

Pilot implementation of a technologically advanced system for the optimization of pre-hospital, trauma patient care

Hastane öncesi dönemde, travma hastasında tedavinin optimizasyonunda teknolojik olarak geliştirilmiş bir sistemin pilot uygulaması

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BACKGROUND

Cooperation between medical informatics, wireless communication and pre-hospital emergency services is essential for the optimal pre-hospital patient treatment. The use of technological innovations improves medical care in the pre-hospital setting with regard to the organization of an integrated center, which coordinates all parties involved for the patient's best interest.

METHODS

A dispatch center was developed in the city of Patras, in southwestern Greece, equipped with a Geographic Information System (GIS), which immediately points out the location of emergency vehicles (EVs) on a digital map depicting the city plan. Additionally, three ambulances of the National Center of Immediate Aid (NCIA) were equipped with a decentralized traffic management system for the vehicle's traffic priority at signaled junctions. The system consisted of a cellular-based (GSM) telemedicine module, a Global Positioning System (GPS) and a web camera system in the vehicle cabin.

RESULTS

The aforementioned system provided considerable assistance to the pre-hospital treatment first by selecting the ambulance closest to the accident's location and then by pinpointing the optimum route to the hospital, thus significantly reducing the overall transportation time.

CONCLUSION

The project's objective to coordinate emergency hospital departments involved in the treatment of trauma patients with other emergency services by utilizing high technology was achieved within this interdisciplinary effort.

Key Words: Geographic Information System; Global Positioning System; pre-hospital care; telemedicine; trauma.

AMAÇ

Tıbbi bilişim sistemleri arasındaki işbirliği, kablosuz iletişim ve hastane öncesi acil hizmetler, optimum hastane öncesi hasta tedavisi için kaçınılmazdır. Teknolojik yeniliklerin kullanılması, hastanın yararına bütün tarafları koordine eden entegre bir merkezin organizasyonu ile ilgili olarak hastane öncesi ortamda tıbbi bakımı iyileştirir.

GEREÇ VE YÖNTEM

Güneybatı Yunanistan'da bir kent olan Patras'da, şehir planını gösteren dijital bir harita üzerinde acil girişim araçlarının yerleşimini hemen işaretleyen bir Coğrafi Bilgi Sistemi ile donatılmış bir görev dağıtım merkezi geliştirilmiştir. Ek olarak, Ulusal Acil Yardım Merkezi'nin üç ambulansı, trafik ışığı bulunan kavşaklarda aracın trafik önceliğine yönelik bir trafik düzenleme sistemi ile donatılmıştır. Sistem, araç kabininde bulunan hücresel esaslı bir teletıp modülü, bir Küresel Konumlandırma Sistemi ve bir web kamera sisteminden oluşmuştur.

BULGULAR

Yukarıda söz edilen sistem, öncelikle kaza bölgesine en yakın ambulansı seçmek ve daha sonra hastaneye doğru optimum rotayı çizmek ve böylelikle genel transport süresini anlamlı şekilde azaltmak suretiyle, hastane öncesi tedaviye kayda değer ölçüde katkı sağlamıştır.

SONUÇ

Projenin, travma hastalarının tedavisiyle ilgilenen acil hastane departmanlarının ileri teknoloji kullanmak suretiyle diğer acil servisler ile koordine edilmesine yönelik hedefi, bu disiplinlerarası çaba kapsamında yerine getirilmiştir.

Anahtar Sözcükler: Coğrafi bilgi sistemi; küresel konumlandırma sistemi; hastane öncesi bakım; teletıp; travma.

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Trauma injuries kill more young people than any other cause on a daily basis and subject even more to impermanent or permanent disabilities. It has been proven that significant reduction in trauma patient mortality can be achieved if proper medical care is provided at the initial phase of an injury - at the stage of the pre-hospital as well as in the setting of the initial hospital medical care.^[1] During pre-hospital care, two major factors play a determining role in the final outcome of an injury: a) the quality of care initially provided^[2] and b) the transportation time required for the definitive treatment in a trauma center. Advanced technological systems can be employed to improve the quality of the patient's medical care prior to hospital admission as well as to reduce the overall transportation time in favor of the injured person.

