# SIMULATION MODEL OF AIRPORT RUNWAY INCURSIONS

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## ABSTRACT

Runway incursions are defined by ICAO as “events that create an incorrect presence of aircrafts, vehicles or persons in airport restricted areas of take-off and landing”. In the Italian National Agency for Flight Safety Report (2001) it can be read: “Runway incursions are defined as one of the highest actual risks of aerial transportation in many airports all over the world. The situation is no more acceptable and it’s necessary to apply all the possible countermeasures with the commitment of public and private institutions and operators to solve the problem”. In fact, even if the most serious accidents are very rare (with a probability of about $1/10^7$ movements), their consequences can be catastrophic. The target of the research is to build a simulation model of ground circulation of aircrafts in aerodromes to evaluate frequencies of occurrence of incursions and the connection of the events to set an analysis on parameters as visibility, technological infrastructures and tower controls. The airport “G.B. Pastine” of Ciampino is presented as a case study, identifying actual status and opportune evolutions.

Keywords: runway incursions, airport safety, object-oriented simulation

## 1. INTRODUCTION

Accidents occurred in Tenerife, 27th March 1977 (583 deaths), and Milano Linate, 8th October 2001 (118 deaths) tragically underlined how safety of passengers and flights is strictly related to the conditions of runways and to the coordination of ground operations.

In the last years, many different studies (Eddowes, Hancox and Mac Innes 2001; Hillestad et al. 1993) estimated the distribution of risk incidents in the different stages of the flight, from take-off to landing. Among these researches, only the most recent reports of Eurocontrol (2004) and Federal Aviation Administration (FAA, 2006) recognized runway incursions as one of the most effective factors that can influence safety: their values are increasing to one incursion a day so to place in “top priority” the reduction and protection of the related accidents.

According to the International Civil Aviation Organization (2004) it’s possible to classify:

- *runway incursion*: any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircrafts;
- *accident*: any event associated with the movement of an aircraft, from boarding to landing, where a person is seriously wounded or dead [...] or when the aircraft is structurally damaged [...], missing or completely inaccessible;
- *incident*: any event, not being an accident, associated with the movement of an aircraft that harms or can harm the safety of the flight.

To give an indication of the residual margin of safety, FAA set four degrees of gravity (from higher “A” to lower “D”, depending on the probability of accident and distance of the agents) and three typology of runway incursions, according to the root cause: air traffic control error, pilot error or third party error interfering with the operations. In the cited reports, segmented studies on different aviations and frequency of occurrence in USA, Europe and Italy show the great impact of the phenomena.

Since April 2004, the Provisional Council definitively approved the European Action Plan for the Prevention of Runway Incursions and is now continuing its works to spread and awaken the different players in applying the recommendations of the document, sharing information and introducing standards of data collection and analysis. According to FAA Flight Plan 2005-2009 (2004), all the organizations involved are setting as the main target to reach before 2009 the reduction of runway incursions, through three different strategies:

- identification, reduction and protection of collision risks;
- development of appropriate innovative infrastructures;
- use of advanced simulation models to design and develop new equipments, procedures and training.

## 2. THE SIMULATION MODEL

An airport is an extremely complex system where thousands of peoples and many different operations are arranged according to accurate procedures.

The target of this study consists of creating a model of airport ground operations (in particular aircraft movements) to carry out a risk analysis of runway incursions, investigating in details all the possible fault events and consequences that can create incidents or accidents. To this extent, considering Wyss, Craft and Funkhouser (1999), an object-oriented analysis was implemented, defining:

- entities with attributes to describe their custom characteristics;
- states to draw their interaction with internal and external environment.

Objects, connected in subsystems and systems, are parametrically modelled in C++ and communicate through messages to represent information, materials or energy flows. Furthermore, an extraction of pseudo-random numbers, associated to normal distribution of probability for event's occurrence, allows an automatic generation of scenarios as:

- for each object, different behaviours are simulated, both correct and erroneous (i.e. an aircraft at a stop bar connection, without clearance, can respect the signal or enter the runway);
- the combinations of objects and events represent all the possible alternatives comprehensive of their different degree of risks, according to FAA classification;
- the evolution of systems and subsystems can identify the most frequent dynamics and their influent parameters.

