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Driven Workflow Orchestration of Patient pathway in Hospital Emergencies

S. BEN OTHMAN and S. Hammadi

*Ecole Centrale de Lille, CRISAL Laboratory
Cité scientifique, 59650 Villeneuve d'Ascq
France
{sara.ben-othman, slim.hammadi}@ec-lille.fr*

Abstract: Since the heat wave of the summer of 2003 in France, regional and national commitments to face the struggle against the peaks of activity and the overcrowding in health care systems have multiplied in order to guarantee a better patient health care. Our objective in this paper is to identify the overcrowding situations through key indicators, model patient pathway using workflow approach and finally offer agent-based decision support solutions for managers to provide better control of activity. In case of uncertainties in hospital emergencies, a coalition of agents is formed to collaborate and negotiate to provide decisions concerning the dynamic orchestration of workflow and minimize the waiting time of patients during their care. This work is a part of the project HOST (Hôpital: Optimisation, Simulation et évitement des Tensions), funded by the French National Research Agency (ANR).

Keywords: collaborative workflow, orchestration, health care systems, overcrowding, multi-agent systems, coalition.

1 Introduction

Hospital emergencies are facing problems related to the increasing demand in their services. Patients arrive to the services randomly and their flow keeps growing. The management of patients is carried out according to different modes related to the type of care required [1]: planned care requiring or not hospitalization, unscheduled urgent and non-urgent health care operations. One of the major problems faced by hospitals is due to the permanent interference between the planned activities, non-planned health care activities and especially urgent and non-planned care activities. The emergency term involves two different phenomena:

- Recurring flows which may present seasonal variations: Even if these flows are apprehended, quantified in volume and nature, the establishment of a management organization and a short-term control is an issue, leading to an efficient healthcare production system.
- Random arrival flows: In this case, the flows are completely unexpected in volume and in nature. If it is possible to adapt and implement traditional and organizational optimization methods for health care tasks scheduling, it is much more complex to control patient flows at emergencies [2].

The problem is not easy in a context where the emergencies are considered by the actors in the health system as the main care system entropy generator. Patients want the best care at the best price. These requirements have produced an interest in optimizing technical and human resources while mastering the costs [3]. Particularly, Pediatric Emergency Departments (PED) have limited resources, in addition to their sensitive and critical environment, joint with acuity. Logistics in health care institutions is therefore needed to improve efficiently the organization by reducing costs and meeting the needs of the different actors. The main challenge of this work is use some tools and optimization approaches in order to manage and anticipate the overcrowding situations in the PED. The experimental field of our study is the PED of the Regional University Hospital of Lille (CHRU de Lille), where patients wait for long hours (sometimes more than 10 hours) before treatment. These long delays can endanger patients' lives. This phenomenon highlights the need to review the emergency management process and the implementation of measures

to preserve the quality of care for patients. In cooperation with the University Hospital of Lille (CHRU de Lille), in order to meet these challenges, we are interested in the development and the implementation of a decision support system to model the architecture of the PED and optimize its operation. This tool offers a refined model for the logistical needs in emergency conditions, taking into account the existing operation.

Our paper is organized as follows: a state of the art about health care management will be presented in the second section. In Section 3, we describe some approaches to improve the functioning of emergencies. The proposed approach is presented in both of the sections 4 and 5. Performance evaluation is given in section 6 followed by simulation and results in section 7. This article is closed with conclusions and an outlook to further work.

