An Integrated Approach for Facility Operational Scheduling at Seaport and Airport

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This paper discusses scheduling problems for an efficient usage of terminal facilities for seaborne and airborne traffic. The former is the berth template problem and the latter is the gate assignment problem. Both studies coincidently have been tackled for over 20 years. While they share the same (or quite similar) feature in the scheduling framework, they have not be discussed in a united way. In this background, this paper attempts to deal with them in an integrated fashion.

Keywords : *seaport, airport, facility scheduling, berth template problem, gate assignment problem*

1. INTRODUCTION

The world economy highly depends on smooth traffic of cargoes and passengers by means of sea and air transportation. This paper proposes a united approach for the optimal scheduling of two kinds of logistics facilities: one in a seaport and the other in an airport. While more than a half of global seaborne traffic is carried by the tramp service, the facility operation complexity at seaport is more intensified in the liner service than the tramp service. Throughout the subsequent part of this paper, we discuss both seaborne and airborne transportation modes; for this reason we assume the liner shipping when referring to the seaborne transportation.

The smooth logistics (including passenger service) by these transportation modes relies on efficient operations at terminals: container terminal for seaborne traffic and airport for airborne one. For each of these important logistics infrastructure systems, lots of academic papers have been published for developing various operational, tactical and even strategic scheduling methodologies for an efficient usage of the facilities in the literature over two decades.

Among other facilities at a marine container terminal, berths are the most important front-end service facility for a cargo switching task between trunk line and feeder as well as land-based hinterland transportation. Meanwhile, airport has a terminal(s) for switching passengers (and/or cargoes) of a flight with other flights and land transportation. In an airport terminal, boarding gate plays the most important role for embarking and disembarking passengers. In a sense, berths and gates function in a similar way while used in different transportation modes; they both have to be efficiently scheduled to be used for a higher productivity. Regardless of container terminal berth scheduling or airport gate scheduling, the facility scheduling that this paper handles determines the assignment of vehicle (ship or aircraft) to facility (berth or gate) and when (or in which service order) vehicles are to be served at the assigned facility.

Since most ship callings at a container terminal and aircraft landings/take-offs at an airport are regularly scheduled and their schedules are widely published in advance. Therefore, scheduling of berth and gate basically belongs to a long-term (or tactical) decision. However, a long-term berth schedule is the relatively recent literature and the primary research topic on berth scheduling has been an operational decision for the last 20 years since the birth of berth scheduling research. The boarding gate scheduling literature also has a 20 year history, but most gate scheduling works are for operational. Although remarkably there is a strong similarity in function and scheduling nature in sea and air terminals, no interactive research disciplines have been observed between sea and air.

Berth scheduling covers short-term (or operational) and long-term (or tactical) scheduling functions. One of the features that attributes a schedule to the tactical one is the fixed planning horizon (or cylinder). In practice, the same berth schedule is repeatedly applied for calling ships every week since most ships call at the terminal once a week. The gate schedule is also repeated but not every week but every day since most flights are daily (of course, some of them are more frequent). In the tactical schedule, no vehicles (ships or aircraft) should be scheduled across the end of the planning horizon because the extended services over the end line may overlap with others in the next planning horizon. In summary, the tactical scheduling has the fixed length of planning horizon while the operational one has the open-ended planning horizon.

As will be seen in detail in the subsequent section, most berth scheduling studies are for operational one whilst some are for tactical. Operational berth scheduling is termed as the berth allocation problem (BAP) whilst the tactical one is referred to as the berth template problem (BTP). The airport boarding gate scheduling is referred to as the gate assignment problem (GAP) and almost all of them are operational.

This paper attempts to introduce an integrated framework for sea and air facilities scheduling in the tactical level. In the above background, we discuss the BTP and GAP for their combined approach.

2. LITERATURE REVIEW

This section reviews seaborne and airborne facilities scheduling literature. This paper focuses on the tactical facility scheduling; however, both operational and tactical berth scheduling problems are reviewed here due to the scarcity of the tactical works.

(1) BAP and BTP

The BAP and BTP are classified into two berthing schemes: discrete and continuous. The berth scheduling study has the large literature; continuous BAPs are not included in this review since the continuous index is less relevant to the integration of berth and gate scheduling. Nevertheless, both location indexes are all reviewed for the BTP due to the small size of the BTP literature.

