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A Mathematical Model for Transporting the Arriving Passengers from the Airport to the City Centre

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In case of considerable traffic congestion in an airport, transportation of passengers to city centre may become a challenging task, since airports are generally located far from the centre. In this study, transportation of passengers, who arrive at an airport, to the city centre has been handled. A mathematical model has been developed, which minimises total costs arising from both, the time passed, while passengers are waiting for a vehicle, and the dispatching of a significant amount of vehicles for transporting the passengers. By utilising the proposed model, in addition to matter of when to dispatch, it is also possible to specify which type of vehicles, and how many of them should be dispatched at each time interval. Ultimately, it is reported that such a plan has a great potential to enhance the productivity.

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1. Introduction

The airline industry, which is one of the leading industries all around the world, is still growing. It is obvious that airports are crucial components in the airline industry. For this reason, many problems, such as ground operations planning, gate assignment, passenger safety related issues, etc. should be faced in the literature.

Since airports are generally located outside the cities, transportation of passengers from and to the airport can be a critical problem. Although some reports about transportation of passengers to the airport can be encountered, a work that explicitly focuses on optimisation of shuttle dispatches for transporting the arrived passengers from the airport to the city centre, in order to mitigate congestion in the airport, has not yet been published, according to the best knowledge of the author.

Therefore, in this study, a mathematical model has been developed, which schedules shuttle dispatches for prespecified time intervals. The proposed model is capable of determining when, how many, and what kind of vehicles should be dispatched at each time interval.

2. Literature review

Although its implementation to real life problems is generally hard, optimisation has a wide range of application areas, e.g. [1–9]. More specifically, the reports that focus on passenger-related airport operation (without claiming that all of them were found) are presented in this section.

In [10], transportation of air passengers to the airport is the subject. In this report a 0–1 mixed integer model under the framework of vehicle routeing problem with time windows has been proposed. A model which allows multi-trips has been proposed in [11] and it has been claimed that the proposed model reduces the operating costs. Recently, in [12], a dynamic environment has been adopted. The proposed algorithm includes dynamic decision making, for the passengers, on which airport to chose. Another recently published work, related to the issue that is handled in this study, is [13]. This report is focused on mitigation of congestion, in the perspective of demand management. Although some links between traffic congestion and airport operations have been established, it seems that subject of transporting passengers from the airport to the city centre is still untouched yet.

As it can be realised from the literature review, a strong claim cannot be made that the transportation of arriving passengers from the airport to the city centre has been sufficiently studied. In order to fulfill this gap in the literature, a mathematical model, which schedules shuttles along the planning horizon, with the purpose of mitigating congestion in the airport, has been proposed in an environment under certainty.

3. The proposed mathematical model

In this section, the proposed mathematical model is defined. The proposed model has six assumptions, which are listed below:

1. If scheduled, the vehicles (shuttles) depart at the end of each time interval.

2. There is no cumulative effect arising from sequential waiting. It means that two values of time of waiting have a ratio-type relationship, e.g. waiting for two hours is considered exactly as waiting two times for an hour for every passenger. For sure, time of waiting, assumed here, may be longer or

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shorter than it is. Moreover, it may depend on the person oneself, which leads the decision maker to the next assumption.

3. No VIP passengers are allowed. All the passengers have equal importance.
4. No one is allowed to wait more than three hours.
5. Every route ends at the airport after at most four hours.
6. There are no passengers that are waiting at the beginning of the planning horizon.

The developed model is given in Eq. (1).

$$\min_{\boldsymbol{X},\boldsymbol{R}} \sum_{i=1}^{n} c_i R_i + \sum_{i=1}^{n}\sum_{k=1}^{m} p_{ik} X_{ik}, \tag{1a}$$

