A CONTRIBUTION TO PROACTIVELY PLANNING AND MANAGING AIRPORT GROUND TRAFFIC USING A STOCHASTIC MODELLING APPROACH

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Keywords : *airport ground traffic, decision logic, stochastic model*

ABSTRACT

Air traffic growth in general and hub development in particular have led to the saturation of major airports. Ground delays are therefore becoming increasingly common. The purpose of this project is to develop a modeling tool for the description and analysis of airport ground traffic. A model is presented to describe airport ground traffic with a view to apron controller decision support. For a generic apron and taxiway layout, ground traffic controllers' decision logic is formalized. It becomes the base of a stochastic model in order to take into account the stochastic nature of traffic events on the apron. The method developed will ultimately support proactive, robust planning of apron traffic. This will naturally complement A-SMGCS systems, that generally allow for improved situational awareness, but not for automated planning.

1 MOTIVATION

Air traffic has enjoyed dynamic and nearly uninterrupted growth for the past 50 years, and in spite of a recent slow-down in the growth of air travel, all industry observers unanimously anticipate air traffic to continue growing. While it is not yet clear whether the pre-crisis path of growth will be regained, a delay of the formerly anticipated growth by 1 to 3 years is already a worst-case scenario [1]. Therefore, adapting the air traffic infrastructure to this increasing need for capacity remains a primordial concern.
Certain airports are operating at or above their maximum capacity. Yet, physical expansion of existing airports or entirely new projects in this field are often a problem due to concerns about environmental impacts of aviation on surrounding communities. [2] For this reason, the aviation community is pursuing technological solutions that have the potential of easing congestion or enhancing capacity by allowing fuller and more efficient use of the airports already in operation.
Much consideration has for a long time been given to runway capacity and to gate capacity. Fewer consideration, however, has so far been given to apron area and taxiway capacity. [3]

In order to achieve the manageability of flights gate-to-gate, a more thorough analysis of the airport apron and taxiways is necessary. This paper analyses possible ways forward to closing the gap between decision support for the runway system and presents a stochastic model that accounts for the uncertainty not only as to when certain events will occur, but also what distribution their duration might be subjected to.

Besides to being a step towards gate-to-gate management of flights, a modeling tool for apron traffic will not only enable tactical planning of apron processes, but also open the door towards optimizing overall airport system capacity, instead of just looking at sub-systems' capacity.

2 PROACTIVE PLANNING

2.1 Problem Statement

Controlling flights gate-to-gate, i.e. providing a flight not only with a slot for take-off, but also for taxiing out, enroute flight segments, landing, taxiing in, and providing it with an arrival gate is currently the aim of several ongoing research projects.

As mentioned above, runway usage and gate allocation have already been widely addressed, which has lead to a number of solutions (e.g. AMOSS, ARRCOS, DEPCOS, DARTS, etc). These decision support systems help air traffic controllers with approach or departure sequencing, or provide apron controllers and airline operations people with IT support for gate allocations planning. Many of them have become operational during the last decade.

The issue of taxiway and apron capacity, however, has obtained far less attention. The taxiway and apron area capacity have in fact mostly been regarded as unlimited resources with most current approaches.

2.2 Operational Conditions

Airport ground movements in the sense of this study is all taxiing or other movement on the apron that surrounds passenger and/or cargo terminals, as well as on any taxiways. Take-off or landing rolls, however, are not accounted for. Since an aircraft landing or taking off blocks the entire runway, there is no point in modelling any movements during those phases from an airport ground movement modeller's point of view. An aircraft therefore enters the space of this model when leaving the runway, and it leaves the space of this model when entering a runway (except if the airplane merely crosses the runway, in which case the runway actually acts as part of a taxiway).

Three types of users move and park on the apron, with right of way in order of decreasing priority:

1. Rescue and fire fighting vehicles
2. Aircraft
3. Service vehicles, e.g. Follow-me cars, fuel trucks, baggage handling equipment or –carts etc.

Since rescue and fire fighting vehicles (Priority 1) luckily are in operation too rarely to be included into an apron traffic model, and all other service vehicles (Priority 3) have to grant any taxiing aircraft way of right, our model of ground traffic is limited to taxiing or holding aircraft.