As described in the previous section, the operational berth scheduling is termed the BAP whilst the tactical one is the BTP. One of the earliest works of the BAP is Imai et al. (1997) who addressed a BAP in discrete location indices (hereafter referred to as BAP in this section) for commercial ports. Most service queues are in general processed on an FCFS (First-Come-First-Served) basis. They concluded that in order to achieve high port productivity, an optimal set of ship-to-berth assignments should be determined, instead of considering the FCFS rule. Their study assumed a static situation where ships to be served for a planning horizon had all arrived at a port before one planed the berth allocation. Thus, their study can be applied only to tremendously busy ports. As far as container shipping is concerned, such busy ports are neither competitive nor realistic because of the long delay in the interchange process at ports. In this context, Imai et al. (2001, 2005a) extended the static version of the BAP to a dynamic treatment that is similar to the static treatment, but with the difference that some ships arrive while work is in progress. Due to the difficulty in finding an exact solution, they developed a heuristic by using a subgradient method with the Lagrangian relaxation. Their study assumed the same water depth for all the berths, while in practice there are berths with different water depths in certain ports. Nishimura et al. (2001) further extended the dynamic version of the BAP for the multi-water depth configuration. They employed genetic algorithm (GA) to solve that problem. In some real situations, the terminal operator assigns different priorities to calling vessels. For instance, at a terminal in China, small feeder ships have priority, as handling work associated with them is completed in a short period of time and larger vessels do not have to wait for a long time. On the other hand, a terminal in Singapore treats large vessels with higher priority because they are good customers to the terminal. Imai et al. (2003) extended the dynamic BAP in Imai et al. (2001, 2005a) to treat the ships with different priorities and see how the extended BAP differentiates the handling of ship in terms of the service time associated with ships. Imai et al. (2007) proposed the BAP with simultaneous berthing of multiple ships at the indented berth, which was potentially useful for fast turnaround of mega-containerships. Cordeau et al. (2005) developed a tabu search heuristic for the dynamic BAP in two versions with both discrete and continuous location indexes. They analyzed the solution quality of the proposed heuristic for the discrete location with the exact solution by CPLEX; however, the applied problem cases were relatively small sized ones. Monaco and Sammarra (2007), inspired by the dynamic BAP of Imai et al. (2001), proposed an improvement in its formulation and also developed the Lagrangian relaxation-based subgradient optimization, which was the same approach for Imai et al.

(2001, 2005a) but with some modifications. Imai et al. (2001, 2005a) proposed three heuristics embedded in the subgradient procedure. Monaco and Sammarra reported that their algorithm outperformed that of Imai et al. (2001, 2005a). However, they did not mention which one of the three heuristics embedded in the subgradient procedure in Imai et al. (2001, 2005a) was used for performance comparison. Hansen et al. (2008) developed a variable neighborhood search method for the BAP. Mauri et al. (2008) applied the Population Training Algorithm with Linear Programming to the dynamic BAP, which was formulated in Cordeau et al. (2005). Imai et al. (2008) extended the BAP developed in Imai et al. (2001, 2005a) for a terminal who assigned some calling ship to another terminal when the terminal was congested. Golias et al. (2009) proposed the dynamic BAP with customer service differentiation based on respective agreements. They formulated their BAP as a multi-objective problem and developed a GA-based heuristic. They also proposed, in Golias et al. (2010), another heuristic based on a lamda optimal. Buhrkal et al. (2011) treated the dynamic BAP and formulated the problem as the improved heterogeneous VRP with time windows based on the discrete version of BAP of Cordeau et al. (2005). Saharidis et al. (2010) proposed a hierarchical optimization for the BAP with two conflicting objectives terminal operators face. Xu et al. (2012) proposed the BAP with different water depths at berths and tidal condition. Imai et al. (2013) discussed a terminal efficiency in terms of berthing ships in different types of innovative terminal designs by comparing the total service time of calling ships when their berth-windows are optimally scheduled with ad-hoc berth allocation problems for those different terminals in discrete location indexes. Recently some studies such as de Oliveira et al. (2012), Lalla-Ruiz et al. (2012), and Ting et al. (2014) proposed new heuristics for the dynamic BAP that had been discussed in Imai et al. (2001), Cordeau et al. (2005), and Monaco and Sammarra (2007). All the three papers tested their heuristics with problem instances that were provided in Cordeau et al. (2005). Ting et al. (2014) indicated that their algorithm outperformed the others.

