Reactive Control System to Manage Strain Situations in Emergency Departments

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Abstract: Current dysfunctions observed in emergency departments (EDs) are mainly due to the unsuitable organization, constraints and changes in their missions, as well as the mismanagement of process flows (patients, information's, resources, etc.). This often results in strain situations. ED managers must master these problems, as well as the internal restructuring reflected by resource pooling, including technical platforms. To make these decisions, they need an adapted decision support system to anticipate and manage such situations. This paper focuses on the development of decision-making model for reactive control of strain situations in EDs. The target is to help ED managers in the choice and the implementation of appropriate corrective actions to manage each potential occurrence of these situations. A case study is used to evaluate the reactive management of strain situations in the paediatric emergency department (PED) at Lille regional hospital centre, France.

1 INTRODUCTION

Emergency departments (EDs) are an important component of healthcare systems because they provide immediate and essential medical care for patients. Thus, these establishments are faced with increasingly difficulties to carry out their missions. With the growing demand for emergency medical cares and the reducing of number of EDs (Kellermann, 2006), the management of EDs has become more and more important, but they are also the most overcrowded component (Boyle et al., 2012; Kadri et al., 2014a).

Facing at a large number of patient visits but limited work force, the ED must provide 24-hours emergency services and must offer a good quality service (minimizing patients' waiting times whilst not compromising the required attention for each patient). It ensures that valuable resources (e.g., doctors' utilization and nurses' time; and treatment equipment) will be well utilized.

This work is to present a decision-making system for the reactive management of strain situations in an ED. The objective is to help ED managers in the choice and the implementation of appropriate corrective actions for each potential occurrence of these situations. This paper is organized in five sections. Section 2 presents and characterizes a strain situation and strain indicators. Section 3 presents the model for reactive control and management of strain situations in an ED. Section 4 shows obtained results of case study. The last section provides concluding comments and future works.

2 EMERGENCY DEPARTMENT

The current dysfunctions observed in EDs are mainly due to many causes. First concerns the changes in their missions and the mismanagement of various process flows. Second, the presence of interference between planned and unplanned activities, especially activities unforeseen emergency. Finally, the EDs must cope with several constraints, in particular, organizational constraints related to problems of internal organization, upstream and downstream of EDs to receive and manage the patient flows.

These problems cause the appearance of strain situations within the ED that affect patients, medical staff, and service quality. To handle these problems, ED managers must anticipate these strain situations

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by forecasting changing in ED demands (patient flows) and ED behavior, and, if necessary, to react quickly to the occurrence of these situations. Hence, EDs must incorporate in their operating mode the capacity to anticipate, to react and to mobilize resources for satisfying patients and avoiding strain situations.

2.1 Definition of Strain Situation in an ED

Most studies including emergency services have been addressing several targets:

- Improve the quality and performance of care in emergency departments.
- Reduce the waiting time and the residence time of emergency patient.
- Manage the hospital activities and the resources in emergency services.

The various works presented above are intended to improve the functioning of an ED. However, gaps can be seen on the definition and modeling of situations arising from the aforementioned issues. The avoidance strategies and management of these situations are lacking.

According to the literature review presented in (Kadri, 2014b and 2015), no studies have been devoted to define, characterize and model strain situations in hospitals. To remedy this lack, interviews were conducted with professionals in the emergency department at the Lille regional hospital. From a "patient flow" viewpoint, a strain situation in an ED is defined as a disequilibrium between the care load flow (demand), and the care production capacity (supply) over a certain time. In this case, defined indicators must be controlled to not exceed a threshold value. The harmful consequences (strain phenomenon) to the proper functioning of the ED will be observed, measured and corrected.

The main identified factors that may affect this equilibrium are (Kadri et al., 2014b):

- *Inputs (patient flow):* seasonal epidemics (in winter: influenza, colds, gastroenteritis, bronchiolitis, etc.; in summer: trauma), health crises, cumulative causes such as the aging population…
- *Care production capacity:* care system performance, number and competence of medical staff (capacity, experience feedback, the availability of physicians downstream), internal and external transfer capacities (availability of care services downstream)…

Based on the proposed definition of strain situations presented above, the ED behavior evolve into two situations: normal and strain. It characterized by three states (figure 1) (V_E is the estimated value of the measured parameter that characterizes the ED's state):

- *Normal State:* the care production capacity is greater than the care load flow.
- *Degraded state:* The care production capacity is lower than the care load flow. In this case, the ED goes from normal to acceptable degraded state of the strain situation. This state is defined as the threshold V_{Mo} ($V_E \geq V_{Mo}$) being exceeded. So specific management must be deployed based on corrective actions to enable the ED to return to normal state.
- *Critical state:* this state represents the unacceptable degradation of the strain situation. This state is defined as the threshold V_{Cr} ($V_E \geq V_{Cr}$) being exceeded. In this case, ED must deploy corrective actions in order to attempt to return to acceptable degraded state or normal state.

