A model of Apron Travel Time for Automatic Aircraft Routing Applications in Airport Taxiways

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ABSTRACT
This paper presents a model of an airport apron that has been developed in order to determine a dynamical model for aircraft travel time in this area. This model is intended for future systems that will support automated routing and taxing of aircraft in airport taxiways. The apron model proposed keeps into account the main issues related to the aircraft ground movements, such as aircraft conflict management. This model was developed to integrate the software tool taXi Route Planner (XRP), a proprietary software of Selex Sistemi Integrati S.p.A. Malpensa Airport was selected as a case study and the model was verified by field testing on real traffic data.

Categories and Subject Descriptors
j.2 [Physical Sciences and Engineering]: Aerospace.

General Terms
Performance, Reliability, Experimentation.

Keywords
Airport automation, surface operation, air traffic management, air traffic control.

INTRODUCTION
The fast growth of air traffic requires a continuous improvement of air traffic management systems and a radical change would be desirable to avoid congestions [1]. Moreover, the new systems will have to support ground controllers without increasing their workload. As a consequence, a series of new systems to support the decision making process of controllers are being developed in the framework of the future Air Traffic Control (ATC) procedures and systems, such as the Advanced Surface Movement Guidance and Control System (A-SMGCS) [2].

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and Collaborative Decision Making (CDM) [3]. These systems will have to provide three functions: routing, control, and movement execution [4]. In particular, the XRP tool has a prominent role in routing and planning.

The routing phase consists in the selection and assignment of a specific route for each aircraft, whereas the planning phase refers to the determination of start/end time of the path. Hence, the XRP must output on-block/off-block time assigning a ground movement route to each airplane so that the tool minimizes taxi time and the number of conflicts.

The XRP tool introduces some important features:
- A model of landing run that includes fast-exits;
- A runway crossing model, using holding points;
- A detailed apron model.

The latter is the subject of this paper.

Aprons are a defined area, on a land aerodrome, intended to accommodate aircraft for purposes of loading or unloading passengers, mail or cargo, fuelling, parking or maintenance [5]. This area is not under direct ATC authority. Currently, Air Traffic Controllers (ATCo) can assign a path only to aircraft that operate in the Maneuvering Area, the part of an aerodrome used for the take-off, landing and taxiing, which does not include aprons [5]. This is due to the intrinsic nature of aprons where pilot visual guidance is the only reliable source of control.

In case of heavy apron traffic a specific Apron Management Service (AMS) [5] can be provided but it is not a part of airport ATC.

For this reason a detailed apron model was developed for the XRP software. It simulates the traffic and dynamics of aircraft in this airport area.

RATIONALITY FOR AN APRON MODEL
The XRP tool includes a module related to apron dynamics that allows estimating the inbound/outbound motion between entry/exit node of the apron and the stand in use. Indeed, a detailed model is needed to provide a prediction of aircraft motion with an rms error of less than 20s. This value is assumed as representative of the typical time
horizon of tactical airport control systems. In particular, XRP must prevent aircraft stops determined by right of way rules when two or more aircraft cross each other in a taxiway junction. Milan Malpensa Airport in Italy was chosen as case study due to its topographic complexity that allowed for modeling the most important elements of a modern airport, such as a multiple runway layout, fast exits, and runway crossings. An initial model with constant apron travel time has been discarded, since the difference of travel time from an apron entry/exit point to a stand can be more than 4 minutes, which is much larger than the 20s time horizon. Therefore, a more detailed model has been developed accounting for more specific features, such as:

- The typical time to get off-block/on block;
- The mean ground speeds reported in regulations [5];
- The length of paths from stands to apron exits.

In order to be used by XRP, the apron travel time determined by the tool can be associated to the vertex of a graph [6] representing the airport.

APRON MODEL ARCHITECTURE

The apron model is developed by means of a step by step process with increasing complexity. First of all, a Single Aircraft Airport (SAA) model is considered. In the SAA condition, no conflict is allowed. This allows estimating the minimum aircraft travel time. The travel time in the SAA model depends on several parameters, such as:

- The stand in use;
- The used runway, in case of high complexity airports;
- The inbound/outbound traffic condition;
- The aircraft wake category.

In this case, the apron travel time evaluation is based on the approximation of uniform speed motion with constant velocity of 5 knots in the blocks and 10 knots in the apron taxiways, as given by regulations [5].