As shown in figure 1, the model represents the interaction, in terms of runway incursions, of three type of elements (the airport, the aircrafts and the control tower) that act independently and are coordinated by a communication network with a black box to record any evolution of the whole system.

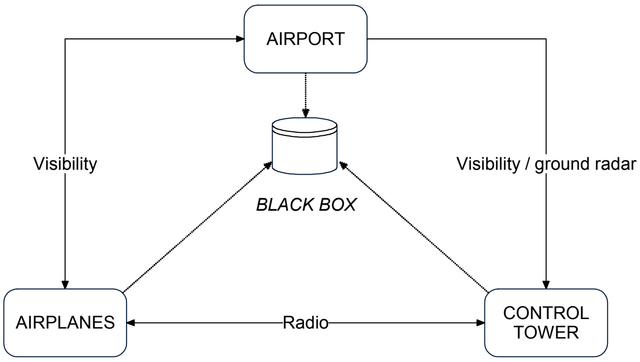


Figure 1: Communication framework

### 2.1. Airport model element

The object represents the environment where the aircrafts and the tower interact. It's constituted of two main elements:

- *the airport map:* it represents the physical set and geometry of all the runways, taxiways, aprons and paths, opportunely divided into coded segments. These information are transmitted to any aircraft, simulating the perception of the pilot on the external environment and his possibility to consult the map or read the signals along the routes;
- *the aircraft list:* it consists of the registration of the correct position of any aircraft in the different segments with its destination and orientation. For example, it allows the pilots to locate, real-time, aircraft taxing position, preserve an opportune distance, verify if a runway is free and monitor any eventual incursion.

To simulate incidents and accidents, causes of errors from the environment were modelled considering:

- unauthorized planes that cross the runways or taxiways;
- authorized planes with an *"hold short of the runway"* command confirmed but bypassed.

### 2.2. Aircrafts model element

Each aircraft is identified by a set of parameters to define both physical characteristics (speed, acceleration, position, dimensions) and information (visual or by radio) that can evolve, during the simulation and according to the other elements of the models, through "flying", "moving" and "waiting" states. Two lists manage the dynamics of any aircraft:

- a waypoint list containing all its expected positions;
- a to-do list with all the tasks to be executed.

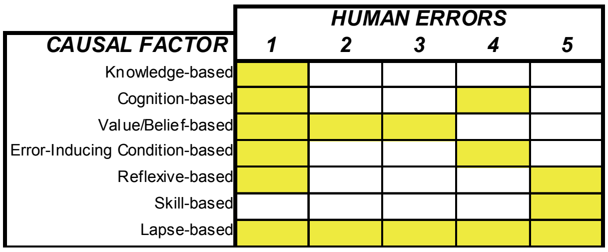
The tasks-cycle of a generic aircraft is represented in figure 2. To simulate incidents and accidents, five causes of errors due to pilots were modelled considering:

1. mistakes on *"read-back"* or *"hear-back"* orders assigned;
2. correct *"read-back"* or *"hear-back"* but different tasks executed;
3. no respect of the command *"hold short of the runway"* and cross the runway or stop taxing on active runway;
4. misunderstanding of radio communication addressed to other pilots;
5. different levels of reactivity.

In table 1, the different human error causal factors are classified according to Marguglio's framework:

- knowledge-based: lack of knowledge of the standard, requirement or need;
- cognition-based: lack of the appropriate level of cognition; lack of ability to understand, apply, analyze, synthesize or evaluate such as to be able to meet the standard, requirement or need;
- value-based or belief-based: lack of respect for or acceptance of the standard, requirement or need;
- error-inducing condition-based or error-likely situation-based: lack of recognition of the condition or situation and/or lack of counteracting behaviour;
- reflexive-based: lack of thought processes and behavioural techniques for conservative decision-making in reacting to an immediate "field stimulus";
- skill-based: lack of dexterity;
- lapse-based: nothing lacking; simply “blew it”.

