Medical Imaging: Exams Planning and Resource Assignment
Hybridization of a Metaheuristic and a List Algorithm

Nathalie Klement[1], Nathalie Grangeon[2] and Michel Gourgand[2]
[1]*École Nationale Supérieure d'Arts et Métiers, LSIS CNRS UMR 7296,*
8 boulevard Louis XIV, 59046 Lille Cedex, France
[2]*LIMOS CNRS UMR 6158, Université Blaise Pascal,*
Complexe Universitaire des Cézeaux, 63178 Aubière Cedex, France
nathalie.klement@ensam.eu, {grangeon, gourgand}@isima.fr

Keywords: Hybridization, Metaheuristic, List Algorithm, Medical Imaging.

Abstract: The presented work is about optimization of the hospital system. An existing solution is the pooling of resources within the same territory. This may involve different forms of cooperation between several hospitals. Problems of sizing, planning and scheduling may be considered. We define the problem of activities planning with resource assignment. To solve this problem, we propose a hybridization between a metaheuristic and a list algorithm. Single based metaheuristics are used. This proposition requires a new encoding inspired by permutation problems. This method is easy to apply: it combines already known methods. With the proposed hybridization, the constraints to be considered only need to be integrated into the list algorithm. For big instances, the solver used as a reference returns only lower and upper bounds. The results of our method are very promising. It is possible to adapt our method on more complex issues through integration into the list algorithm of the constraints. It would be particularly interesting to test these methods on real hospital authorities to assess their significance.

1 INTRODUCTION

Given the current economic situation, everything is done to move towards a better use of goods and services production systems. The hospital system also follows this trend as much or less resources are allocated to it but it should work more efficiently to meet a demand that is increasing. To do so, in 2015, the french government defined the HGT: Hospital Group of Territory, an evolution of the HCT previously presented (Gourgand et al., 2014a). It is a cooperation between public institutions, which are at different places, that implement a common strategy and jointly manage some functions and activities through delegations or skills transfer between them. Some decision support tools are needed to manage this new kind of organization.

The aim of our work is the development of a decision support tool to help to manage HGTs or any hospital cooperations. This tool should be used at different levels: strategic, tactical or operational, to deal with problems of sizing, planning, resources assignment or scheduling. It should be used to anticipate the creation of a new cooperation, to manage this organization day to day, or to react in case of hazard or crisis situation. In this paper, we take the problematic of medical imaging over a HGT as an example. Some material resources, such as X-ray, scanner, MRI, are located at different places belonging to the HGT. Human resources work there and have specific competences on these material resources. Some patients need to pass an exam on such a material resource. The planning horizon can be some days or weeks, divided in periods of half-days. Some incompatibilities and time constraints are defined. The tactical level will be discussed in this paper: the objective is to assign the exams to human and material resources during a period. The other levels can easily be solved by our method which uses some operational research purposes.

2 STATE OF THE ART

Since the last ten years, many methods of operational research have been used to solve hospital system problems. (Rais and Viana, 2011) referenced around two hundred and fifty articles about operational research for hospital system in general. (Car-

Klement, N., Grangeon, N. and Gourgand, M.
Medical Imaging: Exams Planning and Resource Assignment - Hybridization of a Metaheuristic and a List Algorithm.
In *Proceedings of the 10th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2017) - Volume 5: HEALTHINF*, pages 260-267
ISBN: 978-989-758-213-4

doen et al., 2010) referenced more than one hundred and twenty articles about planning and scheduling of operating theater. (Van den Bergh et al., 2013) made a literature review about scheduling human resources and referenced around three hundred articles.

But articles dealing with multi-place system in hospital network are scarce, or their case study are quite limited. Planning surgical vacations by specialty is dealt by (Santibáñez et al., 2007). Availability of operating theater, beds capacity, surgeons preferences and waiting list are considered. The proposed model allocates specialties to operating theater, and is applied to a Canadian study case, composed by eight hospitals, over four weeks. (Everett, 2002) developed a support aid tool to manage the waiting list of patients who need a surgical act. The system is made up by several hospitals, working in cooperation. The waiting list is common for all the hospitals. Each day, each patient is assigned to one place according to the availability of the hospitals. If no hospital is available on one day, patients are assigned the next day. Assignment of resources is not considered. (VanBerkel and Blake, 2007) developed a tool to reduce the waiting time and to plan beds capacity in a surgery service, over several places. It is a problem of allocation of the fixed resources, in an other Canadian example. This tool aims at studying a redistribution of postoperative beds between the places, using simulation tools. Problem of capacity in intensive care unit can result in the cancellation of programmed acts, an overload of medical team or a reject of urgent patients. Thus, urgent patients could be transferred to further places. A cooperative solution is studied by (Litvak et al., 2008), taking into example a case in the Netherlands. Some hospitals belonging to the same territory share some beds to urgent patients.

