Organization and management of hospital patient transportation system

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Abstract—**In this paper, we will deal with the problem of transporting patients in a hospital taking into account additional constraints such as dependencies between tasks and empty moves between missions of transporting are taken into consideration. We first studied the state of the art on the hospital sector mainly the stretching, its characteristics and its setbacks. Second, we modeled the problem with mathematical programming taking into account constraints. Then we solved this model with LINGO solver and we ended up with a set of experiments on the model and a sensitivity analysis.**

Keywords—patient transportation system; hospital system; stretcher; allocation; scheduling; mathematical model.

I. Introduction

The patient internal transportation system is an essential activity in hospitals, regardless of their structures, their sizes and their organizations.

The problems related to patient transportation have a deep impact on the overall performance of health systems. These problems are resources down-sizing, scheduling and coordination of operations.

Mathematical modeling of the problem seems to be an approach well suited to this kind of system. It will take into account all the options and features of the system studied.

Our goal is to start with a mathematical model of a hospital process, namely the process of patient transportation. Then it will solve the obtained model using a solver without neglecting of course, interpretation of the obtained results.

II. State Of The Art

Today, the word “hospital” covers all hospital institutions, it is sometimes limited to public sector. The role of the hospital is to improve the population’s health.

Although health seems priceless from a social perspective hospitals have to spend a lot of money and resources for this reason [2].

The main mission of the patient transportation system is to transport the patients between services in the same hospital [3]. It is a logistic transfer between units in the same institution. This activity is part of the overall process of care of the patient; its performance has a direct impact on quality and security of lodging [3].

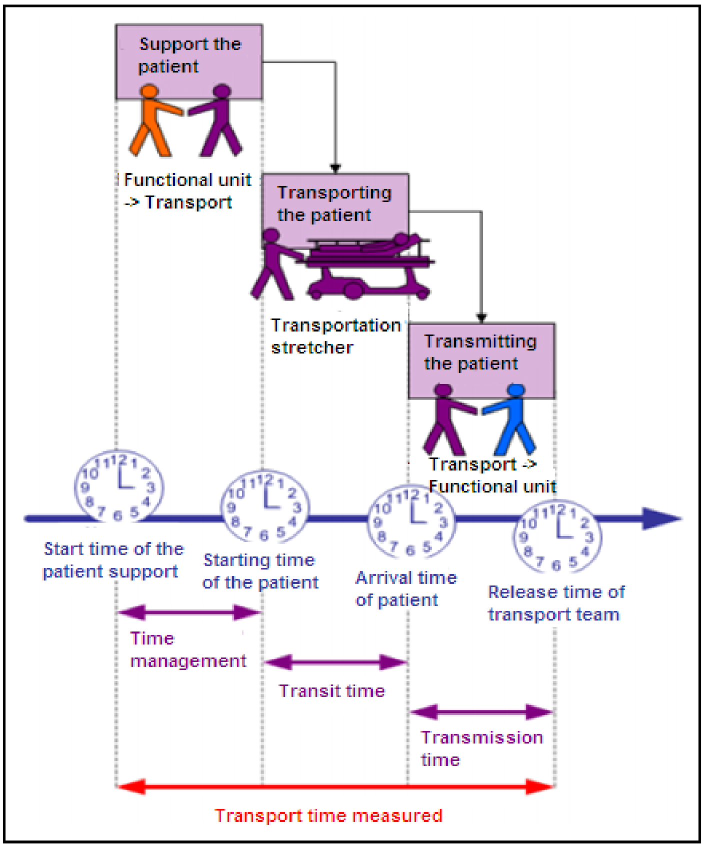

Figure 1. The internal transport of patients [1]

The patient internal transportation system is the succession of three steps as shown in Fig. 1 [1]:

- Supporting the patient at the original functional unit.
- Moving the patient.
- Transmitting the patient to the destination functional unit.

There is no standard organizational model of patient transportation system. Choices must be made between different organizational options [4].

