Patient transporter routing problem

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**Abstract**. The patient transporter is a non-medical staff in the hospital who is responsible for the transportation of patients with their condition, cannot go on their own, when they have to requires medical examination such as X-Ray, MRI or other examinations that have been scheduled. The process transportation of patients in hospital can be reviewed in the routing problem. The Routing problem on the patient transporter can be modeled with Dial-A-Ride Problem (DARP). Focus in the routing problem of patient transporter is cost/distance patient's transporter and patient inconvenience will be minimized

1. Introduction

The hospital became one of the most important organizations in the community. In the operation of hospitals with available resources, staff, doctors, nurses are expected to serve every patient well. Serving every patient well will be done, if the hospital resource management is organized, one of them is a logistics problem. Logistics in the hospital consist of transportation, production, supply and replenishment [1]. In terms of hospital transportation there are transportation of patients, drugs, blood, patient's equipment, food which are done by the transporter. Basically, the service carried out by the transporter varies depending on hospital policy, for example in Vancouver General Hospital (VGH) and St. Paul's Hospital (SPH), the main task of the transporter is to deliver the patient from one place to another, while delivering the blood, the result of X-Ray is only an additional task [2]. Although the transporter receives special training, they are not responsible for providing medical assistance or emergency care [3]. In Indonesia, the transporter service has been applied in hospital X, with the main task is to deliver and pickup of the patients from one place to another within the hospital area. The patient transporter are tasked with moving patients from one location to another within a hospital when the patient requires medical action such as X-Ray examination, Magnetic Resonance Imaging (MRI) or any other examination where the place is used differs from the patient's ward room as well as the patient's condition that is not possible to move themselves.

Although the patient transporter service seems simple, that is to deliver patients from one location to another, but it is influential on hospital operations and costs. For example, the delay of delivery of a patient to a high-cost service unit, such as an operating room or Magnetic Resonance Imaging (MRI) unit, resulted in a reduced utilization of valuable resources. In addition, delayed patient delivery will also interfere with the planned schedule and the worst possible is when the patient arrives after the scheduled start time will result in delayed patient's schedule afterwards so that the patient's waiting time will be higher for subsequent patients. On research Beaudry *et al* [4], mentioned this with the domino's effect as an important role of transporter patient.

Research on the transporter patient has been done by some experts in the disciplines of mathematics, for example application of various scenarios for the assignment of patient transporter with case studies in Vancouver General Hospital, such as totally centralized, one patient transporter dedicated to the operating room (OR), optimized staff schedule with linear programming (LP) [5]. The conclusion of the research that the implementation of staff scheduling optimization scenarios with LP improves for all types of jobs. While Hanne *et al*. [6] relied on simulation techniques to assess the impact of using the proposed dispatching policies.

Mathematical model of the transporter patient as routing problem express by Turan *et al* [7]. On this research, Turan *et al.*  introduces several different models with various conditions. All models are based on the routing problem modelling with dial-a-ride problem.

The Dial-a-Ride Problem (DARP) consists of designing vehicle routes and schedules for n users who specify pick-up and drop-off requests between origins and destinations [8]. Because of DARP deals with passenger transportation so DARP models consider the inconvenience of customers, which can be expressed as a waiting time, travel time, or deviation from the schedule of departure and arrival and also consider the transportation cost. Not a few researchers who examined the DARP model as expressed by Cordeau *et al.* [9] about dial-a-ride model and algorithm, in addition researchers Melachrinoudis *et al.* [10] performs dial-a-ride model with soft time windows and its application to the CAB Health and Recovery Services, Inc.

Furthermore, this paper examined about the routing problem on the transporter patient which is modeled with DARP.

1. Hospital setting and patient transporter operation

Hospitals that become modeling studies are types of hospitals that are structured blocks, which are units scattered in hospital buildings. These hospital units can be grouped into several hospital wards, i.e. hospitalized patients with multiple beds and some hospital facilities to perform medical examinations or surgical venues. In the hospital building there is also a room for a patient transporter called as home depot. Each home depot has coverage area to be served. In this home depot, the patient transporter will receive a list of transport assignments.