Researchs are done about the pooling of resources. (Trilling et al., 2006) dealt with the problem of scheduling human resources over different services in one hospital. The objective is to share resources within larger surgical suite, in order to reduce the costs. At another level, it can be seen as a sharing of resources from different places within larger organization such as HGT. In this paper, concerned resources are stretchers and nurses, who are common resources used for any hospital services and locations.

A lot of researches about hospital system are dedicated. Articles consider three problems: sizing, planning and scheduling. Most of the papers focuses on one particular problem. Their models and resolution methods are not easily reusable. Our proposed model and tool are generic, so they could be reused as often as possible.

3 ANALYSIS

To analyze our system, we split the system into three subsystems: the physical subsystem (physical entities used to perform all the activities, their geographical distribution and their interconnections), the logical subsystem (flows that the system should treat, all activities concerning the treatment of these flows and all entities in the system relating to them) and the decision subsystem (center of decision which contains all the decision rules).

3.1 Physical Subsystem

The HGT is composed by several places. There is a known distance between each place.

On each place, there are one or several material resources. A material resource belongs to a type (for instance X-ray, scanner or MRI). Each material resource has an opening schedule which defines the times when the material resource is available over each period. For example, a given material resource may only be available five hours on Monday because it needs a maintenance operation or because an external doctor reserved it. Overtime may be allowed but is limited in time.

Human resources compose a medical team. The composition of this team depends on the considered exam. This team should have a specific number of stretchers, specialist doctors, nurses, etc. Human resources belong to a given place but can work on other places belonging to the same HGT, allowing a pooling of human resources over the HGT. Moves are not allowed within the same period, but between two periods. A time is given to human resources to go from a place to another. A human resource can use one or several types of material resource according to its skills. A skillful human resource, who can work on several types of material resources, is potentially less efficient than a human resource who can only work on one type of material resource, or one particular material resource. This efficiency should be translated in the processing time of the concerned exams. Each human resource has a planning which defines its regular work time, taking into account break times and holidays. Time to move from one place to another is included in the work time of human resources. Overtime may be allowed but is limited in time.

3.2 Logical Subsystem

The logical subsystem defines the flow: the set of exams to plan and assign, and the relationship between these exams and the resources previously defined.

An exam should be done before a period at the latest, called a due date. Each exam has a known processing time which depends on the assigned human and material resources. Each exam starts at one period and ends at the same one. Each exam has a reference place, where it should be done, if possible.

An exam needs a given number of human resources and one material resource. All required resources must be compatible with each other. By definition, an exam is compatible with some material resources, so the assigned material resource must be compatible with the exam. This material resource belongs to a type, so the assigned human resources must have the needed skill to use this type of material resource. The place where the exam is done is deduced from the one where is located the assigned material resource.

3.3 Decision Subsystem

The objective is to develop a model which, from a set of exams, builds a planning associating the triplet {exam, human resources, material resource} to a period. The study is made in a predictive approach, all the exams can be treated since the beginning of the planning horizon. The objective of this model is not to schedule exactly the exams but to assign one period to each exam. This planning must optimize some criteria and respect some constraints.

3.3.1 Criteria

Three categories of criteria can be defined: economical, about the comfort of the patient, and about the proper functioning of the HGT.

Concerning the economical aspects, criteria are about the costs. Occupation rates of each place, each material resource and each human resource help to ensure the proper use of these entities. To be the most economic, these occupation rates have to be maximized. However, it can be preferable to define a security margin, so the HGT can be reactive in case of hazard. All exams are planned during the considered planning horizon. The makespan is the period assigned to the last exam. It ensures that all exams are assigned as soon as possible. The smaller the makespan is, more time remains free at the end of the planning horizon to potentially treat the next exams. The number of moves of human resources in the HGT should be considered, as well as overtime of human and material resources. Overtime and moves have a cost for the HGT. It is better to minimize them. But it can be interesting to allow some overtime or some moves to increase the number of exams during the considered period.

