention. Handwritten documentation and paper based triage tags only complicate this critical turnover of information.
3. Registration: As with any patient, mass casualty victims must go through a mandated registration process as hospital based care is initiated. ID bands must be issued, preexisting medical information recorded in the admission paper work, and orders written.
4. Workup: Following initial intake, patients receive laboratory tests, radiology studies, and specialty consults. These evaluations often require that patients move throughout the facility.
5. Disposition: Upon obtaining all needed evaluations, the disposition of the patient is determined. They are either discharged for follow-up as an outpatient or they are admitted for definitive care and treatment.

There are countless variables that influence the efficiency of this workflow. By visually integrating real-time location data with the relevant information systems, MASCAL seeks to facilitate these resource allocation decisions, avoid patient flow bottlenecks and maximize system capacity and throughput.

DESIGN REQUIREMENTS

Extensive discussions with disaster management personnel resulted in a set of functional requirements felt to be critical to improving situational awareness. These fall into five general categories:

1. Turnover: The system must ensure that critical information collected in the field is communicated to receiving personnel quickly and accurately.
2. Registration: The system must ensure that all patients and responders are registered and identifiable.
3. Accountability: The system must ensure that patients, staff and equipment are accounted for at all times without over reliance on manual, error prone, processes.
4. Integration: The system must integrate all information relevant to situational management and decision support into a single application.
5. Backup: The system must have contingency capabilities in case of system or network failure.

IMPLEMENTATION

Asset Location System

MASCAL uses a prototype WiFi-based indoor geolocation system from Awarepoint Corporation in La Jolla, CA. This system utilizes any existing wireless infrastructure and has three components: 802.11b RFID tags, fixed transceivers that measure ambient 802.11b signal strength and a central geolocation server that computes location.

The critical component of the system is a series of fixed transceivers (called ‘conditioners’) installed in known locations around the perimeter of the desired coverage area. The conditioners periodically measure the ambient 802.11b signal strength between themselves and any transceivers / access points detected in the area. This data is relayed by UDP protocol messages over the wireless network to a central server that calculates a reference signal strength topology for the coverage area.

Awarepoint tags also measure ambient 802.11b signal strength and periodically broadcast this data back to the location server. The engine compares tag data with the reference topology, effectively triangulating the location of the tag to within a theoretical resolution of ~10 feet. The tag position can be superimposed on a physical floor plan to visualize its location.

The Awarepoint system has a number of appealing advantages over competing technologies. Foremost is the ability to utilize an exiting wireless network to triangulate asset tags. Being able to support real-time asset location services on the same network without costly additional infrastructure upgrades has obvious economic advantages. The system is design to support easy re-configuration of the coverage area that has advantages for applications outside of casualty tracking.

There are, however, a number of engineering trade-offs inherent in the approach. Awarepoint tags are relatively simple devices and currently unable to support encryption other than 128bit WEP. Network security must be ensured at higher levels, but remains vulnerable, as with any wireless system, to denial of service attacks and/or network ‘sniffing’ devices that could masquerade as tags. Reconfiguration of the network may be required to establish a dedicated VLAN for mobile devices if provisions for mobile have not been made previously in the security architecture. Tags must also be individually configured to use the Signal Service Identifier (SSID) established for their use, a somewhat laborious process. Finally, the power requirements of a WiFi chip set are not insignificant and tags have shorter battery lives than competing technologies.

802.11 Infrastructure

The wireless infrastructure for the project consists of an Airespace 4024 switch configured as a central appliance communicating with 24 forward deployed 802.11b access points using Light Weight Access Point Protocol (LWAPP) over a dual homed, redundant, gigabit switched Ethernet. As required by government regulations, the hardware is FIPS-140-2 certified. Access control lists, 128bit WEP encryption, wireless SSIDs and dedicated VLANs manage wireless security ensuring that devices communicate through the switch only with required ports and ip addresses. Future versions of the application will incorporate more sophisticated encryption to better secure asset tags and handheld devices.

Location Tracking Area Coverage

Areas representative of the mass casualty workflow were selected for installation of the tracking system. Covered locations include the emergency room parking lot (the designated triage area), the ER itself, parts of radiology, surgical pre-op, surgical recovery, the operating suites, and three large medical wards.

Hospital Information System

The core of the hospital information system is a cluster of servers running a legacy application called Composite Health Care System (CHCS) that shares a common heritage with the Veteran Affairs' VISTA. Bi-directional access to CHCS is enabled by EsiObjects, an open-source server-side technology that provides a comprehensive object-oriented environment for Java development on legacy M systems.

