INTELLIGENT AIR TRANSPORTATION
– A RESOURCE MANAGEMENT PERSPECTIVE

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Abstract: In this paper we look at the air transportation system from a resource management perspective. In particular, we introduce the concept airport logistics, with the general focus of efficiently managing all the logistic activities and processes at, or nearby, an airport. One important goal is to utilize and process the available information for intelligent resource management. Some previous research in the air transportation system area is reviewed and classified into three categories; airline operations, airport operations and air traffic management. A conceptual framework of a decision support system is presented and motivated with a clear emphasis on the airport system.

Keywords: Intelligent Transportation Systems, Airport, Air Traffic Management, Logistics, Resource Management, Decision Support, Resource Optimization and Simulation

INTRODUCTION

The area Intelligent Transportation Systems (ITS) has during the last decade or so, developed towards a more complete multidiscipline, covering all transport modes and also the transportation of both people and goods. The focus is not primarily on the development of new technology, but rather from a system perspective to assure an intelligent use of the included components in the system. Components in this perspective can include infrastructure, vehicles, crew, technology and any other resources necessary for managing the specific transportation service under consideration. In line with this view of ITS, this overview paper deals with resource management in air transportation, i.e. using the air transportation resources in the most “intelligent” way, and by so, reaching the best utilization and performance of the system.

The White Paper “European transport policy for 2010: time to decide”, published by the European Commission in September 2001 (17), acknowledges the future importance of the air transport sector. This includes meeting the increasing air traffic demand (increases with twice the rate of GDP growth (28) and is expected to be 2.4 times higher in 2025 compared to 2005 (54)) and, at a higher level, supporting the continuation of the economic development of the union. At the same time the challenges (safety, congestion, noise and environmental) which have to be dealt with are highlighted, specifying the inevitable requirements from the society. In this perspective, resource management and system performance must also cope with these future – and contradictory – needs and requirements.

The resources in an air transportation system (ATS) can be broadly divided into airline resources (mainly aircraft and crew), air traffic management (ATM) resources (e.g. airspace and runways) and airport resources (e.g. gates, baggage systems, fuel and food vehicles). In this perspective, the planning and control of the air transportation system is nothing but a gigantic resource optimization problem – unfortunately too large for allowing an overall analysis. This leads to other problems,
best captured by the general and well known quotation by Peter Senge (52): “From a very early age, we are taught to break apart problems, to fragment the world. This apparently makes complex tasks and subjects more manageable, but we pay a hidden, enormous price. We can no longer see the consequences of our actions; we lose our intrinsic sense of connection to a larger whole.”

This is very much the characteristics of the ATS today and the reason why many ongoing activities are focused on this shortening, for example:

- The European airspace and route network is one of the most strained in the word – to some extent self-inflicted, due to the fragmented planning process when every member state is controlling its own sectors and a large part of the airspace is reserved for military use. “The single European sky” (53) is a European Commission initiative that, among other things, strives to organize the airspace based on operational efficiency instead of national boarders and also integrate the civil and military air traffic management.

- The ATS is not only huge and complex; it also involves different actors with different and sometimes contradictory objectives which makes an overall flow management and efficiency even more difficult to attain. Collaborative decision making (CDM) is the summarizing term for all activities and projects going on in this domain. In short, the goal is to enhance the integration between airport, airline and air traffic flow management planning to enable collaborative decision-making through better use of real-time information exchange (56).

A third problem domain and the maybe most critical bottleneck in the ATS today, is the airport – illustrated by the following not very uncommon example: Twenty minutes late from Stockholm, you now sit in the airplane on the way to a business meeting. You are kind of pressed for time so you heave a sigh of relief when the pilot catches up the initial delay and touches down on time. Unfortunately though, the gate your plane is allocated to is occupied so you have to wait, strapped for your chair, for about half an hour before there is a free gate and you can enter the terminal.

Even though there might be several reasons for this scenario and it is not easy to identify the root of the problem, it is well-known that delays in general are very often initiated at the airport. According to Mueller et al (48), only 16 % of the air traffic delays are airborne, while the rest can be derived from gate (50 %), taxi-out (26 %) and taxi-in (8 %). One explanation why most of the delays occur on the ground might be that the ground handling procedures have not been developed to the same extent as other airport activities (57). The example above also shows the lack of communication between different actors, that delay causes new delays, and that a higher en-route speed may not lead to better punctuality, but instead higher fuel costs and more pollution.