About the comfort of the patient, the criterion is the number of exams done at their reference place. If some exams cannot be done at their reference place, the distances between the reference places and the effective ones may be minimized.

About the medical criterion, the number of exams done before their due dates has to be maximized. Thus, if a patient needs other exams, the next ones could be done on time. If an exam is planned after its due date, the tardiness may be minimized.

3.3.2 Constraints

Constraints that Must Be Respected

- Each exam must be assigned to human resources, one material resource and one period. The considered human resources must be assigned during the period at the place where the considered material resource is located.
- Compatibility between the material resource and the exam: the assignment must satisfy the given list of incompatibilities between exams and material resources.
- Compatibility between skill of the human resource and the type of the material resource: for each exam, the human resource must be able to work on the considered material resource.
- If a human resource can move during the planning horizon, its moves are constrained: a human resource can only work at one place during one period.

Constraints that May Be Respected

- Exams should be done before their due dates and at their reference place.
- Material resources and human resources may be used or work during their opening schedule. Otherwise, additional time is considered as overtime. Overtime is limited in time.

4 CONSIDERED PROBLEMS

The considered problem is defined as follow: exams planning and assignment of needed material and human resources. The previous analysis was about the complete problem. Some hypothesis are made to divide this complete problem into three problems.

4.1 Hypothesis

The following hypothesis are made:

- Only one human resource and one material resource are needed to perform exams. Human resources are compatible with one or several types of material resources.
- Processing time of the exams are given and fixed.
- Opening schedules of material resources are equal in every periods.
- To each exam, the release date is equal to the date of appointment decision. These dates are equal to zero: all exams are known at the beginning of the planning.
- Distances between places are taken into account in the time allocated to the human resources to move from one place to another. This time is assumed to be constant, all places are equidistant to the others.
- Overtime is not allowed.

4.2 Definition of the Considered Problems

The complete problem is divided into three problems of increasing difficulty:

- Problem 1 is the more basic: human resources are not considered. Only the material resources are considered.
- Human resources are considered in Problem 2. They can work on one or several types of material resources. They cannot move, they work all the time at the same place. The assignment of the human resources at the places is given.
- Human resources are mobile in Problem 3. They can work on several places, they can move from one place to another. The assignment of the human resources at the places has to be built by the model.

Two criteria are used in the following study:

- Sum of assigned periods to all exams, which ensure that all exams are planned as soon as possible.
- Number of exams assigned before their due date.

4.3 Analogy with the Bin Packing Problem

Our problem can be seen as a bin packing problem (Gourgand et al., 2014a). The bin packing problem considers N items, with a given size, and some bins with the same capacity. The aim is to pack all the items in a minimum number of bins. The size of the packed items has to respect the capacity of the bins. Each item has to be assigned once and only once.

4.3.1 Without Human Resources

Considering Problem 1, the aim is to assign exams to a material resource during a period. The planning horizon is made by couples (resource, period). The objective is to assign exams to couples (resource, period). Exams have to be done as soon as possible: the aim is to minimize the number of couples, (= the number of bins). An example is given by Figure 1, where the assignment of exams to material resources MR_1, MR_2 and MR_3 is considered. Table 1 summarizes analogies between bin packing problem and Problem 1: exams planning with resources assignment.

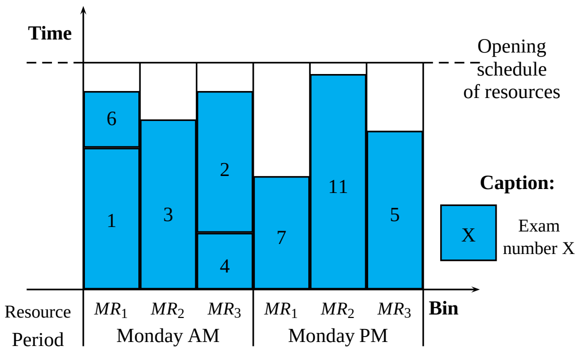

Figure 1: Representation of Problem 1.