Middleware Architecture

MASCAL middleware consists of an Oracle 9*i* database, a Lightweight Directory Access Protocol (LDAP) server and an Oracle 9i application server supporting an extensive suite of Java web services. Web services accessing our human resources database provide staff contact information, medical specialty data, blood type, foreign language skills, and emergency response role (litter barer, decontamination station operator, etc). A series of web services interact with the hospital information system to retrieve patient registration data, demographics, radiology orders, admission diagnoses, and disposition information. Similar services interact with the Awarepoint location server to access real-time position data, and with the major inventory database for equipment information.

Web services also integrate data from a triage system piloted by the US Navy in Iraq. Called the Tactical Medical Coordination System (TACMEDCS), this system enables field personnel using handheld devices to document the demographics, triage condition, injuries, and initial treatment of wounded combatants. This information is written to patient triage tags that use passive 13.56 MHz RFID for storage and also uploads the data into a theater database. The TACMEDCS device has many similarities with triage tags being developed for civilian mass casualty events (1) and could serve as a model for wide-spread use of RFID technologies in mass casualty situations.

Turn-Over & Registration Applications

Triaging every arriving casualty, tagging them, and rapidly establishing an identity within the hospital information system is the critical event in the mass casualty workflow. MASCAL facilitates this process with two applications. The first is a handheld application based on TACMEDCS and its 802.11b capable RFID readers. The application enables receiving personnel to record the arrival of victims and document triage information when communicating with transport personnel. If casualties arrive with TACMEDCS triage tags, the device can retrieve the stored medical records facilitating turnover. The handheld device then enables assignment of a MASCAL tracking device to each patient; intake personnel use it to scan a 13.56 MHz RFID label on the Awarepoint tag encoding the device's MAC address. By doing so, the patient's triage information and tracking tag are linked before being uploaded into the MASCAL database.

A second application allows back office personnel to search the hospital information system for preexisting records matching the demographics of the tag recipients. If none are found, the application directs the clerk to register the patient. Both applications together ensure that every casualty has a MASCAL tag, can be tracked throughout the facility automatically, and is formally registered in the hospital information system even if only as a 'John Doe'.

Staff Registration Application

It is equally important for emergency response coordinators to know who has responded to a medical emergency. The Staff Registration application handles this requirement. During a mass casualty event, all staff personnel initially report to predetermined intake stations. The registration application associates each staff member with a tracking tag in a process similar to that used for registering victims. MASCAL also looks up the individual in the main personnel database, retrieving their medical specialty and the primary emergency response role for which they have been trained. The system then date/time stamps each individual as 'checked-in' and provides all this personnel data to the MASCAL dashboards described below. The system cannot currently process responders who are not registered in our personnel database.

Response Coordinator Application

MASCAL provides two dashboards that integrate and present relevant data in role specific ways. The response coordinator dashboard provides a macro level overview of the entire medical response. It summaries the location of patients, staff and equipment. It displays the triage categories, diagnoses, and radiology orders for casualties. Staff skill sets and their emergency response roles are easily determined. The application can also display the contact information for personnel who have yet to respond, but may be needed to augment scarce resources. Coordinators can project, based on the type and number of injuries, whether available resources are sufficient, can anticipate flow bottlenecks in high demand areas such as the CT scanner, and can visualize opportunities to redistribute equipment to better meet demand.

Location Supervisor Application

A second dashboard (Figure 1) provides location specific supervisors a more granular presentation of assets by superimposing positional data on a facility floor plan and providing more information about each asset tag. Patient demographics, age sex, blood type, radiology orders, and diagnoses are readily available. Additional details about staff responders are also available, for example, how long they have been on station, pager numbers, and language skills. As the display updates every 30 seconds, assets can be tracked in near real-time. Infusion pumps, code carts, or other equipment needed for patient care can be quickly found. Patients, such as a John Doe on a gurney, can easily be located by triage category or by disease. Staff with needed medical skills or language abilities can be rapidly identified without making overhead announcements that only add to the confusion and sensory overload of a crisis.

Contingency Capability

Events resulting in civilian or military causalities might be expected to cause disruptions in other services, including the hospital network. As a contingency, MASCAL prints all known patient and staff locations every five minutes to a printer in the Emergency Response Command Center. In the event of catastrophic system failure, staff can revert to paper or whiteboard tracking methods using up-to-date system information.

System Status

The MASCAL prototype has been deployed and system tested during two small-scale drills using up to 75 assets tags simultaneously. The integration of the various information systems using web services has been validated. The location engine has been confirmed to be accurate within ten feet. The feasibility of tracking large numbers of tags in close proximity without interference has also been confirmed. A large scale drill with several hundred tags and scripted treatment scenarios is anticipated and will be used to collect data about the clinical impact of the system.