This study was developed within the framework of a European Union funded multidisciplinary research project (INNACT-RWG 2002-2003) entitled "Implementation of an advanced technological system for emergency situations (pre-hospital injury support services)" that involved the collaboration of researchers at the University Hospital of Patras, the Architectural Engineering Department and the Electrical and Computer Engineering Department of Patras University as well as a private consulting firm (ATMEL). The aim of this project was the development of an integrated pre-hospital care system that could ensure:

- The immediate tracking of the emergency vehicles (EVs) and their faster arrival to the accident's location;
- The possibility of patient monitoring and medical data recording during transportation;
- The establishment of a decentralized traffic management system ensuring traffic priority for the EV;
- The wide applicability and reproducibility of the system on an everyday basis.

The aim of this study was to examine the possibilities of having such a multidisciplinary project functioning among medical and non-medical participants, as well as to document the possible beneficial effects in terms of reducing transportation time and optimizing pre-hospital treatment in trauma patients. Given that there was no previous experience in the design and implementation of such projects in Greece, the development of innovative solutions has been an indispensable need.

MATERIALS AND METHODS

A dispatch center was created for the implementation of this project at the Emergency Department of the University Hospital of Patras, accommodating both the material and the personnel involved in the study. For the project's needs, the following mapping issues had to be addressed:

- City of Patras and greater area Geographic Information System (GIS) maps.
- The Global Positioning System (GPS) collection system.

Geographic Information Systems (GIS)

Geographical Information Systems (GIS) can effectively link spatial and descriptive information and display it on a map or computer monitor. Therefore, the exact point of an accident can be displayed onto digital maps facilitating the patient's transportation to an appropriate trauma center, based on the existing infrastructure of the reference area.^[3-5]

The research team developed an innovative GIS-based system for the EV's optimum route guidance. The GIS system was based on Arc-Info ESRI software using Map Objects 2.2 and Net Engine 1.2 products. A specific application code was developed for displaying and monitoring EV routing data. Additional features had to be added to the dataset in order to accomplish the digital infrastructure coverage:

- Digital road network of the entire study area
- Satellite images (IKONOS, resolution 1 m)
- Digital cadastral and town planning maps
- Traffic management data

All the above geographic data were transformed into the Hellenic Geodetic Reference System (EGSA '87) and the necessary corrections were performed. The altitude information of 4800 axial junctions included in the cadastral maps was also added to the digital infrastructure data. The road network model structured included 12317 edges and 7051 junctions. The final outcome was the development of a GIS system, relying on the following data layers:

- The entire road network, containing information on speed limits, direction of travel, traffic signals, and other important traffic parameters
- EV GPS data
- References of the accident location according to the data received by the trauma/dispatch center
- Best possible route guidance from the EV's location to the accident location
- Best possible route guidance from the accident site to the University Hospital trauma center
- Updating and expanding the system by introducing new traffic data

Emergency Vehicles Priority System at Signaled Junctions

Preemption provides priority treatment by interrupting the normal cycling of a traffic signal in favor of an EV. This assists emergency personnel in the safe and timely arrival at incidents and back to the trauma center.

The city of Patras, and many other Greek cities, does not utilize a centralized traffic signal control system. Therefore, the project team designed and applied an Original Equipment Manufacturer (OEM) solution so that an EV's approach is detected by the traffic signal sufficiently in advance of its arrival. This is because the signal has to cycle through any necessary timing intervals and arrive at the desired signal display before the EV is at the intersection. The range setting of preemption equipment is therefore critical for proper operation. A vehicle equipped with a preemption emitter can capture its Position, Velocity and Time (PVT) data with a GPS receiver unit.