Table 1: Analogies between both problems.

	Bin packing problem	Problem of exams planning with resources assignment
Data	Item	Exam
	Bin	Couple (resource, period)
	Size of an item	Processing time of an exam
	Capacity of a bin	Opening schedule of resources
	-	Due date
	-	Reference place
Problem	Assign items to one bin	Assign exams to one couple (resource, period)
Constraints	Capacity of bins	Opening schedule of resources
	-	Constraint of compatibility
Criteria	Minimize the number of used bins	-
	-	Minimize the sum of assigned periods

4.3.2 With Human Resources

Exams have to be assigned to material and human resources during one period. Analogy is made between this problem and interdependent bin packing problem.

Let's take p_1 and p_2 two bin packing problems, with a given number of bins. Groups of bins are defined in both problems. A group should be made by one or several bins. Number of bins can be different for both problems, but number of groups is the same. Each item is assigned to one and only one bin in each problem. Interdependence between both problems is defined as follow: if an item is assigned to a bin from group g in problem p_1, it must be assigned to a bin from the same group g in problem p_2. The aim is to assign items in bins of both problem, by minimizing the number of used bins, satisfying capacity constraints and interdependence between both problems.

In our case, both problems p_1 and p_2 can be defined like this:

- p_1: assignment of each exam to a material resource during a period, respecting the opening schedule of the material resource during the period and the compatibility between the exam and the material resource.
- p_2: assignment of each exam to a human resource during a period, respecting the work time of the human resource during the period and the compatibility between the exam and the human resource.

Compatibility between exam and human resource is not directly defined but can be deduced: an exam is compatible with a human resource if and only if this exam is treated by a material resource from one type and this human resource can work on this type of material resource.

Thus, group g is the couple (period, type). In both problems p_1 and p_2, exam has to be assigned during the same period to the same type of material resource. Figure 2 illustrates the interdependent bin packing problem in the HGT case. The lower portion of the figure is the assignment of exams to material resources and periods, in the same way as Figure 1. The upper portion is the assignment of exams to human resources and periods. In both portions, each exam has to be assigned to the same period and the same type (according to the type of the material resource and the competencies of the human resource to use this type).

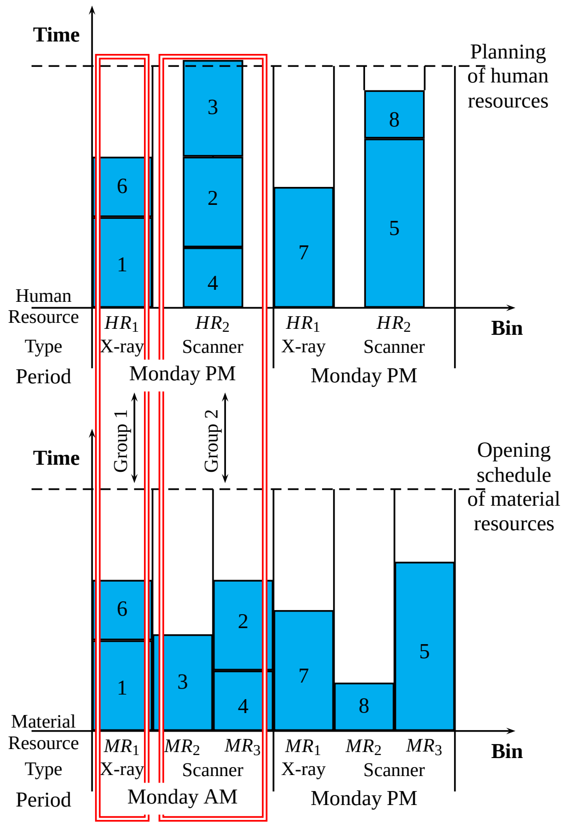

Figure 2: Interdependent bin packing problem.

5 RESOLUTION METHOD

The bin packing problem is NP-Hard (Garey and Johnson, 1979). Our problems are an extension of the bin packing problem, so our problems of exams planning with resources assignment are also NP-Hard. In the following, approximate methods are used to solve them.

Our proposed method is a hybridization of a metaheuristic and a list algorithm. Our tool is convenient because one part is generic: it can be used for any of the considered problems. Only the list algorithm needs to be specific to the considered problem.