Aircraft may be using the apron or taxiways for any of the following purpose:

1. In-service aircraft taxi between runways and aircraft stands at the terminal or on the apron
2. Out-of-service aircraft taxi between aircraft stands and parking or technical service areas
3. Aircraft are parked, being loaded or unloaded
4. Aircraft hold short on taxiways or on the apron, either to grant way of right or to wait for a take-off slot or a gate to become available
5. Aircraft are parked out-of-service, for overnight stops or comparable layovers, or for technical stops

Apron control is on virtually all airports performed manually by apron controllers, with the help of near-range radar ASR (aerodrome surveillance radar) and apron radar ASDE (automatic surface detection equipment). Matching the objects detected by these two radars with the active flights in the flight plan database, however, is mostly still done manually and by visual contact between controllers and aircraft. The ground controller then plans and assigns taxi routings according to his situation assessment and his experience. Aircraft separation is assured by each pilot. This leads to a rapid decrease in capacity during adverse weather conditions, when visibility on the airport diminishes.

Using transponders and secondary radar (SSR), which are widely used for automatic labelling of airborne aircraft, is not a feasible solution for ground traffic, mainly due to the limitation of channels for secondary radar and also due to the resolution which is too low for effective use on the ground.

ICAO's All Weather Operations Panel (AWOP) has therefore specified standards for an Advanced Surface Movement Guidance and Control System (A-SMGCS), capable of detecting and identifying aircraft taxiing at an airport. Examples for A-SMGCS systems are German DLR's TARMAC and Frankfurt Airport's TACSYS/CAPTS. These systems work with a set of different sensors; after a sensor data fusion the situation on the airport can then be represented to aide controllers. Both have proven operational in extended field tests, but have not yet entered everyday operations at a major airport.

3 MODELLING GROUND TRAFFIC

The obvious use of automated reconnaissance of aircraft in airport ground traffic (as implemented in A-SMGCS) would be for a planning logic that makes use of the automatic identification of aircraft on the ground, building a tactical planning tool aiding ground controllers with the decisions necessary in planning and routing every single aircraft.

Figure 1 summarizes the Functions, Processes and Options of ground traffic control. It shows the work share between controller and pilot. A proactive decision support will be able to help the controller with conflict management and congestion management functions, while basic A-SMGCS functions cover conformance and collision avoidance functions. Figure 1 is an adaptation to ground traffic from a more general figure depicting airborne ATC functions taken from [4].

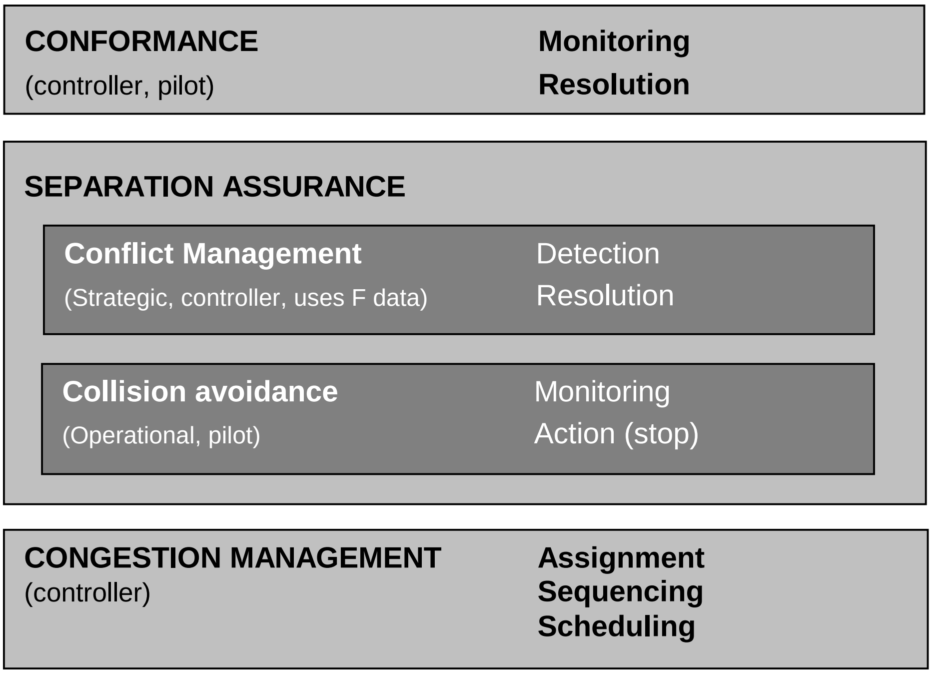

Figure 1: The structure of ground traffic control Functions, Processes and Options

