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Distributed Artificial Intelligence to support the progression of the operating theater process

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Abstract: *That article, presents the model of a control system, based on planner's cooperative agents, that facilitates the management of the operating room process.*
The major advantage of the proposed approach is the possibility of retouching the schedule without redoing it all. This is particularly useful, when the OR process is in progress, for rescheduling surgeries as needed.
We present the auction protocol called "simulated trading" (ST) and we develop the mechanism of its algorithm used to exchange surgical interventions between the rooms to obtain more responsiveness without reducing the overall performance.
This heuristic based on a concept of tendering that has been used in the past to exchange tasks between distributed resources, is used, at any time of the day, to balance the load in surgeries between rooms. The redistribution of tasks is triggered by the current situation and the planning decision for each intervention comes from local rules and negotiations between agents.
The MAS Planner, which is like online software with releasable algorithms at any time, allows for dynamic planning. This cooperative control system functions as an expert system integrating policies and rules to adapt the process control for more responsiveness and performance. This type of control, which is severely lacking today, makes it easy to deal with the frequent disruptions and uncertainties that are inherent in the operating theater process.
Some rescheduling simulations to present features are presented. The experimental results are analyzed for measure system performance.

Keywords: *Distributed Artificial Intelligence, dynamic planning, Hybrid Control, Multi Agent Planner, Operating Theater.*

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I. Introduction

Healthcare facilities need a management system that optimizes their processes by increasing overall performance, but also allows for rapid local responsiveness in the event of disruptions such as emergencies, cancellations, delays and unavailability of resources.

The hospitals need this system mainly in the operating theater. The surgical service has major effects on the finances of the hospital, due to its complex organization, its highly qualified human resources and its very high-tech material resources and their very great cost. It is obvious that this is the sector where we find the most expensive hourly rate cost but also the greatest added value. Responsiveness in this process is one of the essential features of the efficiency and performance of this medical sector. A bibliographical study of previous research on this subject shows that the question of taking into account all disturbances has never been satisfactorily addressed. Nevertheless, an appropriate resolution of this problem is unavoidable to have a management that achieves the overarching goal of health services, we quote: provide excellent patient care while controlling costs.

Let us express the two needs that have involved the development of the MAS planner system: (1) Develop an initial schedule of elective surgeries taking into account all pre-specified constraints and restrictions. (2) Maintain this planning dynamically (modify existing planning on demand or as needed). As the subject of our study is the planning of surgical procedures, the specificity of the process requires a dynamic maintenance of the calendar. In fact, in addition to creating an initial schedule for a time horizon (usually one week), the planning tool must be able to cope with a multitude of unforeseen events: change of room (after a breakdown), unavailable of human resources (change of surgeon without collisions), postponement of the surgery (following the deterioration of the patient's condition), cancellation of the surgery (death of the patient), addition of emergency surgery or new request for late surgery.

II. Problematic and Motivation

To clarify the problem that we propose to solve, we report a part of an audit we conducted with the manager of the operating theater of a prominent public hospital in France.

Question: You dispose of a predefined calendar for each room-day. How do you judge this tool in fulfilling the function of operating theater administrator?

He responds: Obviously, it is a tool of great help when all is fine, but only when all is fine. With the disturbances, very frequent, we are pausing planning aside and we move, in some ways in manual mode. In other words, we are flying on sight.

The feebleness of the management methods proposed so far lies by the models inconsistency with the functional reality of the process. A lot of hypotheses aiming to simplify and overcoming the mathematical resolution of the problem move the model away from the realities of the process. Stochastic models for handling cases with uncertain events or random variables are often complex and only take into account some of these uncertainties. We sum up by saying that approaches using exact methods but relying on many unrealistic assumptions have produced a poor management system. Uncertainty is a major feature inherent to the operating theater process. The ways of adapting and continuously improving conventional approaches to become effective in real constraints are very long or difficult to achieve.

During the last twenty years, a broad spectrum of models has appeared in publications. These models often based on methods of great mathematical complexity have provided excellent predictive schedules. Nevertheless, most of these models are far from satisfactory due to the lack, to our knowledge, of real-time management proposal, better adapted to the nature of this process. Indeed, not only because modern operating theaters are overexploited, planning must be able to be quickly adapted to suit the high dynamics of the sector.

Some public hospitals in France have expressed the need for a tool to help the progression of the operating theater process, especially in its downstream stage, which is frequently disrupted. Motivated by their request, a research thesis, followed by the managers of these hospitals, is launched.

III. Control Architecture

Trentesaux categorize process control architectures in three classes (Trentesaux 2009) [11]:

- Class I, Hierarchical control, efficient with static situations and deterministic data, but does not correspond to dynamic situations and changeability (Marik & al.; 2005) [8].
- Class III, Nonhierarchical control, reactive but the overall performance is poor (Marik & al.; 2005 [8], Ounnar & al.; 2010 [9], Pach & al.; 2008 [10], Veeramani &. al.; 1993 [14])].
- Class II, Hybrid control, is a convenient Class I & Class II combination to optimize overall performance and react relatively quickly to uncertainties as they occur (Zambrano et al., 2011) [18].

As a result, hybrid control architectures target both the high performance of hierarchical architectures and the robustness against perturbations of heterarchical architectures (Bongaerts et al., 2000 [2]). The proposed system of global control for the operating theater is an hybrid control architecture that manages all functions of the process. The study that will be presented in this article, concerns only the functions of the daily local management.