5.1 Genericity

The proposed tool, illustrated by Figure 3, uses a hybridization of a metaheuristic and a heuristic, more precisely a list algorithm. A single solution based metaheuristic or a population based metaheuristic can be used. The encoding used by the metaheuristic is a list Y of exams. The list algorithm L considers the exams according to their order in list Y to plan and assign them to the required resources, considering the problem constraints. This builds a solution X. The objective function H evaluates the solution X. According to this evaluation, the solution is chosen or not by the metaheuristic. At the end of the running, the given solution by the hybridization is the best list Y^* of exams: the one which optimizes the objective function by applying the list algorithm. This hybridization can be used to solve many problems: the specificity of a given problem is only considered in the list algorithm.

5.2 A List Y of Exams

The general scheme of the encoding is given by Equation (1), with Ω the set of all the lists Y and S the set

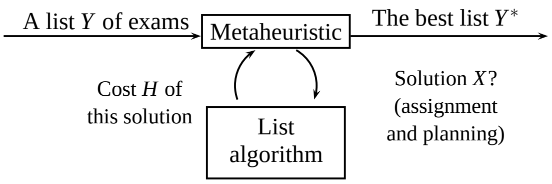

Figure 3: Hybridization metaheuristic - List algorithm.

of all the admissible solutions X built by the list algorithm L.

$$Y \in \Omega \underset{Heuristic\ L}{\longrightarrow} L(Y) = X \in S \underset{Criterion\ H}{\longrightarrow} H(X) \quad (1)$$

The set Ω is the set of all permutations of exams. Cardinal of Ω is $N!$ with N the number of exams. One solution $Y \in \Omega$ is a list of exams. More details about the encoding are given in (Gourgand et al., 2014b).

5.3 Metaheuristic

The metaheuristic performs in the set of solutions Ω. An initial solution is randomly computed: a list of exams randomly sorted between one and the number of exams. Several metaheuristics have been used: some single solution based metaheuristics such as iterated local search or simulated annealing. A neighborhood system is used to visit the set of solutions, it allows to go from one solution to another one. Neighborhood system V is a permutation of two exams in the list Y: the exam at position i permutes with the one which is at position j. V satisfies the accessibility and reversibility properties.

5.4 List Algorithm

A list algorithm is used to build the solution X from the list Y: it assigns the exams to resources and to periods.

List scheduling algorithms are one-pass heuristics that are widely used to make schedules. A standard list scheduling algorithm constructs a schedule by assigning each job in listed order to the first machine that becomes idle (Zhu and Wilhelm, 2006). It is important to work with a list algorithm, because the metaheuristic browses the set of solutions. So the used algorithm needs to consider the order of the list to assign exams to resources and periods.

Our problem has be analyzed as a bin packing problem and some list algorithms have been proposed since the definition of this problem (Johnson, 1973). So our developed list algorithm is inspired by them. For instance, considering Problem 1, in which human resources are not considered, Algorithm 1 is an extension of the First Fit algorithm for the bin packing problem. Other list algorithms can be adapted from Algorithm 1 to solve the cases of Problems 2 and 3, considering human resources.

Algorithm 1: List Algorithm First Fit HGT.

Data: List of exams $(Y_i)_{i\in\{1,N\}}$; opening schedule of all resources during all periods; processing time of all exam

Occupied time := 0 for all resources and all periods
forall the i **do**
    First resource, first period, *assigned* := $false$
    while (*assigned* = $false$) *AND current period* $\leq$ *max of periods* **do**
        while (*assigned* = $false$) *AND current resource* $\leq$ *max of resources* **do**
            if *exam* Y_i *is compatible with current resource* **then**
                if *exam* Y_i *fits in couple (resource, period)* **then**
                    Assign exam Y_i to couple (resource, period)
                    Update occupied time of couple (resource, period)
                    assigned := $true$
            Next resource
        Next period

5.5 Objective Function

Solutions are compared according to an objective function which characterizes the quality of the solution. In our case, the objective function represents the timing aspect of our problem. Exams have to be done as soon as possible, thus the makespan, the period assigned to the last exam, should be considered. Because many solutions may have the same makespan, we choose instead the sum of assigned periods to all exams, so the solutions can be dissociated. This criterion is written H_S. Another criterion is considered to ensure that most of the exams are assigned before their due date. This criterion, written H_D, is computed as the number of exams assigned after their due date. The weighed criteria method is used (Coello, 2000). The objective function is a weighed sum between both criteria, defined by Equation (2). ω_D is chosen equal to 5 because H_S is always smaller than 10^5 so both criteria are easily readable. This function has to be minimized.