There are a few papers dealing with the tactical berth scheduling. Moorthy and Teo (2006) was the first one to present the BTP, by which this study is greatly inspired. Their BTP defines berth-windows of serving calling ships in a continuous space within the predetermined length of the planning horizon. The berth template design takes into account the scheduling of periodicity, that is, the wrap-around effect of the cylinder. Their problem had two objectives: one is to maximize the service level, which is simply defined as the percentage of vessels served within two hours of their arrival, and the other is to minimize the connectivity cost, which is related to the distances between berths within vessel transshipment groups. Another tactical berth scheduling problem is studied by Giallombardo et al. (2010). They proposed the BTP in discrete location indexes with the integration of quay crane (QC) allocation decision. Their BTP aims to minimize the ship service value with a specific set of QCs in use as well as the cost associated with transshipment service. Their study arranges all berth-windows within the time duration, similar to the concept of the cylinder length. Zhen et al. (2011) proposed an integrated template planning model for both berthing location in continuous indexes and yard container stack arrangement with the objective consisting of the deviation of the start of ship handling service from the preferred one and the transshipment cost. In their study, the cyclic scheduling consideration and the QC allocation were both considered. They developed a heuristic with a recursive process based on two stages: berth template and yard template. Hendriks et al. (2012) addressed a BTP under a unique berthing service circumstance where ships can berth at any terminal in a port with inter-terminal service agreements, which allow containers to be unloaded from a ship at a remote partner terminal and transferred by trucks to the terminal the ship was originally scheduled to berth. Their BTP implicitly imposed the cylinder on the model since it assumed to serve cyclically calling ships. It took into account the QC assignment to ships, resulting in the inclusion of the associated QC utilization cost in the objective function, which also considers the inter-terminal container transfer cost. Hendriks et al. (2013) addressed a BTP, with the objective of the minimization of the total distance the fleet of straddle carriers travels in the yard, which deals with berth allocation and yard planning within the cylinder. Lee and Jin (2013) studied a BTP for feeder vessels to determine berth allocation for feeders in discrete locations and yard storage assignment for their transshipment cargoes. The objective of this BTP minimizes the sum of yard container flow distance and the gap between the highest and the lowest workload. Whereas it considered cyclically calling feeders, it did not impose the cylinder on the model. Following the framework of Giallombardo et al. (2010), Vacca et al. (2013) developed an exact-solution algorithm based on the technique of branch and price for the integrated problem of berth and QC planning. Their study does not apply the cylinder, within which all berth-windows are planned to be placed. Instead, every ship calling request has a preferred start and end times of the handling service. This preferred time duration is wide enough to place an actual berth-window of the ship appropriately so as to minimize the objective function. Finally, note that all the above BTP studies implicitly assume that the berthing capacity is large enough to cover all the calling requests. The most recent BTP study is Imai et al. (2014), which addressed the so-called strategic BTP that minimizes the service delay of ships to be served and the penalty cost of those not to be served.

(2) GAP

There exist different types in the GAPs for the planning horizon. One is the GAP for a single period where only the assignment of aircraft to gate is planned, while the other is the one for a multi-period in which in addition to the aircraft-to-gate decision the order of service sequence for multiple aircraft assigned to each gate is scheduled. The GAP with the single-period has the extensions of "-S" and the one with the multi-period has "-M". Also, some GAP studies have the time-window while others do not. So, we add the extensions of "-TW" for time-window and "-NW" for non-time-window to the GAP title.