Table 1: Classification of defined pilot errors



| **CAUSAL FACTOR** | **HUMAN ERRORS** | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| Knowledge-based | 🟨 | | | | |
| Cognition-based | 🟨 | | | 🟨 | |
| Value/Belief-based | 🟨 | 🟨 | 🟨 | | |
| Error-Inducing Condition-based | 🟨 | | | 🟨 | |
| Reflexive-based | 🟨 | | | | 🟨 |
| Skill-based | | | | | 🟨 |
| Lapse-based | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 |

### 2.3. Control tower model element

The object models both the behaviour of the control tower and ground control where the different tasks are divided into two categories: management of clearances and monitor of the ways. The first consists of:

- requests with instantaneous responses, for communications or information the aircraft should know while approaching (i.e. its landing runway, already communicated by the Approach Control);
- requests of path, to indicate the correct route to use to reach a determined point, with a FIFO logic and different level of priority (communications with the Ground Control);
- requests of clearance, with an order list subjected to strict procedures (radio traffic with the Control Tower).

Furthermore, the tower monitor ways and corridors with a frequency depending on the reaction of the operators to avoid eventual faults. When the tower identifies an incorrect action of an aircraft (ex. an alignment for take-off without clearance), it analyzes the situation, verifying the presence of other aircrafts and their relative positions, and gives orders trying to avoid the collision.

To simulate incidents and accidents, causes of errors made by control tower were modelled considering:

- a controller forgetting an airplane, a vehicle, a given clearance, the runway or taxiway state;
- communication errors like misunderstandings or mistake in read-back;
- a controller incorrectly estimating relative distances of aircrafts.