Home depot becomes the starting location of the patient transporter to start the transport process and is also the end location of the transportation process. In the process of transportation of patients, travel time traveled by the patient transporter there are two types of travel time when the transporter delivers the patient from the pickup location to the destination and travel time of the transporter when not delivering the patient is when picking up the patient or at the time of returning to the Home Depot called as empty travel time.

In the process of transportation of patients during the pick-up and drop off process, the patient's transportation in the hospital is differentiated into two types namely inbound and outbound. Inbound transport is when the patient transporter transports the patient from the ward to the examination unit. While the outbound transport is when the patient transporter pick-up the patient after conducting an examination to return to the previous ward. The patient's transportation process can using wheelchairs or wheeled beds depending on the patient's condition. Each patient transporter can only transport one patient in one transportation processing time. Each patient has a scheduled examination or treatment in the hospital unit, so data on the location of the screening and examination time has been known in advance.

It has been mentioned that the examination time has been scheduled. Therefore, the patient may not arrive late to the examination location in accordance with the scheduled time, and the start time of the examination is referred to as critical time. The patient may be delivered early, but this will have an impact on the patient's waiting time. In addition, the patient transporter must pick up the patient after conducting the examination in accordance with the end time of the examination if the patient transporter is delayed then this will also impact the increase in the patient's wait time.

1. Routing model for transporter patient

This model is based on the research Turan *et al.* [7] with modification.

## Model assumptions

There are some assumptions used on the model :

1. The structure of the hospital is a block with ward units and examination rooms scattered.
2. The time between locations in the hospital includes estimated queue time.
3. The examination time data for each patient has been scheduled and the duration is known based on estimated processes.
4. Patient delivery equipment such as wheelchairs or wheeled beds, are in one place with the patient.
5. The patient transporter performs early transportation from the home depot and will return to the home depot when it has finished the delivery of a series of patient transportation requests.

## Set notations

There are set notation that used on the model:

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| --- | --- | --- |
| $$R^{I}$$ | : | the set of inbound transportation requests. |
| $$R^{O}$$ | : | the set of outbound transportation requests. |
| $$R$$ | : | the set of all transportation requests $R=R^{I} ∪R^{O}$. |
| $$S$$ | : | the set of patient transporter . |
| $$R^{\*}$$ | : | the set $R^{\*}=R ∪\left\{0\right\}$ with $0$ is notation for home depot.  |

## Parameters notation

There are parameter notation that used on the model:

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| $$E\_{i}$$ | : | critical time for transportation requests $i$. |
| $$T\_{ij}$$ | : | travel time between node $i$ and $j$. |
| $$S\_{i}^{T}$$ | : | service time for transportation requests $i$, includes the patient's preparation time and travel time from the pickup location to the destination location. |
| $$α$$ | : | penalty time for the patient transporter when empty travel time occurs. |
| $$β$$ | : | penalty time for patient's waiting time. |

## Variable notations

There are variable that used on the model:

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| $$a\_{i}$$ | : | arrival time at the pick-up location of transportation request $i$. |
| $$b\_{i}$$ | : | start time of transportation request $i$ to the destination location. |
| $$c\_{i}$$ | : | arrival time at the destination location of transportation request $i$. |
| $$d\_{i}$$ | : | time when the patient transporter leaves the destination location of transportation requests $i$. |
| $$x\_{ijs}$$ | : | equals 1 if the patient transporter $s$ is assigned to a transport request $j$ after completing the transport request $i$. |
| $$y\_{is}$$ | : | Equals 1 if the patient transporter $s$ is assigned to the transport request $i$. |

## Objective function

The objective function to be achieved is to minimize the total travel time and the patient waiting time. Because the patient must not be late at the destination on the inbound transportation, waiting time for the pickup process should be minimal, which is the difference between critical time the beginning of examination with arrival time to a minimum. In addition, the patient waiting time for the delivery process to the destination location should also be minimal i.e. the difference between the start time of departure with critical time must be minimal.