There are 3 ways of organizing teams of stretchers [1]:

- The pool: all stretchers are bundled in an independent clinical service.
- Dedicated teams: each stretcher is assigned to a particular unit or a corresponding sector.
- The mix pool & dedicated teams.

There are two control strategies of patient transportation system in a hospital:

- Planning: The transport missions are identified in advance.
- Regulation: A control function affects each mission to a stretcher.

When scheduling patient transportation tasks, several issues arise such as [1], [3] and [4]:

- Two types of resources have to be taken into account (stretcher, stretcher equipment).
- Many types of equipment or devices can be used (beds, chairs, etc.).
- Emphasis must be put on empty moves.
- Other agents such as nurses can perform this activity.
- The durations of the missions are heterogeneous.

The internal transport of patients is often overlooked in the search for several reasons [3]:

- The costs related to equipment and stretcher transport patients are much lower than those of human and material resources of functional units.
- The stretcher located at the interface between the units is often excluded from health cycle in hospital.

The patient transportation system is situated at the interface between services and is often excluded from the scope defined in the studies of services. Among these few works that were interested in patient transportation system, there are those that have tried to model the internal transport system mathematically as an optimization problem. Gascon and Michelon [6] studied the problem of assigning tasks to the stretcher. In this paper, two delivery systems of the hospital are compared. According to the objectives of hospital managers, the efficiency of a specific system is measured by the following criteria: the number of carriers and stretchers required by the system, the work load and the space used in the warehouse. A mathematical model is developed and solved by a heuristic method to evaluate the number of stretchers required by the system. The problem is to identify work schedules of carriers. Each task has the following characteristics: time window, duration and place of management and place of discharge. The objective is to minimize the waiting time of stretchers and the number of stretchers. This problem can be modeled as a routing problem where stretchers are the vehicles to transport tasks. Note that the breaks are modeled in the form of specific tasks. In [6], authors present a mathematical model of patient transportation system used to minimize downtime of the stretcher and also the number of stretchers. [5] Presents a model used to assign patients to beds and find a free one during a stay for any patient.

III. MODELING

In this section, we present the model established to determine the planning of the stretchers in the transport of patients.

A. Description of the problem of patient transportation system

- We know the duration of each mission consisting in transporting a patient between hospital units.
- The durations of empty moves are also known as they are also a transport between two units of the hospital.
- The planning is made for stretchers and not for porters.
- Each mission is associated with only one patient.
- Each mission is associated with an earliest starting time.
- A stretcher is allocated at most one mission associated with a single patient over a given period.
- There are dependent missions: it is necessary for the second task to be affected after the first one, even if they are not affected to the same stretcher.
- The duration of treatment and analysis of each mission are known.

Fig. 2 shows the successive moves of a stretcher.

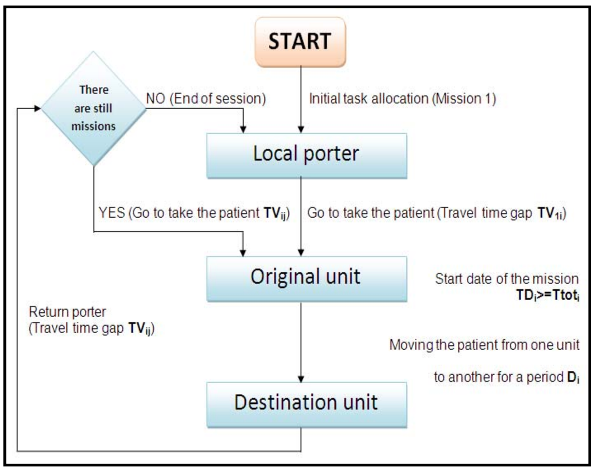

Figure 2. The sequence of moves for the patient transportation system

Our goal is to find an empty stretcher during a mission for each patient. We try to find an optimal allocation. We have chosen to minimize empty moves because we interpret from audits and reports made on the patient transportation system that the empty durations reflected heavily on the allocation and quality of service. We also take into account additional constraints such as earliest starting times and dependencies between tasks.

