Agent based optimization and management of healthcare processes at the emergency department

A. Daknou, H. Zgaya, S.Hammadi and H. Hubert

***Abstract*—** In this paper, a Multi Agent System (MAS) is presented, aiming to minimize the waiting time of patient as well as the cost of care within emergency department. In such organization, a persistent need of efficiently activity scheduling process arises in order to take care of all arrival patients at the emergency department and to improve the quality of care. Software agents were adopted to provide the means to accomplish such real-time application, due to their autonomous, reactive and/or proactive nature, and their effectiveness in dynamic environments by incorporating coordination strategies. Specifically, the objective of the MAS is being able to represent the real conditions, courses, and the human decision behavior. The main aim of this paper is to present the overall design of the proposed MAS, emphasizing its architecture and the behavior of each agent of the model, as well as on the scheduling model which provide the activity scheduling process of care and the agent interaction protocol to ensure cooperation between agents that perform coordination tasks for the users, i.e. the medical staff needed to solve some problems at the emergency department.

***Keywords*—** Cooperation, Emergency department, Multi-agent system, Negotiation protocol, Optimization, Scheduling, Treatment plans.

I. INTRODUCTION

Historically, the emergency department (ED) was the main gateway to the hospital, and an almost obligatory passage for patients before their admission to most hospital services. The ED is a hospital or primary care department that provides initial treatment to patients with a broad spectrum of illnesses and injuries, some of which may be life-threatening and require immediate attention. Emergency departments are then developed during the 20th century in response to an increased need for rapid assessment and management of critical illnesses. This steady increase in the attendance of emergency services is a common phenomenon to all countries that have it. In current systems of health, the emergency departments have become important entry points of access to medical care provided to patients. Upon arrival in the ED, people typically undergo a brief triage, or sorting, interview to help determine the nature and severity of their illness. Individuals with serious illnesses are then seen by a physician more rapidly than those with less severe symptoms or injuries. After initial assessment and treatment, patients are either admitted to the hospital, stabilized and transferred to another hospital for various reasons, or discharged. The ED is also a unit of the hospital that is offered within an appropriate time and by an interdisciplinary team of professionals. The staff in emergency departments not only includes doctors, nurse practitioners but physician assistants (PAs) and nurses with specialized training in emergency medicine.

In recent years, research in multi-agent systems is exploring the advantages offered by the emerging multi-agent software engineering paradigm. By focusing on the relationship between an entity in the real world (an individual, a relationship, an organization) and its corresponding entity in the “electronic world” (an agent, a relationship between agents, a set of agents), design can become easier and quicker. As a result, interesting multi-agent based models of complex social structures have started to emerge. The ED care system is a perfect example. It offers extremely rich interdependent sets of relationships and necessitates coordination between several tasks. Therefore, ED staff must interact efficiently. That's why we need to balance the human resources (medical staff) and material resources (treatment rooms, hospital beds, medical equipment etc.) within the emergency departments.

This article explain how agents can exploit their capacity in order to support ED staff in making decisions, either by cooperating with other agents, or with human actors that they represent in the virtual system. For instance, when a patient arrives at ED, he must perform several tests to confirm his diagnostic. Fulfilling these tests requires the availability of the necessary material for all operations and qualified staff. So, we propose an efficient activity scheduling process of care within emergency department which plays a crucial role in order to ensure the delivery of the right treatment at the right time and to improve the quality of care.

Furthermore, many medical procedures now involve several individuals whose decisions and actions need to be coordinated if the care is to be effective and efficient. To

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A. Daknou is with LAGIS Department, Ecole Centrale, Lille, France. (e-mail: amani.daknou@ec-lille.fr).

H. Zgaya is with LAGIS Department, Ecole Centrale, Lille, France. (e-mail: hayfa.zgaya@ec-lille.fr).

S. Hammadi is with LAGIS Department, Ecole Centrale, Lille, France. (e-mail: slim.hammadi@ec-lille.fr).

H. Hubert is with Institute of Health Engineering of Lille, University of Lille2, FRANCE. (e-mail: herve.hubert@univ-lille2.fr).

provide the appropriate software support for such coordinated health care management at the ED, we have chosen to adopt an agent-based system. This later can operate effectively if the agents are able to exchange information in the form of messages and if they have a common understanding of the possible types of message. To reduce the search space of possible responses to agent messages, interaction protocols can be employed. They specify the sequences in which these messages should be arranged in agent interaction. In this paper we describe our approach to the representation and use of agent.

The remainder of this paper is organized as follows: some of the health care applications based on agent metaphor are discussed in section2. A general description of the problem is illustrated in the section 3. The global architecture of the multi-agent system is proposed in section 4 where we detail the behavior of each agent. In addition we present the proposed scheduler algorithm in section 5. In section 6, we present our agent negotiation protocol. The implementation of the model is described in section 7. Conclusion and future works are addressed in section 8.

II. RELATED WORKS

The software-agent paradigm [2] [3] [4] was adopted due to its autonomous, reactive and/or proactive nature, which comprises important features in real-time application deployment for dynamic systems like the one under consideration. Furthermore, software agents can incorporate coordination strategies, thus enabling them to operate in distributed environments and perform complex tasks. Generally speaking, software-agent technology is considered an ideal platform for providing data sharing, personalized services, and pooled knowledge.