Braaksma and Shortreed (1971) is first concerned with the improvement of airport gate operation efficiency. They employed the Critical Path Method to simulate the details of gate operations. The GAP-S-NW paper in Babic et al. (1984) is the pioneering work to develop an optimization approach for the best assignment of a set of aircraft to a set of terminal gates by minimizing the total walking distance of disembarking and embarking passengers. The GAP solution is exactly found by using the B&B. Mangoubi and Mathaisel (1985) proposed GAP-S-NW that is the same feature as the one in Babic et al. (1984) but some additional more practical constraints such as specific airplane types to particular gates, etc. They exploited two solution methods: one is based on the LP relaxation of the GAP integer programming formulation and the other is an ad hoc heuristic. Bihr (1990) discussed GAP-S-NW that was proposed in Babic et al. (1984), but his solution technique is unknown. Wirasinghe and Bandara (1990) exploited a probabilistic model to estimate the expected amount of aircraft delay that is caused by poorly planned assignments of flights to gates. By using the model, they figured out the optimal number of gates to be constructed at the airport terminal. Srihari and Muthukrishnan (1991) developed an expert system for GAP-S-NW with an objective of the minimization of the total walking distance of transfer passengers. They assumed that airplanes with a long parking time from arrival to departure were moved to remote parking bays. Also, it was assumed that excess flights of airplanes that could not park at gates were able to use the remote bays. Bandara and Wirasinghe (1992) proposed models to estimate a walking distance of passengers to embark and disembark at gates in various shapes of airport terminal for potential use in the GAP optimization modeling. Cheng (1998a, 1998b) developed a simulation model to assess a predetermined set of assignments of aircraft to gates by simulating complicated behaviors of passengers and operation sequences of crew and equipment at the airport terminal. Haghani and Chen (1998) studied the GAP-M-TW. The objective is the combination of local and transferring passengers' walking distance. Due to the transferring passengers, the objective function is quadratic but eventually is linearized in order for the model to be solved by the CPLEX. Yan and Chang (1998) exploited a multi-commodity network flow model for GAP-M-NW that was solved by the subgradient method with the Lagrangian relaxation. While the GAP is a tactical problem in nature, Gu and Chung(1999) proposed an operational GAP (probably GAP-S-NW), which reassigned delayed flights to gates so as to minimize the extra delay caused by the delayed incoming flights. This GAP was solved by GA. Bolat (1999) introduced an interesting variation of GAP-M-NW that minimized the variance of idle time among gates for robust scheduling that was not likely influenced unexpected changes in operation. He developed the B&B for his GAP-M-NW. Also, for GAP-M-NW he proposed two heuristics in Bolat (2000) that overcame a drawback of the B&B in terms of CPU time. Interestingly, his GAP-M-NW in (1999, 2000) associates the cylinder (the fixed planning horizon) with it as the important attribute for the tactical decision making. Yan and Huo (2001) presented a GAP-M-NW with two objectives: the minimization of the total passenger walking distance and the one of the total passenger waiting time. They implemented the weighting method embedded with the column generation technique. The GAP-M-TW in Xu and Bailey (2001) is an extension of the other previously studied GAPs, where their GAP-M-TW not only assign flights to gates but also determine the start time of the gate use (opening time for boarding) so as to minimize the total transit time of passengers between flights to connecting flights. Their GAP-M-NW was solved heuristically by a tabu search algorithm. Yan et al. (2002) developed a simulation model to analyze the effects of stochastic flight delays on static (or tactical level) GAP in real time operational circumstances. Lam et al. (2002) implemented a decision making system for an operational GAP to cope with reassignment of gated caused by daily changes in operation. Zhu et al. (2003) proposed the GAP-M-TW with the objective of the passengers walking distance and the delay of disembarkation between the scheduled gate occupation time and the start of the time-window. Ding et al. (2004, 2005) discussed a bi-objective GAP-S-NW. Their study assumed an overloaded situation where the number of flights exceeds the number of available gates at a time. They assumed some of the flights are forced to park in the apron or tarmac area to the airport terminal. In this background, one objective is the walking distance of local and transferring passengers including the distance between the remote parking place and the terminal building, while the other is the number of flights to park the remote area. Fernandez and Robuste (2007) presented GAP-M-NW to minimize the total time passengers spent in aircraft when taxiing to assigned gates and spent in walking from the gates to exits at the terminal and vice versa. Kim et al. (2013) discussed the GAP with three different objectives but all combined linearly: passenger walking distance, passenger spending time in taxiing to the gate, and the schedule robustness.

3. PROBLEM FORMULATION

While there are two kinds of berthing location indexes for the BTP, the discrete version of the BTP is discussed here due to the similarity with the GAP.

(1) Problem overview

The BTP and GAP are different problems for different transportation modes. This paper attempts to deal with them in a integrated way from the theoretical viewpoint. For this treatment, we introduce a common terminology for them. Berth at a container terminal and gate at an airport terminal are commonly termed as facility and ship and aircraft are referred to as vehicle as shown in **Fig. 1**.

However, there are some differences.

(a) Planning horizon

The first one is the length of planning horizon. As this paper discusses the tactical scheduling, the planning horizon has a fixed length. This length is referred to as cylinder for the BTP literature (which is also used for the GAP in this paper). All service time-windows, which are sets of the time steps (start and completion) of a ship stay for the BTP and those of an aircraft stay for the GAP, have to be placed within the cylinder without any overlap of multiple service time-windows of vehicles. The cylinder length is normally a week for the BTP. On the other hand, it is a day for the GAP since aircraft fly much more frequently than ships cruise.