2.2 Strain Indicators

According to Luan, (2002), an indicator is defined as a selected piece of information, associated with a criterion, aimed at observing the evolution of a system at well-defined intervals.

A strain indicator in an emergency department can be characterized by four elements (***SI = [C, O, SV, AV]***) as follows:

- *Context (C):* the search of corrective actions during the occurrence of a strain situation is strongly guided by the context in which the strain situation occurs. Three elements can be defined: events (epidemic, accident…), situation (degraded or critical) and time (the hour, or period, or day…);
- *Objective (O):* each strain indicator must have a clearly defined objective to allow the evaluation of an event or situation by the ED manager;
- *State variables (S_V):* the state variables must be measurable and easy to interpret in order to define and characterize the different states of the ED;
- *Action variables (A_V):* the strain indicator is only useful if one (or several) corrective action(s) are associated with the exceeding of the predefined thresholds for each state variable.

Identifying the dynamic state of the ED and evaluating the threshold values imperatively require relevant indicators. One can find many types of strain indicators in the literature: waiting times, current number of patients present in the ED, length of stay in the ED (Kadri et al., 2015, 2014b). 33 indicators has been enumerated. However, the characteristics of these indicators are not all accessible or usable. They

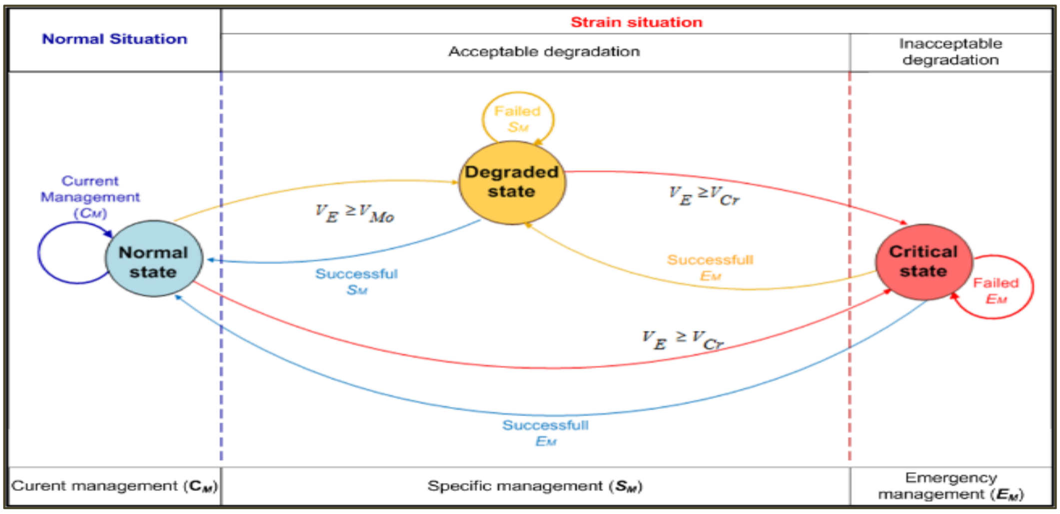

Figure 1: States and transition between states of the ED.

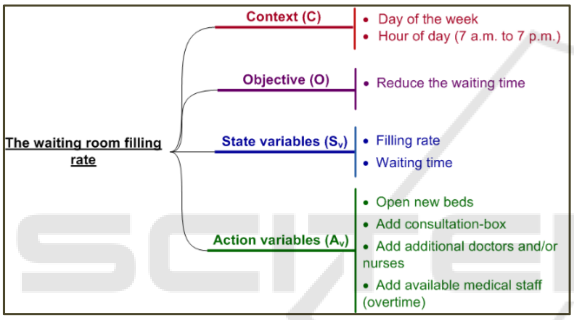

Figure 2: Example of strain indicator: the filling rate in the waiting room.

must be imperatively established and validated by the EDS professionals. Their effectiveness to identify, quantify and represent strain situations in an ED in different contexts must be proved.