2 State of the art

2.1 Health care systems management

The analysis of health care institutions dysfunctions shows that these are due in part to an organization poorly adapted to the constraints, an evolution of their missions and a poor management of patient flow [4] [5] [6]. Thus, the optimization of management and information systems are important levers for the development of these organizations. Therefore, the implementation of strategic, tactical and operational monitoring systems has become essential. To manage the transition, it is necessary to define the new organizational paradigms, new trades for the governance and management of these new organizations and support mechanisms. Reconfiguring and improving the health care system require "reorganization." These are problems whose complexity calls for innovative approaches. Today, emergencies in hospitals have a strategic position in modern healthcare systems and represent the main gateway to the hospital [7] [8]. This key role will be strengthened in the coming years due to the continuous growth in the arrivals of patients who are increasingly demanding. These changes generate many problems to different actors in public health, including operating problems to cope with the increase in consultations and the high cost of health expenditures [9] [10] [11]. However, if the majority of health care systems are facing these problems, the way to deal with them differs from one organization to another [12]. Thus, to better understand the problems and the current challenges, it is important to model the health care activities in the emergencies in order to identify the dysfunctions in patients' pathways and health care processes.

2.2 Strategies for improving the functioning of hospital emergencies

Different strategies have been proposed to improve the patient journey at the emergencies including the change of work schedule, human resources and their roles adjustments and modification of health care management procedures in order to reduce patients' waiting time.

2.2.1 Adjustment of human resources

Although the change of the schedule of the medical staff or the increase of human and material resources can improve the capacity of the emergencies, they may not be achievable in most existing emergencies because of space restrictions and/or budgetary constraints. Alternative methods try to maximize the use of the existing medical staff. The adjustment of human resources includes the planning of the medical staff workload for day shifts as well as the changes in the schedule over a longer period such as one month. The workforce management adjustments can better match available human resources with the different requirements of the fluctuation in arrivals of patients. The observed results show that the pattern of the daily demand is constantly at a low level during the night, and develops a peak at midday [13]. For example, the number of doctors can be programmed to ensure maximum coverage corresponding to the peak demand. The other method for the rescheduling of the medical staff considers more time slots in accordance with the preferences of the medical staff [14].

2.2.2. The adjustment of the roles of the emergencies actors

The "role" of the medical staff can be adjusted to improve the efficiency of the functioning of the emergencies [15]. It is suggested that each medical staff member must mainly perform care tasks adapted to his skills, and be affected according to a required level of skills. The priority to assign a health care task to a medical staff depends on the skills level of this latter. For example, the list of priorities helps to ensure that medical specialists mainly focus on advanced problems and diagnoses rather than on the basic procedures that other doctors are able to perform.

2.2.3 Patient journey improvement

Hospitals can improve their efficiency by improving patient journey. A strategy based on creating pathways for outpatient care was first introduced to speed up the treatment of patients with non-urgent care operations [16]. Five alternative scenarios show that the implementation of the fast track to patients who need minor care could include reducing overall patient length of stay. Research indicates that 85% of emergency requests are due to non-urgent patients or patients with non-serious conditions [17]. Patient flow can be accelerated if the low acuity patients can be evacuated quickly. Many studies have reported that the establishment of a Rapid Care Unit (RCU) can reduce the waiting time of patients [18]. A team dedicated to patients sorting in the RCU can reduce the waiting time of patients and the length of stay in the emergencies [19].

3 Approaches to improve the functioning

Simulation is one of the most used tools in operational research. It has been used to identify potential areas for improvement through an analysis of the various surveys related to health care systems [20] [21]. Simulation can help the understanding of optimal allocation of resources and their use, and the estimation and evaluation of existing and proposed systems. The simulation provides managers of health institutions with a tool to evaluate system performance improvement methods. It can help to understand the optimal allocation of resources, and the estimation and the evaluation of existing and proposed systems [22].

Different research and improvement strategies have been proposed to reduce the overcrowding phenomenon in health care institutions [23] [24]. Previous studies indicate that patients at emergencies spend most of their time waiting for treatment due to an imbalance between resources and requirements [25]. Available improvement strategies include modifying the work plan of the emergencies, the adjustments of human resources and changes in treatment procedures. As the PED is a complex system because of the random flow of arrivals of patients, the uncertain time management and the randomness of the decision, it is difficult to change the treatment protocol without disrupting normal operating procedures. Inspired by the field of industry, different tools and techniques such as workflow were therefore used to model the flow of patients for health care systems' management. These methods have contributed to improve the performance of the service [26]. The workflow was used within emergencies to test their activities and help managers to analyze their adopted management process and the performance of their health facility in order to identify the causes of long waiting times for patients [27].

