Original Article

Bull Emerg Trauma 2017;5(3):171-178.

Bulletin of Emergency And Trauma

A Multi Agent Based Approach for Prehospital Emergency Management

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Received: January 14, 2017
Revised: March 2, 2017
Accepted: March 22, 2017

ABSTRACT

Objective: To demonstrate an architecture to automate the prehospital emergency process to categorize the specialized care according to the situation at the right time for reducing the patient mortality and morbidity.
Methods: Prehospital emergency process were analyzed using existing prehospital management systems, frameworks and the extracted process were modeled using sequence diagram in Rational Rose software. System main agents were identified and modeled via component diagram, considering the main system actors and by logically dividing business functionalities, finally the conceptual architecture for prehospital emergency management was proposed. The proposed architecture was simulated using Anylogic simulation software. Anylogic Agent Model, State Chart and Process Model were used to model the system. **Results:** Multi agent systems (MAS) had a great success in distributed, complex and dynamic problem solving environments, and utilizing autonomous agents provides intelligent decision making capabilities. The proposed architecture presents prehospital management operations. The main identified agents are: EMS Center, Ambulance, Traffic Station, Healthcare Provider, Patient, Consultation Center, National Medical Record System and quality of service monitoring agent.
Conclusion: In a critical condition like prehospital emergency we are coping with sophisticated processes like ambulance navigation health care provider and service assignment, consultation, recalling patients past medical history through a centralized EHR system and monitoring healthcare quality in a real-time manner. The main advantage of our work has been the multi agent system utilization. Our Future work will include proposed architecture implementation and evaluation of its impact on patient quality care improvement.

Keywords: Emergency medical services; Software design; Computer simulation; Emergency medical dispatch.

Please cite this paper as:
Safdari R, Shoshtarian Malak J, Mohammadzadeh N, Danesh Shahraki A. A Multi Agent Based Approach for Prehospital Emergency Management. *Bull Emerg Trauma*. 2017;5(3):171-178.

Introduction

Prehospital emergency is delivered through the interconnection between different distributed healthcare providers, services and applications, thus assigning the right resource to the patient considering their condition is a critical task. Providing patients with specialized care at the right time has a great

impact on patient mortality reduction and outcome improvement. Rapid response time and appropriate resource utilization is also reported to have great impact on emergency patient management. Critical and dynamic circumstances like prehospital emergency calls for intelligent decision support solutions like intelligent agent systems [1]. Multi agent systems with capabilities like autonomy, flexibility, collaboration and negotiation provide a society of interacting agents for distributed decision making environments. These characteristics made multi agent systems a well-known solution for management, coordination, control and modeling in different healthcare problems [2, 3]. Integrating web services and multi agent systems (MAS) Allows a promising computing environment to efficiently manage complex distributed issues provides a promising computing environment for managing complex distributed issues efficiently.

Delivering specialized services and consultation, using specialized vehicle for patient transportation and navigating the patient to the best healthcare provider considering patient's condition in real-time will prevent patients from irrecoverable damages. In the case of patients with critical conditions such as neurological or stroke conditions if the right medical team or healthcare center isn't assigned at the right time the patient will suffer from a lot of complications [4]. Another risk in prehospital emergency care is access limitations to the patient past medical history [5], therefor we need to access patients electronic health record if available, and retrieve past medical history in order to manage and treat patients considering their medical condition. Most of the studies and researches done in this field are focused on emergency or disaster management not specifically prehospital emergency.

Every country should have minimum standards for prehospital care, in Iran there is no integrated trauma system, each organization has its own functions and there are limited equipped hospitals for patient transfer [6, 7]. In this research the pre-hospital emergency process and main components were extracted trough a comparative review of existing pre-hospital emergency architectures. In this paper by applying multi agent systems a new pre-hospital emergency management architecture is presented. The proposed architecture is general and abstract which could be customized for any local setup. The main objective of the work is to automate prehospital emergency process by applying multi agent system capabilities and presenting a solution to provide specialized care to patients according to their condition.