IV. Local Management System

1. Introduction: The Cooperative Control

The choice of the activity management model depends on the performances to be optimized. Global control includes mainly a predictive planning, usually based on the criterions of maximizing a preference function or minimizing a cost function or both. While the proper management of a surgical operating theater must begin with the predictive planning of the elective surgeries, it must also take into account any unforeseen events in the initial planning, such as an emergency or a cancellation, by dynamically adapting the schedule already in progress. This maintenance of the schedule will be done according to several criteria; we quote by way of example the daily cost reduction, the period’s hollow minimization, the over-time reduction, maximization of satisfaction of the doctors and of the patients, etc.

To our knowledge, previous approaches often relate to the predictive aspect of planning. Their evolution is part of a continuous improvement taking into account more and more of elements. Our approach, to develop the management system; will break up with the previous approaches. It is a reengineering of the process management system to ensure its responsiveness in the completion stage. The approach includes real-time monitoring, allowing cooperative control at the local level and leading to near real-time planning. Our proposal integrates the system of performance evaluation into the management system. The evaluation of the performance of the process is made automatically based on multi-criteria. The extra-cost rate and the rate of deferred surgeries are the two main parameters of this assessment because they have a direct impact on the central goal of healthcare institutions: (provide excellent patient care while controlling costs). The management system developed concerns the functionality of the process at the per-operative stage during a day of surgery. The proposed system combines several management functions (emergency assignment, rooms exchange, synchronization adaptation, current situation monitoring module and decision support module).

2. Why do you need "responsiveness "?

Predictive planning works well in a deterministic context. Uncertainties are only partially taken into account in little disturbed activities. The result they give is acceptable in Class I, despite this, the result deteriorates rapidly with increase in the frequency of disturbances (Van Brussel & al.; 1998) [13].

In the exploitation stage, the operating room manager must be able to deal with two categories of defects:

- Exogenous:

• Emergencies whose number, duration and resources mobilized are uncertain.

• Cancellations lead to significant losses in profitability, indeed, all resources may be on the alert but the intervention is suppressed. Thus, in case of cancellation, the management system must react quickly and try to replace it if all the constraints allow it.

- Internal:

• The uncertainty in the duration of each intervention: a significant delay in an intervention, rest the question of day remaining planning.

• The uncertainties that affect the operating theater, such as equipment failures, or unavailability of a human resource, a curative maintenance. The control system must be able to handle these situations.

We are forced to notice that static pre - planning is insufficient and it is necessary to introduce dynamic planning for a complete process control that extends downstream and must include the completion stage.

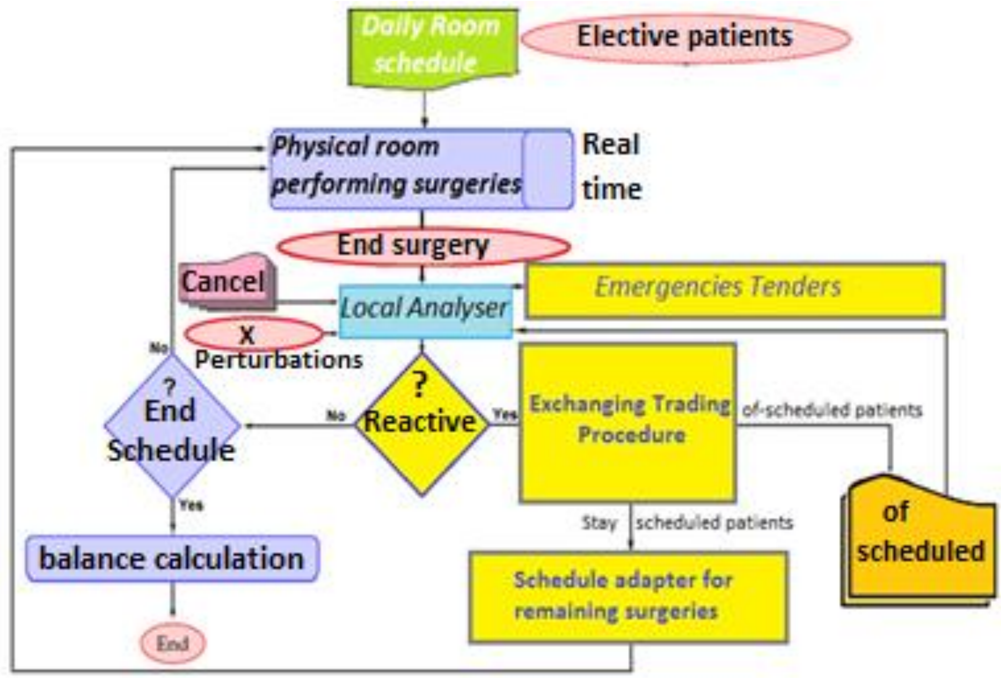

Figure 1: Architecture of local control

3. Local Management Functions

The exact methods of optimizing planning problems in the operating room cannot take into account all the constraints. They are greedy in terms of calculation time and give sub-optimal solutions. In addition, important unplanned events may require resetting the schedule to zero. Thus, the advent of a high-priority emergency that needs to be addressed immediately, regardless of the workload of the operating theater and the process dynamics, can invalidate the program. Interventions canceled on the planned day deviate the economic balance sheets from the targets set (Weiming et al., 2006) [16]. Taking into account mentioned difficulties, our participation in the management development of the operating theater consists of the proposed method which endows the process with the necessary reactivity.

The Multi-Agents System is well known as an effective solution for assigning tasks to distributed resources. Thus, we propose an approach based on fully cooperative agents to permanently maintain an optimized and valid plan. This study focuses on the architecture of MAS modeling of an operating theater, and focuses on the construction of a mechanism describing how agents interact to plan while optimizing their goal of performance. (VR Lesser, 1999) [15].

