Critical care nurses are confronted with a wide variety of information technology in their practice. These technologies help improve information flow and, when effective, ultimately improve patients’ care.

The hospital infrastructure of wires and interfaces to machines and information systems allows the free flow of data between the intensive care unit (ICU) and other departments. Unfortunately, these technologies are not readily available during transport of critically ill patients between facilities.

In this article, we discuss a study based on the development of a system (MobiDoc system) that uses global positioning system (GPS) technology to support and enhance the flow of information about key transfer events and location from an ambulance transport team to the receiving unit. The purpose of the study was to test a method of improving the communication of transport information, including patients’ arrival time and clinical status, thus reducing on-hold or waiting time for care providers. The focus of this article is on improving the accuracy of estimates of patients’ arrival times.

Improving information flow was addressed with our critical care transport team at the University of Maryland Medical Center (UMMC) through a funded project called MobiDoc. UMMC is an integrated healthcare delivery system that includes a large tertiary care teaching facility and heart center. The heart center is a regional referral center that receives patients from the entire state. The Maryland Express Care (MEC) transport team offers ground transport of critical care patients between hospitals and provides advanced monitoring and intervention while en route. The UMMC emergency physicians direct the MEC transport staff, which includes critical care nurses, paramedics, and emergency medical technicians. For transfers to the cardiac catheterization laboratory, members of the MEC...
staff gather required information and coordinate the transfer, because they are responsible for allocation of teams and transport vehicles.

The MobiDoc study was initiated to test the feasibility of a wireless system of communication between critical care transport and the cardiac catheterization laboratory. We anticipate that the design will be refined and implemented for future use in the trauma resuscitation unit and other critical care areas, which receive a high volume of transfers from other hospitals.

The MobiDoc project is a way to enhance information transfer by using GPS satellites to track patients as an ambulance team transports the patients. This pilot study involved field observations before and after implementation of the satellite tracking system. Recorded measures were obtained from the users of the system; these included timing of work flow elements, activity counts from observations, and user satisfaction measures from focus group evaluations. The MobiDoc system reduced the amount of time required for preparation of the cardiac catheterization laboratory by increasing the availability of real-time information. Intelligent software agents have been developed and implemented to manage and coordinate information transfer. This software automatically detects a patient’s location in relation to sending and receiving hospitals and then forwards the derived location information to appropriate personnel. The only human interaction involved is the receiver reading the message on a pager or checking the patient’s transit location on a personal digital assistant (eg, Palm or Handspring) or Web site.

Information Flow

Inefficiency in information flow occurs when the receiving care unit does not have up-to-date information about a patient’s condition before the patient arrives. The lack of real-time information delays scheduling decisions and impinges on coordination of care such as canceling or holding scheduled cases in the cardiac catheterization laboratory. It may also be difficult to determine what types of supplies should be set up before a patient arrives. Real-time information about a patient’s location and accurate estimates of arrival times significantly improve coordination of care between the transport team and the hospital.

Purpose of MobiDoc System

The study team hypothesized that automatic information transfer can simplify communication and improve the quality of reporting by automatically recognizing ambulance locations in relation to delivery systems and improving the flow of information. The MobiDoc system was initiated at 2 sites, a transport unit (MEC) and a receiving unit (cardiac catheterization laboratory).

The schedule of the cardiac catheterization laboratory remains flexible to accommodate very sick patients and patients in unstable condition who may require immediate intervention in the laboratory. Transferred patients can arrive at any time, making it difficult and chaotic for staff to be allocated to accommodate these additional cases. Knowing accurate arrival times for transferring patients enables the staff to be better prepared.

The MEC coordination center service transferred 4868 patients to the University of Maryland hospital in fiscal year 2000. The cardiac catheterization laboratory performed 2044 procedures of all types in fiscal year 2000, of which 928 were on patients who were transferred. Therefore, transferred patients account for a sizeable proportion of the procedures performed. The number of procedures performed indicates the need for the transport coordination center service and also the requirement for accurate and timely information so that transfers can be coordinated.