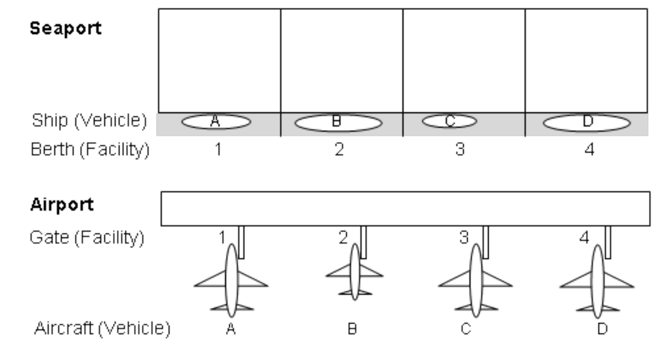

Fig. 1 Seaport and airport arrangements

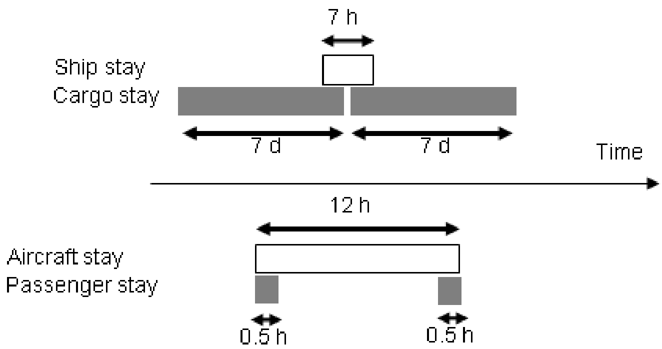

Fig. 2 Stays of vehicles and loaded/unoaded things

(b) Staying time

The second difference is related to the stay length of things to be transported (cargo for the BTP and passenger for the GAP) and the one of vehicles to transport them. As shown in **Fig. 2**, for the BTP the cargo stay at a terminal is longer than the ship stay while for the GAP the passenger stay is no longer than the aircraft stay.

The objectives of the BTPs vary depending on the business disciplines that attribute them to specific container terminals; however, most BTP (and BAP)objectives minimize the length of ship staying time (comprised of wait time for the berth availability and dwell time for cargo handling) at a terminal. One reason for this objective setting is that almost all containership voyages call at multiple ports on route. Most containerships are huge with a large amount of cargoes heading to their destination ports. Since ship is a very valuable property including values of ship and cargo on board, it has to depart a port as soon as cargo handling is finished. And even the cargo handling must be fast by using state-of the art handling machines and efficient scheduling for the machine usage. The cargoes normally stay at the terminal for a long time, ranging from one to seven days. Some cargoes surprisingly stay there even more than a week. Therefore, the cargo stay cannot be sensitive with the ship-berth-service order assignment.

There is some variety in the setting of the GAPs, but the objectives of the GAPs are almost the same; that is the length of passenger walking distance between the terminal entrance to the boarding gate (and vice versa) and the one between two gates for connecting flights. Since compared to passengers, aircraft stay too long at boarding gates to be scheduled, ranging from two to twelve hours; the GAP aims the minimization of passenger walking distance. The aircraft stay, on the other hand, is not taken into account as an objective since its stay is long and subject to the convenience of the next flight by the staying aircraft whose fight has to arrive at the destination airport at the convenient time for the passengers.

(c) Objective

The third difference is also related to the objective function. The GAP minimizes the passenger walking distance since the passengers walk the different distance depending on the gates their flights are assigned to. As discussed in section (b), the aircraft stay has nothing to do with the aircraft-gate-service order assignment.

The BTP minimizes the ship staying time (including the waiting time), which depends on the assigned berth and the service order in which ships berth. In most BAP (operational berth scheduling) studies, the ship berthing length (i.e., start and end of berthing for cargo handling) depends on the berth the ship is assigned to since different berths impose a different cargo handling time on a ship due to the length of cargo movement between berth and yard storage area. Also, the service order which a ship follows to berth affects the length of ship stay (in fact, the length of ship wait). The BTP, on the other hand, has a different feature on the ship berthing length. As the BTP is long-term decision making, the cargo storage in the yard is also optimally planned when the BTP is planned. This implies there is a good chance for ships to stay very close to the cargo storage area in the yard. This likely results in the constant cargo handling time (per container) regardless of berth being assigned to the ship. Of course, for the BTP the ship wait is subject to the service order like the BAP.