In the research literature, there are several agent-based applications reported in the healthcare domain. In particular, one of the earliest examples of work examining the role of multi-agent systems in healthcare is offered by [6]. The focus of the work presented there, and of the broader context, in which it was conducted, is upon appropriate theorem proving in decision support systems that have to deal with complex, incomplete, inconsistent and potentially conflicting data. The agent componenent is designed to support of tasks amongst players in the system. Heine et al [7] simulate an agent oriented environment for German hospitals with the objective to improve or optimize the appointment scheduling system, resource allocation and cost benefit of clinical trials. Nealon and Moreno [8] have discussed the potential and application of agents to assist in a wide range of activities in health care environments. Mabry et al [9] employ the Multi agent system for providing diagnosis and advice to health care personnel dealing with traumatized patients. Nealon and Moreno [10] have discussed various applications of MAS in health care e.g., coordination of organ transplants among Spanish hospitals, patient scheduling, senior citizen care etc. A research project, called PalliaSys is offered by [11]. It incorporates information technology and multi-agent systems to improve the care given to palliative patients. An Intelligent Healthcare Knowledge Assistant [12] was developed which uses multi agent system for dynamic knowledge gathering, filtering, adaptation and acquisition from Health care Enterprise Memory unit. Koutkias et al [13] created a Multi agent system that aims to enhance monitoring, surveillance and educational service of a Medical Contact Center (MCC) for chronic disease management in Greece. The works mentioned above are domain specific, e.g. catering to special types of patients or providing assistance to patients for appointments or supporting doctors in diagnosing specific diseases, etc. These systems are therefore, not capable of handling problems related to taking care of patients at ED as presented in section 1. More precisely, the efficacy of agents in this application area has still not been explored. So, in the subsequent sections we are introducing and highlighting the concept of using agent technology in this regard.

III. PROBLEM DESCRIPTION

Based on detailed analysis of visits to multiple French emergency departments (table1) we identified several types of emergency departments and their processes. We also identified their specific requirements in order to separate and classify particular and common issues among emergency departments.

Table 1 Description of some french emergency departments

Place	Features
CHRU Lille	No information for the rate of admissions by type of emergency. All patients were registered by the reception staff. Orientation of patients by severity. Waiting times vary. Center of excellence for the treatment of severe cases
SAMU Lille	34 permanent 25 of which are general emergency and attached doctors to other institutions, the rest are anesthetists emergency. There are 63 permanencies for the entire department in the north. 800 to 1000 calls are received per day.
CH Dunkerque	At least 85 patients per day and maximum of 165 patients per day. The service is recent creation date in May 2003. The small care sector is open from 8am to 23h. A project is underway to implement a server to access the results in the laboratory.
CH Lens	Resuscitation Area: 3 rooms and 2 patients per room, Continues closer monitoring, a cardiologist.
CH Valenciennes	120 patients per day. There are 17 doctors and 43 nurses

In France, there are two types of emergency rooms: the specialized services (called SAU) and the proximity units (called Upatou). A hospital (public or private) can have a specialized service in emergency care only if it can already take care of the most probable trauma and disease in classical hospitalization: resuscitation unit, general and internal medicine, cardio-vascular medicine, pediatrics, anesthesiology-resuscitation, orthopedic surgery and visceral surgery, including gynecological surgery. The hospital must have two operating rooms (and a wake-up room) with personnel on duty that allow operation at any time and services that can perform examination and analyses at any time: medical imaging (radiography, medical ultrasonography, computed tomography, angiography...), haematology, biochemistry, de toxicology laboratories, etc. The specialized service is managed by an emergency physician. An emergency physician must be on duty anytime, and a specialized physician can be called anytime depending on the specific pathology (i.e. on duty in the hospital, not in the emergency service). The team must have, in addition to the emergency physician: two nurses ; care assistants, possibly child care assistants; a social worker; a receptionist; all must have a specific education for emergencies.

A careful examination of the activity process at the ED reveals that the emergency departments are facing difficulties at the management level, which are mainly related to the unpredictable flow of patients, to the inability to control flows stream up and stream down, to the multiplicity of actors and to the reduced efficiency of care activity which consist of the interrupted tasks, qualification under or over used (i.e. a percentage of the time of the doctor is non-medical) and difficulty in quantifying (Who does what, when, how often?). Medical knowledge, examinations and treatment are distributed functionally, geographically, and also temporally. There is a need for reliable and consistent information flow among all participating subjects. So, the situation demands a system that works beyond these limitations. Then, we propose an architecture based on a multi-agent system capable of handling all patients of ED in order to minimize their waiting time as well as the costs of care, with the respect of the quality of care. Our model aims to make possible to identify a medical actor available at a given time and to assign to him, depending on both of the flow of patients and the medical practices, a set of tasks. Where he can perform those tasks and has an aspect of flexibility relates to the possibility that could have a human resource to perform various tasks with appropriate skills (degree of knowledge). The different agents of the proposed architecture interact to improve completeness and accessibility of information which is a key element to get better the quality of care at the ED.

IV. ARCHITECTURE OF PROPOSED SYSTEM

A. *Multi-agent system description*

Since the care of patients in ED is a complex problem that requires a good division of tasks and data, an agentive representation is implicit in agent-based model of such real world. These characteristics suggest that the properties of intelligent agents (autonomy, pro activity, social capacity) and the architecture of multi-agent systems (distributed information processing, communication, coordination, and negotiation) is a good option for designing a system for providing clinical decision support to healthcare practitioners in the ED with the aim to satisfy the global goal improved health of a patient.

To satisfy these requirements and provide adequate decision support, we propose a dynamic and open multi-agent system MAS based on the interaction of five types of software agents [1]: the Home Agent (HA), the Identifier problem Agent (IdA), the Scheduler Agent (SA), the Monitor Agent (MA) and the Mobile Staff of medical team Agents (MSA). The HA agent as its name suggests ensures the patient's host and the creation of medical records. The IdA agent receives the medical problem and identifies the skills needed for the treatment. The SA agent makes the assignment of MSA agents to medical teams. The MA agent is in charge of the patient's become. Finally, the MSA agent which moves from team to team in depending of the need provides the treatment and the following of the patient (Figure1).