Tendering protocol (TD) is presented as a precious metaphor to provide the optimized solution for various problems notably in the case of a distributed environment. In order to provide the appropriate solution to manage disturbances including emergencies and cancellations, we propose a (TD) algorithm based in multi agent's system modeling the operating theater.

In the cooperative control stage of the completion phase of the proposed management system, three modules are distinguished: dynamic planner, dynamic scheduler, assignment of emergencies. In next, we present some literature works associated with each module as well as our proposed model to solve the associated problem.

• Dynamic Planner: In Gerchak & al. [7] author use dynamic stochastic programming for each day. They analyze and characterize the decision-making policy aimed at selecting surgical interventions to delay or, on the contrary, to insert. The decision criterion is the minimization of the shortfall. We will use in our model this same criterion to decide at every opportunity to re-plan, what interventions will leave planning or, which interventions will join it. (Gerchak Y.; Gupta D.; Henig M.; 1996) [7]

• Emergencies assignment: Wullink et al. [17] regarding the pre-booking of a specific time slot for emergencies. They confront two methods: localize all reservations in a single room dedicated to emergency surgeries or uniformly allocate reserve capacity in all rooms. With minimization of wait times, minimization of overtime and maximization of occupancy rates, the second method is the most efficient (Wullink & al.; 2007) [17]. Van Essen & al. [12] introduce: (Break-In-Moment) time before starting an emergency after ending a planned intervention, and the (Break-In-Interval) between, 2 successive BIM. These works based on these two parameters try predictably to consider emergencies and to minimize the waiting time. (Van Essen; Hans; Hurink; Oversberg 2012) [12]. Smith [3] proposes the **C**ontract-**N**et **P**rotocol (CNP) for tasks allocation in distributed systems, in a setting called (Cooperative Task Oriented Domain) (Fischer; 1994; [6]). We use this protocol to assign emergency surgeries in rooms. Agents representing the operating theater are fully cooperative and communicate with each other to find the best placement according to pre-defined criteria (Davis & Smith, 1983) [3]

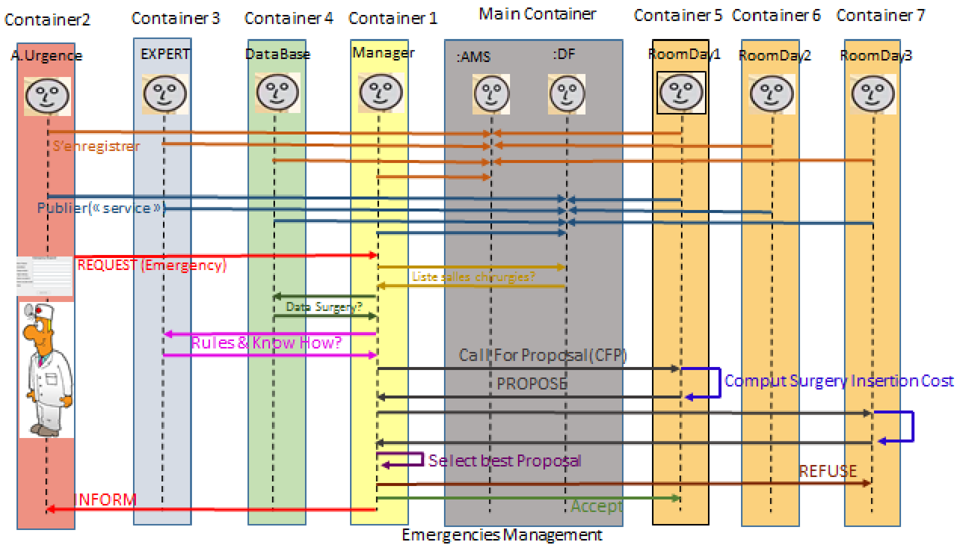

Figure 2: Control-Net-Protocol for emergencies management.

• (Dynamic scheduler) Erdem & al. [4] After having inserted an emergency intervention, the planning is resumed with criteria of minimization of the costs of postponement of the already planned interventions and taking into account the penalty of the fast increase of the cost in overtime, the authors use a genetic algorithm and a MILP Model to reorganize the remaining interventions (Erdem, Qu, Shi 2012) [4].

In Bachem & al. [1], the authors presented the Simulated Trading protocol, which consists in the field of transport by vehicle, of a complex exchange of activities between resources in order to arrive at an optimal distribution in relation to the objectives set. This protocol realized by an iterative heuristic gave optimal proven solutions to the problem of the freight of the vehicles. We think that in the development of the operating theater management system, this algorithm is equally suitable for optimizing current schedule by means of an adequate exchange of surgeries between the rooms (Bachem; Hochstattler; and Malich; 1996) [1]. The proposed approach for dynamically optimizing the schedule of a room for a day is to adapt algorithm of the auction protocol (ST) in MAS modeling the operating theater, in which the agents represent, instead of vehicles, the actors of the operating room process.