Materials and Methods

Multi Agent Systems in Healthcare

Artificial Intelligence and intelligent systems have significantly impacted the health service acceleration. Multi agent systems are widely used in modeling, designing and development of healthcare systems [8, 9]. Multi-agent systems (MASs) are computational systems in which a collection of loosely coupled autonomous agents interact in order to solve a given problem [10].

Various information systems are usually involved in distributed health care systems, Multi agent systems are useful in health environments where different heterogeneous components are interacting. Agents can run on geographically different locations while maintaining the part of knowledge needed to solve the problem. The increased demand for getting access to huge online health information service and finding suitable resources rapidly calls for new artificial technologies like agent to retrieve, analyze and select required information for healthcare providers. The proactive behavior of agents make the system perform actions which are not requested by users but rather in an innovative manner, these agent based healthcare systems are able to actively seek information and deliver right service to patients in emergency situations [8-11].

Data resources and healthcare providers are distributed in healthcare domain, which makes agent based systems a suitable integration and coordination solution. Agent based approaches are applied to different medical fields including: data retrieval and processing, decision support systems, planning and resource management, patient monitoring and system integration [11].

Integrating medical documents from heterogeneous health information systems in a virtual electronic patient record is performed trough multi agent corporation and coordination features [12]. A context-aware hospital information system was designed to respond to patient conditions and needs in real-time [13]. A distributed decision support system was proposed for organs and tissues distribution for transplantation, this system also helps procedure allocation which are required through negotiation and coordination between agent's systems. Multi agent systems are also widely used in chronic disease care like diabetes care and old people monitoring and their future situation prediction [14]. Most the developed systems are prototypes and are not deployed in real environments [11]. The main cause of Multi agent system failure is their communication problems. Their security and maintainability should also be considered more strictly in the future.

The Proposed Method

Managing prehospital emergency patients acquire real-time practices and efficient resource utilization. Multi agent systems (MAS) had a great success in distributed, complex and dynamic problem solving environments, and using autonomous agents provide intelligent decision making capabilities. In this work, prehospital emergency process was analyzed through a comparative review if existing

prehospital management systems and frameworks [1, 4, 5, 15-20] the extracted process was modeled using sequence diagram in Rational Rose software. Considering the main system actors and by logically dividing business functionalities, system main agents were identified and modeled via component diagram and finally the conceptual architecture for prehospital emergency management was proposed. The proposed architecture was simulated using Anylogic simulation software. The proposed architecture presents prehospital management operations and the main identified agents are: EMS Center, Ambulance, Traffic Station, Healthcare Provider, Patient, Consultation Center, National Medical Record System and quality of service monitoring agent.

The behavior of the agents was modeled using state chart diagram and the prehospital emergency process for patient care was simulated using Anylogic process model. Some of the process model timing data was extracted from existing studies while others were estimations and were not based on the real-world data. Considering model timing assumptions, the Patient waiting time was charted and showed in the result section.

Results

Multi Agent based Prehospital Emergency Management

This architecture presents prehospital management operations and the main agents involved. As you can see in Figure 1 the main identified agents are: EMS Center, Ambulance, Traffic Station, Healthcare Provider, Patient, Consultation Center and National Medical Record System and each agent main functions in UML component diagram is shown in Figure 1. Agent functions are used while messaging and interaction between agents and are latter described in detail considering each scenario in next sequence diagrams. Figure 2 shows the sequence of the EMS Center contact operations. As you can see in Figure 2 when a call comes to the EMS Center the EMS Center Agent gets patients current condition and according to patient medical condition selects the best treatment protocol. In the case of accident or special circumstances the EMS Center Agent informs the police station if necessary. the EMS Center Agent in order to reach up-to-date traffic information for ambulance navigation inquires traffic station, finally depending on the selected treatment