3.1 Health care workflow

Health care workflow is an approach to model and manage medical and administrative activities in a health care institution, involving several actors, documents and tasks. It consists of working models for coordinating the activities of each medical staff and ensures their interconnection relying on information systems and existing databases.

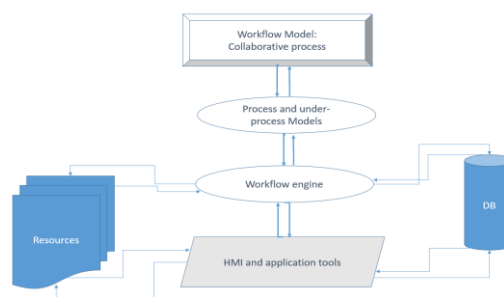


Fig. 1. Phases of Workflow management

In the literature there are several definitions of the workflow approach that most distinguishes documents, information and tasks. This distinction is useless to a data standpoint, since documents and tasks are part of the information, especially in a health information system. We prefer the definition set out in [28]: “The management of a workflow is achieved by a proactive system for the management of a series of tasks that are transmitted to the appropriate participants in the correct order and are supplemented in given time ...”

We consider two main steps in the management of a workflow. The first concerns the design and process definition; and the second is the control and management of process execution. Figure 1 illustrates the relationship between the two main stages.

3.2 Agent-based Systems (ABS)

According to the Oxford dictionary, a behavior is the way in which a person or an object responds to a particular situation. In modeling the emergencies, behaviors related to patients and medical staff can be modeled to monitor and assess the evolution of patient flow in order to reduce waiting time. Patients, nurses and doctors are considered as dynamic and decision-making entities, called agents. Therefore, a model of ABS consists of three main entities: 1) agents, their characteristics and behaviors 2) the relationship between agents, methods and trading results and interaction and 3) the environment of agents or the agent which is in charge of managing agents' coalitions to achieve a specific goal. An ABS uses intelligent and interactive agents to make decisions [29]. An agent can be described as an autonomous entity that makes decisions based on a set of rules. The agent also communicates with other agents in the system and can adapt and change its behavior based on the results of its interactions with its environment [30]. Therefore, these entities are proactive, autonomous and intelligent in a model of ABS. Management rules can be created and applied for the decision. The basic rules are the individual conduct of an agent; as secondary rules can be added to change the ground rules for the different interactions of agents in the system. Agents can also learn from past impacts of their actions on their environments.

The ABS are used to model the emergencies to evaluate the performance with different parameters [31]. The study concluded that the number of patients treated can be increased by approximately 26% following the patient sort adjustment. Optimization techniques can be used with the ABS for optimum configuration of emergencies staff. Another example is the ABS modeling scenarios involving considerable human decision making [32]. A strategy called re-sorting has been tested in which patients who have waited a long time in the waiting room are re-sorted. This research used the ABS to model patients with dynamic attributes and behavior triage nurses to determine the evolution of patient's health. The results show that the re-sorting strategy can improve the average waiting time in the emergency room.

4 Agent oriented approach for collaborative workflow

ABS are provided with autonomy and reactivity. Under the term "ABS for workflow" we gather every distributed approach for executing workflow that involves cooperative entities. Health collaborative workflow models are equipped with workflow execution features in a distributed manner. In fact, ABS are composed of distributed entities (many services at PED), capable of communicating, which may influence the development of process execution. These entities have a specific condition which is not perceived by other entities. Interaction between different entities may generate new solutions for optimization problems, such as, bringing a medical deed to a satisfactory conclusion.

