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Synchronizing Al Mashaaer Train Departure Times with Pilgrims Arrival to Minimize the Expected Waiting Times

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Abstract

Railway transportation is an essential means of reducing traffic congestion, improving urban environmental conditions, and affecting people's social lives. These are some of the aims for which the Al Mashaaer train in Mecca Area was constructed for. However, high waiting times at the stations were noticed that affected pilgrims' service satisfaction levels. The proposed research addresses the problem of generating a plan for pilgrims' departure times to the Al Mashaaer train to achieve their best synchronization. It attempts to maximize the number of simultaneous arrivals of both the trains and pilgrims at the stations. The satisfaction of train users would be targeted by creating a detailed scheme for their departure times from the camps, which would minimize their waiting time at the stations. The whole problem would be formulated into the dynamic graph theory then an optimization technique would be developed for the solving stage.

Keywords: Railway transportation, Al Mashaaer train, Dynamic graphs, synchronization

1 Introduction

The railway planning and operation process commonly include five basic activities, usually performed in sequence: network line design, frequency setting, timetable development, train scheduling, and crew scheduling [1, 2]. It is not an independent activity, so it must be coordinated with other fields such as; land use, economic patterns, and political factors [3]. Furthermore, it must involve formulating and analyzing transportation policy, programs, and project alternatives concerning social goals, budget constraints, and economic objectives [4].

As known, the Hajj is an annual Islamic pilgrimage to Mecca, the holiest city for Muslims, and a mandatory religious duty for Muslims that must be carried out at least once in their lifetime by all adult Muslims [5]. During Hajj, pilgrims join processions of hundreds of thousands of people, who simultaneously converge on Mecca for the week of the Hajj, and perform a series of rituals that depend on physical actions. The most important ritual is going to the plains of Mount Arafat. As a result, huge congestion is formed, which cannot be avoided.

One of the made solutions is the Al Mashaaer Al Mugaddassah Metro Southern Line of an 18.1 km rapid transit line, which primarily serves to carry pilgrims from their camps between the holy sites of Mina, Arafat, and Muzdalifah, see Figure 1. It is constructed to reduce congestion caused by thousands of buses and cars destined to Mount Arafat during the Hajj. However, the train seems to provide a low level of service due to the high waiting times for the Pilgrims to board at each station [5]. This mainly may come from the absence of synchronization between the train and the Pilgrims. We believe that if a good synchronization has been set up, the waiting times would be reduced dramatically.

The motivation of this study is to formulate the problem of scheduling the Al Mashaaer train into the dynamic graph theory, then suggest an optimization technique to solve the problem. The solution is expected to be a complete schedule for both Pilgrims and trains departure and arrival times to achieve the least average waiting time per train user. We expect that the results would increase the train level of service. The most interesting part of the proposed framework is that its application would not afford any capital costs since we would try to confine the methodology to maintain the frequency of the trains.

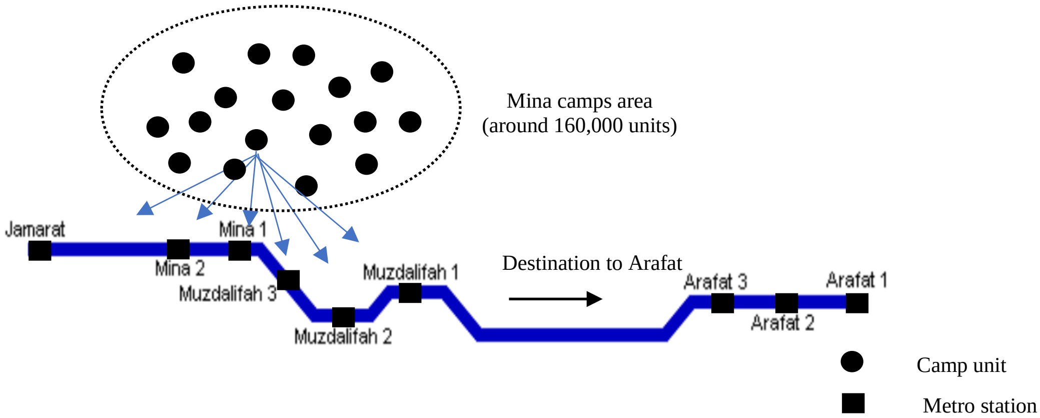

Figure 1: Al Mashaaer Al Mugaddassah Metro

2 Methods

The usual representation of the problem is a network that simplifies the depiction of both the supply and the demand of the offered service. A network is represented as a graph that is built by interconnecting nodes and arcs in which arcs have an associated flow. Two major trends of the network representation are found, namely; static network and dynamic network [6, 7]. Static networks are nodes connected by either directed or undirected arcs, whereas the dynamic ones depend mainly on representing transit networks as time expanded (diachronic) graph, in which each node is copied several times to represent each time slot [8]. Therefore, they are able to simulate passenger real-time movement.