Based on this solution, an open architecture system was designed and applied, where the EVs location was wirelessly transmitted (UHF modem) to the signaled junction by the use of a micro-controller, in order to give the appropriate priorities. The mobile unit was placed on the EVs (Fig. 1a) and the immobile part on selected traffic lights (Fig. 1b).

The central processing unit was receiving data through a serial port RS232 from the EVs and these data transferred were received by the GPS receptor. After processing the vehicle's location data, an encoded RF signal (433.92 MHz) was transmitted, containing information about the location and type of the vehicle received by the corresponding RF receptor. Accordingly, the proper signals were sent to the traffic regulator for the amendment of the signaling schedule taking into consideration the safety times, so that the ambulance priority could be granted. Moreover, the software offers the possibility to classify the priority with regard to the vehicle type as well as to the direction in which it moves.^[6]

Wireless Telemedicine System

For the acquisition of data related to the patient's condition inside the ambulances, as well as for their

wireless transmission to the data reception center, a defibrillator device was selected that can also register and transmit to the trauma center a wide range of vital signs such as:

- 12-lead ECG and automatic diagnostic operation
- Blood Oxygen Saturation (SpO₂)
- Heart Rate (HR)
- Non-Invasive Blood Pressure
- Temperature

The defibrillator equipped with a GSM modem transferred the data collected to the trauma center by using a modem connected to the mobile telephone network and a mobile telephone SIM card. The reception and storage of the signals sent were carried out using specific PC software, which allowed:

- The filing of the incidents received.
- The easy search for incidents.
- The implementation of measurements in order to better evaluate the data.
- The timely and quality monitoring of all incidents - actions - alarms during the transportation of a patient.

With this information, initial evaluation of the patient's condition can be performed in a short time, providing the paramedics advice for improved pre-hospital care.

Global Positioning System (GPS)

The GPS is a world range system, developed by the United States (US) Department of Defense, and is based on an array of 24 satellites at an altitude of 11,000 nautical miles with a rotation period around the earth of 12 hours on six orbital levels, as well as on their ground stations. This satellite constellation accomplishes at any period of time, under any weather conditions, location and navigation of an unlimited number of users.^[7,8] GPS accuracy is affected by a

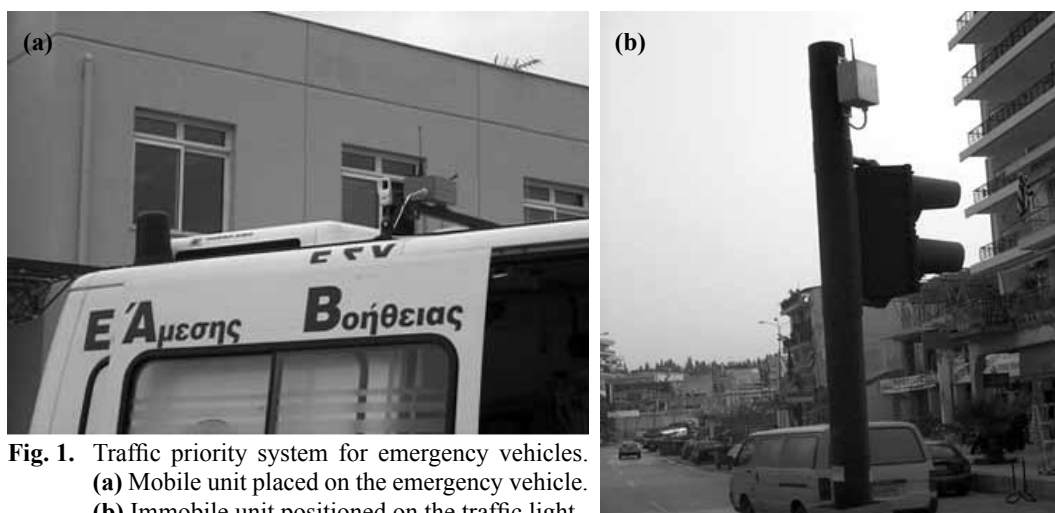


Fig. 1. Traffic priority system for emergency vehicles. (a) Mobile unit placed on the emergency vehicle. (b) Immobile unit positioned on the traffic light.

number of complex factors. Estimated error is calculated by the GPS unit and logged from its data stream by the Host PC used during data collection. Furthermore, the GPS provides accurate velocity data, which can be used to obtain an idea of the +/- position relative to time (i.e. distance traveled in a given time).