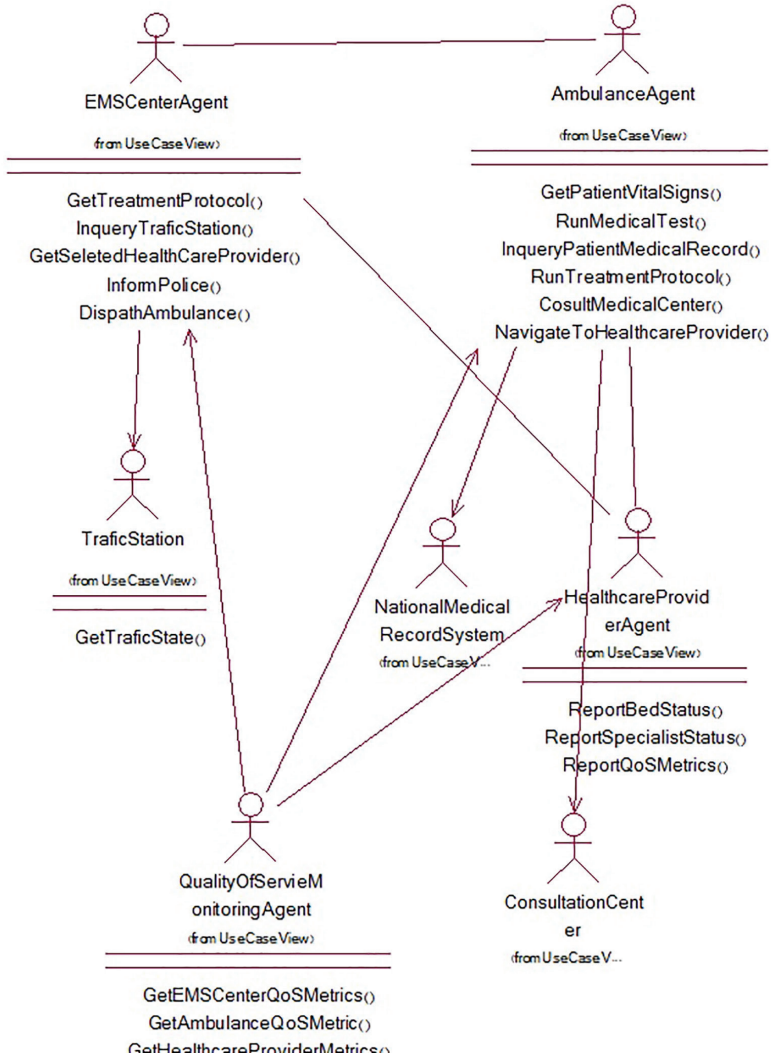

Fig. 1. Multi Agent based Prehospital Emergency Architecture business layer main components

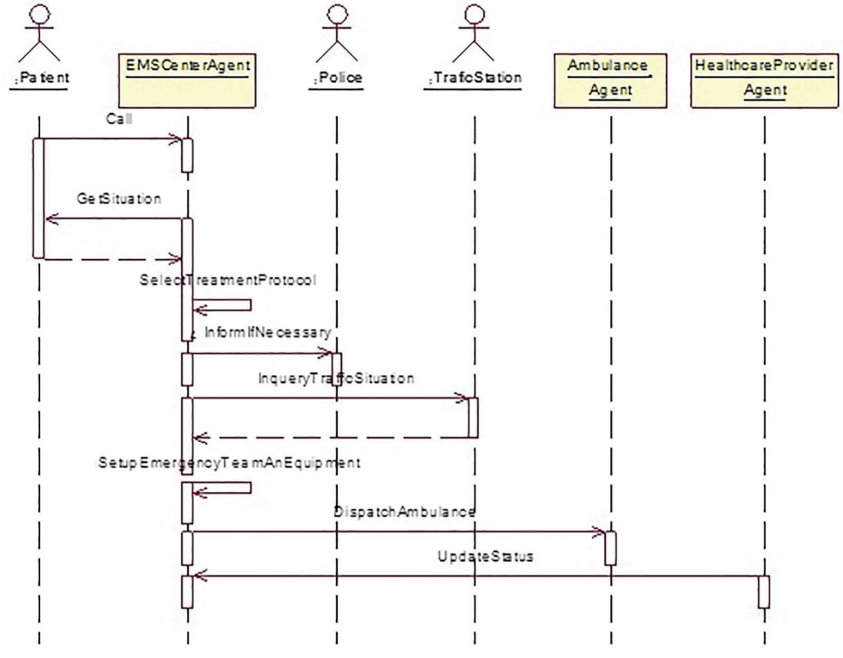

Fig. 2. Sequence Diagram for the EMS Center Contact operations.