In this study, street network and nodes are considered the supported infrastructure to the problem. Representation of the Al Mashaaer train and its infrastructure as dynamic network is given in Figure 2. Given a static graph $G = (N,A)$, a time-expanded graph $G_{T-1} = (N_{T-1},A_{T-1})$ is built so that $N_{T-1} = \{j(t): j \in N, t \in \{0, 1, 2. \ldots\ldots..,T-1\}\}$ and A_{T-1} $\{ (i(t), j(t+\tau_{i,j})), t \in \{0, 1, 2. \ldots\ldots..,T-1- \tau_{i,j} \}\}$ respectively represent the set of nodes and the set of arcs, with $\tau_{i,j}$ indicating the travel time on arc (i , j).

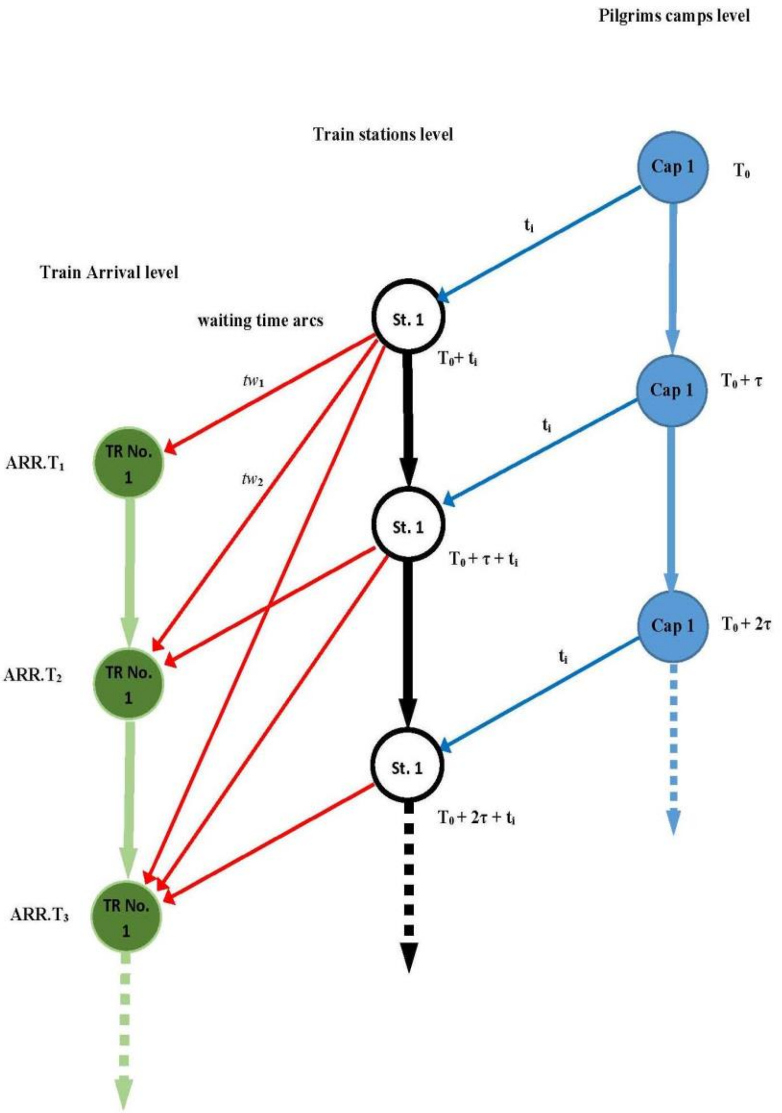

Figure 2: Dynamic Network Representation

Three levels of nodes would be expressed on our dynamic network: camps level, stations level, and trains arrival level. This would help in better representation of users' movement and their interactions with departure decisions. After modeling all the data related to the problem, a mathematical optimization model would be obtained. It would be concerned with minimizing the average user waiting time while achieving certain predefined constraints, such as all pilgrims must depart their camps during the horizon time, stations capacity threshold, and train vehicles capacity threshold.