Workflow agents can be classified into three categories:

- Agents who cooperate at the service of patients. Here, each agent plays a similar role to a physical agent (doctor) at PED, to improve patient care.
- Distributed agents, responsible for the reactive coordination of care tasks. They are based on activities, not on roles. Their coordination is managed by a workflow diagram, without a central execution engine.
- Agents going from one "service point" to another. For example, a doctor agent may migrate from a care team to another team, in favor of the patient having priority.

5 Agent coalition for executing collaborative workflow instances

Collaborative workflow allows to model in a realistic way the patient's position and movements between the PED sites. Because of the unpredictable nature of the care activity and uncertain environment of the PED that require dynamic information management, the formation of coalitions of agents is necessary to solve the health care planning problem, the management of resources and the supervision of the Workflow.

The logic of a coalition is based on agents acting as cooperating actors. Each agent of the coalition is able to monitor the execution of a workflow instance. An instance is composed of operators defining constraints (sequence, parallelism, etc.) and conditions to create complex care tasks. These care tasks can be nested together at all levels [33]. The agents of a coalition must conclude agreements between them to decide whether they need services provided by other agents of another coalition in favor of a health condition of one or more patients. These agreements are called "negotiation". A negotiation protocol was proposed, allowing agents to provide appropriate decisions and set their execution conditions (single or repeated execution of a workflow instance, assignment of medical staff, etc.).

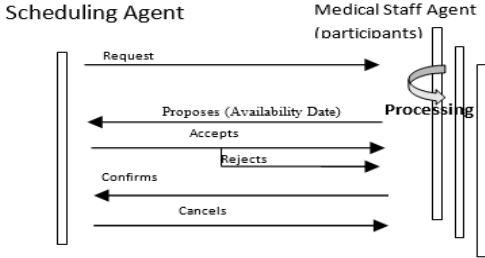


Fig. 2. Negotiation protocol between agents

The negotiation strategy explicitly uses two knowledge bases: the first is declarative for describing the objectives and the context of the negotiation (e.g. adapt the treatment room depending on the health state of a patient). The second includes basic negotiation rules, such a strategy of medical staff assignment for a good quality of health care treatment [43]. The objective is to define a negotiation protocol of agents' coalition for distributed execution of a workflow instance. We propose a two-step approach for the management of a collaborative workflow. The interest is to separate in the model thanks to a coalition of agents, a first phase of assignment and scheduling of health care tasks, which will then be used by the Scheduling Agent (SA) to monitor a second phase of dynamic orchestration, based on a process of negotiation between the coalition of agents (e.g. SA and medical staff agents) [34]. The idea is to separate coalitions depending on the nature (predictability) of knowledge they handle. The second phase is the scheduling and tasks assignment phase in which the SA analyzes the description of a workflow scheme. This scheme defines the inherent properties complying with treatment protocols, set before execution. It includes specifications on existing resources, a list of tasks to be performed, and the links between the precedence tasks. The dynamic orchestration stage is based on a dynamic scheduling methodology. In addition to the time constraints, the availability of resources is also taken into account. During this stage, tasks are scheduled according to priorities calculated while running the workflow. The SA solves the problem of tasks scheduling through an Evolutionary Algorithm (EA). It calculates the starting date of execution of health care tasks regarding the availability of medical staff members and their skills.

Table 1: Assignment: Example of a chromosome pattern characterized by {0, 1, *}

$$\square \quad S^{ch} = \{ S^{ch}_{i,j,k} / 1 \leq j \leq N ; 1 \leq i \leq n_j ; 1 \leq k \leq M \}$$

		MS1	MS2	MS3	MS4
T 1	O 1,1	0	*	*	0
	O 2,1	0	1	0	0
	O 3,1	0	*	*	*
T 2	O 1,2	*	0	0	*
	O 2,2	0	0	1	0
	O 3,2	1	0	0	0
T 3	O 1,3	*	*	0	*
	O 2,3	*	*	*	0

The value " $S^{ch}_{i,j,k} = 0$ " indicates that the medical staff member MS_k is not enough qualified for this health care operation, " $S^{ch}_{i,j,k} = 1$ " indicates that the assignment of the operation $O_{i,j}$ to the medical staff member MS_k is *obligatory* because he is the only one qualified for this task and the symbol: "*" indicates that the assignment is *possible*.