Routings on the tarmac will be requested by each aircraft as it enters this model by leaving the runway, or by going off-block (i.e. starting to taxi from a gate towards take-off). In both cases, it is assumed that the target position of the taxi process is known. Either the aircraft knows it and requests it, or – if the taxi guidance and gate/slot allocation systems are interconnected – the system retrieves it from a database or generates it.

The next step will be to generate a routing proposal. If the airport's taxiway system is represented by a graph, i.e. broken down into vertices and edges, a number of algorithms can be applied to generate an optimum routing. Among them are:

- an A* algorithm can compute the best path and the corresponding minimal time spent between two given nodes
- a Dijkstra algorithm can do the same, but from a given node to all other nodes
- a Recursive enumeration algorithm using the Dijkstra's result can compute the *k* best paths from a given node to another
- a Branch and Bound algorithm can compute all alternate paths lengthening the best path less than a given distance or time (all 4 in [5])

An obvious approach would be to generate the optimum routing for every requested taxi path on a first come first serve basis, and then solve conflicts possibly arising between these routings.

Another approach would be to build a database with standard routings between given nodes / points on the apron, and serve requests for routing clearances from that database. Conflicts can then be detected, and a search for alternate routings can start. Since standard routings are what ground traffic controllers use today in order to structure traffic, this approach will bring less of a change to operating procedures. Tuning the standard routings can bring in expert knowledge from ground traffic controllers.

These two approaches are radically different from each other.

While the generated routing proposals will usually be closer to the optimum and allow faster routes, they might not be the solution of choice. The reason is that they will result in ground traffic patterns that are radically different from the traditional patterns. This raises two main points of concern:

- The acceptance of proposals generated that way by controllers will inevitably be difficult, as has been reported from field tests with several similar decision aiding systems ([6], [7]). This aspect must not be neglected, since apron controllers remain responsible for the traffic they clear. Therefore, unless a fully automatic ground movement control system is implemented (which is not to be expected within the next 15 years), the evidence of the proposals generated by a decision aiding system remains a paramount concern.
- Unless a failsafe strategic conflict resolution tool can guarantee that it will solve any problem without human interference, it has to be assured that a human controller can jump into the process at any time and take over controls.

Further consultation with airports and ATC controllers is planned in order to choose the approach with the greater operational benefit.

4 CONFLICT RESOLUTION

The routings assigned to incoming requests as outlined in Chapter 2.3 have to be verified for conflicts. After a certain number of routings have been assigned, conflicts will inevitably arise. A conflict is defined as an event in which two aircraft would occupy the same vertex or edge at the same time (see Figure 2 for an example graph).

