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An Innovative Approach to Jointly Schedule and Assign a Consultation Time to Patients in the Emergency Department

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Abstract

Emergencies are facing problems related to the growing demand of care. Patients' management is carried out according to the type of care required: already scheduled patients and non-scheduled urgent and non-urgent arriving patients to emergencies. One of the main problems confronted in hospitals is the permanent interference between these different types of patients to be treated under the stochastic behaviors of consultation time and arrival flows which prevents any prior planning. The present work proposes a dynamic scheduling method considering the impact of new patients' arrivals on the treatment of patients already scheduled to minimize the mean waiting time of patients in emergencies. The originality of this work is to assign, at the time of arrival, a scheduled time to each patient in order to reduce their stress. The performance of the proposed method is examined through a concrete application in the Pediatric Emergency Department of CHRU of Lille.

Keywords:

Dynamic scheduling, assignment, emergencies, waiting time.

Introduction

Nowadays, hospital Emergency Departments (EDs) have a strategic place in modern health care systems and represent the main gateway to the hospital. This key role is expected to strengthen in future years due to the steady growth in the number of arrivals and the increasingly demands of patients [1]. These changes set many problems for different actors in public health, including problems of functioning to cope with this increase in consultations and a non-negligible healthcare spending [2] [3] [4] [5] [6]. However, while the majority of healthcare systems in the world are confronted with this reality, the ways to face them differ from one country to another [7] [8]. In order to better understand current problems and challenges, it is first necessary to place emergency services in their general context in order to understand their functioning and their specific characteristics.

Indeed, the question in France is still topical and hospital emergencies are taken into account at the highest level within the national organizations. The Code of Public Health specifies all the missions of these services. It is a mission characterized by:

- The reception: to accept every patient arriving in an emergency, including a psychiatric emergency, 24 hours a day, any day of the year, and take care of him, especially in case of distress and vital emergency.
- Translation, definition of demand, needs qualification of the patient with a symptom analysis work.

- The preservation of life, stabilization of a condition thanks to the care, and "urgent diagnostic and/or therapeutic procedures," adapted to the situation.
- Patient orientation at the right time, in the right sector, to the appropriate services;
- Short-term hospitalization in certain cases, depending on the resources and the reception capacity and according to the functioning of the health care organization.

The care of an emergency patient mobilizes the different resources of health organizations: upstream of the hospital, within the health establishment and downstream of the health facility (other institutions). However, the notion of emergency in the medical field remains a source of great ambiguity. In a literature review, it is not difficult to see that if there is a consensus, it is summed up in the fact that an "emergency" requires an action and an immediate decision. In case of emergency, it is essential to intervene immediately irrespective of the type of emergency and that it is necessary to respond to any request for care even if the latter is non-programmed and is not a source of life-threatening distress, regardless of the seriousness of the problem.

A situation is called "urgent" because it is considered serious and it calls for a quick response. It is often subjective and intimately linked to the value system of the person who states the emergency judgment. This means that between the perception of urgency by the patient (perceived urgency) and the medical definition of emergency by a medical staff (actual emergency), the gap is often important. A gap may be even greater than the urgency of a case considered in relation to the urgency of other cases [9].

Ensuring patients' satisfaction in the ED is part of a continuous improvement strategy [10]. The length of the consultation, waiting time, dissemination of information and interaction with practitioners in the ED have the strongest predictors of patient satisfaction. This does not mean that patients are not aware of the necessary treatment time. But they need to be well informed about the progress of treatments on the one hand and on the overall progression of care on the other hand. In addition, it is so important to give a provisional time of consultation to each patient to reassure him. This also reflects the level of overcrowding as the length of stay of patients appears to increase considerably when the number of patients increases in the ED. Nevertheless, it is difficult to assess patient satisfaction because of the complex interaction between expectations, perceptions and reality.

In this paper, we take into account patient waiting time at different stages of patient journey: waiting time between the registration and the provisional time of consultation called "scheduled time" and between scheduled time and the time of

the first consultation. Waiting times can be the result of the bottlenecks in the ED or the arrival of more urgent cases.