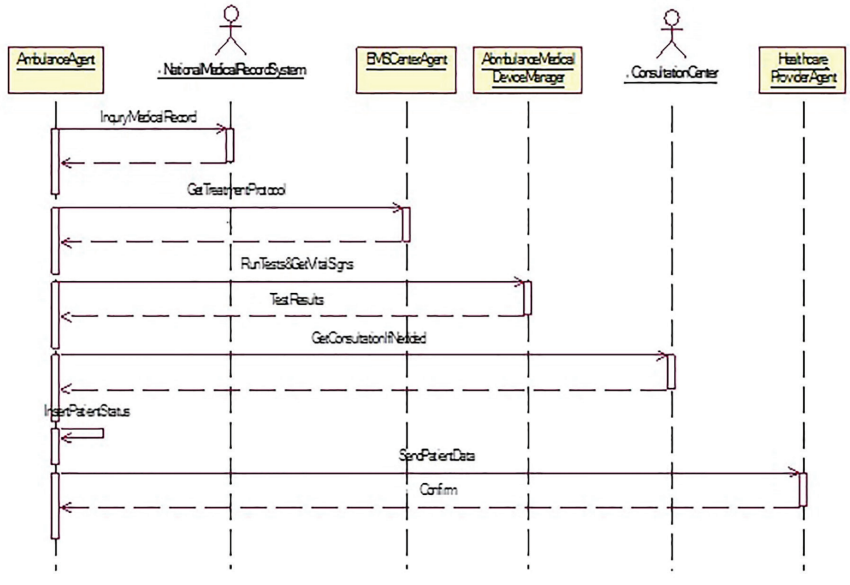

Fig. 3. Sequence Diagram for the Ambulance Agent patient treatment

protocol the suitable equipment and ambulance will be selected. The EMS Center frequently inquiries healthcare provider Agents status in order to update its available bed and service data. The Healthcare Provider Agent will be informed about the new patient and its condition by the EMS Center.

Figure 3 shows the sequence of Ambulance Agent main operations. After the EMS Center Agent dispatches ambulance Agent, the ambulance will Inquiry patients past medical history from National Medical Record Agent (we have assumed that an integrated National Medical Record system has been existed) and will be able to reach patients information including vital signs and test results. Ambulance will consult the consultation agent if necessary, with the respect to predefined treatment protocols, appropriate measurements will be carried out.

Another process which we have included is monitoring quality of care in prehospital emergency this includes getting required quality measures data from EMS Center, Ambulance and healthcare provider Agents and calculating the quality of service indicators and reporting them to the EMS Manager. Figure 4 demonstrates the quality of care monitoring process. Each agent stores specific quality parameters about their actions and timing, the quality monitoring agent gets these data and calculate the quality of service indicators for each agent at specific time interval. The EMS Manager queries Monitoring agent and get the quality indicator reports and makes decision based on indicators sate.

The main goal of this architecture is to automate prehospital process, the assumption is that the healthcare actors which are involved deliver their