B. Mathematical modeling of patient transportation system

Our model is presented as follows:

Data:

- B = number of stretchers.
- N = number of missions.
- $Ttot_i$ = earliest starting time of mission *i*.
- D_i = time duration of mission *i*.
- TV_{ij} = empty move duration between missions *i* and *j*.
- R_i = duration of patient treatment of mission *i*.
- DM = planning horizon and maximum duration of a tour by a stretcher bearer.
- M = a large positive value.
- α_{ij} = 1 if mission *i* must be completed before *j*, 0 otherwise.

Variables:

- TD_{ik} = starting time of mission *i* with stretcher *k*.
- x_{ij}^k = 1 if *j* is assigned to stretcher *k* after *i*, 0 otherwise.

The model:

$$Min \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1}^{B} TV_{ij} * x_{ij}^{k} \quad (1)$$

$$\textstyle\sum_{i=1}^{N} \sum_{k=1}^{B} x_{ij}^{k} = 1,\ \forall j \in [2, N] \quad (2)$$

$$\textstyle\sum_{j=1}^{N} \sum_{k=1}^{B} x_{ij}^{k} = 1,\ \forall i \in [2, N] \quad (3)$$

$$\textstyle\sum_{j=2}^{N} x_{1j}^{k} = 1,\ \forall k \in [1, B] \quad (4)$$

$$TD_{ik} \geq Ttot_i,\ \forall i \in [1, N], \forall k \in [1, B] \quad (5)$$

$$TD_{ik} + D_i \leq DM,\ \forall i \in [1, N], \forall k \in [1, B] \quad (6)$$

$$TD_{jk} \geq TV_{1j} * x_{1j}^{k},\ \forall j \in [2, N], \forall k \in [1, B] \quad (7)$$

$$TD_{jk} \geq \left(TD_{ik} + D_i + TV_{ij}\right) + \left(x_{ij}^{k} - 1\right) * M, \\ \forall i \in [2, N], \forall j \in [2, N], \forall k \in [1, B] \quad (8)$$

$$TD_{jk'} \geq (TD_{ik} + D_i + R_i) * a_{ij}, \forall i \in [2, N], \forall j \\ \in [2, N], \forall k' \in [1, B] \quad (9)$$

$$\sum_{j=1}^{N} x_{cj}^{k} = \sum_{i=1}^{N} x_{ic}^{k}, \forall c \in [2, N], \forall k \in [1, B] \quad (10)$$

$$TD_{ik} \in R^{+} \quad (11)$$

$$x_{ij}^{k} \in \{0,1\} \quad (12)$$

The objective function minimizes the sum of the empty moves between missions is illustrated by (1). Equation (2) presents that the mission *i* must be assigned to a single stretcher k before a single mission *j*, all missions must be assigned. (3) A mission *j* must be assigned to a single stretcher *k* and after one and only mission *i*. (4) The initial mission number 1 (one special mission added to facilitate the management and allocation of other missions) must be assigned at the beginning of all stretchers. (5) The effective starting time of mission *i* must be higher than its earliest starting time. (6) For each stretcher, a maximum tour is set, it is equal to the planning horizon, and must not be exceeded. The completion time must be less or equal to this planning horizon. (7) If mission *j* is assigned to a stretcher just after its initial mission, its starting time must be greater than the empty move duration separating these two missions: *j* and mission number 1, (8) If mission j is assigned right after *i* on the same stretcher *k*, its starting time must be higher than the sum of the starting time of mission *i*, its duration and the duration of empty move between these two missions *i* and *j*. We used the positive value M to make this constraint linear and avoid multiplying two decision variables, (9) If there exists a dependency between missions *i* and j, the starting time of mission *j* must be higher than the sum of the starting time of mission *i*, its duration and the duration of patient treatment, (10) To ensure consistency between missions, each mission c must be assigned to a single stretcher *k*. Constraints (11) and (12) are integrity constraints.