Our objective is to propose an innovative scheduling approach able to solve the problem of the interference between already scheduled patients and non-scheduled urgent and non-urgent arriving patients to emergencies. We aim to optimize patients' treatment process and minimize waiting time in the ED. We take into account the availability of medical staff members belonging to different medical teams.

Methods

Scheduling environment

Assumptions

- There is a medical staff member engaged in the scheduling horizon in an ED. In a scheduling horizon, the number of already scheduled patients is N_s , while the expected number of non-scheduled patients is N_{ns} . All the non-scheduled patients arrive randomly at the ED, then a scheduling time must be assigned to them at the time of their arrival.
- In France, the ED is always opened and each arrived patient p should be registered in the reception desk at time tr_p . All patients who arrive at the ED are accepted and should be treated in the current or the next horizon scheduling.
- Each patient corresponds to a set of health care operations to be executed in a parallel or in a sequential manner by one or more medical staff members (physician, nurse, intern, etc.).
- Medical staff members are organized in teams. Each team contains at least one physician. We can have more medical staff members (nurse, pediatrician, etc.) in one medical team depending of patient pathology.
- The scheduling horizon H starts at time D_H and ends at the time F_H . In this paper, we consider that the duration of one horizon is 4 hours.
- The scheduling horizon is divided into several periods with different length not necessarily the same, if two periods have the same length, the number and the duration of slots in each period may differ and generally one period contains multiple slots. A slot is allocated to one scheduled patient. Each period contains at least one slot. The scheduled time of a slot is given by the starting time of the period to which it belongs. Therefore, if two or more slots are included in a period, the scheduled patients assigned to the same slot have the same scheduled time.
- Under the stochastic behavior of consultation time of medical staff, let $C_{m,\theta}^j$ be the average consultation time of the medical staff member m having the skill θ to treat patient j .
- When the medical staff member becomes available, the waiting patient with the earliest scheduled time is called. If the waiting room is full and there is no possibility to call all the patients in the same scheduling horizon, so the remaining patients and the new arriving patients will receive a schedule time in the next scheduling horizon.
- In ED, priority is given to the most urgent cases. So at the arrival of urgent patients, the current scheduling

can be interrupted and a rescheduling is necessary because these patients should not wait for consultation.

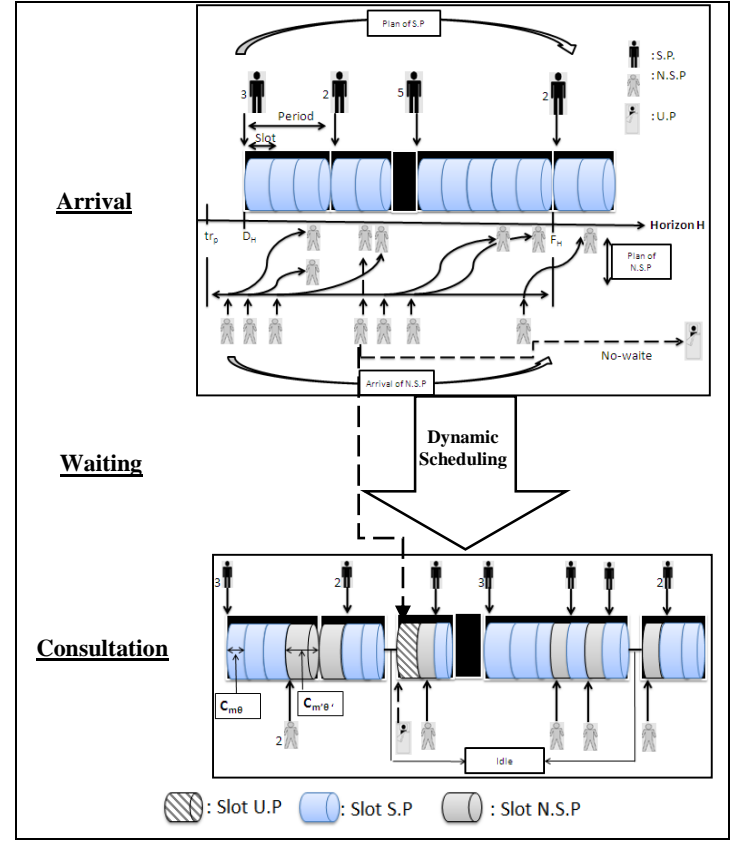


Figure 1–Scheduling Environment

Performance measures

Let the waiting time of scheduled patient P_j , $W_{s,j}$ be the sum of patients' waiting time between the registration and the given scheduled time W_{ar} and the waiting time before the first consultation W_{fc} , where:

$$W_{s,j} = W_{ar,j} + W_{fc,j} \quad (1)$$

$$W_{ar,j} = \max(0, t_{ar,j} - t_{s,j})$$

$$W_{fc,j} = \max(0, t_{fc,j} - t_{s,j})$$

Where $t_{ar,j}$, $t_{s,j}$ and $t_{fc,j}$ represent respectively the arrival time, the scheduling time and the first consultation time of the patient j .

The waiting time of non-scheduled patient P_k , $W_{ns,k}$ be the sum of patients' waiting time between the registration and the given scheduled time $W_{ar,k}$, the waiting time before the first consultation $W_{fc,k}$, where :

$$W_{ns,k} = W_{ar,k} + W_{fc,k} \quad (2)$$

$$W_{ar,k} = \max(0, t_{ar,k} - t_{s,k})$$

$$W_{fc,k} = \max(0, t_{fc,k} - t_{s,k})$$

The two equations (1) and (2) are mathematically equivalent but semantically are different. In fact, the present study proposes a scheduling method that assigns a scheduled time to each non-scheduled patient at his time of arrival and guides him to go to the waiting room at his scheduled time. Thanks to the assigned scheduled time, W_{ar} is calculated for each registered patient. The objective is to comfort patients and reduce their stress by giving them in advance a waiting time till the first consultation. If the first consultation time is equal to the scheduled time therefore the waiting time $W_{fc,j}$ and $W_{fc,k}$ are equal to 0. In case of perturbation (overcrowding situation, absence of medical staff, worsening of patient health state, etc.

), a rescheduling is done and the first time of consultation increases which makes the waiting time longer for patient. Usually most of patients prefer earlier scheduled times especially at their arrival time. To respect these preferences, the waiting time based on the arrival time $W_{ar,k}$ should be reduced by assigning as quickly as possible an available medical staff with an appropriate skill.

In this paper our objective is to minimize the total waiting time W of both scheduled and non-scheduled patients by taking into account dynamically the availability of medical staff members and their skills.

$$W = \text{Min} \sum_{j=1}^{N_s} \sum_{k=1, k \neq j}^{N_{ns}} (W_{s,j} + W_{ns,k})$$

We choose to adopt an aggregative approach without handling appropriate weights to have optimizing solutions. In fact, in real life health care situations, it is very difficult to define suitable weights for these criteria. This work, studies the results of simulations generating some of these criteria separately or some of them jointly.

Scheduling method

Characteristics of non-scheduling patients

As it is mentioned above, the driven idea is to have a scheduling method realizing the shorter waiting time for both scheduled and non-scheduled patient. In order to reduce the effect of the stochastic aspect of arrival flow we assign to each non-scheduling patient a scheduled time at his arrival time.

The present study gives good solutions by focusing on the similarity between the job-shop scheduling in the flexible manufacturing systems where the workload is an important factor for the decision maker. In the complex manufacturing system minimizing the total workload allows to avoid the bottleneck in production system generating a reduction waiting time.

Under the condition of the present work, the Health-Workload $HW_{p,H}$ of each period p in the scheduled horizon H can be expressed by the average consultation time multiplied by the number of scheduled patients in the period. This means that once scheduled patients are set in different periods, the expected workload is specified in each period. The scheduling time of non-scheduled patients is decided at the moment of their arrival in the ED by calculating the expected $HW_{p,H}$ that includes them in the candidate periods. If a maximum value of $HW_{p,H}$ is reached then the next period becomes the candidate.