A strain indicator (SI) can be a number, measured directly in the emergency department (e.g.: number of hospitalization for more than 24 hours) or calculated from measurements performed in the emergency department (e.g.; the average length of stay the urgency in the last 24 hours).

3 REACTIVE MANAGEMENT OF STRAIN SITUATIONS IN EDS

In order to react quickly to the occurrence of strain situation at an ED, the proposed system must help ED manager and take into account the clinical requirements and manager's responsibilities. Several corrective actions must be applied in order to give many alternatives to the ED manager.

3.1 Reactive Mode

In this case, the ED manager has also to react if a situation occurs, which must then be processed in a reactive context (reactive control). Reactive control occurs in real-time, according to the occurrence of unanticipated events and/or disturbances. This control is thus made while the ED is functioning, and without anticipation. It concerns the very short term (minute, hour). It is needed when: i) an unforeseeable and unexpected event occurs, and ii) deviations that lead to degraded or critical state of the ED are detected.

Figure 3 illustrates the case of reactive mode. In this case, we should ideally be able to set up corrective action as soon as it is selected ($t_S = t_P$). Unfortunately, however, the disturbance is not detected immediately, but after T_D time ($T_D = t_D - t_O$). The search for a corrective action then begins at $t_R = t_D$. A T_R time is then required to search corrective actions ($T_R = t_S - t_R$). When the action is selected at t_S and prepared at t_P, T_P time is required to set up selected action. The action is launched during T_L time. Finally the ED needs T_{Rec} time until to recover its normal state.

To make such decisions, the Ed's manager must follow steps listed above:

- Identify the ED state
- Research corrective actions in both the short time and real-time, if a strain situation occurs
- Assess the impact of this corrective action on the behavior of the ED,
- Launch the corrective actions if he estimates that these corrective actions are satisfactory, or search

for an alternative.

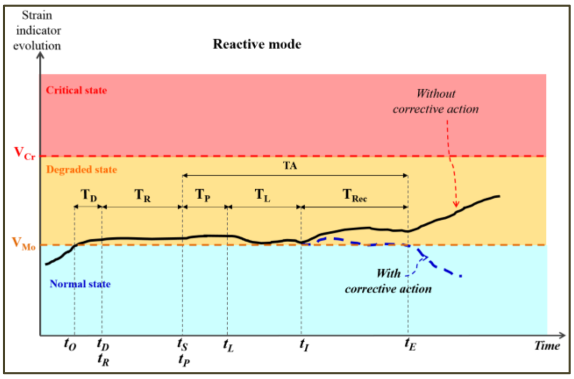

Figure 3: Reactive mode (caption table 1).

Table 1: caption of figure 3.

SI**$_i$**(t)	Strain indicator *i* value at date ***t***.
Dates	
t_O	Date the disturbance occurs
t_D	Date the disturbance is detected
t_R	Date of starting the research of corrective action
t_S	Date the corrective action is selected
t_P	Date the corrective action is prepared
t_L	Date the corrective action is launched
t_I	Date the corrective action takes effect within the ED
t_E	Date the ED returns to normal state
Times	
T_D	Time required to detect disturbances
T_R	Time required to search corrective actions
T_P	Time required to set up corrective action
T_L	Time required to launch the corrective action
T_{Rec}	Time required for the ED to recover its normal state after the disturbance
T_A	Time required to activate corrective action

3.2 Decision Making Process

Four several types of decisions (figure 4) according different situations are identified as below:

- *Direct decision (1):* the ED manager identify a known efficient, corrective action that responds effectively to the detected situation. In this case, he makes decisions directly and chooses the appropriate corrective action(s).
- *Researching corrective actions (2):* the ED manager seeks to identify a previously executed action stored in knowledge data base and used in a similar strain situation. In this case, he can apply the identified actions that are considered effective, after evaluation.
- *Evaluation and validation of an identified corrective action (3):* ED manager identifies potential corrective actions from knowledge base. To verify and validate if the identified actions are relevant in the current context, the manager uses, in this case, the simulation model.
- *Searching for new corrective actions (4):* if the knowledge base does not contain any corrective actions corresponding to the actual strain situation, manager may propose a new corrective action. He simulates and evaluates the corrective actions' effectiveness by using simulation model. If the proposed corrective action(s) are effective, he applies them directly; if not, he proposes other actions and simulates their effects on the ED behavior, and so on. These new validated actions are then stored in the knowledge base.