Literature Review

Few published studies or publications have addressed the use of GPS to improve the delivery of patients’ care and information flow in the healthcare setting. Little research has been done on the effects of wireless data information flow on patients’ care or the coordination of care.

A program in Sweden used technology similar to what we used for emergency medical service (EMS) care provided before patients arrived at the hospital. The EMS team had previously used citizens band radios and wide-area cellular telephones to communicate with hospitals from accident scenes. The new system uses a combination of database management, GPS tracking, wide-area networking, wireless local-area networking, and mobile computing. The new system has been successful. The wireless digital communication and position reporting system resulted in an increase in information flow to the hospitals. Types of information transmitted include the ambulance’s location and patients’ injury severity; therefore,
the receiving hospitals are better prepared for patients’ arrival.1

A second study2 tested the reliability of GPS for directing EMS helicopter response in rural areas. The GPS allowed pilots to determine the precise location of a helicopter in an unfamiliar area regardless of time of day, topography, or weather conditions. Results of this study indicated only the reliability of location data; no response times were measured.

Another study3 involved use of a GPS-enhanced computer street map navigator by EMS response teams in an urban setting. An assessment was done to determine if the GPS navigator could improve the ability of the EMS drivers to locate their destination and shorten response times. Findings of this study included faster response times and improved performance by a GPS team versus a standard map team.

**Technical Overview**

The University of Maryland Team and Nortel Networks Team (http://www.nortelnetworks.com) jointly developed the MobiDoc system. The system was developed to explore the potential applications of location-based automated data transfers in healthcare. The MobiDoc system comprises 3 main components: (1) an automatic vehicle location system, (2) custom software, and (3) user interfaces, which include Web page, pager, and a personal digital assistant. These parts of the system perform the following functions: information collection, information processing, and information delivery (Figure 1).

MobiDoc was installed on 2 ambulances of a dedicated critical care transport team that performs as many as 224 critical care transports between facilities per month. Many of the critical care transports are for patients with acute coronary artery syndromes. Patients are transferred from outlying hospitals directly to the cardiac catheterization laboratory at UMMC for urgent percutaneous interventions. The ambulances travel as far as 150 miles 1 way from UMMC. These long trips often mean the transport team is caring for a critically ill patient for hours during the transport between facilities. If an accurate estimate of arrival time of a patient being transferred is not available, it is difficult to fit the patient into the busy schedule of the cardiac catheterization laboratory.

**Automatic Vehicle Location: Information Collection**

A typical automatic vehicle location system consists of 2 parts, a method for identifying the location...
of the vehicle and a method for transmitting that information to a central location. The automatic vehicle location system of the MobiDoc system uses the digital data from the GPS unit to identify the location and then transmits that data by digital cellular phone directly to the dispatch center at UMMC.

The GPS receives timing signals from multiple satellites, a process that allows triangulation for the accurate determination of each ambulance’s position as latitude and longitude. The position, heading, and speed of each ambulance are then calculated by onboard GPS hardware and relayed to the wireless system. In addition to the automatic vehicle location system, each of the ambulances is also fitted with sensors to detect engine and door state, these data are combined to determine vehicle location. Also, there is a box with a switch that, when activated, allows paramedics to communicate certain messages without using voice-based systems such as radio or cell phone. These messages may indicate a request for a report or other clinical data. The benefit of the automatic vehicle location system is to save time verbally communicating vehicle location and allow the transport team to concentrate on patients’ care. This benefit could be especially important when a patient’s condition is unstable.

Software: Information Processing

The software of the MobiDoc system was designed to integrate the location information relayed by the wireless system and to automate data transfer. The software on the hospital campus gathers information about each ambulance and automatically transfers that information to the appropriate recipients. For example, the cardiac catheterization laboratory is only interested in seeing information about inbound cardiac patients. The software displays only the appropriate data, such as map and clock view (Figure 2), to personnel at the cardiac catheterization laboratory on the laboratory’s local monitor. These views show location of medic unit and the time and distance to the receiving facility. Using custom algorithms, the software continuously estimates the time of arrival of the ambulance to both the sending hospital (where the patient is) and back to the tertiary care facility, on the basis of the ambulance’s current position and hospital locations.