By selecting an adequate solution for scheduling patient that allocates a sufficient initial $HW_{p,H}$ to each period p and by assigning each non-scheduled patient to an appropriate period in order to get a reasonable $HW_{p,H}$, the conflicting criterion W is balanced. Controlling and keeping the total $HW_{p,H}$ for each period p and each horizon H below the specified maximum value $HW_{p,H}$, will complete shorter waiting times of patients as well as shorter total idle times of medical staff members.

Dynamic scheduling method of non-scheduled patients

This work assumes that the scheduling horizon which represents consultation time window is divided into several periods as already mentioned above. To calculate a scheduled time of a non-scheduling patient, we use a first empty slot in the period as shown in Figure 2.

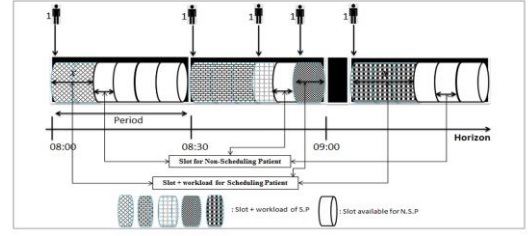


Figure 2—Example of determining patient scheduling time based on free slots

In principle, the start time of the first empty slot gives the scheduled time of the patient. The maximum number of non-scheduled patients accepted in the period is difficult to estimate because slots have different lengths in the same period.

Algorithm: Search-First-Free_Slot (Period p , Horizon H , Patient w , Deb_p , Fin_p)

Inputs:

Nbs_p : Number of slots in the period p .
 $TAB [1... Nbs_p]$ a table contains the length of each slot.
 $FREE [1... Nbs_p]$ a table contains 1 or 0.
 $FREE(i) = 1$ the slot i is free else the slot i is full.

Output:

T_w the start time of the first free slot

Begin

Calculate $HW_{p,h}$;

If $(HW_{p,h} + C_{m,\theta}^w < HW_{p,h,max})$ then

begin

Assign-patient- w to the period p ;

$T = Deb_p$: the slot starting time

For $i=1$ to Nbs_p do

If $FREE[i] == 1$ then return T

Else $T = T + TAB[i]$

End_For

If $(T == Deb_p \text{ and } i == Nbs_p)$ then

begin

$T = Fin_p$

Return T

End_If

Else return the period p is overloaded

End_Search-First-Free_Slot

Algorithm: Scheduling_arrived_patient (Patient w , Time t , Horizon H)

Input:

Deb_H : Starting time of the horizon H represents the starting time of consultation;
 t : Current arrival time of patients
 Fin_H : The ending time of the horizon H ;
 $NB_{p,H}$: Number of periods in the horizon H ;
 TAB_H : Table $[1... NB_{p,H}]$ contains the different lengths of each period.

Output:

T_w the starting time of the first consultation specifying Horizon, period and slot.

Begin

If Urgent_patient then No-wait-consultation

If $t \leq Deb_H$ then $p = 1$ (the first period in the horizon)

Else

For $(i = 1 \text{ to } NB_{p,H})$ do

If $t \leq Deb_H + TAB_H[i]$ then

$p = i$;

Save the starting time of the period Deb_p

Save the ending time of the period Fin_p

End_If

End_For

End_If

$T_w = \text{Search-First-Free_Slot}(p, \text{Horizon } H, \text{Patient } w, Deb_p, Fin_p)$

End_fSearch-First-Free_Slot

The ending time of the consultation window $t_{\max,H}$ is used for the scheduled time for patients who are not included in any of the periods in the horizon H . The present study assumes that each period p may have its own length Δp , and the starting time of each period is x minutes behind the starting time of its first

free slot. The maximum workload level per period is $HW_{p,H,\max}$. For example, if there are 3 scheduled patients j and 2 non-scheduled patients k in period p, then $HW_{p,H}$ is given by $HW_{p,H} = 3 * C_{m,\theta}^j + 2 * C_{m,\theta}^k$.