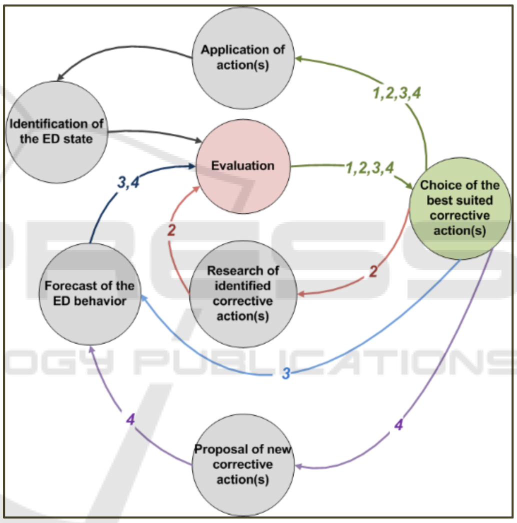

Figure 4: Generic decision-making model.

4 CASE STUDY: PED OF LILLE

Lille Regional Hospital Centre (CHRU) serves four million inhabitants in Nord-Pas-de-Calais, a region characterized by one of the largest population densities in France (7% of the French population). The Paediatric Emergency Department (PED) in Lille regional hospital centre (CHRU) is open 24 hours a day and receives 23 900 patients a year on average.

Based on the analysis of the questionnaires and interviews conducted with the PED medical staff, we established a dynamic model of the care process. Each stage is characterized by its activity duration, nature and type of care staff(s) required and the different waiting times are shown figure 5.

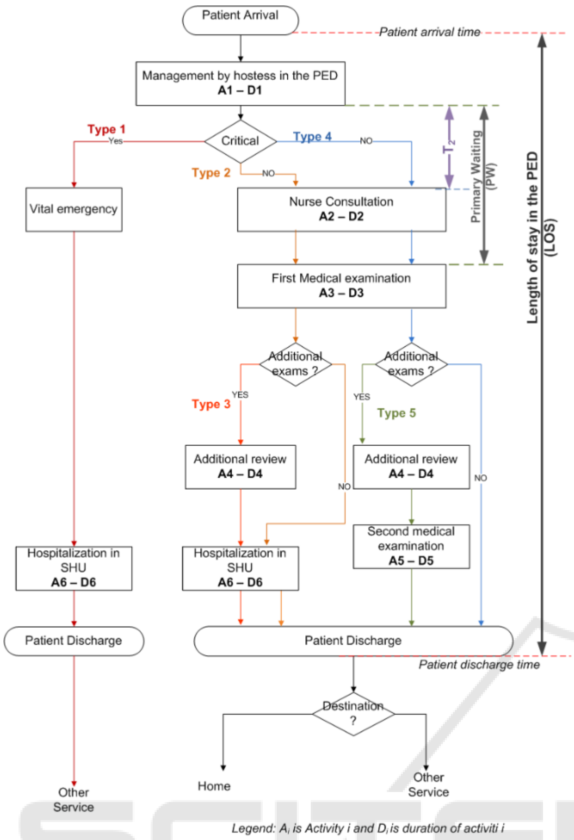

Figure 5: The main activity durations in the care process at the PED.

4.1 Strain Indicators

The PED staff was involved (by means of questionnaires and interviews) in the selection and classification of the relevant strain indicators. The main strain indicators selected and validated with the PED medical staff are:

1) Primary waiting time (PW): waiting-period between the care by the hostess, and the beginning of first medical examination.
2) T_2: waiting time between the end of the management by hostess and the beginning of nurse consultation.
3) N_p: the current number of patients present in the PED at the arrival of a new patient.
4) PP: ratio of the number of patients present in the PED by the number of physicians.
5) (Q_S%): the ratio of the actual length of stay (LOS(t)) by the theoretical length of stay (LOS_{th}) for the non-urgent patients.

The strain indicators and their threshold values use in this study are tabulated in table 2. The threshold values were defined and validated by the pediatric medical staff.

Table 2: Characteristics of the strain indicators used in the case study.