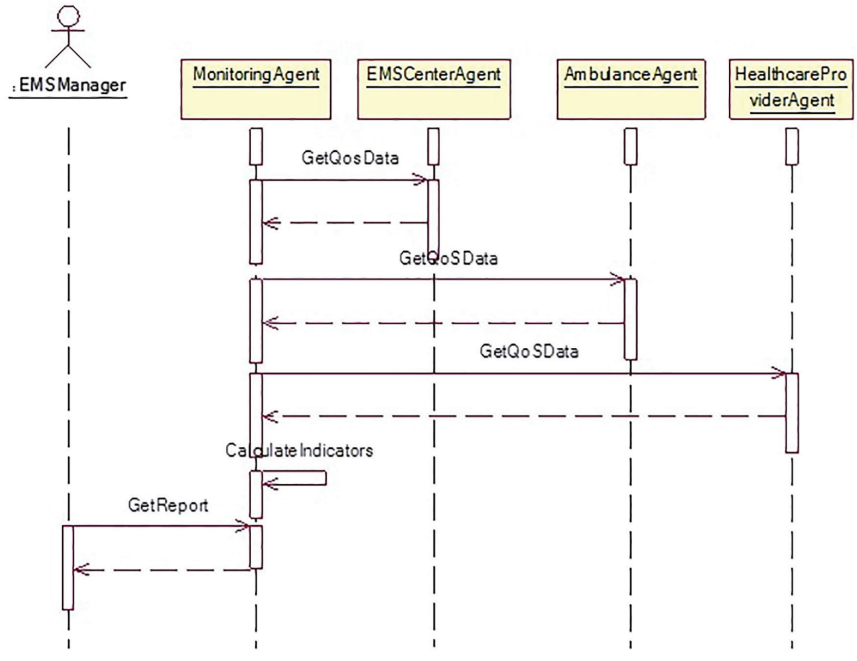

Fig. 4. Sequence diagram for prehospital emergency quality of care monitoring

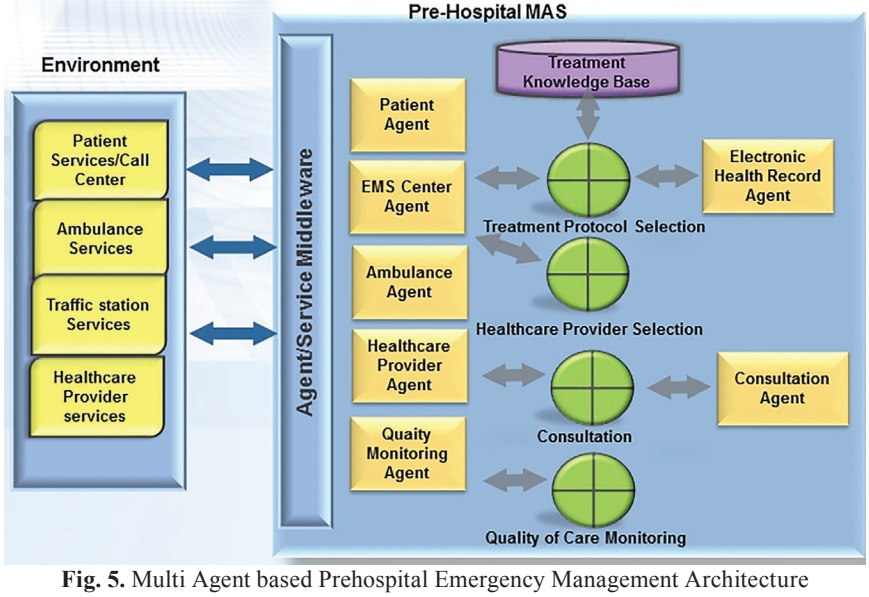

Fig. 5. Multi Agent based Prehospital Emergency Management Architecture

operations as web based services and they interact with the multi agent based system through agent/service translator middleware.

Figure 5 shows the overall architecture components. As you can see in Figure 5 each service in the environment is associated with a corresponding agent through an agent/service middleware. Since web service standards and technologies are different from multi agent systems, the two technologies must be integrated using a middleware layer.

The patient calls are delivered by the call center to the patient agent and the patient agent connects to the EMS Center agent. The EMS Center Agent acts as decision support module and will choose suitable treatment protocol considering patient registered condition and past medical history retrieved from Electronic Health Record Agent, manages healthcare provider selection and ambulance navigation Ambulance Agent takes care of patients according to their selected treatment protocol, and makes consultation if necessary, then delivers them to healthcare provider. The Quality of Care Monitoring Agent is responsible for monitoring the EMS Center Agent, Ambulance Agent and Healthcare Providers. The Electronic Health Record Agent provides a repository of patient's medical history and the Consultation Agent provides remote consultation to Ambulance Agent and Healthcare providers.