$$H(X) = 10^{\omega_D} \times H_D(X) + H_S(X) \qquad (2)$$

5.6 The Best List Y^*

Algorithm 2 describes the whole method with the example of stochastic descent as the used metaheuristic. Stochastic descent may be used in an iterated local search. The set Ω of the lists of exams is browsed thanks to the metaheuristic using neighborhood system V. Lists are compared thanks to the list algorithm L and the objective function H. According to an acceptance criterion, some lists are selected. At the end, the metaheuristic gives the best found list Y^*.

Algorithm 2: Hybridization between stochastic descent and a list algorithm.

Data: Initial solution Y
$X := L(Y)$
while *necessary* **do**
    Choose uniformly and randomly $Y' \in V(Y)$
    $X' = L(Y')$
    if $H(X') \leq H(X)$ **then**
        $X := X'$
        $Y := Y'$
Result: $Y^* = Y$

6 EXPERIMENTS

The data are randomly generated but the characteristics and the size of the data represent real instances. The HGT is composed by 3 places. The planning horizon is made by 8 to 40 periods. As a remind, one period represents one half-day, thus the planning horizon is between 4 and 20 days. 4 to 8 resources are available. 50 to 500 exams need to be planned and assigned. Incompatibilities between exams and resources are randomly generated. Each processing time is between 5 and 100. Each material resource has an opening schedule equal to 300 minutes.

The results are detailed in Table 2. The host machine is powered by an Intel Xeon X5687 quad-core CPU running at 3.6 GHz. The computation has been stopped after thirty minutes. Each reported result is the value of the objective function for the best solution found in less than thirty minutes, but most of the time, the best solution is found in a few minutes. The results are presented as a couple of values $(H_D; H_S)$ with H_D the number of exams assigned after their due dates, and H_S the sum of assigned periods to all the exams. The results compare three methods:

- The resolution of the mathematical model with an exact method by using the solver CPLEX. If no optimal solution has been found in less than thirty minutes by the solver, no result is written.
- Our results from the method previously published in (Gourgand et al., 2014a), using two single solution based metaheuristics (iterated local search and simulated annealing) in a classical way: the best value found by all these methods is reported.
- Our results from our proposed method detailed in the current paper. The used metaheuristics are distinguished: iterated local search and simulated annealing, written ILS* and SA*.

The results are promising. Firstly, this problem has been solved by CPLEX thanks to our mathematical model previously proposed. The solver finds an optimal solution only for small size of problems (less than two hundred exams over four days). The solver does not find any solutions when the size of the problem increases. Then, it has been solved with two approximate methods: in a classical way, and with a hybridization. Both methods find an optimal solution for the small instances. For biggest instances, the hybridization between a metaheuristic and a list algorithm outperforms our previous method. Simulated annealing seems to work better than iterated local search.

7 CONCLUSION AND PERSPECTIVES

The current hospital context needs to find solutions to improve efficiency of hospital systems. Hospital cooperation has emerged, as Hospital Group of Territory. A pooling of resources may cause a better use of the different places in a same territory. But this cooperation needs some decision support tools to improve or optimize their running. In this paper, we defined the general problem of activities planning with resources assignment in a multi-place hospital context.

Because this problem is NP-Hard, we propose an approximate method to solve it: a hybridization between a metaheuristic and a list algorithm. The results are promising: our method finds good results in a few minutes. An improvement of the results is in process, using a population based metaheuristic: Particle Swarm Optimization. Using PSO, the results are very good for small instances: an optimal solution is found in a few seconds, but the method still needs some tuning for the biggest instances.

Thanks to the hybridization, our method can be easily reusable. Indeed, to solve other problems, only the list algorithm needs to be modified. The metaheuristic part will still be the same. Any kinds of planning, assignment or scheduling problem can be

Table 2: Results: (number of exams assigned after their due dates; sum of assigned periods to all the exams).