where

$$R_{i+1} \geq R_i + F_{i+1} - T_{i+1},\ \forall\ i = 1,2,...,(n-1), \tag{1b}$$

$$T_i \leq \sum_{k}^{m} a_k X_{ik},\ \forall\ i = 1,2,...,n \tag{1c}$$

$$R_{i-1} + F_i + F_{i+1} + F_{i+2} \leq T_i + T_{i+1} + T_{i+2},$$

$$\forall\ i = 1,2,...,(n-2), \tag{1d}$$

$$X_{ik} + X_{(i+1)k} + X_{(i+2)k} + X_{(i+3)k} \leq S_k,$$

$$\forall\ k = 1,2,...,m\ \wedge\ \forall\ i = 1,2,...,(n-3), \tag{1e}$$

$$X_{ik},\ R_i,\ T_i \in \mathrm{I}_+, \tag{1f}$$

where $i \in I$ and $k \in K$ are the set of time intervals and set of vehicle types, respectively; $X_{ik} \in \boldsymbol{X} \subseteq I_+^{nm}$ denotes the number of k type vehicles that are scheduled in time band i; $R_i \in \boldsymbol{R} \subseteq \mathrm{I}_+^n$ indicates the number of passengers that have not yet been transported in time band i, while $T_i \in \boldsymbol{T} \subseteq \mathrm{I}_+^n$ is the number of passengers that are transported in time interval i; $F_i \in \boldsymbol{F} \subseteq \mathrm{I}_+^n$ denotes the number of arrived passengers, that demand a vehicle in time interval i; $S_k \in \boldsymbol{S} \subseteq I_+^m$ indicates the number of type k vehicles in the fleet; $a_k \in \boldsymbol{A} \subseteq I_+^m$ is capacity of type k vehicle; $c_i \in \boldsymbol{C} \subseteq R^n$ stands for cost of waiting an hour per passenger in time interval i, while $p_{ik} \in \boldsymbol{P} \subseteq R^{nm}$ is the cost of dispatching type k vehicle in time band i.

4. Case study

For the case study, real data, which is the numbers of arrived international passengers, have been collected from Istanbul Atatürk Airport (IST). An hour was chosen as the length of time interval in this study. Monthly forecast, which has been obtained by utilising the design proposed in [14], has been converted into hourly data, based on certain instructions. Thus, $\boldsymbol{F}$ has been forecast for a planning horizon of one week. Based on similar instructions, $\boldsymbol{S}$, $\boldsymbol{C}$, $\boldsymbol{P}$, and $\boldsymbol{A}$ have been determined. Then, the optimization according the proposed model has been carried out in MATLAB environment. For the solution process of this mixed integer program (MIP), the problem has been relaxed to its linear program (LP) as the first step. Then, branch & bound (B&B) has been employed in order to reach optimal solution, for which some other assumptions have been made.

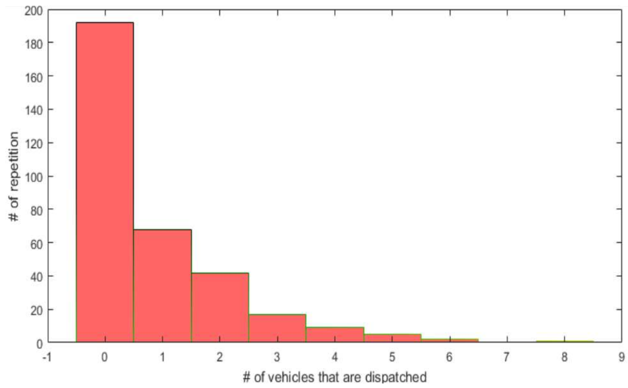

Fig. 1. The number of vehicles dispatched in each time band.

According to the results, transportation of passengers from the airport to the city centre in the planning horizon, can be realised for 2545 Turkish lires. Since a global optimum has been reached, it is assured that a better solution does not exist for this problem. The numbers of vehicles that are dispatched in considered time bands are given in Fig. 1.

5. Conclusions

A model, which allows the decision maker to schedule when, which type of vehicles, and how many of them should be dispatched, has been proposed in this study. Thus, passenger congestion is expected to be effectively mitigated. Correspondingly, besides the expectation of significant cost savings, service quality of the airport is expected to be improved.

Although cost of dispatching vehicles is considered, cost of assigning crews is not considered in the model. Future works may consider costs arising from routeing both the vehicles and the crews. Perception of service quality is another important component, which may be also considered. Multi-modal transportation options may be included in the future work. Finally, it is very likely that uncertainties in time, required for a route, the number of passengers at time i, etc. may enhance the quality of future work.

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