Simulation

In this section we demonstrate how we have simulated our model using Anylogic simulation software. Multi-agent system (M.A.S.) is a computerized system composed of multiple interacting intelligent agents within an environment although there is considerable overlap, a multi-agent

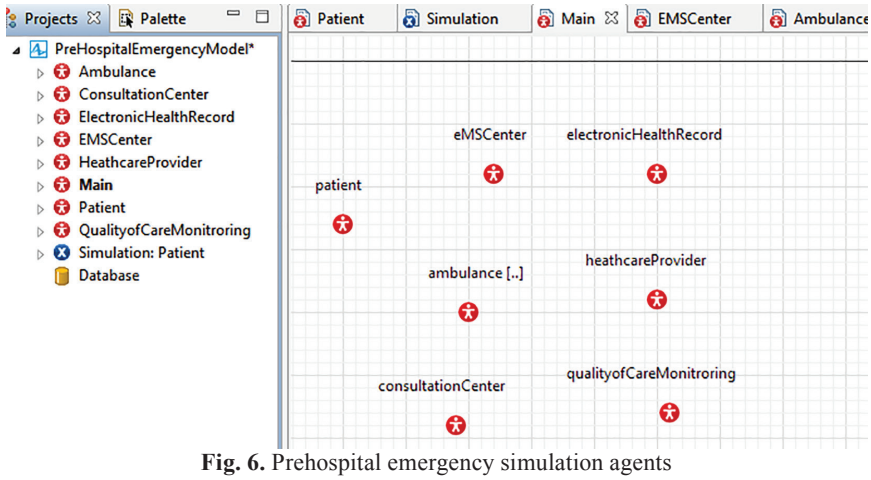

Fig. 6. Prehospital emergency simulation agents

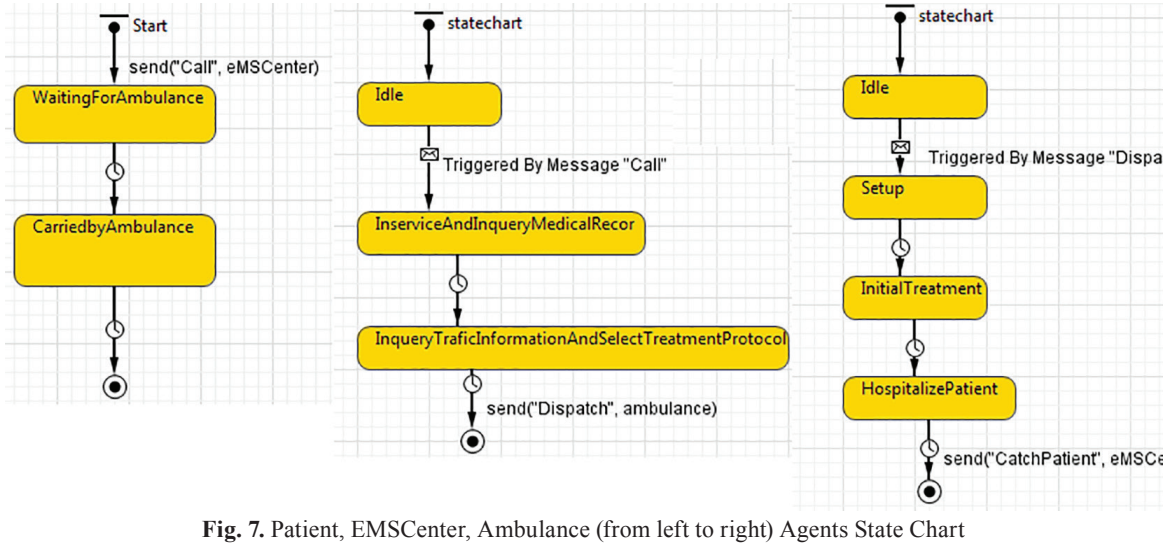

Fig. 7. Patient, EMSCenter, Ambulance (from left to right) Agents State Chart

system is not always the same as an agent-based model (ABM). The goal of an ABM is to search for explanatory insight into the collective behavior of agents [21].

