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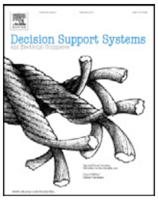

A decision support methodology for dynamic taxiway and runway conflict prevention

Steven J. Landry [a], Xin W. Chen [b], Shimon Y. Nof [a,*]

[a] School of Industrial Engineering, Purdue University, USA
[b] Department of Industrial and Manufacturing Engineering, Southern Illinois University-Edwardsville, USA

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ABSTRACT

Logic needed for decision support to detect and resolve airport surface conflicts is defined in this article based on complex network theory. In this article, conflicts in airport surface operations are defined, along with a methodology to model and analyze airport surface constraints. The conflict detection and resolution logic take advantage of properties of complex conflict networks for effective conflict detection and resolution. It is demonstrated and validated with the case of a modeled Hartsfield Atlanta International Airport. Further research will also include validation of the conflict detection and resolution logic with real airport surface operations data.

1. Introduction

The U.S. National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) are interested in developing and implementing surface trajectory prediction-based conflict detection and resolution (CD&R) for aircraft and other vehicles. Surface trajectory prediction can be computed using surveillance data provided by Airport Surface Detection Equipment (ASDE-X) or Automatic Dependent Surveillance-Broadcast (ADS-B) equipment, which enable sharing of vehicle-based position and intent information among airborne and ground-based aircraft, ground transportation vehicles, and control authorities. There is an increasing number of runway incursion incidents, which are precursors to actual accidents [13]. Runway accidents can be among the most catastrophic, including the highest fatality aviation accident on record in Tenerife in 1977.

CD&R is a critical component of surface operation automation. CD&R attempts to ensure safety while increasing the efficiency and throughput of surface operations. Previous research was focused mostly on CD&R for airborne aircraft, e.g., trajectory flexibility preservation and constraint minimization [e.g., 14,20,22], although there has been an increasing amount of work focused on surface trajectory prediction and CD&R [6,12,21,31]; most of this work focuses on either trajectory prediction or on route optimization, with very little focused on automated decision support for CD&R [3]. Surface operation automation requires the detection (before or after occurrences) and resolution (alerts and advisories to prevent or resolve) of conflicts between taxiing aircraft, ground transportation vehicles, and/or aircraft close to the airport surface. It is desired to prevent (before occurrences) and resolve all conflicts. Ground-based surface CD&R expands the role of centralized control and provides essential information to the decentralized aircraft-based CD&R.

Conflicts in airport surface operations can be defined as cases in which predefined three-dimensional and time-based (4D) constraints are not satisfied. That is, conflicts are incompatibilities between combinations of constraints; constraints are based on 4D trajectory predictions. Conflicts can arise under a number of conditions, including when new trajectories are added, resulting in new constraints, when aircraft deviate from their assigned clearance, or when trajectories are updated based on new information.

Given such a definition, the four significant challenges of this decision support research are:

1 How can dynamically changing constraints due to moving aircraft and ground vehicles, and also due to necessary airport operations adjustments, be modeled to detect conflicts?
2 How can relationships between constraints be captured and analyzed for effective CD&R?
3 When a conflict is detected, what are other conflicts that might occur due to this conflict?
4 If an advisory is issued to prevent or resolve a conflict, will the advisory cause new conflicts or will it resolve other conflicts?

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* Corresponding author at: Grissom Hall, 315 N. Grant St., W. Lafayette, IN 47907-2023, USA. Tel.: +1 765 494 5427; fax: +1 765 494 1299.
E-mail address: nof@purdue.edu (S.Y. Nof).
URL: https://engineering.purdue.edu/~nof (S.Y. Nof).

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The research question is, "can a decision support system based on complex network theory detect and resolve ground conflicts on taxiways and runways?" Based on this research question, this decision-support research models and analyzes 4D constraints from a complex network perspective [8–10] and develops CD&R logic to dynamically detect and resolve conflicts.

2. Decisions based on constraint modeling and CD&R logic

In order to support the decision process for detecting and resolving conflicts, it is necessary to have accurate predictions of the locations of the vehicles and the times at which it will reach those positions. For consistency with airborne trajectory prediction, these will be referred to as "4D" trajectory predictions, although the vertical dimension is ignored for ground traffic. The capability to create such trajectories is under development [6]. In this section, we will assume the availability of such 4D trajectory predictions, and identify and resolve conflicts through the use of 4D constraint modeling and resolution.

Current 4D trajectory prediction technology for airborne traffic is not deterministic; the trajectory predictions are stochastic. The accuracy of the predictions is affected by various sources of error, including wind prediction, modeling error, and position error. Moreover, even if such error is minimized, predictions cannot account for control applied by pilots and air traffic controllers; in such cases, predictions, which are estimates of the future open-loop trajectories, could differ from the actual closed-loop trajectories that occur. (The latter case is not error, but simply differences that could not have been predicted.)