Number of exams	CPLEX	(Gourgand et al., 2014a)	ILS*	SA*
50	$(0;51)$	$(0;51)$	$(0;51)$	$(0;51)$
50	$(1;150)$	$(10;147)$	$(1;151)$	$(1;150)$
100	$(0;131)$	$(0;131)$	$(0;131)$	$(0;131)$
100	$(0;517)$	$(2;535)$	$(1;516)$	$(0;518)$
200	$(0;266)$	$(0;266)$	$(0;266)$	$(0;266)$
200	-	$(3;1197)$	$(0;1154)$	$(0;1135)$
300	-	$(0;548)$	$(0;537)$	$(0;534)$
400	$(0;830)$	$(0;890)$	$(0;841)$	$(0;835)$
500	-	$(0;1350)$	$(0;1241)$	$(0;1234)$
500	-	$(194;8218)$	$(19;6382)$	$(18;6659)$

solved thanks to this tool by changing the list algorithm: for instance, it has been used to solve an industrial problem (Silva et al., 2016). Problems with human resources can easily be solved by developing some new list algorithms dedicated to them. Then, a direct application to a hospital system could be envisaged. Other applications in the hospital field could be done, in other hospital services, with other resources, etc. We could extend our current work about medical imaging to medical surgeries. More constraints about medical team should be considered. The next problematic is to consider patients with several exams or surgeries, by taking into account precedence constraints between them.

REFERENCES

Cardoen, B., Demeulemeester, E., and Beliën, J. (2010). Operating room planning and scheduling: A literature review. *European Journal of Operational Research*, 201(3):921–932.

Coello, C. A. (2000). An updated survey of ga-based multiobjective optimization techniques. *ACM Computing Surveys (CSUR)*, 32(2):109–143.

Everett, J. (2002). A decision support simulation model for the management of an elective surgery waiting system. *Health Care Management Science*, 5(2):89–95.

Garey, M. R. and Johnson, D. S. (1979). *Computers and Intractability: A Guide to the Theory of NP-completeness*. WH Freeman and Company, New York.

Gourgand, M., Grangeon, N., and Klement, N. (2014a). Activities planning and resource assignment on multi-place hospital system: Exact and approach methods adapted from the bin packing problem. In *7th International Conference on Health Informatics, Angers, France*, pages 117–124.

Gourgand, M., Grangeon, N., and Klement, N. (2014b). An analogy between bin packing problem and permutation problem: A new encoding scheme. In *Advances in Production Management Systems. Innovative and Knowledge-Based Production Management in a Global-Local World*, volume 438, pages 572–579. Springer Berlin Heidelberg.

Johnson, D. S. (1973). *Near-optimal bin packing algorithms*. PhD thesis, Massachusetts Institute of Technology.

Litvak, N., van Rijsbergen, M., Boucherie, R. J., and van Houdenhoven, M. (2008). Managing the overflow of intensive care patients. *European journal of operational research*, 185(3):998–1010.

Rais, A. and Viana, A. (2011). Operations research in healthcare: a survey. *International Transactions in Operational Research*, 18(1):1–31.

Santibáñez, P., Begen, M., and Atkins, D. (2007). Surgical block scheduling in a system of hospitals: an application to resource and wait list management in a british columbia health authority. *Health care management science*, 10(3):269–282.

Silva, C., Klement, N., and Gibaru, O. (2016). A generic decision support tool for lot-sizing and scheduling problems with setup and due dates. In *International Joint Conference - CIO-ICIEOM-IIE-AIM (IJC 2016), San Sebastian, Spain*. ICIEOM.

Trilling, L., Guinet, A., and Le Magny, D. (2006). Nurse scheduling using integer linear programming and constraint programming. *IFAC Proceedings Volumes*, 39(3):671–676.

Van den Bergh, J., Beliën, J., De Bruecker, P., Demeulemeester, E., and De Boeck, L. (2013). Personnel scheduling: A literature review. *European Journal of Operational Research*, 226(3):367–385.

VanBerkel, P. T. and Blake, J. T. (2007). A comprehensive simulation for wait time reduction and capacity planning applied in general surgery. *Health care management Science*, 10(4):373–385.

Zhu, X. and Wilhelm, W. E. (2006). Scheduling and lot sizing with sequence-dependent setup: A literature review. *IIE transactions*, 38(11):987–1007.