Meta-heuristics for surgical scheduling problem with hospitalization

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Abstract: In this work, we deal with surgical scheduling problem including the hospitalization stage before and after surgery in addition to pre-surgery, surgery and post-surgery stages. The problem is considered as a four stages hybrid flow shop scheduling problem with recirculation, resource synchronization, and no wait/ blocking constraints. It consists of assigning surgery patients to different resources and determining their sequencing over a one day period, while taking into account different temporal and resources constraints. The objective is to minimize the patients' average length of stay (LOS) in the hospital. To deal with this problem, we provided two meta-heuristics; Iterated Local Search (ILS) and hybrid Genetic Algorithm (HGA).

Keywords: Surgery scheduling, Hospital ward, hybrid flow shop scheduling, meta-heuristics

1/Introduction

The operating theatre planning and scheduling problems have been widely treated in literature by the management science and operational research communities (Cardoen et *al.*, 2010; Guerriero & Guido, 2011). The operating room planning and scheduling problems have been treated simultaneously in several papers (Roland et *al.*, 2010; Liu et *al.*, 2011; Marques et *al*,. 2014; Cardeon et *al.*, 2010; Guerriero & Guido, 2011). The surgery scheduling problem is proved NP-hard (Fei et *al.*, 2010; Cardoen et *al.*, 2009; Xiang et *al.*, 2015). Mathematic models and approximate methods have been proposed in literature (Fei et *al.*, 2006, 2010; Guinet & Chaabane, 2003; Jebali et *al.*, 2006).

In this paper, we address a daily surgery scheduling problem with the integration of patients' hospitalization. The objective is to minimize the patients' average length of stay (LOS) in the hospital. The problem is similar to the one studied by Hachicha & Mansour, (2016), but we add nurses and anesthetists in the stage of surgery, and impose a no-wait constraint between the three stages of surgery (pre-surgery, surgery and recovery). Moreover, we take into account only electives patients. Various resources constraints are considered: the resource availability (surgeons, nurses, anesthetists, operating rooms, PHU beds, PACU beds and beds in the hospitalization unit), the surgery priority constraint, constraints on the surgeon specialty and surgery complexity. We take into account diverse assumptions: open scheduling strategy; surgeons are non-homogenous, i.e. different specialty and experience, whereas other resources are considered multi-functional and homogenous, i.e. PHU/PACU beds, hospital beds, operating rooms, nurses, and anesthetists. Each surgery should be performed by a team of specialized staff, with a duration that varies according to the surgeon, even for same type of surgery; the durations of surgery, pre-surgery, recovery time and hospitalization before and after surgery are known in advance; the operating theatre is

open all the day (24h/ 24 h). To deal with this problem, we provided two types of approximated algorithms: Iterated Local Search (ILS) and hybrid Genetic Algorithm (HGA).

2/ Iterated Local Search

The main features of this approach are two: firstly, it is a stochastic method based on single solution; secondly, its effectiveness lies to explore the neighborhood of the current solution to gradually improve its quality during the various iterations. The principal steps of this approach are local search and perturbation (Lourenço et *al.*, 2002). The framework of the ILS approach is summarized as follows: x_0 is an initial solution on which we apply local search in order to obtain a better solution $\hat{x}$. The local search contains two neighborhood structures (N1 and N2): The neighborhood N1 consists of inserting a patient between two other patients in the sequence and the neighborhood N2 consists of swapping two patients within a sequence at random. We apply all possible moves to the incumbent solution until the first improvement is occurred. To avoid local optimum, a perturbation is performed to $\hat{x}$ in order to find a new solution x_1 where the perturbation is a random swap between two patients in a sequence. The local search is applied again to x_1 in order to obtain a new local optimum $\tilde{x}$. If the acceptation criterion is met, the solution $\tilde{x}$ replaces $\hat{x}$ and the process continues i.e. apply again the local search. An evaluation procedure is proposed to transform each sequence to a feasible solution. We taken the set of patients that will be performed on the scheduling day and we assigned them to hospital beds (stage1) according its order in the list. Then, they are discharged from stage (stage 1) and assigned to PHU beds (stage2), after, they are assigned to the operating rooms (stage 3), then stage 4 and finally they return to available hospital beds (stage 5). After the filling of all stages, a *t* time, the first patient in the list will inserted to an available hospital bed and he/ she remains waiting until all resources in the three surgery stages of will be available. In each time we discharged a patient from stage and inserted his to the follow stage with respecting the temporal and resources constraints. When the patient finished its recovery in stage 4, he is returned to an available hospital bed which has the nearest availability date to the completion time of this patient in the stage 4. We repeat this procedure until all patients are performed.

3/ Hybrid Genetic Algorithm

We proposed a combination between the genetic algorithms (GA) (Goldberg, 1989) and the local search procedures (LS) to obtain a hybrid genetic algorithm (HGA). Our hybrid approach GA&LS is motivated by the fact that in the case of a large search space, the use of the LS may fall into local optimum quickly. Therefore, we use LS to refine the GA search through successive iterations and maximize the chance of convergence to an optimal solution through using various search spaces. For generating an initial population, we apply *npop* times a random swap between the set of patients, where *npop* represents the population size. The selection method is the roulette-wheel selection process (Goldberg, 1989). Its principle is to first assign to each solution a probability of being selected based on its fitness value. We consider the same crossover procedure provided in (Murata & Ishibuchi, 1994) according to a probability P_c: an offspring X_{new} is obtained by appending the beginning (resp. the end) of the first parent to the end (resp. the begning) of the second parent. The mutation operator leads to randomly swapping a pairs of patients location in a sequence (Aldowaisan & Allahverdi, 2003) according to a probability P_m. We proposed a LS algorithm as an improvement procedure after mutation using the two structures of neighborhoods *N1* and *N2*

that are applied in the ILS. The obtained solution is compared to the worst individual in the population, and the best one is kept inside the population.

4/ Computational results

To make computations, we considered data from Xiang et *al.*, (2015) related to the three stages of surgery in the operating theater of a medium scale hospital in China. We added data concerning the duration of hospitalization and the number of hospitalization beds inspired from Hachicha & Mansour, (2016). Three instances have been generated to test our algorithms. Table 1 shows the numerical results related to the Iterated Local Search approach and the Hybrid Genetic Algorithm in terms of objective value (average length of stay of patients in the hospital) and computation time (CPU in seconds). Thus, according to the computational experiments, the results of HGA outperform the results giving by ILS algorithm.

Table1: the results of meta-heuristics approaches (ILS and HAG)

Instances	**ILS (mn)**		**HGA (mn)**	
	LOS	**CPU (sec)**	**LOS**	**CPU (sec)**
Inst 1	1663	19	1507	10
Inst 2	1335	30	1234	14
Inst 3	954	27	888	10
Average	1317.5	25.5	1210	11.5

Numerical results show that the HGA outperforms the ILS in terms of objective value and CPU time. So the hybridization process between GA and LS has a favorable effect in this problem case. Therefore, it combine between two main advantages of these algorithms, where LS offers a local exploration tool to the GA and the latter offers a global exploration, i.e. large diversification of solutions, by giving a good beginning for the LS which covers a large part of the search space. Thus, the hybrid approach can provide more robustness.

5/ Conclusion

We studied the surgical scheduling problem which is an NP-Hard Problem. Two meta-heuristics approaches have been provided to find good solutions in a reasonable time. We tested these approaches on three generated instances based on rules from the literature. The numerical results are promising and show the superiority of the HGA. The future work will focus on the improvement of the algorithms improvement.

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