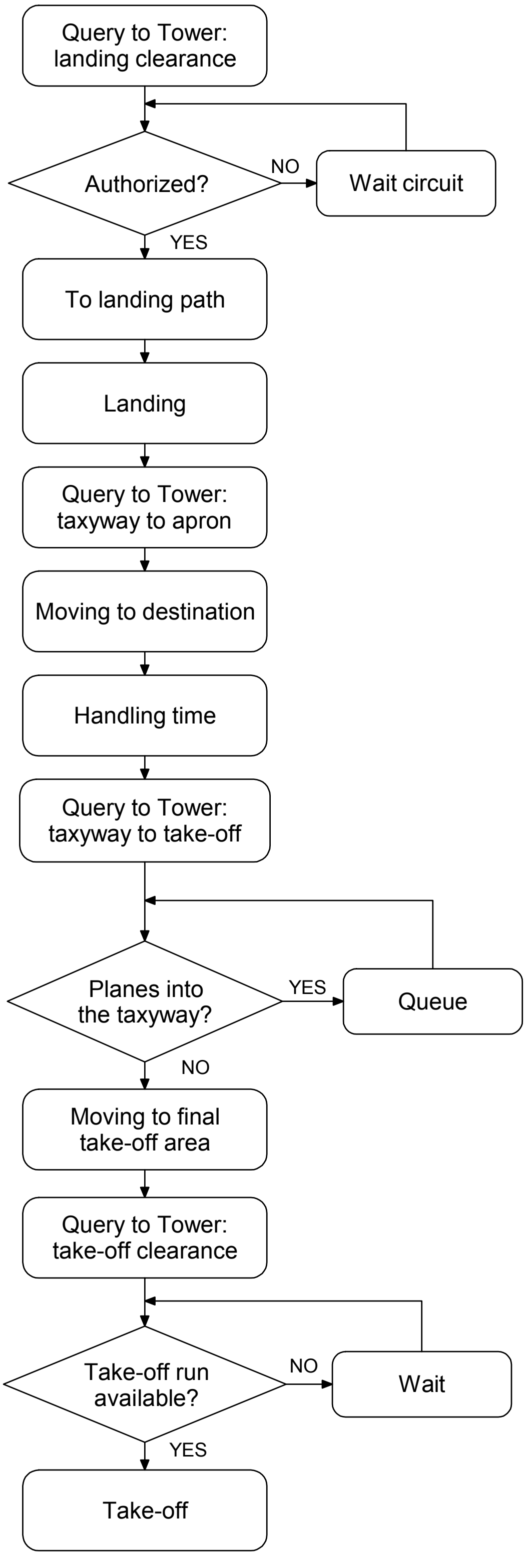


Figure 2: Life-cycle of aircraft element

### 2.4. Communication network model element

Communications act in two different ways: radio Ground/Air/Ground and visual perception of objects in the environment. Any aircraft interfaces the tower by radio communication to make requests and receive clearance, but instructions are subjected to delays, reaction times and human errors (wrong communication or wrong destination).

The complete network allows the model to know the correct position of all the aircrafts in the airport: each object can so visually identify its relative position while the tower can interrogate the airport to know the position of the aircrafts on the ground.

### 2.5. Black box model element

To gather information on the evolution of the model, a black box was modelled to record various information coming from the objects, to describe not only dynamics of the incursions but the complete sequence of events, states, properties and communications. It can be represented as a buffer of information, with a structured output including the list of all the faults, a summary of the simulation and a detailed log for the analysis of the events.

## 3. THE CASE STUDY

### 3.1. Ciampino airport

The simulation model was applied to the Ciampino International Airport of Rome, a medium size structure, with a traffic of about 30.000 movements/year and a positive trend of 30% in the last years, both on military (18%) and civil aviation (82%) .

The schematic layout, shown in figure 3, is very simple: a single runaway, with two threshold (15 and 33) and two parallel taxiways, A on the south side and B on the north side, currently unusable. Taxiway A takes to the main apron (south) and to a secondary apron (north) actually dedicated to military traffic. All the procedures are so simulated with compulsory routes and task lists coherent to the layout.

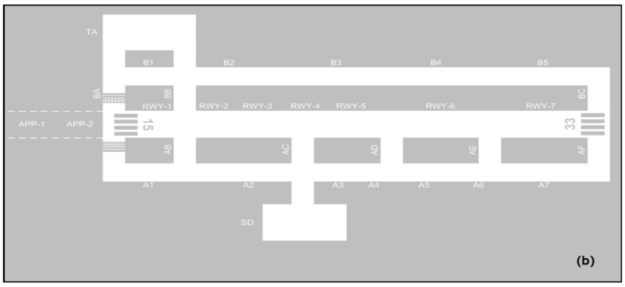


Figure 3: Layout of Ciampino Airport

Civil aviation uses threshold 15 as preferential and 33 only seldom, daily and with optimal visibility. Standard procedure commands to free the runway on the right, using the first possible junction, except for commercial aviation (mainly B737) that uses typically the end of runway junctions; subsequently the aircrafts exit on the left to the southern apron. Military flights, destined to northern apron, approach threshold 15 and, being taxiway B not accessible, have to free on the left, cover all the taxiway, get the junction and cross again the runway before destination.

ANSV data (2002, 2003 and 2004), direct interviews with airport personnel and comparison with similar structures (for visibility and traffic volumes) showed an indication of about 5 incursions every 100.000 movements for a total of 15 in about 10 standard years. As the only root cause of incursions is an unauthorized entry for take-off, the probability of wrong occupation is about $1/10^4$.

As ICAO doesn't give an analytic specification on how to classify incursions, it's first necessary to define these rules depending on the presence of vectors on runways and thresholds, their relative position and speed. In the model it is assumed that, when an aircraft is entering the runway without authorization, the incursion will be classified as follows:

- *class A:* another aircraft on the runway with relative speed higher than 70 m/s;
- *class A:* no aircraft on the runway but at least one approaching the threshold from a distance of less than 1 km;
- *class B:* another aircraft on the runway with relative speed lower than 70 m/s;
- *class C:* no other aircraft on the runway but at least one approaching the threshold from a distance of more than 1 km;
- *class D:* any other case configuring an incursion.