AnyLogic supports Agent Based modeling and allows its efficient combination with other modeling approaches. AnyLogic allows creating flexible models with agents, interacting with each other and their environment. AnyLogic supports all known ways of specifying the agent behavior – statecharts, synchronous and asynchronous event scheduling [22].

We have created an agent based Model for the prehospital emergency management and added the agents we described in the previous section to the model. We have modeled the behavior of agents using state charts. Agents Interactions have been simulated using the messaging technique used in any logic. Figure 6 shows the main agent model and identified agents and Figure 7 shows their corresponding state charts. Patients can be either waiting for the ambulance or be carried by the ambulance, the EMSCenter may be idle or inquiring patient medical record or it may be in the state of inquiring traffic status and selecting treatment protocol. The ambulance may be in one the following states:Idle, setup, Initial treatment and transport and hospitalization.

In order to model the patient prehospital emergency process and calculating the patient service time we have used Anylogic Process Model library. We have assumed having 6 emergency patients per hour in a region and having 5 ambulances in service. We have considered the waiting time for ambulance having Triangular(8,12,16) minutes distribution that has been inspired by the numbers which have been reported in [23], the initial treatment delay time with Triangular (10,15,20) minutes, healthcare provider distance with Triangular (2.5,5,7.5) kilometer distribution, the ambulance speed with Triangular(30,50,70) kilometer per hour distribution. Figure 8 shows the process model simulation as you can see in the simulation there is a source of patients starting the process, when each patient is generated it goes to the waiting for ambulance state and after the delay that follows the ambulance waiting distribution after ambulance (conveyor in the simulation) reaches the patient, the patient will go to Initial treatment state with the treatment delay time and will be transferred to the hospital considering the distance distribution and ambulance speed distribution. Figure 9 shows the patient mean time(minutes) spent in the system per number of users.