This allocation scheme (Table 1) becomes the chromosome model of our EA. This chromosome is well adapted to the properties and the constraints of the problem and is used in the construction of individuals in order to integrate good properties and good performance of medical protocols. Having a valid chromosome pattern, EA are more efficient and faster by building solutions promoting the reproduction of individuals respecting the right patterns. In the case of our scheduling problem, the difficulty of the implementation of this technique is important because it needs to develop a particular coding that could both describe the problem

data and use schema theory. This chromosome pattern covers the entire interesting possibilities to affect the care operations. However, it has prohibitions that can sometimes be costly in terms of workload of health care staff. However, assignments belonging to this model do not guarantee an optimal solution in terms of workload balancing. Some assignments can be spread by EA when they do not lead to good solutions. Indeed, during the phase of reproduction, whether the individual violating the chromosome pattern it will be automatically removed. Such an approach allows to restrict the search space that will accelerate the convergence of the algorithm and ensure good quality of solutions.

6 Performance evaluation of dynamic orchestration

The assessment of the orchestration performance is measured by the satisfaction of the waiting time criterion Cr for a currently running workflow.

$$Cr = \sum_{j=1}^N \max(0, c_j - d_j) \text{ with:}$$

N : the total number of patients to treat,

c_j : the theoretical completion time of patient P_j treatment,

d_j : the theoretical ending time for P_j treatment.

Indeed, this criterion is evaluated by orchestrating the workflow in a static way (where the order of care tasks remains unchanged during the entire execution) and in a dynamic way. For each type of orchestration, we calculate the average value of the criterion for a number of patients during the simulation period.

Let GCr be the gain corresponding to the criterion Cr for a dynamic orchestration of the workflow $WD(Cr)$ relative to a static orchestration $WS(Cr)$.

$$GCr = \frac{WD(Cr) - WS(Cr)}{|WS(Cr)|} \times 100$$

If $GCr < 0$ then Cr has been enhanced with a dynamic orchestration,

If $GCr > 0$ then Cr has been degraded with a dynamic orchestration compared to a static orchestration,

If $GCr = 0$ then there are no changes in the values of the criterion.

7 Simulations and results

In order to have an objective view on the reasons for bottlenecks, databases provided by the PED list all the patients registered in the emergencies, their pathologies their emergency degree, their length of stay in the service as well as the medical exams that have been allocated to them. From this database we were able to identify some characteristics related to the patient journey in the PED such as the annual number of visits which reached 25 000, the number of times the patient's location was changed during his stay at the PED (5.5 times) and the average waiting time of patients which is a key data for the analysis of the overcrowding phenomenon, it is about 4 hours, including additional examinations and awaiting the results.

7.1 Patient pathway description of the PED (CHRU de Lille)

Patient pathway at a PED may have 2 types of entries:

- Emergencies: it is the entry mode for the majority of patients, whether they have come by their own means (parents, family, etc.) or via an ambulance which may not have informed the hospital of its arrival. This entry is common to all the persons entering the CHRU through Emergencies, children or adult. Parents or other family members must follow the administrative admission procedure before being redirected to PED.
- SAMU1 : the arrival of a patient is done directly on the ambulance entry platform, the patient is immediately redirected to PED, while a family member will be sent to the administrative office in order to complete hospital admission files.