A software module was developed to calculate triggering events when an ambulance is within 0.4 to 8 km (0.25-5 miles) of a target hospital. Automatic triggering events are used to send notification messages about specific events, such as the ambulance arrival at the outlying hospital. The software also attaches to each ambulance transport some information about the patient (eg, the patient’s identification number, sending hospital, receiving unit, chief complaint, age, sex, and name), which has been entered by the ambulance coordination center. This information is displayed on various terminals at UMMC for instant updates on the patient’s location and clinical condition as entered by MEC.

User Interfaces: Information Delivery

Three user interfaces were developed for the MobiDoc system: (1) a Web page showing the arrival and departure times and a moving map display of the ambulance’s location, (2) an alphanumeric paging capability with text messaging at triggering events during transfer, and (3) a wireless personal digital assistant used by physicians and nurses to
pull current arrival information from the MobiDoc server. The user interfaces can be categorized into 2 groups, push and pull. A pull interface is one that requires user intervention to make a request for information; for example, a physician uses the computer terminal in the cardiac catheterization laboratory to retrieve or “pull” an update on a patient during transport. A push interface is one that receives information automatically or is “pushed” from another source and does not require the user to make a specific request. For example, the triggering event of the arrival of the transport team at the referring hospital is automatically relayed to the cardiology staff members’ alphanumeric pagers. The benefit of a push device is that no user intervention is required and information is sent as appropriate. However, the downside can be information overload. The benefit of a pull device is that a user can obtain information whenever desired, but the time-sensitive important information may not always be known at near real time. For example, if a pager alerts and the user does not view the message immediately, real-time information becomes delayed information.

**Web Page Interface**

The Web page interface can be considered as both a push and a pull interface. In normal operation, both the transportation coordination center and the receiving unit have access to the server Web pages. The Web page displays both a map with vehicle locations and an estimated time of arrival (ETA). The Web page is continuously updated at a user-defined refresh rate, either every 10 seconds, 20 seconds, 30 seconds, 1 minute, 2 minutes, 3 minutes, or not at all. This continuous display and constant updating do not require user intervention. The Web page is a pull interface because the users have the ability to request updates on specific information when needed, hence pulling information from the Web server.

In the transportation coordination center, the Web interface is displayed continuously by a ceiling-mounted projection system. Each receiving unit has a desktop personal computer that continuously displays the MobiDoc Web site. The map display is configurable by the user so that the viewer can zoom to a regional view, a statewide view, a city view, or a street-level view. The system also can zoom to the location of a specific ambulance. The Web page displays the ETA to both the receiving hospital and the sending hospital, engine status, current speed of the ambulance, stretcher position (in/out), rear door status (open/closed), and time stamp of the last set of data from the ambulance (Figure 2).

**Paging Interface**

The second information delivery mechanism is 2-way paging that is initiated automatically (Figure 3). The Motorola Arch 2-way pager Talkabout is a 2-way device that allows the MobiDoc software to receive an acknowledgment. This acknowledgment confirms that the page was received by the receiving unit’s pager, thus closing a loop for the information transfer.

The MobiDoc system automatically pagers the receiving unit at several predefined triggering events (Table 1), giving the current ETA for the ambulance.