Simulation and Results

For simulations, we did observations in the Pediatric Emergency Department of CHRU of Lille, our partner in the project ANR HOST. We have a 3-years database 2011-2012-2013 characterized by overcrowding and pics of activity.

number	Arrival Date	Exit Date	duration	MD	diagnostic	echographie	scanner	radiologie	biologie	interventions	coded
69452	26/11/2013 08:13:00	26/11/2013 13:18:00	305	3091	Autres pneumopathies bactéri	0	0	0	0	0	0
69454	26/11/2013 08:19:00	26/11/2013 08:44:00	305	3091	Gale	0	0	1	1	2	0
69459	26/11/2013 08:33:00	26/11/2013 08:45:00	2	3092	Intoxication par autres antid	0	0	0	0	0	0
69456	26/11/2013 09:14:00	26/11/2013 12:25:00	191	3091	Fractures multiples des mem	0	0	0	0	0	0
69457	26/11/2013 09:27:00	26/11/2013 13:41:00	174	3091	Gastroentérites et colites d	0	0	1	1	2	0
69458	26/11/2013 09:31:00	26/11/2013 14:40:00	299	3091	Nécessité et renversement	0	0	1	1	2	0
69459	26/11/2013 09:54:00	26/11/2013 14:24:00	290	3091	Morsure de la joue et de la l	0	0	1	0	1	0
69460	26/11/2013 09:54:00	26/11/2013 12:57:00	141	3091	NAL	0	0	1	0	2	0
69461	26/11/2013 09:40:00	26/11/2013 11:19:00	99	3092	Autres difficultés liées à l'em	0	0	0	0	0	0
69462	26/11/2013 09:42:00	26/11/2013 14:57:00	115	3091	Contusion des/des d'ongles sans	0	1	0	0	0	1
69463	26/11/2013 09:50:00	26/11/2013 09:50:00	1440	3092	Laryngite (aiguë)	0	0	0	0	0	0
69464	26/11/2013 10:13:00	26/11/2013 13:02:00	169	3091	Mélanie	0	0	0	0	0	0
69465	26/11/2013 10:14:00	26/11/2013 13:46:00	62	3092	Diabète sans insulino-déper	0	0	0	0	0	0
69466	26/11/2013 10:21:00	26/11/2013 13:43:00	202	3091	Adénite, sans prése	0	0	0	0	0	0
69467	26/11/2013 10:25:00	26/11/2013 10:34:00	1421	3092	Gastroentérites et colites d	0	0	0	0	0	0
69468	26/11/2013 10:30:00	26/11/2013 12:27:00	197	3091	Psychiatrie (non classé)	0	0	0	0	0	0
69469	26/11/2013 10:35:00	26/11/2013 14:27:00	215	3091	Autres coréophtalmies	0	0	0	0	0	0
69470	26/11/2013 10:35:00	26/11/2013 13:07:00	248	3091	Hypotension et perspiration	0	0	1	1	2	0
69471	26/11/2013 11:02:00	26/11/2013 20:34:00	552	3091	Plaie ouverte d'autre partie	0	0	1	0	1	0
69472	26/11/2013 11:05:00	26/11/2013 15:21:00	296	3091	Bronchite (aiguë), sans pré	0	0	0	0	0	0
69473	26/11/2013 11:07:00	26/11/2013 15:54:00	287	3091	Bronchite (aiguë), sans pré	0	0	0	0	0	0
69474	26/11/2013 11:15:00	26/11/2013 15:05:00	230	3091	Rhinopharyngite (aiguë) (thu	0	0	1	1	2	0
69475	26/11/2013 11:32:00	26/11/2013 13:02:00	690	3092	Convulsions, autres et sans pr	0	1	0	1	2	0
69476	26/11/2013 11:47:00	26/11/2013 14:57:00	190	3091	Rhinopharyngite (aiguë) (thu	0	0	0	1	1	0
69477	26/11/2013 12:00:00	26/11/2013 12:00:00	0	3091	Hernie inguinale, (considérée	0	0	0	0	0	0
69478	26/11/2013 12:00:00	26/11/2013 12:00:00	0	3091	Rhinopharyngite (aiguë) (thu	0	0	1	0	1	0
69479	26/11/2013 12:12:00	26/11/2013 17:11:00	299	3091	Douleur aiguë	0	0	1	0	1	0
69480	26/11/2013 12:30:00	26/11/2013 14:40:00	251	3091	Néphrite kudo-intestinales	0	0	1	0	1	0
69481	26/11/2013 12:30:00	26/11/2013 18:28:00	352	3091	Entorse et foulure de la chev	0	0	0	0	0	0
69482	26/11/2013 12:46:00	26/11/2013 12:46:00	170	3091	Mélanie	0	0	0	0	0	0