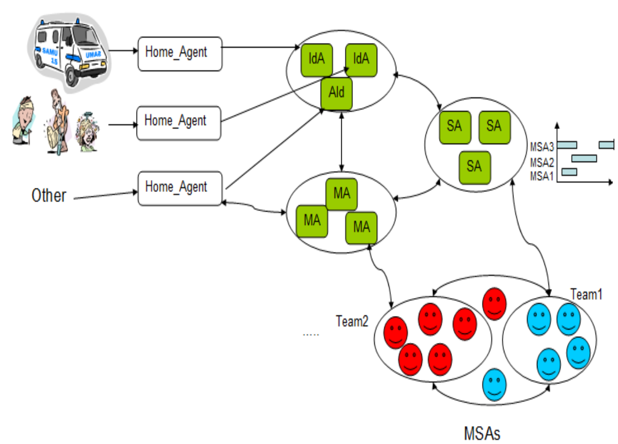

Fig. 1 A multi-agent architecture

At a time t, the arrival of a patient requires the creation of a Home Agent and triggers the creation of an Identifier problem Agent, a Scheduler Agent, a Monitor Agent and a number of Mobile Staff Agents of medical team. These same agents are available if they will take care of new patients otherwise we will create agents as required. After a period of inactivity $\Delta\infty$ i.e. in the absence of patients, the agents will be destroyed and they will be automatically created if necessary.

We call IdA, SA, MA and MSAs agents created at time t, the agent's society Pt. If at time t + Δε all agent's society previously created are unavailable, then the arrival of new patients triggers the creation of a new agent's society Pt + Δε and so forth. Once an agent's society Pti created at the moment ti, is available, it is ready to manage patients in the ED. However, as soon as the availability of an agent's society or HA agent reaches period of inactivity $\Delta\infty$, the agent's society or the HA agent is automatically destroyed (Figure 2).

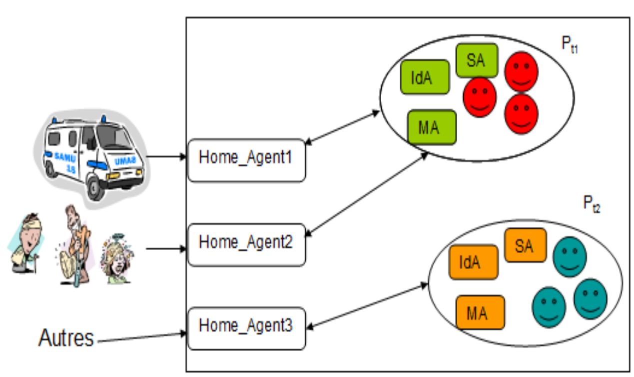

Fig. 2 Dynamic behaviour of the system: agent's society

The MAS is designed according to the requirements for effective diagnosis and delivering the treatment plans for patients at the ED. It provides an interaction mechanism with the healthcare professional at ED and delivers diagnosed disease and suggests treatment plans as per the supplied sign-symptoms.

B. *Application scenario*

The MAS provides a clinical decision support to a healthcare professional dealing with the patient illnesses at the ED. For instance, the arrival of a patient who suffers from Hypertension. Hypertension is one of the major prevalent diseases that influences the prognosis of chronic diseases. Primary care should attract much attention in the management of hypertension. A home agent uses the GUI to create patient record and to pass the sign-symptoms and other observations. The IdA agent will be created to decide the disease, choose the degree of severity and generate treatment plan based on protocol care. Table2 depicts a hypothetical case scenario of a patient at ED suffering from hypertension.

Table2. Disease Identification and Treatment Plan

Disease	Treatment	Severity level	Skills needed
Hypertension	-Measuring blood pressure -Gradual intravenous treatment	high	Doctor Nurse Care assistant

The summary report is then sent to SA agent to make the assignment of tasks to MAS agents who represent the medical team composed of a doctor, a nurse and a care assistant. Finally, the MA is created to manage the patient become.

C. *Description of the different agents*

A set of agents was developed for solving coordination problems of different actors (physicians, patients, nurses) at the ED. The proposed MAS requires delegation of task to various agents in the system. In the following section, we will describe the organization of these different agents.

GUI for ED practitioner

The GUI for ED practitioner has been designed for providing an interface. It is being used for the following purposes:

• Displaying the account identification issued by the ED system,

• Feeding the main problem, sign–symptoms, and observations of the ailing patient,

• Passing the information to the HA and;

•Displaying the diagnosed disease, treatment plans and the result generated in the process.

Home-Agent (HA)

This agent interacts with the emergency's patient within the GUI by creating his medical records. Once a patient come into the ED, a HA agent is created in real time to help and save him in the system. The same agent can provide this task several times as there is an input stream of patients or it can be destroyed by the system and another HA agent is created as considered necessary, and so on. Thereafter, the HA agent sends the problem to the IdA agent then directs the patient to the recommended room care.

Identifier Problem Agent (IdA)

An available IdA agent interacts with HA to receive the main problem and some details that help in deciding the disease and generating the treatment plan. If there is still no IdA agent available in the system, a new IdA agent is automatically created. Initially, the IdA agent begins by consulting the medical history (pre-existing medical protocols). If the problem is not already covered, the IdA agent must identify the skills and the material resources needed to deal with the emergency. Finally, the IdA agent transmits generated data to the SA agent that will optimize the choice of different MSA agents of medical team as well as the material resources required depending on emergency case.