### 3.2. Standard conditions

A sensitivity analysis on 6.000.000 movements with an average traffic of 27.000 (correspondent to year 2002 data) can show the variation of A+B incursions every 100.000 movements (FAA standard indicator), depending on the system main parameters.

The control time $\Delta t_c$ (figure 4) of the tower models the level of attention of human and technological support infrastructures. This points out as an interval of about 5 seconds (ex. granted by an Advance Surface Movement and Guidance Control System A-SMGCS) allows a significant reduction of the parameter, while a reduction of the frequency generates a subsequent sharp increase that tends to an asymptote when control interventions become ineffective.

Once defined the standard level of the two parameters, the simulation returns a global rate of incursions of 5,37 every 100.000 movements with 1,06% of A+B for a total of 0,057 (every 100.000 movements).

The visibility harshly affects the number of incursions when decreasing below 1300m (the critical distance from the control tower to the threshold 15 and its two junctions AA and AB), as shown in figure 5. In these conditions, both pilots and control tower reduce their ability to relieve incursions, perceive dangerous situations and carry out corrective actions.

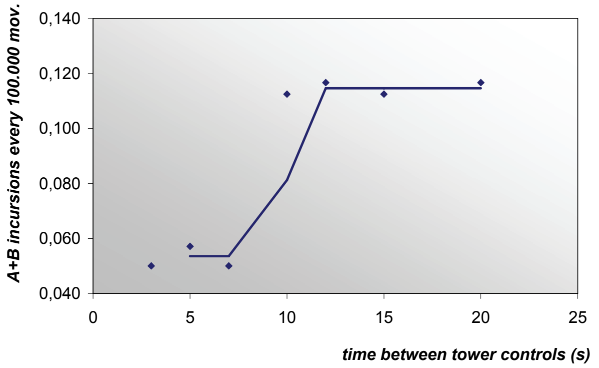


Figure 4: A+B incursions depending on control interval.

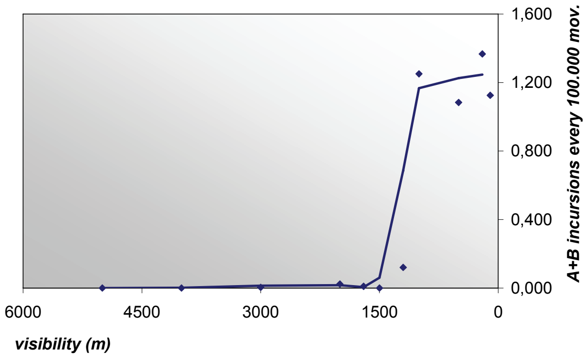


Figure 5: A+B incursions depending on visibility.

### 3.3. Airport evolution

Considering the fast development of Ciampino in the last years, mainly due to low-cost flight companies, it's necessary to show the relative impact it had. The target of the simulation is to make a further analysis of A+B incursions, starting from the actual traffic to evaluate the capacity limit of the airport and possible evolutionary scenarios.

Structural interventions, already planned, define a new configuration where 40% of the traffic is destined to north apron (opening it to civil aviation) and a potential restoration of the taxiway B, to simplify the circulation (figure 6).

Figure 7 shows the general trend of the two configurations to notice, as expected, a direct increase in the number of incursion with the airport congestion. Considering a traffic of 36.000 movements/year that soon will involve Ciampino, the evolved situation allows a risk reduction of about 50% and a diminution of total incursions rate from 6 to 5,1. Furthermore, the restoration of taxiway B generates an increase of airport capacity, contemporarily diminishing the risk of accidents in accordance to FAA standard requirements. In fact, the actual ratio of 0,057 can be further reduced of 15% in four years, granting a further residual capacity.