Each EV emits its position to the data reception center, which is acquired through the GPS system installed, together with other necessary data, such as the EV identity number. These data are received from the data center and are displayed on special software. This software is compatible with the transmission system in the EV and allows the proper and immediate reception of data. The EV's position is displayed on the detailed map of the greater Patras area with an obvious light signal. This signal is updated as soon as allowed by the combination of the position update rate from the GPS and the transmission speed of the signal. Detailed data about the route of the ambulance may be stored and retrieved for further statistical processing and analysis, in order to achieve more optimized routes in the future.

System Web Camera

A small web camera was installed in each EV that participated in the study. This allowed a constant reception of image and sound from the ambulance, thus enabling an ongoing monitoring of the patient. With the patient's data and image received, doctors from the trauma center can provide instructions to paramedics, while the patient is still enroute to the hospital. An experimental Wi-Fi network was used to send data. A significant advantage was the fact that this camera was mobile and could be taken outside the ambulance to obtain pictures from the accident scene, providing the trauma center with a more global view of the injury severity and the conditions of the accident.

Trauma Center Operation

The trauma/dispatch center, located in the Emergency Department of Patras University Hospital, has been the center of reception, management and evaluation of signals-data. The center consists of two workstations equipped with three PC monitors, each one displaying exclusively:

- The digital map of the greater Patras area, the current location of the EVs as well as the accident's location.
- Still images and video transmitted from the wireless cameras installed in the EV cabin, allowing the monitoring of the patient's condition and the control of the crew's actions.
- Continuous monitoring, recording and managing of the patient's vital signs, displayed in the form of diagrams.

Human Resources

The project's human resources consisted of two main groups:

1) The medical group, including eight physicians participating in the project who were trained to use the technological systems as well as to evaluate the incoming data 24 hours/day on three 8-hour shifts. This group was supervised by five physicians of different specialties who were available on a 24-hour basis to back up the rest of the medical group and help tackle complex medical problems.

2) The technical group staffed the signal reception center on a 24-hour basis in order to resolve any technical problems that could arise as well as to supervise the effective operation of the whole system.

In addition, the crews of the mobile units that participated in the project were also trained regarding technologic innovations of their vehicle's equipment, and were in continuous contact with the technical and medical groups.

The Mobile Units

For the purposes of the project, three ambulances of the National Center of Immediate Aid (NCIA) (Fig. 2) were equipped with the following:

- System for traffic priority at signaled junctions
- Telemedicine system
- Position tracking system
- Web camera system

These vehicles were also staffed with specially trained crews. It should be mentioned that during the study, the ambulance drivers always drove in accordance with the traffic regulations and respected to the letter the speed limits both within and without the city boundaries.



Fig. 2. Emergency vehicle cabin after installation of the electronic devices.

System Operation

The system was activated once the NCIA received a call for assistance. By the time the ambulance reached the site of the incident, the patient was connected to the telemedicine system while the wireless camera transmitted pictures of the accident scene. Hence, the physician on duty at the dispatch center was instantly aware of the conditions of the accident as well as the patient's medical status, as estimated by the continuous monitoring of his vital signs (ECG, SpO₂, pulse rate, temperature, and systolic, diastolic and average arterial pressure).