Scheduler Agent (SA)

From its inception, the SA agent plans dynamically the sequence of the tasks which implies a dynamic generation of the actors' activity plans. Knowing the profile of the agent which corresponds to the tasks that it can perform, the SA agent proposes the MSA which will carry out the announced tasks. So, the SA agent calculates an actual number of MSAs agents of medical team that will create and then assigns at each one a role as it updates whenever the flow of entry of patients varies considerably. IdA agent procured to SA agent some data that it will try to optimize. The data received correspond to a set of tasks required, to all needed skills of the MSA agents and to material resources. A SA agent must optimize the treatment plan of the patient by minimizing the waiting time of patients (forced vital emergency) and the total cost with the respect of the quality of care. All MSA agents selected correspond to the medical team. An emergency alert as a result of the need for a MSA agent triggers a process of updating the plan made by the SA agent for the medical team which may necessitate the relocation of MSAs agents from one team to another. Finally, the SA agent communicates to MA the eventual required treatment after the intervention of the medical team.

Monitor Agent (MA)

A monitor agent can take care of patients who need particular supervision or treatment like as exit unit of quickly hospitalization, transfer to an another care unit. Thus, the monitor agent is not only in relation with MSAs, but more with the IdA agent in case of deterioration of the patient's medical condition. In addition to the monitoring on the patient's health, the MA will manage the hospital rooms and beds available in order to optimize costs.

Mobile Staff of medical team Agent (MSA)

The MSA agent on a mobile device (e.g. PDA) is able to migrate with information to contact the SA agent. Furthermore, MSA is able to move from one team to another in order to perform the solicited task by the SA agent. If there is a need for cooperation between medical staffs, the SA will arrange a meeting of related medical staff in order to make more accurate decision. Therefore, the MSA agents act as a collaborative team of specialists. In addition, this agent will share the parameters of the treatment and monitoring of patients with MA agent.

In our agent-based model, agents act as federated, collaborative team of different skills on behalf of a patient. As with a team of physicians and nurses working on a patient, each agent provides specialized skills and knowledge. Each member agent's opinion is trusted as an expert in its particular domain. This description of the system shows the importance that plays the SA agent in the ED. So, generating a high quality solution is a challenging task, since different goals (i.e. all the activities are scheduled as soon as possible, the patient waiting time is minimized, the device utilization is maximized) could be achieved and a large set of constraints (i.e. every device can be used by only one patient at time, the treatments have to be performed in an exact time order) should be taken in account. Our continuing goal is to advance the agent based system towards a real-time system that enables resource allocation.

V. BEHAVIOR OF SCHEDULER AGENT

The problem of scheduling human resources (medical stuff) in ED is of great importance in a context of insufficiency of resources, of increased demand for care, of encouragement to control health costs and of improving efficiency and productivity of the ED. Thus, more and more these services need to have tools for allocation and scheduling its resources. The process of an ED is committed in real time as the flow of patients arriving in the day at the moment t. However, a scheduling established at the moment t, which specifies the order of arrival patient is often not respected because of the different types of hazard that may happen. Among these uncertainties, we can cite the uncertainty in predicting the time of care and treatment, the case of unexpected complications and the arrival of vital cases that have a medical priority. The objective of the proposed method of scheduling is to give the possibility to insert a new patient in scheduling which is in progress. We have assumed in our study that material resources (the treatment rooms and equipment) are still available. The method of resolution will be as follows [14]:

Phase1: Scheduling

The first phase is to make an initial scheduling of patients attending the ED at the moment t according to a priority rule based on algorithms of lists. More specifically, at the moment t, among the available operations, the operation of highest priority is affected. More generally, algorithms of lists proceed first to develop a priority list which is then used to construct a solution. In our problem the priority rule is dynamic and is estimated using the intervention deadline before which operations must be carefully allocated to the available agents of medical staff.

Phase2: Insertion

The second phase is to explore the feasibility of introducing patients who arrive at the moment t + dt in scheduling already established and who's have a highest priority. This possibility is determined by considering a time limit by which the urgent intervention should begin, on the other hand, the residual time of availability of resources as they are being used. At the beginning, we look at the operations of the new patient if can be inserted while maintaining the sequence of the scheduling already established. The solution of insertion of emergency is completely up to the end of this second phase. However, if the insertion of emergency induced exceeded the scheduled time of emergencies then the patient can only be inserted if it remains possible to make interventions that can not be delayed. It is to apply a method of re-scheduling. The final solution of insertion of patient is given after the 3rd phase of the method. In all cases where it is possible to accept the patient, at the end of the 2nd phase the beginning time of inserted intervention will be determined.

Phase3: Reschedule

The third phase aims to seek re-scheduling of emergency allowing pre-emption for an operation in progress and that has a lower priority than the one that has just arrived. Moreover, we must look for a reordering of the remaining interventions that have been shifted and which are not as urgent. Thus we have as a result the sequencing of interventions.