Despite of the difference in the vehicle stay length at a facility, both BTP and GAP can be treated in the same way by introducing the variable staying time of vehicle on the facility. Both problems assume the constant staying time (excluding the wait for the facility availability). So, all the variable staying times are set the same value for any different facilities. Because both BTP and GAP are tactical decision making, the wait does not substantially occur. With a long-time facility schedule (which is “template” for the BTP) resulting from the BTP and GAP solutions, vehicles are arranged by the operation companies to arrive at the facilities at the scheduled times. So, the wait for the BTP and GAP should be interpreted as the gap between the preferred and scheduled starts of stay.

(d) The problem objective in this study

As a result from the above discussion, the most critical issue among the three different factors is the objective. No BTP studies adopt the inconvenience related to cargo pick-up and set-out when cargo owners bring containers in and take them away from the terminal. However, while it is a minor issue, the cargo handling-related inconvenience may have to be evaluated since there is a long queue of container drayage trucks waiting to enter the terminal gates for picking up containers.

Regarding the GAP, the aircraft dwell time is normally long and therefore out of consideration for the scheduling. However, a poorly scheduled gate assignment may make some aircraft land on the runway and use the gate at the time, which deviates from the preferred one. Such an inconvenience may be caused by the service order that results from the wrong schedule. Therefore, the GAP should take into account the aircraft dwell time (or the gap between the scheduled and originally preferred times of aircraft arrival).

(2) Formulation

From the above viewpoint of the objective, the facilities allocation problem (FAP), which is a generalized model concept to cover both seaborne and airborne facility scheduling (i.e. the BTP and GAP), has two objectives: one evaluates the vehicle’s staying time and the other considers the inconvenience related to things on board.

The FAP model assumes the followings:

(a) Each facility (berth for BTP and gate for GAP) serves a single vehicle (ship or aircraft) at a time.
(b) Each vehicle has its preferred target time to start the stay for handling cargoes and passengers. It also has a time-window, within which it has to be served even if it is not to be served at the preferred time.

(c) All the vehicles must be served within the cylinder. If the number of vehicles to be served are too many compared to the cylinder length, a solution may not be found.

(d) The gap between the scheduled time and the preferred time of stay means the wait if the former time is no earlier than the latter. However, as the FAP is a tactical problem, vehicles (in fact, their operating companies) adjust themselves to arrive, just in time, at the facilities they are assigned to. Therefore, no vehicles are to wait substantially in the operation phase. Also, both negative and positive gap values are evaluated in the objective function.

Parameters and decision variables used in the formulation are as follows:

Parameters

$i(=1,\cdots,I)\in B$: facility

$j(=1,\cdots,T)\in V$: vehicle

$k(=1,\cdots,T)\in U$: service order

M : large positive constant

CT : length of planning horizon

E_j : earliest arrival time of vehicle j

L_j : latest arrival time of vehicle j

W_j : weight associated with vehicle j (which corresponds to the cargo amount or the number of passengers)

A_j : preferred time of arrival of vehicle j

C_j : dwell time of vehicle j at facility i

Y_{ij} : inconvenience associated with vehicles j for using facility i

$X_{iji'j'}$: inconvenience associated with relation between vehicles j for using facility i and vehicles j' for using facility i'

Variables

n_j : earliness of arrival of vehicle j

p_j : delay of arrival of vehicle j

b_{ijk} : occupation start time of vehicle j as the kth vehicle at facility i (also entering time of vehicle j for the system)

f_{ijk} : departure time of vehicle j as the kth vehicle from facility i

$b_{\min}$: minimum occupation start time among all vehicles

$f_{\max}$: maximum departure time among all vehicles

x_{ijk} : =1 if vehicle j is assigned to facility i as the k th vehicle, =0 otherwise

$z_{iji'j'}$: =1 if vehicle j is assigned to facility i and vehicle j' is assigned to facility i', =0 otherwise

The FAP may be formulated as follows:

[FAP]