The resuscitation of the patient commenced upon transportation, under the guidance of the medical group through the NCIA Center. At the same time, the ambulance followed the shortest possible route according the GPS and GIS indications while the optimal use of the traffic priority system modified the traffic lights in favor of the EV until its arrival to the trauma center.

For the evaluation of the project, a specific 12 km urban route was selected, extending from the center of Patras to the University Hospital, along which 16 traffic lights function. This route represents the main exit from the city to the national highway and generally carries a heavy traffic load. During a three-month time period (September to December 2003), many virtual and real transportations were performed by the EVs participating in the study and the functionality of the system was tested. Of significant importance was to record all the factors that impede the ambulance's progress when moving in the city's road arteries. In order to fully comprehend these factors as well as for data quantification purposes, before the activation of the program, the transportation time through the specific road axis was measured at two time periods: the first one included the heavy traffic load (07:00 to 19:00) and the second one the light traffic load (19:00 to 07:00). At the same phase of the study, the transportation time with or without the use of lights and sirens was also measured, in order to evaluate whether the use of this equipment helped in reducing the overall transportation time. The system operated when the University Hospital of Patras was on general duty, on Monday, Wednesday and Friday as well as on the 1st and 3rd Sunday of each month.

Statistical Analysis

Statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS 13.0, SPSS Inc, Chicago, Illinois, US). Variables were analyzed using Fisher's exact test for the investigation of difference in proportions, while Pearson's chi-square test was applied to compare the mean values of all parameters. A level of $p < 0.05$ was considered statistically significant.

RESULTS

The entire system developed within the research project operated effectively. The coordination and collaboration of the multidisciplinary team participating in the project was successful, while training of the medical, paramedical and technical staff rendered the participants surprisingly capable of effectively using the above novel technologies.

During the three-month study period, 56 transportations were examined before the implementation of the project, serving as controls, and 45 after the implementation of the project, with properly equipped ambulances. The causes of the emergency transportations are summarized in Table 1. The majority were trauma cases, followed by acute medical or cardiological incidences.

Transportation Time Reduction

Reduction in pre-hospital transportation time represented the main criterion of success in our study. Table 2 depicts the time required for transportation before and after the implementation and operation of the system in the different groups that were examined. A significant reduction in transportation time was found when the total time required for the transportation in the 56 controls was compared with the 45 cases after the implementation of the system ($p < 0.000002$). When the subgroups with and without the use of sirens and lights were analyzed, still a significant reduction in the transportation time was found after the implementation of the project ($p < 0.000002$ and $p < 0.03$, respectively). A significant difference was also noted in the groups not using sirens and lights, independent of the traffic load at the time period examined. There was no difference in the groups using sirens and lights, before and after the implementation of the project; however, the numbers in these last groups were too small to generate statistical conclusions.

Time of Patient's Stay in the Emergency Department

The telemedicine system and the wireless web camera provided continuous data about the mechanism, kinematics and type of the injury, the vital signs of the injured patient before and during transportation

Table 1. Nature of transported incidents

Nature of Incidents	Before Regulations	After Regulations
Multiple injuries (car accidents, etc)	32	28
Pathology and regular incidents	16	11
Cardiological incidents	8	6
Total	56	45

Table 2. Transportation time

Transportation time	Stage I	Stage II	p
Total time without using sirens and lights	12.34 min (n=48)	10.20 min (n=40)	0.000002
Total time using sirens and lights	12.07 min (n=8)	9.40 min (n=5)	0.03
In the time period 07:00-19:00 without using sirens and lights	12.40 min (n=31)	10.36 min (n=22)	0.0005
In the time period 07:00-19:00 using sirens and lights	12.00 min (n=3)	9.00 min (n=3)	0.13
In the time period 19:00-07:00 without using sirens and lights	11.51 min (n=17)	9.53 min (n=18)	0.007
In the time period 19:00-07:00 using sirens and lights	12.30 min (n=5)	9.36 min (n=2)	0.09
Total time	12.36 min (n=56)	10.21 min (n=45)	0.000002

and all the treatment actions taken by the paramedics before hospital admission.