The concept presented in this paper is focused on resource management in the airport system and covers all logistic activities and sub processes – and corresponding resources – that are involved in and influence the air transportation process. It does not only cover the activities on ground, but also nearby airside activities. We call this Airport Logistics.

The vision with airport logistics is to develop a complete picture of all processes and activities at the airport; in particular a real-time overview and controllability over all resources in use, or available for supporting the ATS. With this information at hand, it would be possible to, at a tactical basis, optimize the planning and utilization of all the resources, and at an operational level, be able to reschedule due to disturbances in the system.
Outside the scope of this paper, resource management has also a political dimension, in the sense that better use of the resources (lean airport management) may lead to increased traffic flows which in turn implies an even more vulnerable planning and higher environmental load. This is however a political decision and different from the tactical and operational focus of this study.

The remaining of the paper is organized as follows. In the next section, previous research on resource management in the ATS is reviewed and classified, with focus on research approaches related to the airport logistics concept. This concept is further defined and discussed in the third section of the paper, where also the future development of a decision support system is outlined and motivated.

**RESOURCE MANAGEMENT IN THE AIR TRANSPORTATION SYSTEM**

There are three main actors in the ATS: airlines, airports and air traffic control (ATC). The airlines’ primary planning objective is to achieve the most efficient transportation of passengers and cargo between various airports. For this to be possible, airlines need to offer their services at airports where these services are requested. Airlines need to have an appropriate fleet of aircraft as well as an effective schedule in order to meet these needs while flying the routes, at times that are most profitable. Airlines are an airport’s primary customers, but airports also profit from passengers who use the airport facilities and the services they provide, including restaurants, shops and parking spaces. In order to create an effective flow of passengers, cargo and airplanes to and from airports, a well developed infrastructure and support organization are necessary. The air traffic control authorities have the main objective of guaranteeing safe air traffic, but they are also responsible for managing the total flow of aircraft to reduce congestion and delays. This is referred to as air traffic management (ATM). In Figure 1 we illustrate the resource management tasks performed by airlines, air-
ports, and ATC. As can be seen from the figure, some of the tasks have to be accomplished jointly by more than one actor.

The complexity of dealing with ATS management in its entirety necessitates a decomposition approach. For this reason, most of the previous work on ATS management studies some component of the system, usually a planning problem found at one of the actors. A convenient although incomplete approach to review the current literature on ATS management is therefore to consider three categories of resource management issues: airline operations, airport operations and ATM. The current trend, however, is a shift from the decomposition approach towards integrated planning, of which CDM (e.g. (6)) is probably the best example. Airport logistics, which we detail in the next section, can be regarded as the efficient planning and control of the airport operations, which is why the focus of our research overview is the airport operations category.

Resource management in general involves many scientific disciplines. Among them, a particularly important one is operations research (OR). We refer to (7) and (15) for surveys of OR applied in the ATS, and (41) that surveys the potential applications of OR to European air traffic flow management.

Resource management in airline operations is typically revenue- and cost-driven. Several resource management issues in airline operations have been studied in the literature. A strategic planning issue is schedule design, in which the schedules of flights for serving potential markets are determined. Models and solution approaches for schedule design have been presented in, for example, (10) and (45). A second problem in airline operations is fleet assignment that involves assigning aircraft types to legs (a non-stop flight) in the schedule. Models and methods based on mathematical optimization have proved to be effective for dealing with this problem (e.g. (34) and (51)). Once the aircraft type of a leg is determined, the next step is to assign an individual aircraft of that type to the leg. Assigning an aircraft to a sequence of legs creates the routing of an aircraft. Since an aircraft must receive maintenance at regular intervals, aircraft routing also involves the planning of time and place for maintenance (e.g. (31) and (33)). In addition to managing the aircraft fleet, an airline operator must plan the aircraft crew. The most extensively studied topic in this area is crew scheduling, which consists of creating minimum-cost crew schedules (called crew pairings) and the assignment of the schedules to individual crew members (called crew assignment). We refer to (9), (23) and (37) for excellent surveys of this topic. Although the resource management issues discussed here have traditionally been tackled separately, there is an increasingly amount of research on integrated management. For example, combined fleet assignment and aircraft routing with maintenance have been studied in (8) and (25). The recent work in (16) suggests that it may be favourable to jointly consider crew scheduling and maintenance planning.