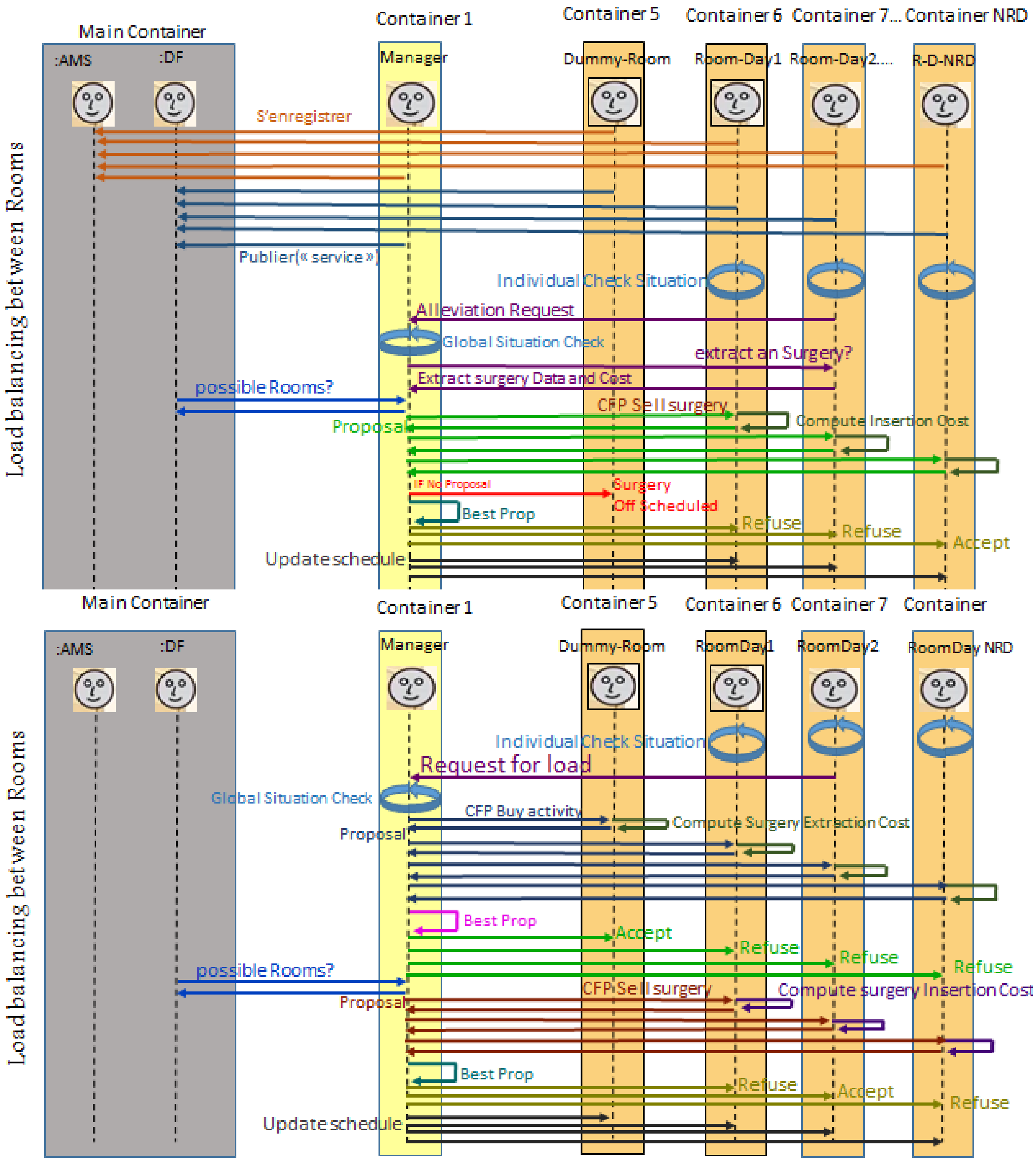

Figure 3: Optimization by Dynamic scheduler.

4. Logic Of Local Management

As we said before, the solution to the rescheduling problem stems from a negotiation between the agents. Two types of agents are particularly involved in this negotiation: The Manager-Agent (MA) and the Room Day-Agents (RA). (MA) manages a market species to somehow affect every surgery to the better bidder.

The basic idea is that the agent manager (MA) manages a stock exchange where his clients the Room Day-Agents can offer to sale operation at a saving price and buy operation with insertion price. That bursary allows (MA) to compose a coherent set of surgeries to exchange places, in order to optimize its schedule and increase its responsiveness.

Each Room Day- Agent RAi is responsible for managing, in accordance with his schedule Ri, the room (i) that he represents. When time passes, the surgeries are performed. An intervention includes the stages of anesthesia, surgery and postoperative monitoring. RAi who has already begun to roll out his day schedule can participate in a call for tenders to add an emergency for example.

When the agent begins to execute the plan, Room Agent may experience problems such as delays due to surgical complications, unavailable resources, or simply the possibility of exceeding the specified time of closure. Therefore, an adjustment of the plan would become necessary. Three cases stand out:

1) If the disruptions have, by reference to the rules defined in advance, tolerated consequences on the schedule, the Room Day-Agent uses its local scheduling procedure to spread its local plan, then (RA) continues to execute its rectified schedule.

2) If local rescheduling is not possible because the remaining workload exceeds the capacity of the resources. The (RA) asks the Manager-Agent to start the procedure (ST) to balance the loads. If after the (ST) all interventions are placed, it is a solution to the problem. Otherwise, the MA places the come-out surgeries in a Dummy room and he is waiting for the day to end, in the hope that the workload will be lightened and that these surgeries will be reintroduced into an upcoming ST. At worst, MA informs Surgeon-Agent concerned the deferral of the operation.

3) It is not uncommon for late cancellations of surgeries to occur. The Room Day- Agent representing the room corresponding to this cancellation has a schedule with a free time slot. The AR tries to buy a surgery by first starting with the surgical procedures placed in Dummy-Room. If it finds surgery compatible with his schedule, it inserts it into his plan and reorganizes it. Otherwise RA asks MA to start a ST.