IV. Resolution

We propose to solve the mathematical model. It is important that the computation time of the solution is not too high to validate the use of the method. To solve the mixed integer linear program, we used the solver LINGO 11, whose editor is LINDO SYSTEMS, on an Intel ® Core ™ I5 M480 2.67 GHz machine.

We conducted experiments with simple examples to show the feasibility of the proposed model. Then, we performed a test set by varying the following variables: the number of missions, the number of stretchers, the number of dependencies between missions, and the planning horizon.

A. Sample resolution

We choose to illustrate the results for the case of 10 missions and 4 stretchers over a period of 6 hours: this case is freely inspired from orders of magnitude from reality. The maximum duration of a tour is 6 hours. Table 1 shows the data for each mission: duration D, earliest starting time Ttot and duration of patient treatment R. Dependencies between missions are shown in Fig. 3 and empty moves durations between the units are shown in Fig. 4. If A_{ij} is equal to 1 then mission i must be completed before j, otherwise A_{ij} is equal to 0. All times are in minutes.

TABLE I. ASSIGNEENT OF 10 MISSIONS WITH 4 STRETCHERS

Missions	D	Ttot	R
Mission 2	15	30	45
Mission 3	30	42	5
Mission 4	20	66	0
Mission 5	20	25	5
Mission 6	40	64	0
Mission 7	50	23	10
Mission 8	15	68	10
Mission 9	30	24	0
Mission 10	10	37	20
Mission 11	25	88	0

```
A =  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
     0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
     0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0,
     0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0,
     0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
     0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0,
     0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
     0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
     0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
     0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
     0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0;
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Figure 3. *Dependencies between the missions*

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TV = 0, 5, 30, 10, 30, 20, 30, 30, 30, 30, 30,
     0, 0, 10, 30, 30, 30, 30, 30, 30, 30, 30,
     0, 30, 0, 30, 30, 30, 10, 30, 30, 30, 30,
     0, 30, 30, 0, 10, 30, 30, 30, 30, 30, 30,
     0, 30, 30, 30, 0, 30, 30, 5, 30, 30, 30,
     0, 30, 30, 30, 30, 0, 30, 30, 30, 20, 30,
     0, 30, 30, 30, 30, 30, 0, 30, 30, 30, 30,
     0, 30, 30, 30, 30, 30, 30, 0, 10, 30, 30,
     0, 30, 30, 30, 30, 30, 30, 30, 0, 30, 30,
     0, 30, 30, 30, 30, 30, 30, 30, 30, 0, 5,
     0, 30, 30, 30, 30, 30, 30, 30, 30, 30, 0;
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Figure 4. *Empty moves durations*

The solution obtained with LINGO solver is a global optimal solution reached in 1 second, which corresponds to 1037 iterations, to 959 constraints and 550 decision variables (excluding slack variables).

The value of the objective function is 115 minutes of empty moves (minimum).

Out of a total of 10 missions with 4 stretchers were 3 dependencies. The planning horizon is 6 hours.

Fig. 5 and Table 2 show the results.

Fig. 5 illustrates the planning stretchers obtained after solving the linear program with LINGO. We can see that the effective starting times are greater than earliest starting times for each mission and also satisfy the dependencies between missions.

The initial mission number 1 is a one special mission added to facilitate the management and allocation of other missions.

Mission	Start	Stretcher
1	0	0
2	30	3
3	55	3
3	66	1
5	96	1
6	64	2
7	95	3
8	121	1
9	146	1
10	104	4
11	119	4

Figure 5. *Display of the allocation of 10 missions with 4 stretchers*

TABLE II. TOURS OF 10 MISSIONS WITH 4 STRETCHERS

Stretchers		Missions				
Stretcher 1	Tour	1	4	5	8	9
	Start time	0	66	96	121	146
Stretcher 2	Tour	1	6			
	Start time	0	64			
Stretcher 3	Tour	1	2	3	7	
	Start time	0	30	55	95	
Stretcher 4	Tour	1	10	11		
	Start time	0	104	119		

B. Comparison of results

To compare the results obtained by the solver, we performed a test set by varying the input variables: the number of missions, the number of stretchers, the number of dependencies between missions, and the planning horizon.

Then, we interpreted the interactions of the system and output variables as a function of input variables.

We are interested in the change of the solution time and the change in the effective working rate.

- Effective working rate = real working time / duration of commitment for the stretchers