Figure 3– Database of the PED of CHRU of Lille

Currently, there is no decision support system or information system able to manage the PED and the problems corresponding to an overcrowding situation. Medical staff members give the highest consultation priority to the most urgent patients and $HW_{p,H,\max}$ the already scheduled patients. Non-scheduled patients in the PED have to wait in the waiting room and sometimes in corridors without obtaining a scheduling time for the first consultation which increases their stress.

Our proposed approach performance is tested by comparing it to the current traditional method used in the PED. The database analysis allowed us to define the evolution of patients' waiting time which sometimes seems to be excessive.

Experimental conditions

From the database we choose an overcrowded day (25th of February 2013) divided into 6 horizons, the duration of each one is 4 hours. Each horizon represents the consultation time window.

Table 1– The average values under different maximum workload levels

$HW_{p,H,\max}$ (min)	Number of urgent patients with different pathologies	Scheduled patients		Non-scheduled patients		Total idle time (min)	Mean time of no-wait consultations (min)
		\bar{W}_{ar} (min)	\bar{W}_{fc} (min)	\bar{W}_{ar} (min)	\bar{W}_{fc} (min)		
120	2	21,71	10,20	27,89	12,21	11,20	20,28
	4	21,29	9,80	24,17	12,94	10,40	25,40
	6	21,00	9,56	20,32	13,20	9,20	26,20
	8	20,90	8,94	27,10	15,37	8,30	32,01
110	2	19,80	9,76	26,58	14,62	9,10	25,50
	4	19,10	9,20	26,23	16,50	8,88	24,75
	6	18,65	8,70	28,10	17,02	8,00	22,00
	8	18,25	8,52	30,00	18,43	7,45	27,50
100	2	20,24	12,40	28,54	15,60	4,80	30,00
	4	21,00	13,43	29,00	16,83	5,24	32,42
	6	23,89	15,17	29,50	18,15	5,50	35,79
	8	26,27	15,50	31,12	18,70	6,10	40,31

For simulations, we consider that the periods and the slots have different lengths. Each consultation time window is composed of 5 periods. The length of each one is alternatively 1 hour and 30 min. The one-hour period has 8 slots whose length is alternatively 5 min and 10 min. The 30 min period is composed by slots of 5 min and 10 min. We consider for the scenario that the

medical staff is represented by only physicians in this numerical example. The mean consultation time of scheduled patients $C_{m,\theta}^j$ is 5 min and the mean consultation of non-scheduled patients $C_{m,\theta}^k$ is 10 min. The arrival of non-scheduled patients follows a Poisson distribution. The mean inter-arrival time of non-scheduled patients is 10 min. So, we have 24 arriving patients to the PED in one horizon.

Table 1 summarizes the average values under different values of $HW_{p,H,\max}$ (min) .

According to the table, when $HW_{p,H,\max}=100$ min, the average waiting times of scheduled and non-scheduled patients have increased. The idle time of physicians has decreased. This is due to the arrival of urgent patients to the PED. In fact, these patients have complex pathologies which need more consultation time.

This phenomenon proves the impact of the interferences between scheduled, non-scheduled and urgent non-scheduled patients. These interferences depend on the number of incoming patients and their pathologies.

Figure 3 represents the relationship between the number of no-wait consultations and the total idle of physicians.