¹NT: Ambulance Emergency Services

If the patient has entered the hospital via Emergencies, the moment he arrives to PED, he undergoes a first diagnose established by a nurse, which determines priority order to access services. This priority order depends on a 5 level scale for immediately treating the most severe cases. These emergency levels are represented by the CCMU (Classification Clinique des Malades aux Urgences). After a more or less important waiting time, depending on service saturation and emergency condition, the patient is finally treated by a doctor.

After the medical diagnose established by a doctor, he may choose –in function of the medical condition and available infrastructure- to let the patient go back home or to keep him in observation, even to hospitalize him. During observation, the patient is practically constraint to stay in hospital for a short time at PED because of the lack of top-down structures allowing for reception. In fact, there generally are no available beds under ongoing supervision at a hospital. What is more, there is no central patient alarm. Equally, if the doctor decides to hospitalize the patient for a period longer than 12 hours (maximum short hospitalization stay), he is obliged to keep the patient at PED waiting for a bottom-up structure to be available. Finally, patient reorientation to less charged hospital structures, if that is available, are very rare, due to the lack of communication between hospitals, and the impossibility to know the overcrowding level of their structures.

7.2 Collaborative workflow for patient circuit under overcrowding state

The specificity of PED functioning under overcrowding state has led us to define a new patient pathway which considers the possibility of using resources which have not been assigned to tasks, because doctors can relocate them. These resources mainly concern service rooms: we focus on this aspect for redefining patient pathway. In this way the entry -which has so far remained administrative- does not change at all as regards permanent modeling. In fact, it is important to correctly register the patient according to administrative and legislative criteria. As regards the exit, this cannot be modified because there is no reason for reoriented patients to come back to the service. On the other hand, exits are, as entries, purely formal administrative stages which imply purely external bureaucratic services and which serve to ensure correct patient monitoring, from admission to exit. These services enable the hospital to be prepared in case of conflict with a patient, following complications in the patient’s condition.

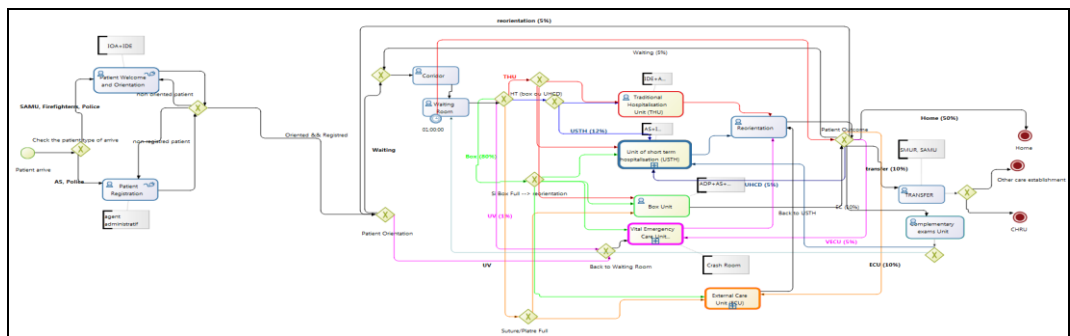


Fig. 3. PED process modeling under overcrowding state

Each service (simple consultation, operation, plaster, short term hospitalization, etc.) can be performed at different rooms. It is then convenient to have classified patients in function of the care they have to be provided for and to separate them again in function of the room where they will receive treatment. This operation multiplies the possibilities of care and makes his pathway more complex. On the other hand, classification must be correctly modeled, because it does not follow explicit rules. Indeed, doctors choose, at the last minute, which room the patient shall be led to. For example, Vital emergency rooms are only used in the last resort, because it is devoted to treating patients whose life is in danger. Evidently, the preferred room will be the one indicated for a special type of care. Then, other rooms are automatically assigned, without particular priority.