A. Modeling of the scheduling problem

Usually, scheduling deals with the allocation of the patients to the treatments over time, by respecting precedence, duration of sequence of treatments and incompatibility constraints, in order to achieve the optimal using of resources or the optimal accomplishment of tasks. In this paper we consider a dynamic scheduling case where the schedule of arrivals is revised continuously over the day based on the current state of the system. This is applicable since patient arrivals to the ED can be regulated dynamically generally involving patients already arrived. It is worthwhile to observe that patient scheduling at the ED differs from the classical scheduling problem because of the unpredictability of the flow of patients. We aim to organize the care of patients which are received at the ED by the existing medical staff and minimize their waiting time. The total staff is noted by M. Each patient at the ED is a matter of urgency which is represents by PBj (t) with $1 \leq j \leq PB$ at the moment t. This problem requires intervention that consists of a number n_j of ordered operations. Each operation i of the problem PBj (t), noted $O_{i,j}$, can be performed by a team with multiple skills. The assignment of an operation $O_{i,j}$ to a person P_m, $m \in \{1,...,M\}$, make the occupation of such person for a period $d_{i,j,k}$. All persons are available at the time t = 0. We identify the skills mastered at the ED by C_k, $k \in \{1,...,K\}$. Here, we have to take into account the flexibility of these medical stuff by using a degree of knowledge θ_k belonging to [0.1] for any P_m. If the level equals to 1 then the person has the best competence for applying this skill. The second possibility when the level is between 0 and 1 then the person can intervene in support of aid another medical stuff whom the appropriate skills or replacing them. Finally when the level is 0, i.e. the person has not the suitable skill. Each problem can not be handled after the intervention deadline $dl_{i,j}$. The order of operations for each problem is fixed from the beginning (precedence constraint). A staff can not handle more than an operation at a time t (human resources constraint). The resolution of this problem requires the allocation of each operation $O_{i,j}$ to the person with the appropriate C_k and a minimum level of knowledge θ_k. Then, it must calculate its both start date $t_{i,j}$ and its end date $tf_{i,j}$ of execution. That for analyzing the waiting times for each patient at the ED. The objective of this work is to assign the MSAs to the different operations that are needed to the medical intervention. This assignment aims firstly to stabilize the emergency state and then to treat the patient disease. In addition, this work allows us to highlight the work plan of each medical actor and the final operations scheduling (time and date of treatment). As a result, we have five types of decision variables:

- The binary decision variable $X_{p, k, i, j}$: this variable can assign a medical person (p) with his competence (k) to an operation (i) of the problem (j).
- The variable of assignment skills $C_{m, k}$: this variable is equal to θ_k if the person P_m controls the competence C_k with a level equal to θ_k, $\theta_k \in [1 , 0]$.
- The duration variable $d_{i,j,k}$ is the duration of the operation i when we have the problem j which must to be performed by the competence k.
- The starting time variable $t_{i,j}$ must respect the precedence constraints between operations.
- The time variable of availability of staff is represented by the vector Dispo_Perso [m]. This vector gives the time when the suitable person is free to any assignment $X_{p,k,i,j}$ of operation $O_{i,j}$ to the medical team with multiple skills.

As we mentioned previously, we have problem scheduling constraints which should be taken into account are:

- The precedence constraints: describe the order between different operations care. By respecting these constraints, we realize the normal medical treatment plan.
- The constraints of skills availability: these constraints check the availability of medical staff to be assigned to an operation. Those constraints will allow assignment of skills that their degree of knowledge are above or equal to a minimum level set by an expert in the field.

The objective function aims to minimize the waiting time between the arrival moment of patients receiving at the ED and the first medical consultation.

$$Min(\sum_{i=0}^{PB} Max(0, Wait_R - Wait_{Th}))$$

B. Three Phase Reactive Scheduling Algorithm

The SA agent will apply a **3 P**hase **R**eactive **S**cheduling **A**lgorithm 3P-RSA which provides scheduling of operations care needing multiple skills. This 3P-RSA calculates the start times $t_{i,j}$ of execution taking into account the availability of skills and precedence constraints. The rule of priority for each patient will to be according to the gravity of the case. A dynamic integer value of priority $pr_{i,j}$ is assigned to each patient by the agent AId depending on deadline intervention $dl_{i,j}$. The lower value of priority, the higher the severity of the patient's illness.

The 3P-RSA Algorithm

```
Initialize the vector of availability of skills Dispo_Perso[m]=0,
for any m ≤M ;
//Build the set of persons who control theCk competence.
For (k=1 ; k ≤ K)
      For(m=1 ; m≤ M)
            If (Cm,k = θk) then bk ← Pm;
            EndIf
      EndFor
EndFor
Phase1 : Scheduling
For(j=1 ; j≤PB)
  For(i=1 ; i ≤ nj)
     For (k=1 ; k ≤ K)
        // Build the set Ei of operations to schedule from an
initial time table; Ei= { Oi,j as di,j,k > 0}
          If (di,j,k > 0) then   Ei ← Oi,j ;
          EndIf
      EndFor
  EndFor
EndFor
Sorting Ei operations in increasing order of priorities pri,j
For each Oi,j  of  Ei Do
      For (k=1 ; k ≤ K)
            If (di,j,k > 0) then
                 For each Pm of bk  Do
                     If  Min ( Dispo-Perso[m]) Then
                      Team(i,j) ← { Pm }
                    EndIf
                 EndFor
            EndIf
      EndFor
Calculate the start dates of execution using the formula:
   ti,j  = Max(Dispo_Perso[m] as di,j,k >0 and  Pm belong to
team(i,j)) ;
   Update the vector of availability of skills
   Dispo_Perso[k]= ti,j + di,j,k
EndFor
Phase2: Insertion
For each new operation Oi',j' Do
  If there is Pm  as  Dispo-Perso[m] <= dli'j' then
    Team (i',j') ← { Pm}
    Calculate the start dates of execution using the formula:
   ti,j  = Max(Dispo_Perso[m] as di',j',k >0 and  Pm belong to
team(i',j')) ;
   Update the vector of availability of skills
   Dispo_Perso[k]= ti',j' + di',j',k
 Else go to phase3.
Fin pour
Phase3: Rescheduling
If Oi',j' has priority pri',j' < pri,j. Then
Interrupt an operation Oi,j  with priority  pri,j > pri',j'  assigned
to the  needed skill..
Assign Pm to the team (i',j').
Go to phase1.
Else
Go to phase1.
EndIf
```

C. Illustrative example

We suppose the arrival of 3 patients to the emergency department provided by 4 medical actors whose have 3 different skills with degrees of knowledge between 0 and 1 (see Table 3 and 4). The first patient suffers from a mild cranium trauma without loss of consciousness. The second patient suffers from a cardiac arrest and the third patient is suffering from not complicated pneumonia. Initially, the agent AId sends to the SA agent an array of assignment skills to the operations care with the times which is presented in table 5.