Although not statistically evaluated, the impression was the application of the above system resulted in better and earlier coordination of all medical specialties involved (surgeons, orthopedics, neurosurgeons, radiological department, etc.), in a way that, parallel to the patient's resuscitation (already started during transportation), the plan of diagnostic work-up had also already been initiated.

Coordination of the Parties Involved

An incident, either simple (car accident) or complicated (massive destruction), requires the collaboration of several authorities and organizations, such as police, the army, the port police, the fire department and the NCIA. The coordination of all parties directly or indirectly involved represents a crucial parameter for the fast and effective confrontation of the trauma incident.

The implementation of the system developed within the presented project rendered the dispatch center the junction that offered the possibility to notify and coordinate all these parties, ensuring their fast, effective and efficient mobilization.

DISCUSSION

It has been proven that 50% of deaths due to injury occur before the injured person reaches the hospital,^[1] while mortality rates could be significantly reduced when fast and specialized pre-hospital care is provided. There are two main pre-hospital parameters that seem to significantly affect the final outcome: the quality of care provided and the time required for the patient's transportation to the hospital.

Pre-hospital care is defined as the provision of specialized medical care at the accident site, stabilization of the patient's vital signs, preparation for transportation, decision-making about the safe onset of transportation, and finally the secure transportation from the accident site to the receiving hospital center.

The overall transportation time depends on four individual time parameters. Reducing each one of these

time components, through the integration of new technologies and knowledge, results in faster initiation of the definitive treatment. These parameters are:

- The time required for the notification of the control center about the accident;
- The time required for the arrival of the EV to the accident site;
- The time spent by the mobile unit and the paramedics at the accident site;
- The time required for the transportation of the victims to the appropriate trauma center.

The time required for the notification of the control center varies from a few minutes, if the accident takes place in a residential area, to several hours if it occurs in distant, rural areas, especially when the victims are not capable of seeking help themselves. In order to reduce notification time, during the last decade, Automatic Crash Notification (ACN) systems have been under construction and evaluation in the US, Europe and Japan.^[9] These systems integrate GPS and automatic vehicle location (AVL) technologies^[10] and were first reported by the US Department of Transportation in 1994.^[11] At the same time, private companies in the US, especially car manufacturers (Mercedes - tel-aid system), developed systems for the timely notification and the prediction of the gravity of injuries of passengers.^[12,13]

Studies performed on the tele-notification systems, both by independent scientific or state organizations and their manufacturing companies, have shown a significant improvement in the injured person's final outcome when these systems are applied in the pre-hospital setting.^[14-17] In 2000, 20,000 cars equipped with ACN systems were manufactured in the US, whereas it is predicted that their number will reach 5,000,000 in the coming years.^[18,19] In their full implementation, ACN systems combine GPS technologies, third-generation mobile telephony networks (UMPS) and AVL systems^[20] providing the possibility of detecting, locating and predicting the possible injuries of a car accident.^[21,22] The pilot program of the current study did not integrate any of the above-mentioned systems at the phase of the pre-hospital patient care.

The rescuers' ongoing training and the adoption of pre-hospital care protocols (PHTLS-Pre-hospital Trauma Life Support, BLS-Basic Life Support, etc.) have significantly contributed to the decision-making for the safer and faster onset of the patient's transportation.^[23] It is worth noting that telemedicine has been used since the mid-90s for transmitting medical information long distances. During the initial phases of its development, it was used for data emission by non-medical personnel (ECG, blood tests) towards tertiary hospital units.^[24,25] Telemedicine has found a wide application field in sparsely populated geographic areas (Alaska, oil drilling platforms, etc.) where the establishment of integrated hospital units could not be justified. Nowadays, in their full application, telemedical systems combine high speed telephone technologies (DSL) and are also used for continuous monitoring of high-risk patients suffering from chronic diseases. Private companies as well as tertiary hospital departments have developed independent units for the management of such cases.^[26-28]

Special traffic code regulations have been established worldwide for reducing EV total transportation time, such as the use of specific traffic lanes, the use of lights and sirens as well as the adaptation of flexible rescue vehicles (helicopters, motorcycles, etc.).^[29-31] The lack of previous experience in the design and execution of similar projects both on a national and European level as well as the limited application of high technologies in Greece, a country with an excessive number of traffic accidents annually, has rendered the development of such a system in our country particularly necessary.