Strain indicators	PED states		
	Normal	Degraded	Critical
PW(minutes)	$PW < 60$	$60 \leq PW < 90$	$PW \geq 90$
T_2 (minutes)	$T_2 < 25$	$25 \leq T_2 < 50$	$T_2 \geq 50$
N_P (number)	$N_P < 12$	$12 \leq N_P < 20$	$N_P \geq 20$
PP (%)	$PP < 4$	$4 \leq PP < 7$	$PP \geq 7$
Q_S (%)	$Q_S > 0.8$	$0.8 \leq Q_S \leq 1.5$	$Q_S < 1.5$

4.2 Corrective Actions

The corrective actions have been defined with the PED staff according 3 classes:

a) Actions on Human Resources: add a nurse and/or doctor during a given period (in our case: two hours).

b) Actions on Material Resources: transform one room in the Short-term Hospitalization Unit (SHU) to a consultation box.

c) Actions on the Patient Flow Admitted to the PED: four rules of priority have been chosen to manage the patient flow in the waiting room:

1) **Rule 0:** The classic rule FIFO (First In, First Out).
2) **Rule 1:** in ascending order of the type of patient. The most urgent patient-cases are given a higher priority.
3) **Rule 2:** in descending order of time already spent in the PED. Patients with the highest residence time are given a higher priority.
4) **Rule 3:** in ascending order of their advancement in the care process. Patients early in their care processes are given a higher priority.

Three alternatives were defined according to the launch-time of the corrective action(s) (T_L). Table 3 summarizes the different characteristics of these corrective actions. 31 scenarios were defined and assessed for each alternative A, B, and C (for a total of 93 scenarios). The results of the different scenarios were compared and analyzed. In the next sub-section we present the principal results.

Table 3: Characteristics of the corrective actions.

Scenarios	Action on human resources		Action on material resources	Rules of priority	Launch-time T_L
	Nurse	Doctor	Consultation box		
Scenario i	0 or 1	0 or 1	0 or 1	Rule 0 or Rule 1 or Rule 2 or Rule 3	$T_L = 0$ min (Alternative A) $T_L = 60$ min (Alternative B) $T_L = 90$ min (Alternative C)

4.3 Results

As an illustration, the results of some simulations are given below for the strain indicator PW. **A0** is defined as the initial scenario without corrective actions.

a) Actions on Human Resources : Impact of Adding a Doctor

Figure 6 presents the results of adding one doctor in different scenarios: **A2** (*TL=0 min*), **B2** (*TL=60min*) and **C2** (*TL=90min*).

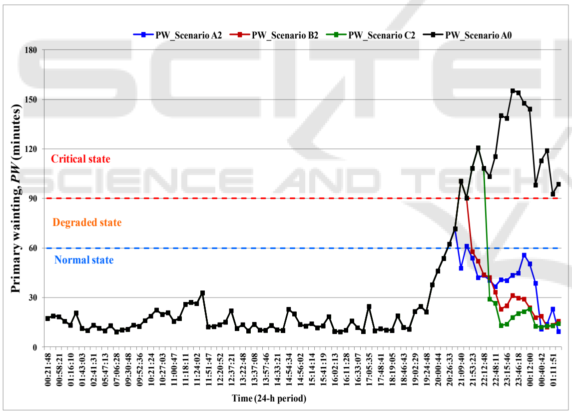

Figure 6: Impact of adding a doctor.

As observed in figure 6, in all cases, adding a doctor reduces the primary waiting-time (PW) of patients in the PED. It can be concluded that the addition of a doctor is always interesting, regardless of the launch-time (T_L).

b) Actions on Material Resources: Impact of Adding a Consultation Box

Figure 7 presents the results of transforming one room in the SHU into a consultation box in different scenarios: **A3** (*TL=0 min*), **B3** (*TL=60min*) and **C3** (*TL=90min*).

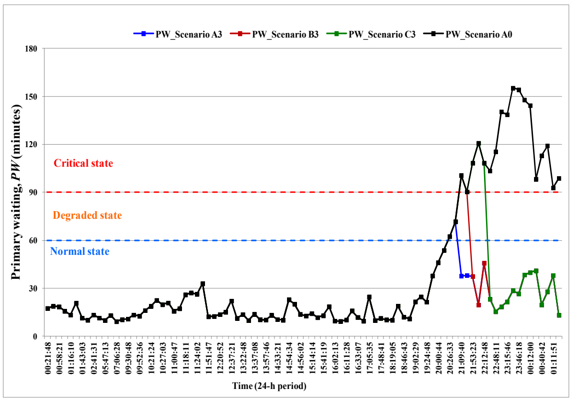

Figure 7: Impact of adding a consultation box.