Table 3. Description of medical staff

IdPerson	Description
P1	Emergency Doctor
P2	Nurse1
P3	Nurse2
P4	Healthcare helper

Table 4. Table of degree of knowledge of the medical staff

	Persons			
	P1	P2	P3	P4
C1	1	0,4	0.4	0
C2	0,9	1	1	0,6
C3	0,7	1	1	1

Table 5. Table of assignment of operations which need multiple skills

	Operations (deadline of intervention)						
	$O_{1,1}$ (12)	$O_{2,1}$ (14)	$O_{1,2}$ (5)	$O_{2,2}$ (7)	$O_{3,2}$ (9)	$O_{1,3}$ (10)	$O_{2,3}$ (11)
C1	2	0	2	2	0	2	0
C2	2	2	2	2	1	2	2
C3	0	2	0	2	1	0	2

The results of the 3P-RSA algorithm at t = 0 is given by the Gantt diagram of figure3. The diagram shows a preliminary scheduling, which can be rectified in real time depending to the flow of patients as we can see the availability of medical staff and their report activities.

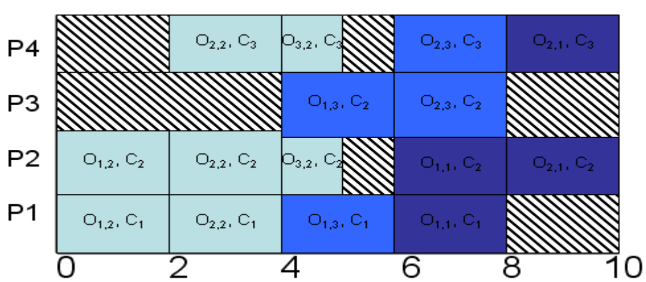

Fig 3. Gantt diagram of scheduling

We suppose the arrival of a fourth patient at the moment t = 2 who suffers from hypertension requiring urgent care, a fifth patient who suffers from injured knee and a sixth patient, who has a flu state. The operations and the needed skills are given in table 6.

Table 6. Table of assignment of operations

	Operations (deadline of intervention)					
	$O_{1,4}$ (10)	$O_{2,4}$ (12)	$O_{1,5}$ (16)	$O_{2,5}$ (19)	$O_{1,6}$ (15)	$O_{2,6}$ (16)
C1	2	1	0	1	0	2
C2	2	2	1	1	2	2
C3	0	0	1	0	0	0

From the data given in the tables 3 and 4, we can see that the patient 4 is more critical than the patient 1 so a new scheduling operation is given by the 3P-RSA algorithm. All that, because there is no way to insert the operations care of patient 4 when the staff is busy with another treatment patients whose have a higher value of priority. Thus, by following the execution of the 3P-RSA algorithm, the operations of patient 1 will be shifted. On the other hand, for the patient 5, the necessary skills for his treatment are available after the scheduling already established. As a result, it would be wise to include operations care of patient 5 in the scheduling as it does not affect the carrying out of more urgent operations. Finally, the patient 6 will be picked up at the end because he has the lowest priority value and can not be inserted. The new scheduling at the moment t = 2 has shifted operations care of patient 1 to take care of the patient 4. Similarly, the algorithm has allowed the integration of operations of the patient 5 in the scheduling already established. And finally, the algorithm has provided the planning treatment of the patient 6. The result is given by the Gantt diagram in Figure 4.

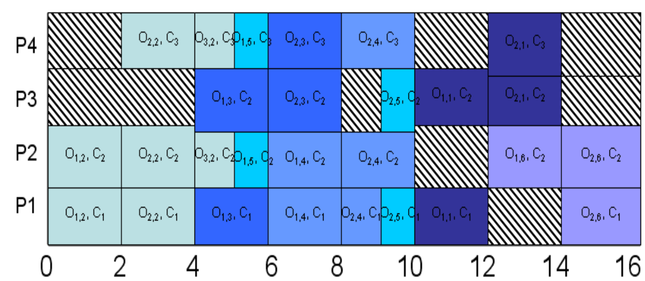

Fig. 4 Gantt diagram of scheduling

In this example, we have showed the systematization of care which is provided to patients at the ED by using our model. This is due to the sorting done using the priority values given to each patient and the pertinent management of the emergency staff. Moreover, the activity of each medical actor is identified by the system.

VI. AGENT NEGOTIATION PROTOCOL

In this paper, we focus on one of the important properties of an intelligent agent which is its social ability. Agents interact with other agents via an agent-communication language. The Foundation for Intelligent Physical Agents (FIPA) [17] ACL standard language was chosen to represent the messages exchanged among agents in our multi-agent system. This agent communication language specifies a domain specific vocabulary (ontology) and the individual messages that can be exchanged between agents. Interaction protocols specify the sequences in which these messages should be arranged in agent interactions. A group of rational agents complies with an interaction protocol in order to engage in task-oriented sequences of message exchange. Thus, when an agent sends a message, it can expect a receiver's response to be among a set of message indicated by the protocol and the interaction history. With a common interpretation of the protocol, each member of the group can also use the rules of the interaction in order to satisfy its own goals. In other words protocol constrains the sequences of allowed messages for each agent at any stage during a communicative interaction (dialogue). Protocol plays a central role in agent communication. It specifies the rules of interaction between communicating agents and the first thing should be done by the designer developing any particular real-time system is to impose interaction protocol.