Minimize $$\sum_{j\in V}\left(p_j+n_j\right) \quad (1)$$

Minimize $$\sum_{i\in B}\sum_{j\in V}\sum_{k\in U}W_jY_{ij}x_{ijk}+\sum_{i\in B}\sum_{j\in V}\sum_{i'\in B}\sum_{j'\in V}W_jW_{j'}X_{iji'j'}z_{iji'j'} \quad (2)$$

Subject to $$\sum_{i\in B}\sum_{k\in U}x_{ijk}=1 \quad \forall j\in V, \quad (3)$$

$$\sum_{j\in V}x_{ijk}\le 1 \quad \forall i\in B,k\in U, \quad (4)$$

$$E_j\le\sum_{i\in B}\sum_{k\in U}b_{ijk}\le L_j \quad \forall j\in V, \quad (5)$$

$$\sum_{i\in B}\sum_{k\in U}f_{ijk}=\sum_{i\in B}\sum_{k\in U}b_{ijk}+\sum_{k\in U}C_jx_{ijk} \quad \forall j\in V, \quad (6)$$

$$\sum_{j\in V}f_{ijk}\le\sum_{j\in V}b_{ij,k+1}+M\left(1-\sum_{j\in V}x_{ijk}\right) \quad \forall i\in B,\ k\in U\setminus\{T\}, \quad (7)$$

$$Mx_{ijk}\ge b_{ijk}\ \forall i\in B,\ j\in V,k\in U, \quad (8)$$

$$Mx_{ijk}\ge f_{ijk}\ \forall i\in B,\ j\in V,k\in U, \quad (9)$$

$$\sum_{i\in B}\sum_{k\in U}b_{ijk}-A_j=p_j-n_j\ \forall j\in V, \quad (10)$$

$$b_{\min}\le b_{ijk}+M\left(1-x_{ijk}\right) \quad \forall i\in B,\ j\in V,k\in U, \quad (11)$$

$$f_{\max}\ge f_{ijk}\ \forall i\in B,\ j\in V,k\in U, \quad (12)$$

$$f_{\max}-b_{\min}\le CT \quad (13)$$

$$z_{iji'j'}\ge\sum_{k\in U}x_{ijk}+\sum_{k\in U}x_{i'j'k}-1 \quad \forall i,i'(\ne i)\in B,\ j,\ j'(>j)\in V, \quad (14)$$

$$x_{ijk}\in\{0,1\}\ \forall i\in B,\ j\in V,k\in U, \quad (15)$$

$$z_{iji'j'}\in\{0,1\} \quad \forall i,i'\in B,\ j,\ j'(>j)\in V, \quad (16)$$

$$b_{ijk},\ f_{ijk}\ge 0 \quad \forall i\in B,\ j\in V,k\in U, \quad (17)$$

$$p_j,\ n_j\ge 0 \quad \forall j\in V, \quad (18)$$

Objective (1) minimizes the cost of deviation from the target arrival times A_j. Objective (2) minimizes the inconvenience associated with vehicles caused by the assigned facilities. The first term is the inconvenience for local traffic while the second is the one for transshipment (or transit) traffic between two vehicles. Constraints (3)-(4) altogether specify an assignment of vehicles to facilities. Constraints (5) assure that the start time of occupying a facility is subject to the time-window. Constraints (6)-(9) provide the relation between the facility occupation and departure times. Equalities (10) define the earliness and tardiness of the occupation start time from the preferred one. Constraints (11) define the minimum occupation start time while (12) define the maximum departure time. Inequality (13) guarantees all vehicles are to be observed within the fixed length of planning horizon. Constraint set (14) ensures the relationship between x_{ijk} and $z_{iji'j'}$.

4. DISCUSSION ABOUT THE SOLUTION PROCEDURE

This paper does not propose any specific solution procedures. However, looking at the model structure of the FAP, the subgrdient method with Lagrangian relaxation might be promising since the FAP has a feature of the classical assignment problem (AP). If the relaxed problem reduces to the AP, its optimal solution could provide a good lower bound to the original problem (FAP).

5. CONCLUSION

We discussed an efficient usage of terminal facilities for seaborne and airborne traffic. The former is the berth template problem and the latter is the gate assignment problem. Both studies coincidently have been tackled for over 20 years. While they share the same (or quite similar) feature in the scheduling framework, they have not be discussed in a united way. In this background, this paper attempted to consider a comprehensive model framework to deal with them in an integrated fashion. Although the solution methodology was not discussed in this paper, an insightful implication was found. By using this implication, an ad hoc solution technique will be able to be developed.

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