- Real working time = Sum (periods) for all missions.
- Duration of commitment for the stretchers = Sum (End of last mission assigned to the stretcher – Start of first mission assigned to the stretcher) for all stretchers.

TABLE III. THE VARIANCES OF THE INPUT VARIABLES

N°	Number of missions	Number of stretchers	Number of dependencies between missions	Planning horizon (hours)	Value of the objective function	Solution time (seconds)	Real working time	Effective working rate
1	20	4	7	8	235	4	533	0,47
2	20	5	7	8	245	2	533	0,34
3	25	4	5	8	280	2	630	0,66
4	30	4	5	8	330	2	755	0,65
5	35	4	5	8	395	3	872	0,68
6	40	4	5	8	450	4	998	0,68
7	40	4	6	8	450	3	998	0,68
8	40	4	8	8	450	3	998	0,65
9	40	6	6	8	470	8	998	0,68
10	40	6	8	8	470	7	998	0,66
11	40	6	10	8	470	6	998	0,66
12	50	8	10	8	565	23	1205	0,62
13	50	10	10	8	585	33	1205	0,79
14	60	8	6	8	675	44	1445	0,71
15	60	8	10	8	675	78 (1m18s)	1445	0,51

1) Change in number of missions: We first try to interpret the influence of variations in the number of missions. We can conclude that:

With any mission added, the domain of feasible solutions increases where we have three cases:

- If the part added in the domain of feasible solutions does not contain a new optimal solution, the resolution time increases because the distance between the optimal solution and the beginning of the resolution of the solver increases and it is a very special case.
- If the part added in the domain of feasible solutions contains a new optimal solution, the resolution time increases if there is a new optimal solution further to the beginning of the resolution of the solver than the previous optimal solution (as between examples 4 and 5, 5 and 6 of Table 3).
- If the part added in the domain of feasible solutions contains a new optimal solution, the resolution time decreases if there is a new optimal solution more close to the beginning of the resolution of the solver than the previous optimal solution and it is a very special case.

With any mission added the value of the effective working rate increases with the value of the duration of this mission. Also, the duration of commitment for the stretchers increases with the value of the duration of the mission and value of duration of empty moves. Similarly, the probability of increasing the total waiting time of stretchers increases and we distinguish three cases:

- If the duration of the mission added is greater than the sum of the duration of the empty move and the waiting time of stretchers, the value of the effective working rate increases (as between the two examples 4 and 5 of Table 3).
- If the duration of the mission added is less than the sum of the duration of the empty move and the waiting time of stretchers, the value of the effective working rate decreases (as between the two examples 3 and 4 of Table 3).
- If the duration of the mission added is equal to the sum of the duration of the empty move and the waiting time of stretchers, the value of the effective working rate remains the same and it is a very special case (as between the two examples 5 and 6 of Table 3).

2) Change in number of stretchers: Then, we try to interpret the influence of variations in the number of stretchers. We can conclude that:

With all added stretchers, the domain of feasible solutions increases, we distinguish three cases:

- If the part added in the domain of feasible solutions does not contain a new optimal solution, the resolution time increases as the distance between the optimal solution and the beginning of resolution of the solver increases and it is a very special case.
- If the part added in the domain of feasible solutions contains a new optimal solution, the resolution time increases if there is a new optimal solution further to the beginning of the resolution of the solver than the previous optimal solution (as between examples 2 and 7, 9 and 12 of Table 3).
- If the part added in the domain of feasible solutions contains a new optimal solution, the resolution time decreases if there is a new optimal solution more close to the beginning of the resolution of the solver than the previous optimal solution and it is a very special case (as between the two examples 1 and 2 of Table 3).

With all added stretchers, the total waiting time increases because the stretcher added have also its own waiting time. But it can also be used in other missions, which reduces the total time waiting of stretchers. We distinguish three cases:

- If the value of waiting time of the stretcher added is greater than the sum of waiting times of the missions served by this stretcher, the value of the effective working rate increases (as between the two examples 12 and 13 of Table 3).