A. Application Context

In an emergency processing centre, the medical staff is often confronted to treat several patients at the same time. So a patient can be treated by various doctors and nurses. Thus, the medical staff is organized in a cooperative group sharing the same resources, i.e. patients. Because of the strong dynamicity of the system and the great quantity of information handled by the medical staff, sometimes it happens that one medical personal neglects one of the tasks which was allocated to him. This weakens the human actors' cooperative process. The intervention of an artificial system is essential in this first level in order to organize and to supervise the activities of the human actors' cooperative system. The medical staff works on the basis of an activity plans dynamically generated by SA agent which contains the times and places of the services to be performed for various patients. This coordination is accomplished by having suitable interaction protocols between agents.

B. Agent Cooperation

In ED complex, a robust cooperation is essential between all the members in order to offer the best services because of the vital character of the acts achieved by these members. The cooperation of these members is carried out through the cooperation of the artificial agents integrated in our system.

A significant question to ensure this cooperation between the agents is: which protocol to use to ensure an effective allocation of the system's tasks?

The proposed protocol (figure 5) used for the communication (transmission of messages) is inspired from the well-known FIPA-Request protocol between MSA agents, representing the participants of the negotiation, and SA agents who are the initiators. This is the protocol that fits best with the needs of process, since the SA agent has to send a message to each MAS agent with the action that it must perform and the required parameters for that, and later the SA agent has to receive the result of this action. And this protocol is used exactly for that, to request an action to an agent and get a result. The SA agent initiates a FIPA-Request protocol with each MSA agent sending it a Request message and asking as service that it execute the solicited action, that is to say, that it performs the treatment of a patient.

When the MSA agent receives the Request message, it checks whether it understands the content and whether it can perform the required service. If everything goes well, it sends an Inform message to the SA agent with the result of action, that is to say, with the required information to update the schedule.

In our proposed solution, we allow a Modification Request message by the initiator of the negotiation (SA agent) in case of emergency's cases. A renegotiation process is necessary while there are vital tasks which need to be assigned. The purpose of this solution is to allow the MSA agents to cooperate and coordinate their actions in order to find solution to assure the treatment of patient whose life is threatening. When the MSA agent receives the Modification Request message, it checks whether it can perform the required service and whether it can interrupt the action in progress. If the participant agreed to do the task, it sends an Inform message with additional information if needed.

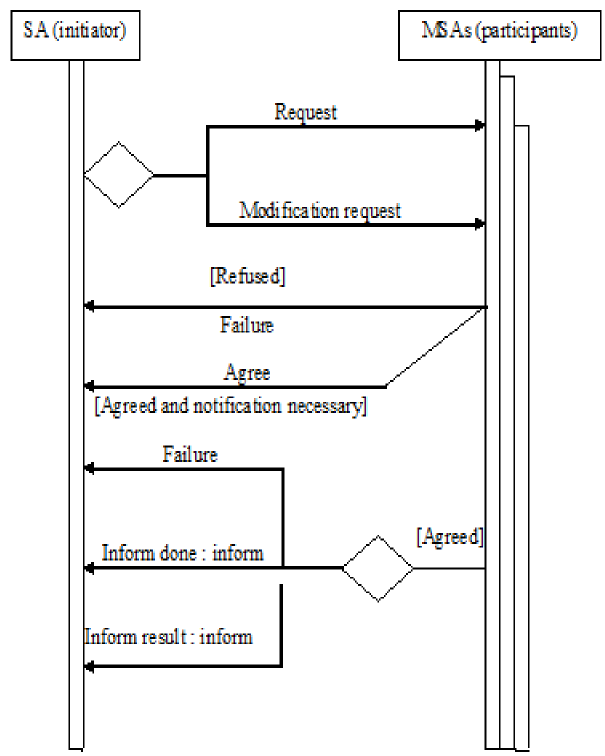

Fig 5. Proposed protocol

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VII. SYSTEM IMPLEMENTATION

We are developing our system, with the JADE platform (Java Agent DEveloppement Framework) [16]. JADE is a middleware that allows the execution of a flexible multi-agent systems, it offers an effective transfer of messages between agents to ensure communication between them through the

FIPA-ACL language (Agent Communication Language) who meets the specifications FIPA [17]. JADE is written in Java, supports mobility, and it is one of the few existing multi-agent platform which tolerates the integration of Web services. JADE has several interesting features that at least make the process of implementation easier. One of these features is the agent Sniffer that enables user to observe message flow among agents. Figure 6 summarizes the communication between the agents of our system at the arrival of a patient. For our example, the patient received at the ED was supported by a medical team consisting of three mobile agents MA1, MA2 and MA3.