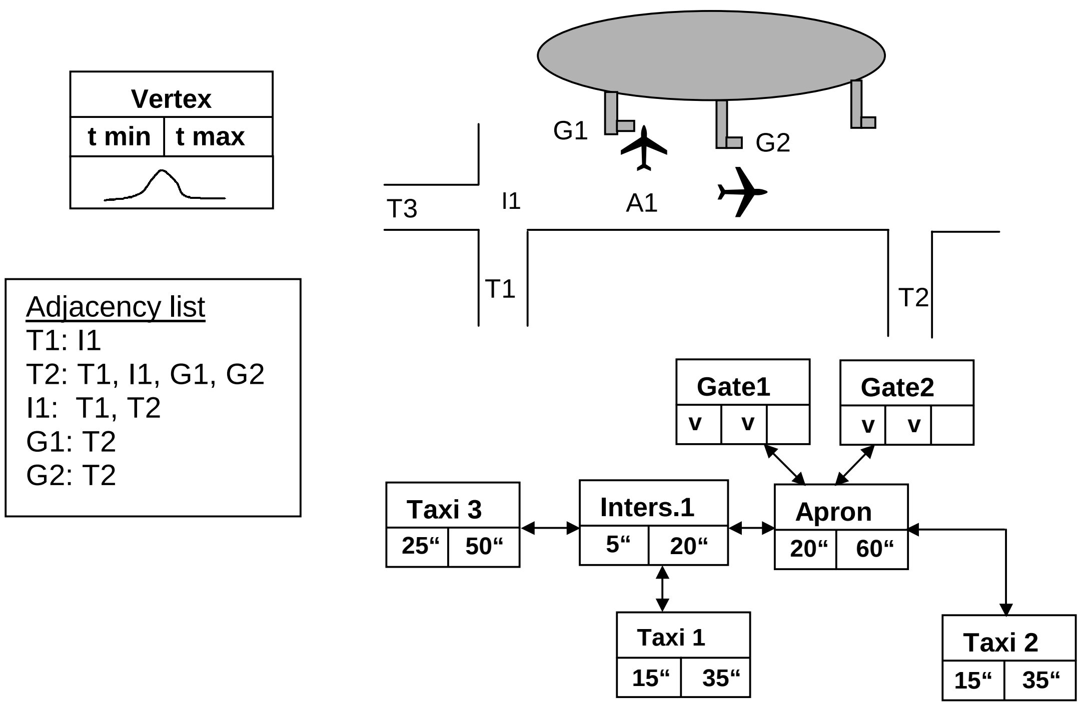

Figure 2: Sample apron with passenger terminal and graph representation

Figure 2 also illustrates the stochastic model that enables conflict detection: the vertices are depicted together with a normal distribution, that will at first be assumed. The vertices show the 5% / 95% percentile values, i.e. the times that it will take 90% of all aircraft passing this vertex to clear it. As a result, conflicts will occur with a certain probability.

The model should then look at alternative solutions. Three different approaches for conflict resolution are conceivable:

1. The first routing assigned to an airplane has priority, i.e. way of right in any possible conflict.
2. Priority is granted on a road-like, case-to-case basis, which organises each single conflict without looking ahead.
3. Priority is granted on the basis of a hierarchical classification, which makes sure that a conflict resolution does not initiate another conflict. The proposed order of priority for the resolution of ground traffic conflicts is this:

Priority	Guideline	Rationale
1	"Aircraft taxiing out have priority over those taxiing in"	Avoid deadlocks close to the terminal, where the space for manoeuvring is limited
2	"Re-direct an aircraft if this does not divert it from its general direction"	Avoid halting aircraft that can pursue their mission via an alternate path
3	"Halt an aircraft if only re-directions away from its general direction are possible"	Avoid directions that divert an aircraft farther than necessary from the shortest path
4	"Prefer in-service aircraft over a/c being towed or taxiing empty around the airport"	Delay payload as little possible
5	"Prefer directions within the usual orientation of traffic, if any"	Minimize risk of collision in the event of the violation of a direction
6	"Solutions still equivalent are randomly prioritized"	Avoid inconsistent priorities downstream.

Figure 3: Evaluation of multiple feasible solutions

Validation of the model once implemented shall first be done with generic data. In a second step, validation with real scenarios are planned.

5 SUMMARY

The aim of this project is to contribute to development of a proactive planning tool for managing airport ground traffic processes. While past efforts have been to model and optimize the runway sequencing and gate allocation problems individually, these approaches could not optimize the entire airside system of an airport. This research project hopes to fill this gap by providing a modeling tool for apron traffic that will not only enable tactical planning of apron processes, but also open the door to optimizing overall airport system capacity.

For the first time in airport apron traffic planning, it is thus accounted for that the pilot remains ultimately at the control of the taxi process, and durations of individual elements of the chain therefore can and will vary. The modelling approach will allow for robust planning, since the uncertainty of the duration of events is built into the model. It will also make possible an analysis as to how far into the future planning is useful. The answer to this question will vary depending on the topology of the airport under consideration.

6 ACKNOWLEDGEMENT

I would like to thank the Deutsche Forschungsgemeinschaft DFG (German National Research Foundation) for generously supporting my work on this project. (GK 621/1)

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