- If the value of the waiting time of the stretcher added is less than the sum of waiting times of the missions served by this stretcher, the value of the effective working rate decreases (as between the two examples 1 and 2 of Table 3).
- If the value of the waiting of the stretcher is equal to the sum of waiting times missions served by this stretcher, the value of the effective working rate remains the same and it is a very special case (as between the two examples 7 and 9 of Table 3).

3) Change in number of dependencies between missions: Finally, we try to interpret the influence of variations in the number of dependencies between missions. We can conclude that:

With any dependency added, the domain of feasible solutions decreases, we distinguish five cases:

- If the part reduced in the domain of feasible solutions does not contains the previous optimal solution, the resolution time decreases if the part diminished must be solved by the solver before the optimal solution (as between the two examples 14 and 15 of Table 3).
- If the part reduced in the domain of feasible solutions does not contains the previous optimal solution, the resolution time remains the same if the part diminished removes some already excluded by the rules of algorithm Branch & Bound or it must be solved by the solver after the optimal solution (as between the two examples 7 and 8 of Table 3).
- If the part reduced contains the previous optimal solution, the resolution time decreases if there is a new optimal solution closer to the beginning of the resolution of the solver than the previous optimal solution (as between examples 6 and 7, 9 and 10, 10 and 11 of Table 3).
- If the part reduced contains the previous optimal resolution the solution, time increases if there is a new optimal solution further to the beginning of the resolution of the solver than the previous optimal solution.
- If the part reduced contains the previous optimal solution, the resolution time remains the same if there is a new optimal solution than the distance separates it from the beginning of the resolution of the solver is equal to the distance separating the previous optimal solution and the beginning of the resolution of the solver and this is a very special case.

With any dependency added, the probability of increasing the total waiting time of stretchers increases and we have two cases:

- If the dependency added does not have an influence on the optimal solution, the value of the effective working rate remains the same (as between examples 6 and 7, 10 and 11 of Table 3).
- If the dependency added has an influence on the optimal solution, the value of the effective working rate decreases (as between examples 7 and 8, 14 and 15 of Table 3).

V. CONCLUSION

Our work is in the context of scheduling and allocation of transport missions of patients between units in the same institution. We began by studying the literature in the field by presenting research and techniques used to improve the system. Then, we focused our research on the stretching activity and its setbacks. We also tried to identify the main constraints of this activity. We have chosen to present a mathematical modeling of the stretcher service taking into account constraints such as empty moves, dependencies between tasks and earliest starting times. We solved this model by LINGO solver that uses Branch and Bound algorithm. We studied the sensitivity of our model due to variation of parameters. A good-quality schedule obtained with LINGO is better than those made manually: you can spend hours a day preparing schedules of stretchers while LINGO finds an optimal solution in less than 10 minutes. Health systems have shown great interest in using the solvers to develop planning schedules satisfying all the constraints.

We believe that our work raises many issues that could be interesting future prospects. We can cite in particular, the use of other optimization techniques to solve the problem of affectation of missions to stretchers as discrete event simulation with simulation tools or the use of heuristics such as heuristics for the vehicle routing problem and the traveling salesman problem. We can also find techniques that solve the problem of variations in the time resolution. We can extend our work by solving other services problems of the hospital such as the emergency department, operating theaters, the allocation of beds, nursing affectation, scheduling of ambulances. So the study of management and the use of information systems improve hospital systems.

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