An agent communication act adopted by SA agent to assign tasks to one of the MSA agents of medical team is shown below:

(REQUEST
:sender (agent-identifier :name
SA@home:6677/JADE: addresses (sequence
http:// home: 6677))
:receiver (set (agent-identifier :name
MA1@home:6677/JADE))
:content "((action (agent-identifier :name
MA1@home:6677/JADE: addresses (sequence
http:// home: 6677))
(\"Measure blood pressure.\")))"
: language fipa-sl
: ontology Disease_Ontology)

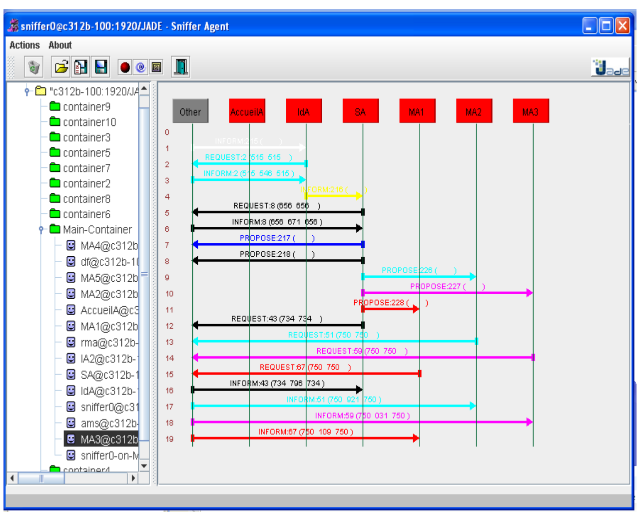

Fig 6. Exchange message between agents

According to the diagnosis provided by the national mission of hospital expertise and audit Meah [15], a patient requiring a simple consultation expects to average 55 minutes before seeing a doctor. This period may even reach more than 2 hours for 15% of patients.

To assess the impact of the use of our 3P-RSA algorithm, measured on a waiting time of 100 patients in ED. This evaluation showed a significant reduction in the time between home and first consultation as evidenced by the graph in figure 7.

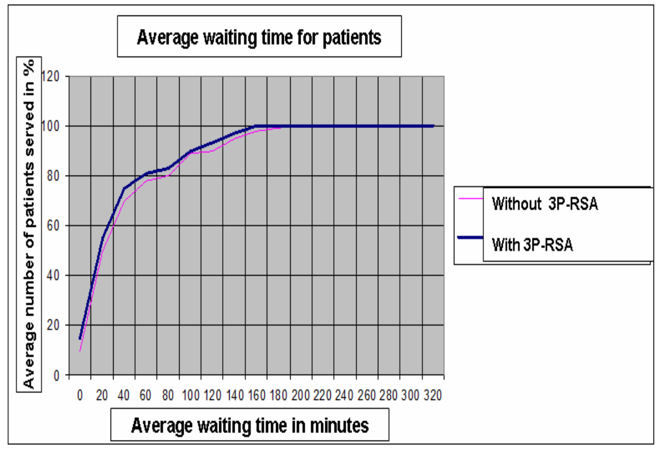

Fig 7. Average waiting time for patient

VIII. Conclusion

The ED healthcare delivery system in France can be improved by integrating it with the advancements of information technology. For that we need a system that demonstrates features such as, autonomy, reasoning, knowledge sharing and cooperation. A promising solution to this requirement is agent-based system. The system based on agent metaphor can be used to sense a particular situation, analyze it and make search for the desired goals.

The proposed multi-agent system in this paper is suitable to the prevailing situation of healthcare of patients at the ED for tackling some crucial case of emergency. This application demonstrates the utility of the methodologies proposed by the multi-agent community. On the other hand, our system provides the scheduling of ED's patients, generates their treatment plan and manages the interactions between the SA agent and MSAs agents to take care of patients at the emergency department. The proposed interaction protocol can handle the interactions between the SA agent and MSAs agents in case of perturbation of patient's health at the emergency department by introducing a new phase which we call: Modification Request. In a future work, we aim to establish the scheduling of material resources in order to achieve the optimal use of resources or the optimal accomplishment of tasks. Besides we propose to use specific application ontology and to incorporate it in the agent messages to provide a common understanding among agents.

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Amani Daknou is actually a doctorate in LAGIS laboratory at the high France School, Ecole Centrale de Lille (EC-Lille) in the Optimization, the Artificial Intelligence and the Logistic field. Born in Tunis (Tunisia) in 1983. She received the BSc degree in Software Engineering from INSAT (Tunisia) in January 2007. She obtained her master's degree in Artificial Intelligent Systems and Applications in July 2007 from Jean-Perrin University, Lens (France). She was member of the Organizing Committees of international congress on "Logistic and Transport" LT'2007.

Dr. Hayfa Zgaya is teacher-researcher in computing science in LAGIS laboratory within the high France School Ecole Centrale de Lille (EC-Lille) where she obtained her PhD degree in July 2007. Her main research areas are the Optimization, the Artificial Intelligence and the Logistic field. Born in Tunis in 1978, she obtained her master's degree in computer science in November 2001 from the France polytechnic high school of Nantes University. She takes an active part in the national working group ORT of GDR MACS and she was responsible of the Organizing Committees of international workshops MHOSI' 2005, LT'2006 and LT'2007.

Mr. Slim Hammadi is a full Professor of production planning and control at the Ecole Centrale de Lille (French « Grande Ecole »). Born in Gafsa (Tunisia) in 1962, he has obtained by 1988 the Master degree in Computer science from the University of Lille (France). Pr Hammadi obtained a P.h.D degree in job-shop scheduling and control in 1991 at Ecole Centrale de Lille. He is a senior member of IEEE/SMC and has served as a referee for numerous journals including the IEEE Transactions on SMC. Pr. S. Hammadi was Co-Organizer of a Symposium (IMS) of the IMACS/IEEE SMC Multi conference CESA'98 held in Hammamet (Tunisia) in April 1998. He has organized several invited sessions in different SMC conferences where he was session chairman. He was chairman of the International congress on "Logistic and Transport" LT'2004, MHOSI'2005, LT'2006 and LT'2007. His teaching and research interests focus on the areas of production control, production planning, computer science, discrete and dynamic programming and computer integrated manufacturing.