The surgery procedure begins as soon as the patient leaves his room to be transferred to the operating theater. Then, it is forbidden to move this operation in the planning. Thus, even if disturbances occur, the Room-Agent must execute the operation considering only the patient's safety. If the safety of the patient cannot be guaranteed, the Room-Agent hands over to Manager-Agent, who considers and treats this intervention as a high-priority emergency one.

5. Simulated Trading Auction

During the day, when the protocol ("CNP") is inactive, each room agent has a valid individual program that deploys over time. In the interest of continuous improvement in overall performance, Manager-Agent has the authority to trigger and conduct an optimization process by exchanging operations between Room-Agents. The latter are fully cooperative and only interested in overall performance. The approach envisaged is to practice a negotiation simulation protocol for rescheduling, provided that the new individual schedules are eligible and that these new plans are globally beneficial.

Simulated Trading (ST) is a distributed artificial intelligence protocol that is applied by means of a heuristic that implements the mechanism of a negotiation procedure to exchange activities between distributed resources. We used ST to determine convenient set of cross-trading between rooms (Trading-Matching). (TM) is built under a set of predefined constraints; in order to optimize the overall cost function.

The trading graph $TG = (Vs \cup Vb, E)$ models the trading mechanisms. Each offer is represented by a link and each seller or buyer is represented by a node. To be able to handle cases of complex exchanges, offers to buy or sell are classified at different levels of decision.

For a better understanding of this notation, we imagine this trading suggested by Baschem & al. [1]:

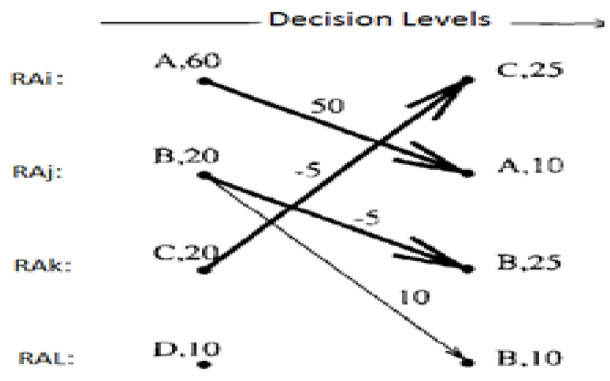

Figure 4: Trading Matching (in bold) and Trading graph by Baschem et al. (96)

RAi: vs1 = (RAi ;l ; −A ; 60)
RAj: vb1 = (RAi; l; +A; 10) provided; vs2 = (RAj; l ; −B; 20).
RAk: vb2 = (RAk; l; +B; 25) provided vs3 = (RAk; l ; −C; 20) in (t1; t2)
RAl: vb3 = (RAl; l; +B; 20) provided; vs4 = (RAl; l ; −D; 10)
RAi: vb4 = (RAi ; l ; +C; 25) in [t1; t2] prov; vs1 = (RAi ; l ; −A ; 60)

MA: $e_1 = (v_{s1}, v_{b1}, A, +50)$; $e_2 = (v_{s2}, v_{b2}, B, -5)$; $e_3 = (v_{s3}, v_{b3}, C, -5)$
A buy node $vb = (RA, l, +ks, \rho+) \in Vb$,
A sale node $vs = (RA, l, -ks, \rho-) \in Vs$
That RA= (RoomDay-agent); ln = (decision-level); Ks =(to be negotiated- surgery) and ρ = (cost).
To every bipartite proposal = (vs,), we insert a directed edge $e = (vs, vb, sk, w)$, Each edge carries the weight that represents the balance between the cost of sales and the purchase value.
$v_s = (\mathrm{RA}_i, l_i, -s_k, \rho^-) \in V_s \Leftrightarrow \mathrm{RA}_i$ avec $R_i^{l_i-1}$ roomday plan updated with level (l_i-1), makes a sell offer with level (l_i) surgery s_k have deletion cost: $\rho^- = C^-(R_i^{l_i-1}, -s_k) = C(R_i^{l_i-1}) - C(R_i^{l_i-1} - \{s_k\})$

$v_b = (\mathrm{RA}_j, l_j, +s_k, \rho^+) \in V_b \Leftrightarrow \mathrm{RA}_j$ with $R_j^{l_j-1}$ room day plan updated with level (l_j-1), makes a buy offer with level (l_j) the surgery s_k have insertion cost: $\rho^+ = C^+(R_j^{l_j-1}, +s_k) = C(R_i^{l_i-1} + \{s_k\}) - C(R_i^{l_i-1})$
$e = (v_s, v_b, s_k, w) \Leftrightarrow w(e) = \rho^-(v_s) - \rho^+(v_b)$= edge ($e$) weight v_s sell $s_k$to v_b buy s_k.

If surgery insertion is impracticable (non-compliance with mandatory constraints) then it is unallowable by the attribution of a voluntarily huge cost.
At a given moment, the MA seeking to improve the performance of its schedules launches a simulation of a surgeries exchange market. It tries to identify and select a coherent exchange scenario with a positive delta-cost. The algorithm (ST) consists mainly of two stages:

5.1. Buy & Sell stage:

At the stage (buy / sell), iteratively at every level of decision li< lmax and for each room day; $R_i^{l_i}$ the simulated planning leveled, is revised. We determine the parameters to decide the type of action to be taken (a sale or a purchase or no exchange) to take at this level and for which surgery.
The selection of surgery that will be affected by the current action is done according to the cost criterion. To be able to choose, we calculate for every one the coefficient for incentive priority.
Incentive to sell: $P_{s_h}^{R_i^l} = \frac{C^-(R_i^{l-1}, s_h)}{\sum_{j=1}^{n_i} C^-(R_i^{l-1}, j)} \quad \forall \ s_h \in R_i^{l-1}$
Incentive to buy: Let $S = \{s_1, \ldots, s_k\}$ register of sales; let {sv (1) ,., sv (k)} according savings prices; let R_i room i plan.