The purpose function is represented in the equation (1) using a weighted sum approach. Weights in the objective function show penalties for each of sub objective functions. Coefficient $α$ is a penalty for total empty travel time of the patients transporter while the $β$ coefficient is a penalty for the total patient waiting time, with $α, β>0$. This penalty represents the priority of the sub objective function.

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| $$α\sum\_{i\in R^{\*}}^{}\sum\_{j\in R^{\*}}^{}\sum\_{s\in S}^{}x\_{ijs}T\_{ijs}+β\left(\sum\_{i\in R^{I}}^{}\left(E\_{i}-c\_{i}\right)+\sum\_{i\in R^{O}}^{}\left(b\_{i}-E\_{i}\right)\right).$$ | (1) |

## Constraints

There some constraints that need to be consider

* + 1. Constraints for patient transporter service. Based on the assumption each patient transporter can only serve one patient at the same time.

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| $$\sum\_{s\in S}^{}y\_{is}=1, ∀i\in R.$$ | (2) |

* + 1. Constraint back to home depot. Based on the assumption that each patient transporter will return to the home depot after conducting patient transportation. It is represented in the equation:

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| $$y\_{0s}=1, ∀s\in S.$$ | (3) |

* + 1. Network constrains. Network constraints relate to route travel between two points.

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| $$\sum\_{j\in R^{\*}}^{}x\_{ijs}=\sum\_{j\in R^{\*}}^{}x\_{jis}, ∀i\in R^{\*},∀s\in S.$$ | (4) |

* + 1. Estimated arrival time to the destination location. Arrival time of patient to the destination can be estimated from departure time plus service time includes preparation time before departure and travel time between pick-up location and destination location. It is represented in the equation

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| $$c\_{i}=b\_{i}+S\_{i}^{T}, i\in R.$$ | (5) |

* + 1. Sequence time constraints. Arrival time for the patient transporter is early or equal to the departure time to the destination location, while the arrival time of the patient transporter at the destination location must be early or equal to the time when the patient transporter leaves the destination location.

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| $$a\_{i}\leq b\_{i}, ∀i\in R.$$ | (6) |
| $$c\_{i}\leq d\_{i}, ∀i\in R.$$ | (7) |

* + 1. Critical time constraints. Based on the previous explanation that there two types of the transportation request, inbound and outbound. Note that for inbound transportation, the arrival time of the patient to the examination location must be less than or maximum equal to the time of start of the examination procedure. While outbound transportation, the start time of the transportation of the patient back to ward will done by the patient transporter at least when the procedure time of examination is over.

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| $$c\_{i}\leq E\_{i}, ∀i\in R^{I}.$$ | (8) |
| $$E\_{i}\leq b\_{i}, ∀i\in R^{O}.$$ | (9) |

* + 1. Constraints between two transport requests. If $x\_{ijs}=1$ then arrival time of the patient transporter $s$ at the pick-up location $j$ equals to the time when the patient transporter left the location of transportation request $i$ with the addition of travel time between transportation request location $i$ and $j$.

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| $$d\_{i}+T\_{ij}\leq a\_{j}+M\left(1-x\_{ijs}\right), ∀i,j\in R^{\*}, ∀s\in S.$$ | (10) |
| $$d\_{i}+T\_{ij}\geq a\_{j}+M\left(1-x\_{ijs}\right), ∀i,j\in R^{\*}, ∀s\in S.$$ | (11) |

* + 1. Binary variables. There are two binary variables, i.e. the assignment variable of the patient transporter s on the transportation request i and the assignment variable on the transporter patient on the transportation request j after performing the transportation request i.

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| $$x\_{ijs}\in \left\{0,1\right\}, ∀i,j\in R^{\*}, s\in S.$$ | (11) |
| $$y\_{is}\in \left\{0,1\right\}, ∀i\in R^{\*}, s\in S.$$ | (12) |

* + 1. Positive variables.

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| $$a\_{i},b\_{i},c\_{i},d\_{i}\geq 0, ∀i\in R^{\*}.$$ | (13) |

1. Conclusion

Problems of the patient transporter in a block-structured hospital is part of the routing problem and can be modeled using Dial-A-Ride Problem (DRAP).

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