Some other decision-making issues in airline operations fall into the practice of revenue management. Revenue management deals with models, strategies, and policies for overbooking, mixing fare classes, and seat inventory. A nice survey of these topics is provided in (47).

In a short-term perspective, airline operators (as well as airports) have to deal with disruption management, i.e., to perform recovery and minimize the negative consequences when the planned schedule (of flights and crew) is disrupted due to delays and other unforeseen events. Operations research has been widely used for disruption management in the literature (e.g. (2), (43), (44) and (64)). Surveys of this topic are presented in (32) and (38).

It should be remarked that the above cited works on optimizing airline operations do not consider the capacity of logistic processes at airports in any detail. Clearly, the capacities of the logistic proc-
esses (in addition to the capacity of an infrastructure, such as runways) at an airport highly influence the operational plans of the airline operators.

Previous work on resource management at airports, i.e. airport operations in Figure 1, is closely related to our concept of airport logistics. However, whereas most of the previous work cited below focuses on a certain type of process at the airport, airport logistics is intended to capture the interaction between the processes, and perhaps even more important, between the airport processes and ATM.

Relevant elements in resource management at the airside of an airport include runway capacity, runway sequencing and taxiing, slot allocation, and gate allocation. There is a vast amount of literature on these topics. Below we provide a brief discussion of some of these issues together with examples of references.

- **Runway capacity.** Traditionally, the runway has been considered as a capacity bottleneck at the airside of an airport. The definition of (arrival) runway capacity can be tracked back to (13) in the late 50s. This basic runway model was extended to consider departures in (36). Examples of applying queuing and delay models for analyzing runway capacity are (12), (30) and (40).

- **Runway sequencing.** Runway utilization can be improved if the landing sequence of aircraft approaching an airport is optimized. Optimized sequencing also gives less delay and a higher throughput. Runway sequencing deals with determining the landing sequence subject to separation requirements between any two successively-landing aircraft. A natural extension of this problem is mixed arrivals and departures at one single runway. Also, taxiing operations affect runway throughput. We refer to (1), (22), (35) and (49) for some research work addressing runway sequencing and taxiing.

- **Slot allocation.** At many airports, time slots for landing and take-off are scarce resources. Thus the policy used for allocating slots plays an important role in managing the overall airport capacity. The possibility of improving capacity through slot allocation is heavily dependent on regulations (e.g. (29)) and the instruments available. We refer to (46) for an up-to-date review of the current instruments and proposals of enhanced slot allocation procedures.

- **Gate assignment and scheduling.** Assigning gates and stands to aircraft is an (often on-line) operation performed at every large airport. Optimized gate assignment and scheduling leads to efficient utilization of the gate resource, as well as minimum delay caused by the unavailability of gates and passenger transfer between gates. We refer to (26) and (66) for some recent work on applying mathematical optimization to gate assignment. A comprehensive survey is provided in (27), which contains over 50 references on this topic.

At the landside and terminal areas of an airport, previous work (e.g. (21) and (65)) has focused on models and analysis of passenger terminal operations. In (14), the authors present a simulation tool, named SLAM (Simple Landside Aggregate Model), for analyzing the throughput of various facilities in airport terminals in order to identify capacity bottlenecks.

Simulation is also a very powerful tool for modelling and analyzing the performance of airside operations (18). A number of airside simulation packages are available. A widely-used simulator is the Airport and Airspace Simulation Model (SIMMOD, (55)), intended for in-detail simulation of both airport surface operations and aircraft movements in nearby airspace. SIMMOD simulates the movement of every individual aircraft, taking into account the capacity of airport airside facilities (e.g., runways and gates), operating policies (e.g., taxiing patterns), as well as the airline operations...
(e.g. schedule). The Total Airspace and Airport Modeller (TAAM, (60)) is another large-scale simulator for off-line or real-time simulation of both airside operations and traffic movements in the airspace. In addition to the movements of aircraft on the ground, TAAM can simulate ATM systems and ATC rules.

Two simulation packages focus on airfield flows and capacity. The first is The Airport Machine (62) developed by Airport Simulation International (ASI). The Airport Machine simulates every aircraft movement on runways, taxiways, as well as apron areas (the asphalt area next to the terminal where the gates and stands are marked), from a short time before landing to the moment of take off. The second simulation package is the Mantea Airfield Capacity And Delay Model (MACAD, (59)). MACAD models airside facilities (such as the configuration of the runway system and the number of aprons and gates), traffic demand (number of arrivals and departures), and ATC procedures (e.g., the required separation between aircraft).