If($\forall \ s_h \in S, \ [\mathrm{sv}(s_h) - C^+(R_i^{l-1}, s_h)] = \mathrm{cst}$)
then $P_{s_h}^{R_i^l} = 1 / k$. (Equipriority)
Else $m = \min_{j=1}^{k} \mathrm{sv}(s_j) - C^+(R_i^{l-1}, s_j)$,
$P_{s_h}^{R_i^l} = \frac{\mathrm{sv}(s_h) - C^+(R_i^{l-1}, s_h)}{\sum_{j=1}^{k}(\mathrm{sv}(s_j) - C^+(R_i^{l-1}, s_j)) - \mathrm{k}m}$ End if.

The decision to change rooms for surgery should not be founded on real cost criterion only. The decision can be ameliorated by taking into account other criteria such as the surgeons' preference and the relative ability of the surgery room to perform this category of surgery. We introduce later the virtual cost a generalized notion of cost, which takes into account these criteria.
In case of a surgery sale, it will be placed in the sales register. For a purchase action, we select in the sales register, the surgery that achieves the best gain. Each decision of sale or purchase induces the creation of a corresponding node in TG.
We add a v_b purchase node, and then we place a weighted link from the v_b sales node to the v_b purchase node. Thus, TG is built progressively and level after level.

For the planning need, we added a (Dummy- Room). At the (Buying & Selling) end, all the surgical procedures available for sale but not found a buyer are placed in this room. The dummy room offers for sale all the interventions it contains for each new ST. We seek to reintroduce these interventions into the daily planning.

Buy & sell phase computation is as:
For i=1 to nr, $R_i^0 = R_i$, $l_i = 0$, end for, Initialization,
Sell all of the surgeries in the (DR):
$nd = card(DR)$,
For k=1 to nd
$s_k = DR(k)$, $\rho = dr(k)$,
$S = S + \{s_k\}$, $s(k) = \rho$, Add intervention s_k to register S
$v_s = (DR, 0, -s_k, \rho)$, Add node v_s to TG
End for
DR = ∅; Empty DR;

Procedure of buy & sell:
For i = 1 to card(rooms) : (rooms loop)
Check situation of local planning of Room
Decision (what action buying or selling)
If (action = selling) alors
Select "best" intervention for sell $s_k \in R_i^{l_i}$
$l_i = l_i + 1$
$R_i^{li} = R_i^{l_i - 1} - \{s_k\}$
$\rho = C(R_i^{l_i-1}) - C(R_i^{l_i-1} - \{s_k\})$, Deletion cost
$S = S + \{s_k\}$, $s(k) = \rho$, insert surgery s_k to register S (selling)$v_s = (RA_i, l_i, -s_k, \rho)$, Add selling node to graph
End if (end **S** action)
if (action=**B**uying) alors
Seek in S, "best" intervention to buy $s_k \notin R_i^{l_i}$
If (suitable operation found =ok) then
Mark s_k as touched by a purchase offer,
$B = B \cup \{s_k\}$
$l_i = l_i + 1$
$R_i^{l_i} = R_i^{l_i-1} + \{s_k\}$
$\rho = C(R_i^{l_i-1} + \{s_k\}) - C(R_i^{l_i-1})$, Insertion price
$w = s(k) - \rho$, Computing balance of transaction
$v_b = (RA_i, l_i, +s_k, \rho)$, Add v_b node to TG
$e = (v_s, v_b, s_k, w)$, Add edge e to TG
endif (end **B** action)
endfor (fin boucle salles)

Dummy room buys all unsold surgeries:
$\bar{B} = C_B^S = \{sr/sr \in S \text{ and } sr \notin B\}$, $\overline{nb} = card(\bar{B})$,
For k=1 to $\overline{nb}$
$s_k = \bar{B}(k)$, $\rho = s(k)$, $dr(k) = \rho$,
$v_b = (DR, 1, +s_k, \rho)$, Add v_b node to TG
$e = (v_s, v_b, s_k, 0)$, Add e edge to TG
Endfor (unsold surgeries in DR)

5.2 Search phase of Trading-Matching (TM):

$TG = (V_s \cup V_b, E)$, TG trading graph formed in phase of buy & sell
It may be necessary to remove some edges and nodes of TG to obtain its eligibility, and thus become a trading matching

A trading graph would be eligible if it fulfills:
$\forall v_b \in V_b / \exists\ v_s \in V_s \text{ with } e = (v_s, v_b, \ldots) \in E$
$\forall\ l_1 < l_2 < l_3 / (RA, l_1, .), (RA, l_3, .) \in V, \exists\ (RA, l_2, .) \in V$
The first condition means that each purchase proposal is adjacent to at least one selling proposition. The second condition means that, $R_i^{l_i}$ has a strictly continuous evolution according to the decision levels.