The SAA assumption is often not adequate for describing the aircraft ground traffic. To account for the condition of multiple airplanes moving into the apron, its surface is divided into several areas. In the particular case of Milan Malpensa, the area division is given by an accurate analysis on the paths that connect the stands and the maneuvering area. These are clearly defined in airport regulations [8].

To account for the delay due to aircraft conflicts into the developed model, an iterative process has been developed to evaluate the number of aircraft that simultaneously move in a specific area $A$. Hence, if $T_{in}$ and $T_{in}$ describe the final and the initial time, respectively, of a generic time interval, and $T_c$ a generic instant of this interval, an iterative process can be represented by the condition $T_c(n+1)=T_c(n)+\Delta T$ in which $\Delta T$ represents the increasing time and $n$ is the index of the iteration. The initial condition of iterative process is $T_c(0)=T_{in}$. Referring to a timetable, all the planes that cross the area $A$ in their path must be considered with reference to the time interval $[T_{in} T_{in}]$. If $T_{ex}$ and $T_{ex}$ are the entry and exit time, respectively, of a generic flight in the specific area $A$, then, the flight would be considered in the area at time $T$, if the condition $T_{ex}\leq T \leq T_{ex}$ is verified. The number of aircraft simultaneously crossing the same area can then be easily computed. The total aircraft number that moves at the same time in the whole apron can also be computed making the sum over all the relevant areas.

Once more than one aircraft is in movement, conflicts must be taken into account. Two aircraft are considered in conflict when the area entry time related to the first aircraft is included between the entry and exit time of the other one. Denoting with $T_{en}$ and $T_{ex}$ the area entry and exit time of the first plane and with $T_{en}$ and $T_{ex}$ the ones of the second plane, the (mutually exclusive) conflict conditions are:

$$T_{en}\leq T_{en} \leq T_{ex} \quad (1) \quad T_{en}\leq T_{en} \leq T_{ex} \quad (2)$$

The conflict duration is equal to the duration of the time interval when both planes travel inside the same area. The conflict can be modeled in terms of delay by adding a fixed delay in the on/off block time to one of the planes involved in the conflict. Indeed, a change of route is not feasible in the apron area since the paths covered by planes are commanded by regulations. Hence, a priority level is assigned to each plane in order to resolve the conflict. Planes with low priority level must hold at holding points in order to give way to planes with high priority level. The following rules are adopted to manage the conflicts:

- The takeoff sequence provided by the Departure Manager (DMAN) must be respected;
- An outbound flight has priority over an inbound one;
- If the involved flights are both outbound or inbound a first-come-first-serve approach is adopted;
- The Calculated Take-Off Time (CTOT) [9] must be kept to schedule;
- The flight status, e.g. State Flight, affects the priority;
- The “holdover time” related to anti-icing procedures must be taken into account, if needed.

After the selection of the priority flight, the other flight involved in the conflict must be delayed. In particular, the imposed delay time is related to one of the conditions represented in Figure 1. In this figure, the sequence of time instants $t_1$, $t_2$, $t_3$, and $t_4$ represents the entry or exit area time of the planes involved in the conflict and $\Delta t$ the time gap related to the presence of the two planes in the same area.

![Figure 1: Cases of area entry/exit time of Priority (P) flight and Non-Priority (NP) flight.](image-url)
Denoting with $T_{enP}$ and $T_{exP}$ the area entry and exit time of the priority flight and with $T_{enNP}$ and $T_{exNP}$ those of non-priority flight, the condition $T_{enNP}=T_{exP}$ must be respected to solve the conflict. In general, the delay time $dt$ to assign to the non-priority flight is given by eq. (3).

$$dt = T_{exP} - T_{enNP} \tag{3}$$

**CASE STUDY: MILAN MALPENSA AIRPORT**

Milan Malpensa Airport is characterized by two runways that are 3920 m. long and 60 m. wide. They are oriented at heading 349°N (or 169°N depending on the run direction). The runways can be used both for take-off and landing in the two directions: if they are run in south-north direction they are called 35R and 35L, while in the north-south direction they are called 17L and 17R. In nominal conditions runways 35 are used. Two aprons characterize the airport: the West Apron that is close to Terminal 1, and the North Apron that is close to Terminal 2. More information about Malpensa airport is reported in the Aeronautical Information Publication (AIP) [10]. The utilization of apron taxiways, as stated in the regulations, is related to the used runway that determines the direction of the path covered, depending on the stand in use and the inbound/outbound condition. The analysis of aircraft movements shown in this paper is based on the preferential use of the taxiways and apron connections.