7.3 The impact of dynamic orchestration over Workflow

In order to evaluate the impact of dynamic orchestration over Workflow, we have chosen the real scenario of a tense day which took place at PED on February, 7th, 2013. Throughout this day, PED received around 119 patients, registering a remarkable annual activity peak. The difficulty lies in smoothing these activity peaks and reducing

patients' waiting time. To start simulation, we define a patient arrival flow and we calculate the necessary resources for executing care operations, taking into account the skills of medical staff and resource availability.

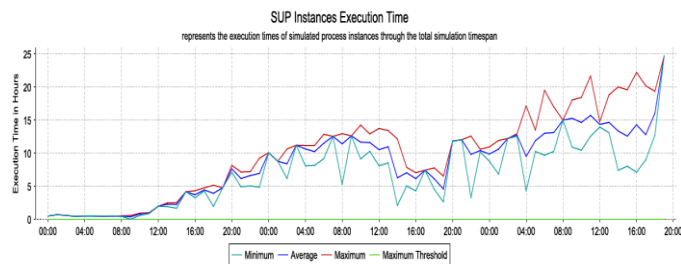


Fig. 4. Average waiting time using only the EA

The results obtained represent curves displaying overall minimal, maximal and average waiting time of patients at PED. In the first place, we introduce the results given by the SA, who is in charge of schedules using an evolutionary approach, with static orchestration. Then, we show that the communication of SA with other agents so as to dynamically orchestrate patient pathway Workflow makes it possible to reduce waiting time. According to Figure 4, we observe that on this overcrowding day, average waiting time differs. Average waiting time is estimated in 10 hours. Medical staff is then incapable of facing the increase in patient flow arriving at PED.

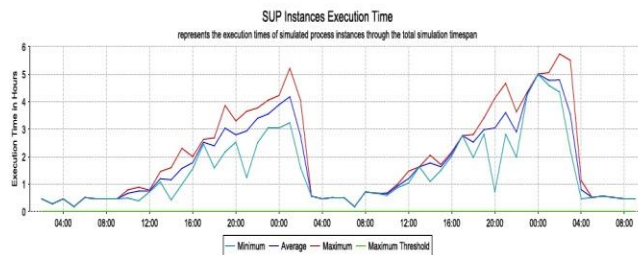


Fig. 5. Average waiting time with dynamic orchestration

Figure 5 shows that the optimization approach based on the alliance between scheduling and ABS approaches has made it possible to smooth up activity peaks at PED and to minimize patient average waiting time. Indeed, the SA plays the role of orchestra director, coordinating his actions with the other agents so as to ensure a dynamic orchestration adapted to the real situation of PED. In this case, waiting time fluctuates between 1 hour and 4 hours. Nevertheless, we observe that there is always a midnight activity peak that disturbs PED.

The previous orchestration actions have not succeeded in absorbing all the PED activity peaks. Because of this, it is necessary to resort to negotiation between the agents of the formed coalition in order to dynamically reorchestrate the Workflow of remaining patients. This negotiation is based on the consideration of additional examination results (biological tests, X-ray, echography, RMI, etc.) for making decisions about the patient's orientation.

8 Conclusion

The use of workflow tools for managing processes at a health establishment is today largely accepted. However, its use in the inter-hospital context bumps into numerous obstacles, for example, the difficulty in transferring a patient file between the different services and the lack of standardization in the interconnection of different local workflows. Workflow tasks are subject to temporary constraints (precedence constraints, deadlines, etc.) and resource constraints (human or machines). Considering the distributed nature of collaborative workflow, unforeseen events may happen at every moment. Thus, the coordination of the execution of tasks must be done in a dynamic manner, in order to neutralize or to reduce the impact of disturbances. Many simulation results have proved the efficiency of the alliance between optimization and ABS. The strength of our system relies on the formation of agent coalitions and their negotiation protocols, in order to make orchestration decisions and thus improve waiting time during patient care, as well as to face the hazards which may come up at PED. However, the use of these approaches in the context of inter-hospital still faces some challenges which will be treated in our future work.

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