The "Simulated Trading" procedure consists in selecting, in all eligible trading graphs, a set of pairs of nodes (vs, vb), with a condition: each node appears once in this set. the set we are looking for is constrained by:
If $TG\ (V = V_s \cup V_b, E)$ is an eligible TG, let $M_e \subset E$;
let $M_s \subset V_s$; let $M_b \subset V_b$;
M_s Sale proposal to which there is at least one offer to buy in M_e: $M_s = \{v_s \in V_s / \exists\ v_b \in V_b \text{ with } e = (v_s, v_b, \ldots) \in M_e\}$
M_b Buy proposal there is one & only one offer to sale in M_e: $M_b = \{v_b \in V_b / \exists\ \mathbf{1}\ v_s \in V_s \text{ with } e = (v_s, v_b, \ldots) \in M_e\}$
Let M_V set of touched nodes: $M_V = M_s \cup M_b$
M_e is **T**rading-**M**atching **(TM)** if it fulfills conditions:
$[\ \forall (RAi, l, k, .) \in M_V;\ \forall l^* < l, (RAi, l^*, \ldots) \in M_V]$
$w(M_e) = \Sigma w_e (e \in M_e)$, weight of TM M_e
The optimization of the TM to be decided consists of examining all the possible eligible and feasible TMs, evaluating for each the expected gain, then selecting in $TG^* (V^*, E^*)$ the one that corresponds to the best gain TM (M_e^*).
The buying & selling procedure and the procedure for selecting optimal TM is start over again at every level of decision, until the level of decision remains below the predefined maximum level.

5.3. Concrete readjustment of the planning.

When launching the ST protocol, the management system creates a copy of the individual room programs. Each Room-Agent pursues his work by continuing to run his valid original plan. So, The ST algorithm starts with the copy version. Then it is deployed on successive versions of schedules that are all, in a way, theoretical and not validated. During this phase, which is an optimization phase, the original schedules are not affected. At the end of the ST procedure, if it results in an acceptable, feasible and better solution, the Manager-agent decides to adjust the schedules to execute according to those of the solution found by the ST. Of course, these new schedules that have been modified are now considered as the original schedules. If an emergency happens, when the ST has not finished and is still in the optimization phase. This entire cycle of ST is stopped and canceled. Since the original schedules are not affected, a CNP procedure can be started and all agents can participate with their original plan valid.

6. Multi-Agents Planner System

Every room of the operating theater is entirely autonomous to perform each intervention that has entrusted to it. Each room has its own process and its own integrated means. The management system only intends to choose, in near real time, the room that will be used to perform the surgery. This management is based on a distributed artificial intelligence and realized by means of a system of cooperative multi-agent. In what follows, we present the architecture of this multi-agents planner system.

At the bottom of the control system lays the physical stratum containing human resources and operating theater. For the software aspect, the proposed architecture comprises two layers: the distributed artificial intelligence layer consisting of a multi-agent system and the mediating layer that provides interfaces between the Multi-Agent System and the physical layer.

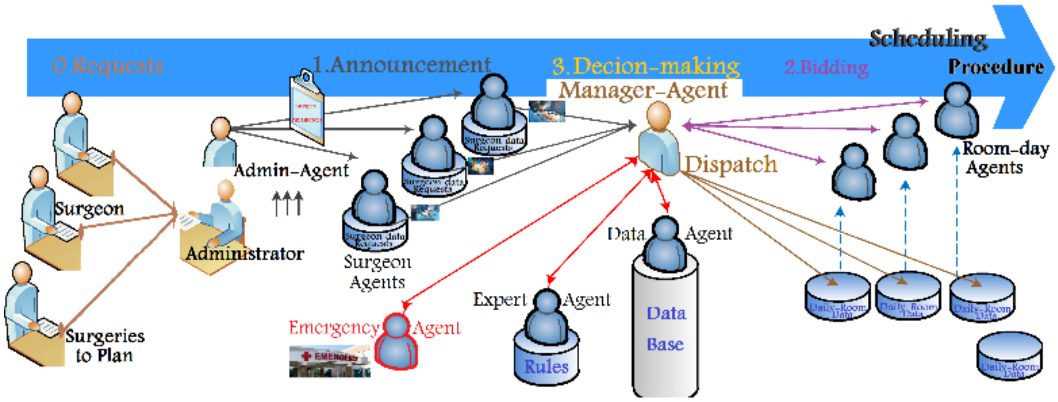

Figure 5: Multi-agent Planner system for an operating theater management.

The MAS is composed of seven types of agents, namely: Admin Agent, Manager Agent, Room-Day Agents, Surgeon Agent, Emergency Agent, Database Agent and Expert Agent. The emergency department is represented by the Emergency Agent, who has a specific graphic interface that allows it to announce emergencies. Admin-Agent is the link with surgeons, through which requests for surgeries or cancellations are made.

The Agent Manager (MA) is the sole decision-maker for the scheduling function. When he receives a request to insert a surgery (which may be an emergency or not) into the planning, he enriches its file, containing the characteristics of the surgery requested, by additional specific data obtained from the expert agent and from the database agent. He starts the protocol (CNP) to find an assignment for this surgery. It analyzes the offers of the Room Day-Agents and decides on the attribution of the intervention to the winning Room-Agent.

Room Day-Agents (RA) are the basic subset of the planning system, which includes the individual schedules of each Room Day. Each Room Day-Agent represents a physical surgery room on a given day. Each (AR) is responsible for establishing its individual plan by collaborating with the Manager-Agent. The (RAs) participate in negotiations of (CNP) protocol. They use their own local planner to supplement or adjust their individual schedule. (MA) seeks to optimize the overall performance of the operating room; its decisions are based on predefined criteria and rules. (RAs) work together to provide (MA) the elements of a good decision. In addition, individual plans are updated, as needed, by communication with the database agent.

A complete management system supposes the existence of means of feedback at the end of the surgery. It is also the responsibility of (AR) to return the useful data to Database Agent; who is responsible for filtering, classifying and storing data in a predefined format and extracting that data as needed.