**RESULTS**

The results refer to the West Apron of Milano Malpensa Airport and are based on real flight timetables of November 4th, 2009.

The first assumption of the constant apron travel time model, considers a fixed travel time regardless of the path length, the stand in use and the apron connection. However, the extended apron assumption and the application of the SAA model show that, on average, about 4 min. are needed to cover the apron. Moreover, Figure 2 shows that the difference between the maximum and the minimum apron travel time is larger than the temporal horizon of airport control systems in the tactical phase (20s.).

A further refinement in the apron model considers the condition of multiple airplanes moving at the same time inside the apron. First of all, this model has to perform the evaluation of the aircraft number that simultaneously moves in each area. Figure 3 shows the time history of the number of aircraft moving in the West apron of Milano Malpensa between 10:00 AM and 12:00 AM. This number is extremely variable and cases with more than one moving flight are very frequent.

Finally, a comparison between experimental data and apron travel times resulting from the models shown can be done.

**Figure 2:** West Apron travel time related to a SAA model.

**Figure 3:** Aircraft traffic in the West Apron between 10:00 AM and 12:00 AM on November 4th, 2009.

The last issue that must be modeled is the delay due to aircraft conflicts inside the apron. According to the conflict resolution strategy stated above, the delay must be assigned to the aircraft that has the lower priority level in the conflict. This model determines an increase of the apron travel time for some flights. The flights that never come in conflict with others or that are always priority when a conflict occurs do not increase their travel time for this model. In the actual flight data, the maximum delay time is 557s, the average delay time is 23s with a standard deviation of 64s. Figure 4 shows a statistics obtained by dividing the entire day in six time slots which contain a comparable number of maneuvering aircraft. In particular, the mean delay time and the standard deviation related to each time slot are reported.

Finally, a comparison between experimental data and apron travel times resulting from the models shown can be done.

**Figure 4:** Time slot statistics from actual flight data (b). In particular the experimental mean apron cover time (300s) is presented in the Figure 5 with a horizontal line. Referring to the 0:00-9:00 AM time slot, Figure 5 shows...
how, from a condition of constant travel time to a conflict resolution model, the apron travel time is increasingly closest to the real scenario, at least in terms of mean values. It is worth noting that the average apron travel time using the de-conflicting strategy is 283s., which differs from the experimental data mean value of less than 20s.

Figure 5: Comparison between experimental data and apron cover times coming out of the apron model in the 0:00 – 9:00 a.m. time slot.

Further improvements are needed to attain a model that meets also the standard deviation. Indeed, during experimental measurement the estimated standard deviation was about 260s, whereas the one of the tool is of about 150s. Indeed, some improvement can be added by introducing in the model other level of realism such as the movement of non aircraft ground vehicles.

CONCLUSIONS
A model of the aircraft traffic in airport aprons is presented for evaluating the apron travel times. In fact, it has been developed to support predictions of aircraft taxi times inside the apron. In particular, the apron model has been developed to be integrated into a Taxi Route Planner software tool, which is designed for aircraft surface movements routing and planning. Indeed, a detailed model is needed to provide a prediction of aircraft motion with an rms error of less than 20s, i.e. a typical time horizon of airport control systems in the tactical phase.

The present study aims at establishing the level of detail needed to model aircraft movements in the apron area, by comparing different apron travel time models on a case study. The development process for the system has been realized by adding a series of elements in order to attain the desired level of accuracy, i.e. an rms error in the order of the time horizon. First of all, the apron cover time has been determined considering the movement of each aircraft independently from other planes moving at the same time in the apron. Hence, the delays related to conflicts within the apron have been modeled by adding a penalty to aircraft that are moving in the same apron area at the same time.

The resulting performance determined a good fit of the model in terms of mean apron cover time. Indeed, it was compared to data from real flights measured by controllers at Milan Malpensa Airport. The difference was in the order of 10s that is less than the time horizon of 20s.

Future activities will deal with increasing the realism level, in order to fit also the standard deviation of experimental data. These activities will include modeling delays due to the presence of ground vehicles moving in the apron.

REFERENCES