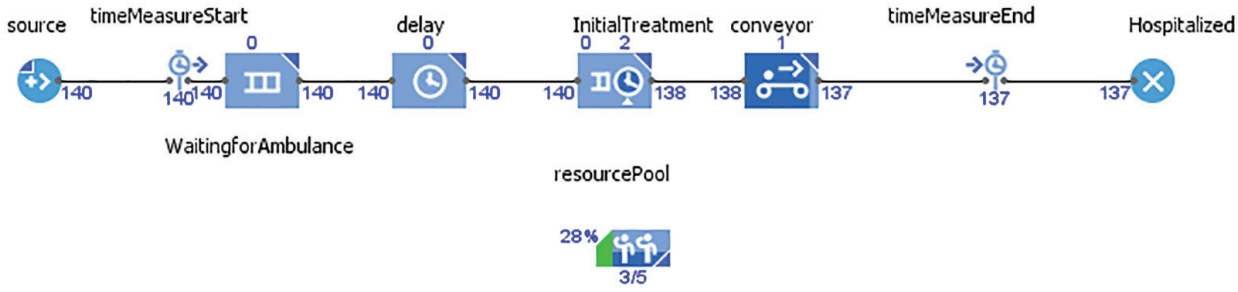

Fig. 8. Prehospital emergency service process model

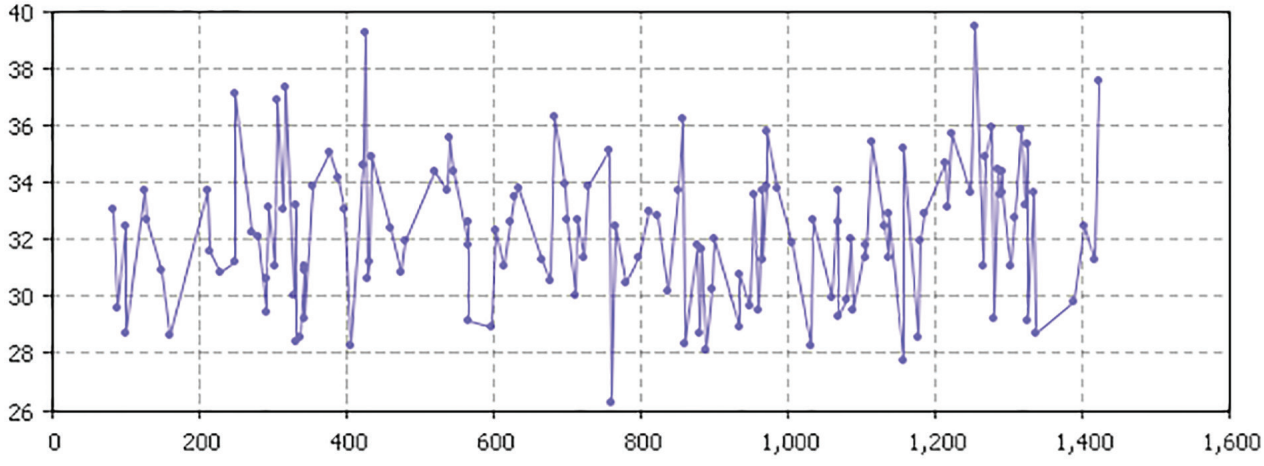

Fig. 9. Patient mean time spent(minutes) in system

Discussion

Every country should have minimum standards for prehospital care, in Iran there is no integrated trauma system, each organization has its own functions and there are limited equipped hospitals for patient transfer [6, 7]. In this research the pre-hospital emergency process and main components were extracted trough a comparative review of existing prehospital emergency architectures.

In [4] they had introduced a multi agent system for coordinating ambulances and they had addressed the problem of assigning services to ambulances. A cloud based architecture for an electronic emergency patient record had been presented in [5], that provides functionality for retrieving, transforming, exchanging and storing emergency case information in a distributed manner. In our work we presented an EHR Agent which acts as a middleware in order to retrieve and update patient medical record. A interoperable and scalable technology network architecture was presented in [19] they had integrated medical technologies such as pulse oximetry and end-tidal carbon dioxide (CO2) monitoring, continuous positive airway pressure (CPAP) devices, and 12-lead electrocardiograms (ECGs) and patient are encountered on handwritten patient care reports (PCRs) through wireless transmitter's with patient electronic medical record.

Multi Agent Systems can also be used to provide healthcare services for rural regions in emergency cases [24]. Most had studies and researches done in this field are focused on emergency or disaster management not specifically prehospital emergency.

In the case of patients with critical conditions such as neurological or stroke conditions if the right medical team or healthcare center isn't assigned at the right time the patient will suffer from a lot of complications [6]. Another risk in prehospital emergency care is access limitations to the patient past medical history [7], therefor we need to access patients electronic health record if available, and retrieve past medical history in order to manage and treat patients considering their medical condition. Most of the studies and researches done in this field are focused on emergency or disaster management not specifically prehospital emergency. In [15] they proposed a Multi-Agent Decision-Making Support Model for Prehospital Emergency Services, their main focus had been on human resource optimization, scheduling and vehicles(ambulance) optimization based on agent interaction model, in our work we have tried to cover treatment protocol selection, healthcare provider selection, Inquiring past medical history and quality of care monitoring in advanced.

The main contribution of the work is to apply multi agent systems to prehospital emergency process and to take advantage of their capabilities like autonomy, flexibility, collaboration and negotiation to provide a society of interacting agents for distributed decision making in complex prehospital emergency environment.

In conclusion, an emergency patient won't

receive specialized medical treatments if she or he isn't placed in a proper healthcare center with the appropriate medical team. In this paper by applying multi agent systems a new pre-hospital emergency management architecture is presented. The proposed architecture is general and abstract which could be customized for any local setup. We have introduced a prehospital emergency architecture to cover prehospital emergency process including: treatment protocol selection, healthcare provider selection, Inquiring past medical history and quality of care monitoring. The main advantage of our work has been the use of multi agent systems which are considered as a well-known solution for management, coordination, control and modeling. One of the disadvantages of our work is that the data which have been used for different timings in the simulation has not been based on real world data, there for extracting and using the real-world data are considered as our future study. The lack of security and maintainability of multi agent systems should be considered more strictly, patient data should be kept under secure policies which is considered as future work. Future works also will include treatment protocol selection algorithm based on patient's situation and to implement the proposed architecture.

Conflicts of Interest: None declared.

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