**Personal Digital Assistant Interface**

The third information delivery mechanism is a wireless personal digital assistant. A 3Com Palm VII, which is equipped with wireless data service, was used for evaluation. By tapping an icon on the screen of the personal digital assistant, the user can find the current arrival times of

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**Table 1** Triggering events for signaling of 2-way pagers

<table>
<thead>
<tr>
<th>Receiving facility</th>
<th>Sending facility</th>
</tr>
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<tbody>
<tr>
<td>Ambulance leaving</td>
<td>Ambulance arrival at</td>
</tr>
<tr>
<td>Ambulance 15 minutes from</td>
<td></td>
</tr>
<tr>
<td>Ambulance 10 minutes from</td>
<td></td>
</tr>
<tr>
<td>Ambulance arrival</td>
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all of the ambulances that are carrying patients. The Palm.net wireless data service pulls a customized screen from the MobiDoc server (Figure 2). Table 2 describes the 3 user interfaces.

**Observation of Cardiac Catheterization Laboratory**

The users of the MobiDoc system were interviewed to determine how well the system met their expectations. This input was used to aid in fine-tuning the software and hardware to make the transfer process between hospitals more effective. The interviews occurred 2 weeks after initial implementation of the system.

One attending physician in the cardiac catheterization laboratory was asked to keep a diary, a handwritten account of his experiences, to track his use of the MobiDoc system. Another data collection tool was created for all cases in which the transport coordination center transferred patients to the cardiac catheterization laboratory from a secondary hospital. This tool consisted of preestablished triggers that were used to note timing of the event. A subset of this collection tool was created for each of the 4 main roles in the cardiac catheterization laboratory: same-day area nurse, charge person, attending physician, and fellow. This tool focuses on the various preparatory actions and decisions that each staff member of cardiac catheterization laboratory makes while in his or her role, on the basis of the information the staff members receive about an incoming patient. An example for the same-day area nurse would be to prepare a nitroglycerin infusion ahead of time if the patient is having active chest pain while en route to the cardiac catheterization laboratory. An example of the type of actions and decisions that the charge person performs are to communicate directly with the heart center and adjust the staffing of the cardiac catheterization laboratory according to the patient’s status.

Among the 3 information delivery methods of the MobiDoc system, the personal digital assistant was not used because it was not user friendly. The user of the device stated it was cumbersome, because it was larger to carry than a pager, and several steps were required to access the Internet and pull the information to the device. These necessary steps were more time-consuming than receiving the paged messages or looking at the Internet page.

Because personal digital assistants are becoming widely used, their potential capability cannot be underestimated. The Internet-capable handheld computer, if used, may become a powerful tool when implementing a system such as MobiDoc. The time-specific data collected with the role-specific tool in the cardiac catheterization laboratory were analyzed and compared with data from preimplementation studies to assess time benefits of the new system as opposed to the process without the MobiDoc system. This information is still being analyzed.

**Observation of MEC Transport Coordination Center**

The previous process of communication between the ambulance crew and the coordination center via cellular phones and radios required numerous calls to indicate when the ambulance departed from and arrived at each hospital. This time-consuming process has been eliminated with the use of the MobiDoc system because the location of the ambulance crew is continuously projected on the projection screen at the MEC transport coordination center. The times projected on the transport coordination center’s screen were compared with the times recorded on

<table>
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<tr>
<th>Component</th>
<th>User</th>
<th>Data provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web page</td>
<td>Staff in the catheterization laboratory and Maryland Express Care</td>
<td>Graphical map display</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sending facility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Receiving unit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ambulance location</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Departure and arrival times</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Estimated time of arrival</td>
</tr>
<tr>
<td>2-way signal pager</td>
<td>Physician and charge nurse in the catheterization laboratory</td>
<td>Patient information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selected times ambulance en route such as leaving,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 min, 5 min, arriving</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Location of ambulance</td>
</tr>
<tr>
<td>Personal digital assistant</td>
<td>Physician</td>
<td>Graphical map display</td>
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<td>Receiving unit</td>
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the paper transfer reports to detect any delay or errors in the MobiDoc system. Timing reported with the MobiDoc system was accurate to within 1 minute according to time comparison data.