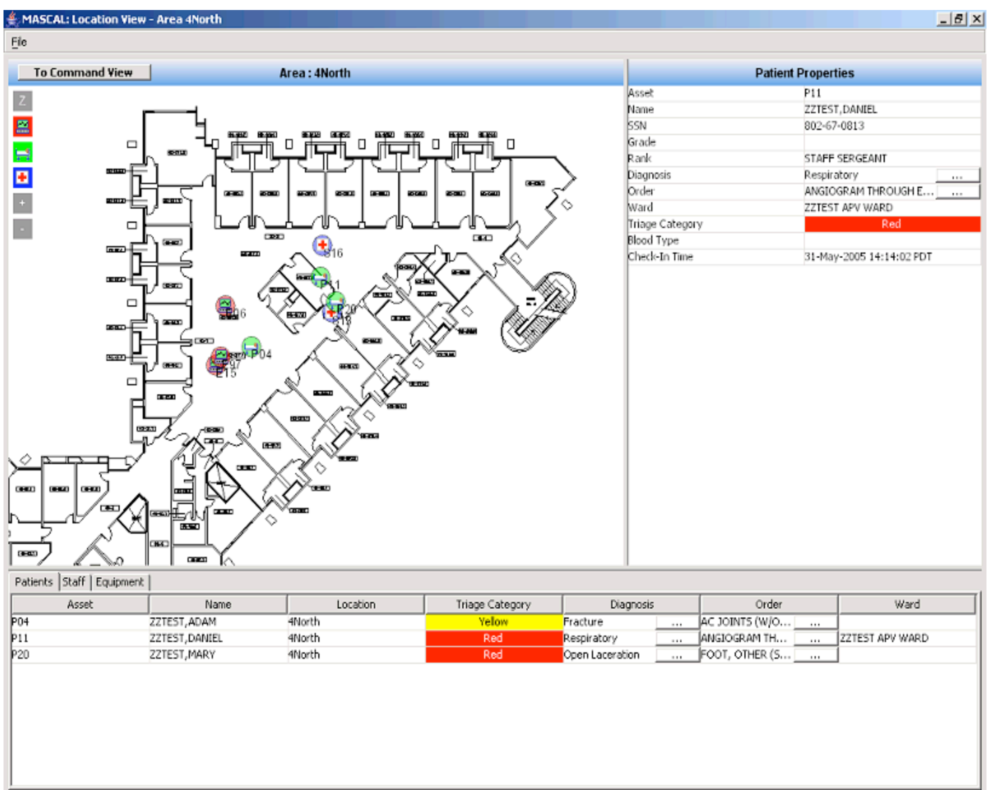

Figure 1. Location Specific Supervisor Dashboard

DISCUSSION

The MASCAL system creates an end-to-end environment to manage casualties from a battlefield or a catastrophic civilian event. The system utilizes positional information from wireless asset tags to reduce dependencies on manual processes, and improves situational awareness over inherently chaotic events. Its potential value lies in providing visibility into supply and demand workflows, augmented with select data considered helpful in making appropriate management decisions.

Relatively little work has been performed on computer systems to facilitate emergency response. Noorgraf, Berman and colleagues have described the development of computer systems for such purposes (2) and the use of bar-coding systems to track patients' progress through hospital systems (3). Rafalski and colleagues have described geopositioning systems in ambulances to enhance situational awareness. (4) Others have described systems for integrating data from attack sites with hospital computer systems. (5) The WIISARD system also uses active RF 802.11 tags for geolocation of victims and personnel and includes an integrated location–aware medical information management system, but is focused on enhancing field care of victims at disaster sites. (1) The use of active RFID technologies deployed in MASCAL is a logical and necessary extension of such work to the hospital setting.

Location monitoring systems have heretofore largely focused on asset tracking systems, typically in manufacturing (6). MASCAL is one of the first examples for the use of real time location aware systems in medicine. Clinical utility is achieved by tight integration of position data with clinical information systems to create tools that enhance situation awareness.

While MASCAL reinforces certain business practices, such as the patient/staff registration processes, it does not currently model any specific workflow nor can it calculate predicted outcomes. Human supervisors must still evaluate the data and make all resource allocation decisions. However, the comprehensive data model we have achieved can readily support more analytical capabilities. An operating room workflow model might be used to predict throughput, resource requirements, and optimal case sequence for our 18 operating rooms according to the surgical requirements of incoming casualties. Similarly, average length of stay by diagnoses, an important determinant of bed occupancy rates, could be used to calculate projected system capacity and resource requirements in real-time. We are actively investigating both these decision support capabilities as the logical next step in system development.

It remains to be seen whether the wealth of information currently presented in the dashboards actually improves the effectiveness of the emergency response. Indeed, can coordinators who typically are not exposed to such qualitative data in their daily routine process real-time positional data efficiently? Are the data elements exposed useful or do they just add "signal noise"? Perhaps the greatest value of the MASCAL application is there is now a reference framework on which studies can be designed to answer some of these questions.

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