(EA) is the Expert Agent he has the responsibility for the accumulation of laws and rules relating to know-how or the operating theater jurisdiction and it is responsible for its extraction. He mainly cooperates with the (MA) by giving to him the knowledge that will enable him to make an informed decision. It has a specific database in which the rules and laws are cumulated.

The intermediate layer establishes a correspondence table between the multi-agent's system layer and the physical one. It contains the specific data of the physical layer that is needed for a good representation of it by the multi-agent system. It also contains the logical interfaces between these two layers.

The multi-agent's system is implemented on the JADE platform. Interfaces modules with physical layer will be computed with Java.

7. Performance Metrics

When each surgeon prepares his list of elective surgery requests, he declares, for each intervention, his preferences in the form of a set of time slots associated with the references of the rooms. These data represent (hours and rooms) ideal for performing this operation, according to the surgeon. He also declares another series of time intervals representing the moments of his availability of the week, that is to say, his presence in the operating room. The satisfaction of each surgeon is evaluated as follows.

We considered the indicators of performance measure:

1) The ratio $\tau_{1notconf/total} = card(notconf)/card(total\ surgeries)$ an indicator that informs us about the rate of an activity that is not conform to the ideal planning based on surgeon preference.

2) The extra gap rate:

$\tau_{2T\,extragap/T\,available} = timeextragap/timeavailable$ an indicator informing us about the rate of extra gap between surgeries (surgeon is available to operate but no surgery to perform)

3) The ratio:

$\tau_{3T\ overtime\ /T\ available} = overtime\,/\,timeavailable$ an indicator informing us about the rate of overtime outside specified uptime

4) The Surgeon Satisfaction Indicator:

$SSI = (1 - \tau_1)x(1 - \tau_2)x(1 - \tau_3)$

The overall satisfaction coefficient is calculated as an arithmetic mean weighted by the load density of each surgeon (card individual surgeries / card all surgeries).

The assessment of the satisfaction of surgeons has been conceptualized following the audit of a dozen surgeons from a French public hospital. The calculation of the satisfaction coefficient is based on the triple concern of the surgeons found in their answers.

The cost of the same surgical procedure depends heavily on the workload of the operating room where the operation will be performed, the timing of the operation and the resources that perform it. Hourly cost increases rapidly for late hours. After regular working hours in an operating theater, later surgery is performed; the higher is its cost. In addition, the dissatisfaction of the surgeon must be taken into consideration in the calculation of the cost. The removal of an intervention outside the time slots or room requested by the surgeon must be more expensive than placing it at the requested location. To account for the surgeon convenience, we propose adding a fictitious extra cost that corresponding to a penalty associated with the surgeon non-preference. We introduce the concept of virtual cost of surgery:

$virtualcost(S) = cost(S) + (p) * cost(S)$

With p extra cost penalty rate.

8. Testing Modification Of An Existing Plan

To can evaluate the proposed approach, simulation experiments were conducted to test performance of both functions: Emergency assignment using the protocol (CNP) and schedule adjustment using the protocol (ST).

The operating theater consists of 12 surgical rooms; each room has a schedule filled with interventions belonging to 11 surgeons. The normal working period of the operating theater is between 7:00 and 20:00. An obligation is fixed not to exceed 22:00, legal closing time of the operating theater. The duration of each surgery is a random multiple of 15 minutes selected within a range of 60 to 180 minutes. The experiment involves inserting five surgeries into the daily schedule with random parameters each (Surgeon, type, delay, "earliest and latest" start time, etc.).

A first series of 100 tests consists of inserting the five surgeries in the initial schedules of the day randomly. The so-called overloaded schedules are obtained at each test. Then we apply the simulated trading protocol on the overloaded schedule to obtain the so-called optimized schedule. A second series of 100 tests consists of using the protocol (CNP) to insert in the initial schedules of this day the five surgeries. At each test, the so-called augmented schedules are obtained.

The initial schedules, the overloaded schedules and the augmented schedules are evaluated in cost and in satisfaction of the surgeon.

Simulated trading had a significant positive impact on the average of indicators. The average satisfaction of all surgeons after the optimization was 95.42% (compared to 94.06% of overloaded schedules, the difference is + 1.36%). the additional cost of surgeries after optimization was 15.67% (versus 23.01%, a difference of -7.34%). Note that this cost increase was caused by an average increase in load of 8.02% caused by the additional load induced by the five surgeries added. It should be noted that no resource collisions subsisted after optimization.

CNP had a fairly positive impact on the average of the indicators. The average satisfaction of all surgeons after the augmentation was 94.74% (compared to 94.06% of overloaded schedules, the difference is + 0.68%). the additional cost of surgeries after augmentation was 16.76% (versus 23.01%, a difference of -6.25%).

V. Conclusion

In this article, we have highlighted the management aspects of the operating theater in hospitals, and we have identified the main functions of its management system. After presenting the specificities of possible control architectures, we have structured the proposed management system with a hybrid architecture that ensures good overall performance and fast local responsiveness. Next that, the study focused on the management of the process in its completion phase, a part of the adopted architecture. Distributed Artificial Intelligence (DAI) stands out as the appropriate answer to this issue. DAI allows dynamic planning in this application where unpredicted are frequent. In our approach, the optimal schedules emerge from the negotiation between cooperative agents representing the operating theater with respect to the predefined rules. The proposed multi-agent planner system was analyzed in detail and developed. Some experimental results show that this approach satisfactorily solves dynamic planning problems of the operating theater.

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