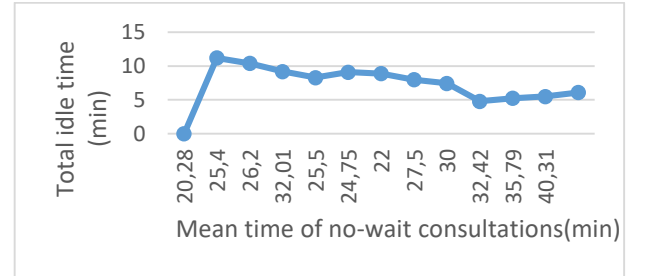


Figure 4– The relationship between the number of no-wait consultations and the total idle of physicians

Through figure 4, we notice that there is sensitivity between the number of urgent patients and the different waiting times. The mean time of no-wait consultations is inversely proportional on the total idle time of the physician. This also indicates that, while adjusting the total idle time of physicians, the frequency of no-wait consultations is minimized. In fact, when the pathology of urgent patients is complicated to treat, the idle time of physicians becomes smaller. In this case, scheduled patients in the next periods are able to receive earlier consultation which therefore decreases the value of W_{ar} .

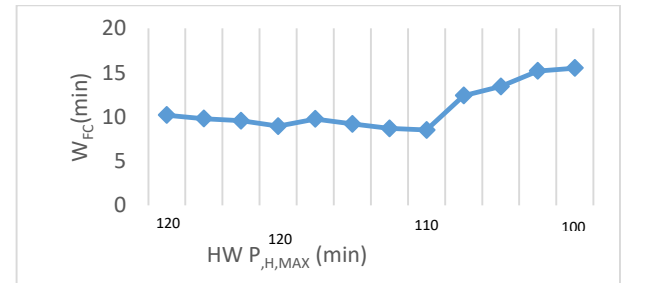


Figure 5– The relationship between the waiting time before the first consultation and the maximum health workload

When the maximum workload $HW_{p,H,\max}$ in the period p for the horizon H is reduced, it leads to reduce the scheduled times of scheduled patients and non-scheduled patients. The increase of $HW_{p,H,\max}$ leads to longer waiting times for both scheduled and non-scheduled patients (see figure 5).

Discussion

In the PED of CHRU of Lille, we noticed that patients are often dissatisfied, many feel that their waiting is excessive and that their care should be immediate. This is also a matter of subjectivity, or of poor ranking in the order of priorities of patients. Because it should not be forgotten that in these circumstances, priority is given to patients in vital emergencies. In sum, the main cause of overcrowding situations is that the demand exceeds the supply generated by the functioning nature of this structure, because the notion of appointments does not exist. This limits the margin of organization and planning. The situation becomes even worse, when several patients arrive at the same time to the PED.

Usually, in the waiting room, patient with the earliest scheduled time is called first for consultation. However, under the stochastic and irregular consultation time and arrival of more urgent patients, determining a method for assigning a scheduled time to each patient arriving is a research issue. Perturbations that can occur during the treatment of patients already scheduled are able to modify the scheduling. A considerable research effort has been devoted to scheduling problems related to emergencies. Although the arrival of new patients and the appearance of urgent and non-scheduled patients produces a complicated situation in patients' scheduling, it seems that this kind of scheduling problem attracts little attention in the literature.

Our main consideration in this work is the development of dynamic scheduling solutions with rolling horizon to simplify the work of medical staff and minimize the average waiting time in the PED for both scheduled and non-scheduled patients. Through assigning a scheduled time to patients, medical staff members can have an idea about their workload during the horizon and patients are reassured. The proposed approach is also able to adapt the available human resources in the PED in order to afford a good quality of health care for patients. In fact, the arrival of urgent patients in the case of an overcrowding situations leads to the minimization of the total idle time of medical staff. Our approach is based on the dynamic and reactive generation of treatment plans. The information and especially the treatment timestamps are given through a dynamic orchestration workflow architecture modeling the patient journey through agents [11].

Conclusions

In this paper, we have proposed a dynamic scheduled system with rolling horizon by assigning a scheduling time to each patient at the time of his arrival. Our innovative scheduling approach is able to solve the problem of the interference between already scheduled patients and non-scheduled urgent and non-urgent arriving patients to emergencies. Our target is to optimize the treatment process of patients and minimize their waiting time in the ED. For future work, we aim to improve this approach through an alliance with genetic algorithms and multi-agent systems in order to solve the problem of multi-skill health care tasks scheduling in the ED.

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