The addition of a consultation box, by transforming one of the SHU rooms, reduces the PW. The immediate launch of this action (TL = 0) gives the best results and ensures that the PW does not reach a critical state (PW = 90 minutes). The addition of a consultation box is an action already used in the PED, and it is still an interesting solution.

c) Actions on the Patient Flow Admitted to the PED: Impact of the Application of a Priority Rule

We want to observe the behavior of the PED when applying different priority rules. The idea here is to see the impact of flow management techniques with same resources on the ED performance to cope with strain situations. In this case we used the scenarios of the alternative A (*TL = 0*) as follows: **A8** (*Rule 1*), **A16** (*Rule 2*) and **A24** (*Rule 3*).

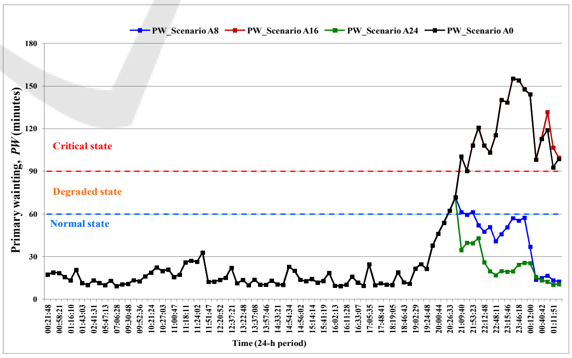

Figure 8: Impact of the application of a priority rule.

We observed that there is a significant impact in the choice of the priority rule, on the PW values. This leads us to conclude that avoiding these tense situations can be achieved not only through increased resources, but also by reflecting on the impact of the PED's internal organization. In some cases, applying simple priority rules should help better manage tense situations. We noted that Rule 1 and Rule 3 have a positive impact on PW values. Rule 2 was not a successful experiment. Therefore, the patient's length of stay is not considered as a priority parameter.

d) Combination of the Corrective Actions

Figure 9 presents the results of the scenarios where 1 nurse, 1 doctor and 1 extra box are added and Rule 3 is applied: **A31** (*TL=0 min*), **B31** (*TL=60min*) and **C31** (*TL=90min*)

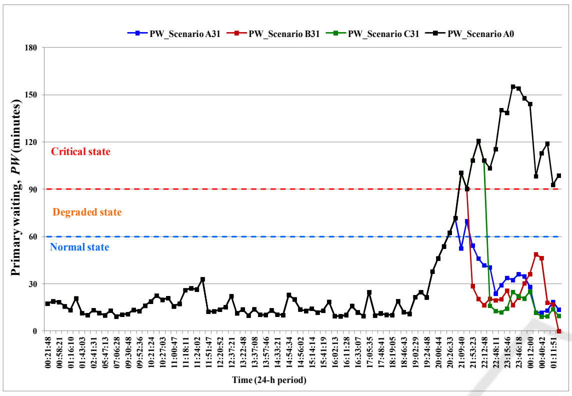

Figure 9: Impact of the combination of corrective actions.

As expected, the combination of corrective actions (human and material resources), and priority rules, reduced the PW.

From the results presented above, we observed the impact of various corrective actions on the behavior of the PED. The launch-time of corrective actions plays a key role in some cases. The series of experiments conducted on the priority rules applied to patients flow showed their interest. They are therefore to be considered to increase the availability of resources to the PED manager.

5 CONCLUSIONS

The objective of this work is to improve the management of strain situations that may occur in an emergency department (ED). To achieve this goal, we defined the ED transition states, the strain situations, the strain indicators and the associated corrective actions in the case of the Paediatric Emergency Department (PED) in Lille regional hospital centre (CHRU), France. To manage these strain situations we proposed an operating process for reactive control of these perturbations. The preliminary results show the interest to have such system. It should also be noted that if we tested a large number of scenarios, it will also be necessary to analyze those which can really be implemented in reality, taking into account the organization of human resources, as well as the regulation and economic aspects.

The perspective of the work in the immediate future consists in the specification and design of a decision support system (DSS) for the proactive and reactive control of ED activities. The main function of this DSS have i) to improve the reception of emergency patients, and facilitate the work of staff, ii) avoid the occurrence of strain situations, and also limit their impact if they do occur, and iii) help to better adapt an organization in terms of human and material resources. The second issue must concern the application of this DSS in other EDs and study the impact of organizational culture on its application.

The future works must be conducted with researchers in ergonomics and psychology to cope with exogenous factors such as: discomfort, fatigue and psychological stress faced by nurses and physicians …. In strain situations.

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