**Focus Group**

A focus group of staff from the cardiac catheterization laboratory and the MEC was used to get input on the effectiveness, usability, and value of the MobiDoc system. Questions addressed how often the system was used, the group’s overall impression of or the general appeal of the system, and suggestions to improve the system and user interface. Specific feedback and enhancements are given in Table 3.

Feedback from the receiving unit indicated that staff at the unit would like to correlate the frequency of pages with the severity of patients’ conditions; for example, a patient with a higher acuity or in unstable condition may require more pages be received. The greater number of pages would alert the staff to a patient’s condition and allow them to expedite processes in the cardiac catheterization laboratory. These concerns are being resolved by the study team.

Feedback from the transport team indicated that several improvements are required for the prototype to be accepted in everyday practice. One such improvement is to include more medical information, such as a 12-lead electrocardiographic data, in the digital stream. Doing so could help in scheduling patients for procedures on the basis of the patients’ acuity. A second improvement is to have an automatic system that records the transfer timings of each ambulance into the database. Automating this process would ease the workload of both the ambulance clinical team and the transport coordinators by eliminating redundant documentation of existing data. These issues are being addressed.

Feedback revealed a deterrent to successful implementation of the MobiDoc system, which the ambulance referred to as the “snitch factor.” This factor is the perception of ambulance staff that their managers will use data recorded by the system (eg, speed) to punish or discipline them. This issue could hinder implementation, and care should be taken to work closely with the user team in managing this concern. In order to eliminate this immediate problem, speed was removed from the Web page display.

**Potential Benefits**

As the reliability and accuracy of this system are improved, it could become the primary tool for certain tasks, with the current processes used as backup. MEC benefits would include eliminating voice communication to report times of arrival and departure, as well as eliminating the task of entering these times into the MEC database. The cardiac catheterization laboratory would benefit by more efficient scheduling of patients, specifically when information on a patient is included on the computer interface screen. This system will also enhance patients’ care by allowing the receiving unit to be better prepared for admission.

**Conclusion**

The MobiDoc project uses a vehicle-locating device that can automatically push location data to end users. These real-time data were useful for decision making and for preparing patients during critical care transport. The use of wireless technology provided better coordination of care and decreased the need for labor-intensive voice communication. Other communication...
modes such as paging and a Web interface eliminated the need to phone updates to the cardiac catheterization laboratory of the medic unit status en route. Coordination of care was improved as nurses and physicians knew the actual time of arrival of patients. Some difficulties affected a fully successful implementation of the MobiDoc system, and concerns about the usability and reliability of the technology will require further development efforts.

MobiDoc showed that use of such a system could improve the coordination of care during the transfer of critically ill patients. This informatics intervention allowed a real-time data interface between the transport team and the referral hospital. New technologies coming to the market will overcome some of the current limitations of the pilot system.

The nursing implications of the MobiDoc system involve resource management issues such as staffing. Improved efficiency through a decrease in downtime and overtime created a financial benefit. Decreased preparation time increased quality of care for transferred patients. Critical care units often receive patients transferred from other hospitals. The ability to establish a mechanism to be kept informed of a patient’s ETA is an important benefit of a wireless system. For example, critical care nurses can obtain actual ETA online and can then coordinate patients’ care better. This improved coordination may involve contacting the necessary personnel, such as an on-call nurse, physicians, radiology technician, and ancillary services to expedite the admission process. Quality of care may be improved by accelerating patients’ access to the healthcare and by the nurses and physicians’ receiving more up-to-date information about patients.

Healthcare settings are unique, dynamic, fast-paced environments that have distinctive communication system needs. The MobiDoc project used the concept of dynamic information transfer and wireless technology to improve the existing communication systems and flow of information in the healthcare environment. The pilot involved a single critical care area with the anticipation that this technology will be expanded to other units. The ultimate goal of this technology is to offer critical care nurses the opportunity to provide more hands-on care to patients. The use of wireless technology may be a solution for critical care nurses to provide patient-focused care that is safe and efficacious. The use of wireless technology is still in the beginning stages of implementation in healthcare, but it has infinite potential.

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