2.1. 4D constraints modeling

Conflicts are defined as cases where predefined 4D constraints are not satisfied. A constraint describes how resources are utilized by aircraft and ground transportation vehicles. In the context of airport surface operations, resources include taxi ways and runways. Fig. 1 shows an example of two runways (27L/09R and 27R/09L) and four taxiways (A, B, C, and D). For the purpose of CD&R, each runway or taxiway may be divided into sections.

For example, runway 27L/09R is divided into three sections: 1, 2, and 3. (In a practical system, the sections would most likely be smaller than are used here.) Section 1 is between the departure end of runway 27L, which is also the arrival end of runway 09R, and the intersection of the runway and taxiway B. Section 2 is between two intersections: the intersection of runway 27L/09R and taxiway B, and the intersection of 27L/09R and taxiway C. Section 3 is between the intersection of runway 27L/09R and taxiway C, and the arrival end of runway 27L. In general, there are three types of resources S (a total of 22 in Fig. 1) in surface operations: taxiway segments, runway segments, and intersection segments. Symbolically:

- Taxiway resources: T_A^1, T_A^2, T_B^1, T_B^2, T_C^1, T_C^2, T_D^1, T_D^2
- Runway resources: R^1_{27L09R}, R^2_{27L09R}, R^3_{27L09R}, R^1_{27R09L}, R^2_{27R09L}, R^3_{27R09L}
- Intersection resources: I^A_{27L09R}, I^B_{27L09R}, I^C_{27L09R}, I^D_{27L09R}, I^A_{27R09L}, I^B_{27R09L}, I^C_{27R09L}, I^D_{27R09L}.

Constraints are defined to meet the requirement of surface operations. There are two types of constraints: trajectory time constraints and capacity constraints. Trajectory time constraints contain the predicted times of arrival for entering and exiting intersection segments, runway segments, and taxiway segments. Capacity constraints specify the acceptable number of vehicles, including aircraft and ground transportation vehicles, on a runway section, a taxiway section, or an intersection at a given time. For instance, the capacity constraint for any runway is defined by regulation as 1.

Consider the following simple example, using the airport diagram shown in Fig. 1. Suppose an aircraft (N123) lands on runway 09R, Section 1 and is predicted to travel to the terminal through taxiway C. Trajectory prediction software can be used to identify trajectory time constraints as follows (Con indicates constraints):

- ${}^{\underline{\mathrm{t}}}Con^{N123}_{R^1_{27L09R}}$: $\underline{t}\left(R^1_{27L09R}, N123\right) = 15$: aircraft $N123$ enters R^1_{27L09R} at $t = 15\,\mathrm{s}$
- ${}^{\overline{\mathrm{t}}}Con^{N123}_{R^1_{27L09R}} = {}^{\underline{\mathrm{t}}}Con^{N123}_{I^B_{27L09R}}$: $\overline{t}\left(R^1_{27L09R}, N123\right) = \underline{t}\left(I^B_{27L09R}, N123\right) = 25$:
  aircraft $N123$ exits R^1_{27L09R} and enters I^B_{27L09R} at $t = 25\,\mathrm{s}$
- ${}^{\overline{\mathrm{t}}}Con^{N123}_{I^B_{27L09R}} = {}^{\underline{\mathrm{t}}}Con^{N123}_{R^2_{27L09R}}$: $\overline{t}\left(I^B_{27L09R}, N123\right) = \underline{t}\left(R^2_{27L09R}, N123\right) = 27$:
  aircraft $N123$ exits I^B_{27L09R} and enters R^2_{27L09R} at $t = 27\,\mathrm{s}$
- ${}^{\overline{\mathrm{t}}}Con^{N123}_{R^2_{27L09R}} = {}^{\underline{\mathrm{t}}}Con^{N123}_{I^C_{27L09R}}$: $\overline{t}\left(R^2_{27L09R}, N123\right) = \underline{t}\left(I^C_{27L09R}, N123\right) = 57$:
  aircraft $N123$ exits R^2_{27L09R} and enters I^C_{27L09R} at $t = 57\,\mathrm{s}$

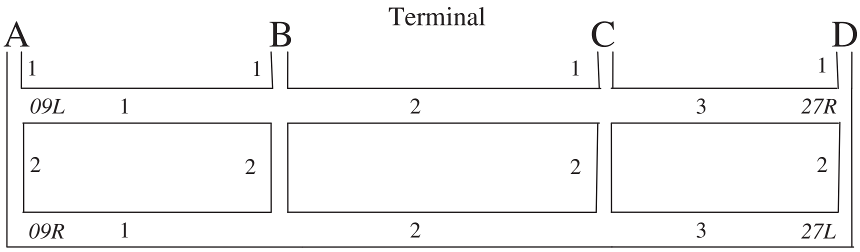

Fig. 1. Resource examples in airport surface operations.