## 4. CONCLUSIONS

The final results of the simulation consist of an evaluation of runway incursions risk level of a particular airport, segmented in classes of gravity.

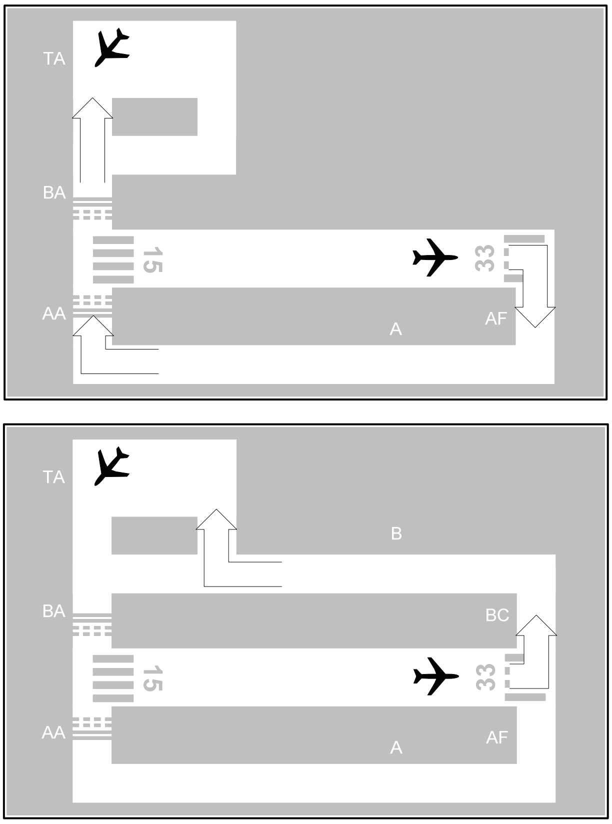


Figure 6: Layout evolution.

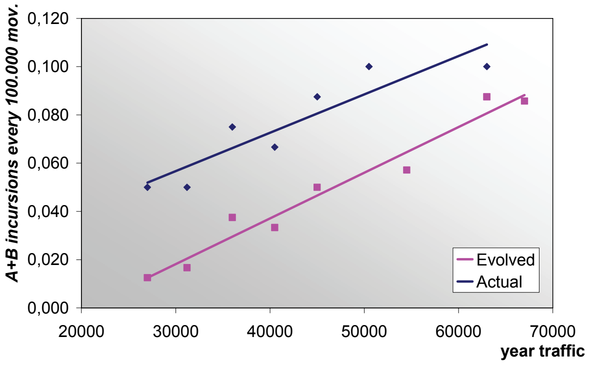


Figure 7: A+B incursions in layout evolution.

The study is in still its first stages of evolution and particular refinements can be applied. First of all, a simple integration of vehicles and pedestrians could complete the possible root causes. Furthermore, a collection and acquisition of specific data (ex. detailed analysis of the airport signs, impact on pilot's perception and integration of studies on human reliability) will tune the model so to strictly define lines of intervention and priority, both technical and organizational.

The object-oriented technique has shown, even in a feasibility and demonstrative application, that the approach allows to simulate a complex environment without defining a priori scenarios and dedicated analysis, as for fault-tree or event-tree, only observing the evolution of the system.

Sensibility analysis can be easily implemented to evaluate the impact of the structural parameters, the definition or re-arrangement of circulation procedures of aircrafts and adoption of innovative informative, visual or control tools. All the investments, on people, infrastructures and management logic, can so be tested and classified in terms of protection or reaction to events, defying the most opportune level of safety to characterize the airport.

In the end, the model has to be supported by an accurate cost-benefit analysis to list and compare opportunities and criticalities. Once this evolution is completed, the model can be simply added as an independent engine in all the applications that simulate standard operations of an airport (both commercial or dedicated), introducing systematic levels of uncertainty and alarms to define, implement or set effectiveness of recovery actions.

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