In this pilot study, the traffic priority system was developed in three consecutive traffic lights within the borders of Patras, which a traffic and city planning study revealed to be related with significant traffic jams. Therefore, after blocking these traffic lights, a reduction in the overall transportation time was observed in all individually measured groups, with a proportional minor reduction during the heavy traffic load timetable. It seems that traffic load becomes the most important delay factor when the traffic lights operate in favor of the EV.

Earlier onset of the trauma patient's resuscitation plays a major role in the final outcome of an injury. A significant advantage of the proposed system is that correct medical care can be provided as soon as the EV arrives at the accident site, following instructions of the expert at the dispatch center. The establishment of a continuous online communication with the dispatch center, along with direct pictures of the patient at the accident scene, provides the opportunity to tackle any patient's problems immediately and to alter, if necessary, the ongoing medical care provided. This allows

utilization of the transportation time for the patient's benefit, as any alteration in the patient's response to the resuscitation efforts could change the staging of the injury and therefore the final destination. Under these circumstances, the overall transportation time to the receiving center could be reduced, avoiding any intermediate stops to inappropriate medical centers.

The occurrence of an incident requires the collaboration of more than one entity, depending on the nature of the incident. The police, the army or the port police are responsible for safeguarding and securing the scene, the fire service for freeing the injured persons and the medical mobile unit for immediately providing initial aid and transporting any victims to a trauma center. Therefore, in this scenario, it is essential that all parties involved are aware of their exact locations, their abilities and the manpower of all collaborating forces. The implementation of the current system, with the integration of GPS and GIS technologies, led to rational mobilization of all the above parties and the full exploitation of their manpower. Moreover, they can become aware of the safety exclusion zone and the possible traffic modifications set by the police, i.e. streets that have been closed off or altered to one-way traffic for more effective transaction of the incident. Under these circumstances, the optimum route for transportation is pinpointed, avoiding road arteries with traffic jam and achieving faster and safer patient transportation.

Today, Greece has the manpower and the technology required for the development of such innovative wireless networking applications while properly trained personnel can easily integrate this technology in their everyday routine. Collaboration between and successful coordination of the participating groups are feasible. Despite the difficulties initially encountered during this pilot application, the proper training, enthusiasm and professionalism of the participating parties rendered possible the concretization of the project. The originality and difficulty of this attempt has to be underlined since many dissimilar groups of people, scientific or not, with a different knowledge background and working mentality, cooperated successfully for the first time. The pilot nature of the project, the restricted time of implementation as well as the Greek legal framework did not allow the quantification of parameters other than the patient's transportation time on a specific route.

Acknowledgments

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The group consisted of three Departments of Rion

University Hospital:

- University Department of Surgery
- University Department of Orthopedics and
- Emergency Department.

Three University Laboratories of Patras University:

- Laboratory of Town Planning, Department of Architectural Engineering,
- Laboratory of Automatism and Robotics, Department of Electrical Engineering and Computer Science and
- Laboratory of Wireless Communications, Department of Electrical Engineering and Computer Science.

The other entities of the group were the following:

- The National Center for Immediate Aid (NCIA) and
- ATMEL Company (Private participation).

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The successful deployment and application of this system at the University Hospital of Patras led to the fourth position on a European level out of the total studies that participated in the EU INNACT-RWG 2002-2003 project and synchronously motivated the Greek authorities to plan a wider application of the principles of this project in the near future.

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