The reliability of existed (or collected) data plays a major role in achieving the aim of the proposed research. We could conclude the required data on the following items:

- Pilgrims numbers and their spatial distribution in Mina and Moztalfa, see Figure 1.
- The routes leading to Al Mashaaer Al Mugaddassah Metro stations and the capacity of each route.
- The number of train vehicles under service and the maximum capacity of each vehicle.
- The minimum allowed headway and the already deployed timetable.
- The capacity of each station platform.

3 Results

This study aims to present an inexpensive solution to Al Mashaaer Al Mugaddassah Metro congestion problem. The expected results of the presented framework would be summarized in the next points:

- Evaluating the current performance of Al Mashaaer Al Mugaddassah train project.
- Presenting the acting of both pilgrims and trains during Arafat day into a dynamic network structure.
- Developing a new optimization technique to solve the formulated problem.
- Attaining a complete optimal plan for pilgrims' departure from their camps.

To evaluate the proposed method, we redefine a new computation model for the Mobility (M) to suit our case as follows:

$$M = \frac{\sum_{(i,j,n,\bar{t})\in R} p_{i,j,n,t}\, T_{i,j,n,t}}{\sum_{(i,j,n,\bar{t})\in R} \bar{T}_{i,j,n}} \qquad (1)$$

Where; *R* is the set of all trips (made by the crowd) in the area under study. An origin-destination pair (O-D pair) is described by $(i\ ,j)$, where i is the index for origin, j for the destination, $p_{i,j,n}$ is a penalty for the late departure of trip (i, j, n) from the required departure time $\bar{t}$. ($i, j, n, \bar{t}$) represents a single trip and n is the index of trip repetition for the same O-D pair (i , j) with the same departure time $\bar{t}$. $T_{i,j,n,t}$ is the planned travel time for the trip (i, j, n) with the new departure time t. $\bar{T}_{i,j,n}$ is the best theoretical travel time for the trip (i, j, n) in the desired departure time $\bar{t}$. It is clear that the optimal value for M = 1 which means that every individual would depart on time and reach his destination in the fastest way [9].

One of the artificial intelligence algorithms is the Reinforced Learning (RL) algorithm, which can learn from the existing state overtime to optimize its future decisions. Many successful applications have resulted after being proved by the RL algorithm [10], which suggests there could be promising results in respect of the proposed model. For example, the optimal Mobility state ($V(s^*)$) can be deduced after several trials using the (RL) technique as follows:

$$V^*(s) = \max R_s^a + \gamma \sum_{s' \in S} P_{ss'}^a \, V^*(s') \qquad (2)$$

where $V^*(s)$ is the optimal state-value function (the optimal M value overall policies), R is the reward function, S is the set of states for every state (s), a is the action (mobility plan) taken by the AI in the learning stage, and P is a state transition probability matrix to represent the uncertainty existing in the real world.

4 Conclusions and Contributions

The railway investments are always to reduce congestion and increase capacity since congestion at the stops leads to crowding discomfort and lower service reliability. Unbalanced use of public transportation could also lead to partial capacity utilization on some periods of service span and unserved demand on the other periods. This implies that a cost-benefit analysis based on the intended investment should be done in advance.

This methodology framework may incorporate two levels of decisions; the first is real-time decisions which may depend on a greedy method to obtain a rapid response, and the second are decisions that come from learning which are being optimized over time. Eventually, an artificial intelligence methodology would learn the optimal congestion management rules required to control the assignment of available transport supply modes to the users.

The state of the art of Operation Research would be adapted to provide a whole plan for pilgrims transferring from their camps to the train stations to minimize the expected waiting times. The departure times (as decision variable) would be modeled into dynamic graph representation then optimized to get the targeted results.

We have presented the problem and the proposed solution. Thus, the research could be decomposed into these stages:

1. Data collection
2. Modeling stage.
3. Evaluating the current state.
4. Developing a solution algorithm (Built-up Software).

5. Obtain the best plan

Synchronization is the most challenging part for a transit scheduler because he attempts to create departure times in the timetable while complying with the required frequency, the efficient trip assignment of each route, and the synchronization part.

The primary source of problem difficulty is the random arrival of passengers to the stations, which is difficult to be predicted. Many arrival probability distributions are assumed to simplify the solution stage. On the contrary, in our case, we have the superiority to control the passenger arrivals by developing a plan for their departure times. This would give the best utilization of the existing supply facility of the Al Mashaaer train.

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