A recent development in air traffic and airport simulations is the trend of integrating airside and landside simulation tools (e.g., (3)). OPAL (Optimization Platform for Airports Including Landside, (67)) is a recently developed platform for integrating the SLAM and MACAD simulation tools mentioned above. Two good examples of current integration efforts are the THENA (THEmatic Network on Airport Activities, (63)) consortium and the SPADE (Supporting Platform for Airport Decision-making and Efficiency Analysis, (58)) project within the EC 6th framework. THENA acts as a coordination and collaboration environment for research activities aimed at improving the efficiency of airport operations. A particular goal of THENA is to integrate state-of-the-art simulation models and tools for airside and landside. The main objective of SPADE is to develop a user-friendly decision support system for airport stakeholders and policy-makers. SPADE facilitates the integration of simulation models by means of a common interface, through which models developed for airside and landside can communicate.

We would like to point out that although most of the simulation packages are descriptive, there has been some work on embedding active decision making (often based on optimization) into a simulation environment. In (18), for example, the authors present an apron simulation model, in which a shortest-path-based algorithm is used for finding the optimal path between the runway exit and a gate or a stand.

In addition to airline and airport operations, resource management is equally important in ATM. The sky is a scarce resource in the ATS today. From a modelling standpoint, a widely investigated issue is to avoid potential conflicts between aircraft. A nice review of this topic is given in (39). In the context of airport logistics, the most relevant operation of ATM is Air Traffic Flow Management (ATFM) that deals with coordinating traffic flows at regional, national, and international level. The decisions made in ATFM, in their turn, regulate the traffic at the airports. Conversely, the capacity of airport operations, e.g., those involved in a turn-around process, should be integrated into the decision making process in ATFM. Some measures in ATFM are re-routing (i.e., choosing another route for some aircraft), metering (i.e., controlling the aircraft arrival time), and ground holding (i.e., delaying the departure of flights in order to avoid overload). Models and strategies for these types of decision-making processes are presented in, for example, (4), (5), (11), (20), (42), (50) and (61).

**AIRPORT LOGISTICS**

The existence of the air transportation system (ATS) is due to the demand for quick transportation over long distances, for example between the airports A and B in Figure 2. It is instructive to view
the air transportation system as a network having flows. In this context, the flows that generate value in the ATS are passengers, possibly travelling with baggage, and cargo. These flows will henceforth be called value flows.

In order to facilitate the value flows, support flows are necessary; the two most evident being the flows of aircraft and aircraft crew. These are also the only two support flows that connect the airports in the system.

Most users of the ATS interact at the airport. Apart from the airport, which may be regarded as an actor in the system, the users include airlines, handling companies, passengers, cargo owners and air traffic control (ATC). The overall efficiency of the system is a (complex) function of the individual efficiency of every single participant in the system. To maximize the overall efficiency, the operations of one actor should be made available to all other actors. This is the core concept of collaborative decision making (CDM). In CDM, airlines, airports, handling companies and ATC should all have access to the same information within the system. An actor should be able to influence decisions that will affect their operations, including decisions made by another actor.

The technical prerequisites for an effective CDM system, such as the possibility to create safe and secure communication channels, exist today. Furthermore, there exist solutions for navigation, surveillance and control of aircraft, which are superior to the radar based systems in use today. These technical advances result in an increasing amount of information to each actor in the ATS, which, correctly used, might lead to improved resource utilization, as well as reduced delays and waste. However, the growing amount of information also leads to a mounting complexity in the decision making process, as the number of options available for the decision makers grows. Thus, improvement in efficiency requires that each actor has the ability to handle and utilize the new information.

When a single airport is studied, the logistics of the ATS is limited to airport logistics. Airport logistics is the planning and control of all resources and information that create a value for the customers utilizing the airport. The customers in this aspect are the passengers and cargo service consumers, as well as airlines, restaurants, shops, and other actors operating at the airport. In the context of CDM, the goal of airport logistics is to utilize and process the information made available via CDM to achieve intelligent resource management.

Looking closer at airport A in Figure 1, the airport is divided into three geographical areas; landside, terminal and airside. These are commonly used notations, but the definitions vary. In some sources landside includes all activities on the ground and airside includes everything happening in the air, while other sources place the border between landside and airside at the security control. The definitions used here can be found in Table 1.
Airside is the area where activities related to aircraft movements, like approach, taxing and take-off, as well as turn-around (e.g. fuelling, push-back and services by other types of vehicles), take place.

Landside includes the areas and the associated activities on the curb side of the terminal, like parking spaces and bus stops.

Terminal includes the area and all activities occurring inside a terminal building. Note that this may be a cargo terminal as well as a passenger terminal.

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Table 1: Definitions of airport areas

Most of the flows enter and leave the ATS through landside (see Figure 2). The passengers may e.g. travel by car, train or buss to the airport, and will reach the landside area before entering a passenger terminal. Cargo often arrives by truck and might be unloaded at a cargo terminal. The aircraft flow does not normally leave the ATS, but enters and leaves a single airport system through airside. The process of unloading passengers and cargo, re-equipping the aircraft and loading new passengers and cargo, is called turn-around.

One way of increasing the resource utilization in the ATS is to reduce the turn-around times. During turn-around, several activities are performed; passengers and baggage have to be unloaded, and the aircraft has to be cleaned and fuelled. The toilets have to be emptied and the food supplies re-stocked. Sometimes snow and ice have to be removed before the aircraft can take off again. The efficiency of each of these processes has a direct impact on the turn-around time of the aircraft. The turn-around process is essential in the airport system, as most of the other relevant processes and activities connect to each other during the turn-around.

As mentioned in the introduction, the vision with airport logistics is to develop a complete picture of all processes and activities at the airport, which will make it possible to analyze and optimize the operations. This picture is also the fundamental base for a decision support system (DSS) containing strategic, tactical and operational components.

Developing the DSS consists of three phases:

1. Modelling
2. Consequence analysis
3. Recommendations and service development

In the modelling phase, the flows and processes in the airport system will be analyzed in order to create a conceptual model of the system. This model itself can be used for visualizing the interaction between different airport processes, and for highlighting the connections and dependencies between the different actors operating at the airport. It will also be used as a base for a simulation model capable of capturing the relevant flows and processes in the system. Such a simulation model is well suited for consequence analyses and for answering “what if” questions like:

- What happens if the number of movements increases?
- What if the ground handling operations are carried out in a manner that is geographical-area oriented instead of airline-oriented?
- Is it beneficial to prioritize aircraft with many transferring passengers?
- How much can the turn-around time be reduced if more airport resources are available?
- Is the airport infrastructure a bottleneck?

The simulation model will also be used to analyze consequences of process changes. These analyses will be evaluated from a wide range of aspects. Some of the aspects are essential for resource efficiency, such as capacity and availability. Others include environmental load and profit. At all times, safety and security are basic qualifiers that can not be compromised.

In the third phase of the development process, the descriptive simulation model will be used to identify bottlenecks and critical processes at the airport. Based on this, recommendations can be made on how to increase the capacity and ensure a robust planning of the relevant processes. Furthermore, tools for supporting efficient utilization of the resources will be developed. These tools range from simpler scheduling rules to optimization based planning tools.

![Diagram](image)

**Figure 3: Components and processes in the decision support system**

The DSS will be designed such that applying the DSS follows the Shewhart cycle (23), see Figure 3. According to the cycle, the first step of applying the DSS is to Plan an improvement (for example, a process change). This potential improvement can then be tested using the simulation platform, which corresponds to the Do step in the cycle. The next step is to Check the consequences of the improvement (consequence analysis). If the process change is successful, it should be implemented as a general measure in the Act step. Based on the results from the Check step, some sort of decision support tool can be developed or utilized in the Act step to further enhance the efficiency of the process change. If the Check step does not reveal any promising results, the Act step is dropped.

The DSS described above can be used for supporting strategic and tactical decisions, like infrastructure planning and resource scheduling. The decision support tools developed in the DSS can typically assist in the planning of various sub-processes, and also in the operational control of resources in these processes.

Within the framework of Airport Logistics, which focuses on the entirety of the airport and integrates many research areas, the DSS makes it possible to plan and manage the airport resources in an intelligent way. Furthermore, such a system makes it possible to find solutions optimal for the entire airport, rather than those optimized for an individual actor. Addressing the aspects mentioned in the white paper (17), like safety, efficiency and environment, as well as capacity, which is the key topic in previous research, airports adopting the concept of airport logistics are ready to meet the goals of “intelligent air transportation”.

9
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