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**4 AUTHORS**, INCLUDING:

Mickael Causse

Institut Supérieur de l'Aéronautique et de l'E…



Mathieu Cousy

Ecole Nationale de l'Aviation Civile

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Zarrin Chua[1], Mickaël Causse[1], Mathieu Cousy[2], and Fabien Andre[2]
[1] Institut Supérieur de l'Aéronautique et de l'Espace, Toulouse, France
[2] Ecole Nationale de l'Aviation Civile, Toulouse, France

Evaluating future technology concepts for air traffic control ground operations requires exploration of work scenarios of differing complexities, i.e. scenarios that create more or less taskload for air traffic controllers. While the link between traffic load and workload has been well-characterized in the literature and is often the only complexity variable applied to validation studies, there are other operational events that can augment controller workload. Through a series of interviews and on-site observations of professional and student air traffic controllers, we defined seven general operational events that can be applied to all airport ground operations. We discuss the development of two scenarios of different workloads (average and hard) and their validation with air traffic controllers.

## INTRODUCTION

In addition to augmenting the number of aircraft in the air space, the forecasted growth of air traffic also increases the number of ground movements at busy airports (Eurocontrol, 2013), adding increased collision risk, time delays, pollution, and stress for the air traffic control (ATC) officer (ATCO). As feasible solutions are explored, most of which involve the inclusion of ground automation and in-cockpit or in-tower technology, it is important to ensure that such solutions are robust to the ATCO's workload. Therefore, work scenarios of different workloads (i.e., taskloads) and complexities must be designed and evaluated. In particular, it is important to characterize the different sources of complexities for the tower ATCO. Much has been written in the literature regarding link between workload and traffic load, visibility, and tool utility, but less has been discussed regarding operational events. Such events can be used individually or in combination depending on project aims and the general experience of the participant body. Furthermore, the majority of the work done in this field has focused on air traffic management en route and not on the ground.

This paper describes the general operational events that can contribute to scenario complexity specifically for the ground (GND) ATCO. We begin with a review of current literature regarding scenario complexity in tower ATC operations. Next, the general methodology is described, including the demographics of the persons interviewed and observed. The first half of this paper concludes with a definition of the seven operational events that can be used to increase taskload complexity of the GND controller. The second half of the paper introduces two scenarios, Average and Hard, that were developed for the evaluation of modern taxiing techniques and ends with the scenario validation and concluding thoughts.

## LITERATURE REVIEW

The role of the tower ATCO controller is to direct traffic on the runways, taxiways, and parking stands at the airport. Depending on the size of the airport, this role may be broken into several parts, with one person managing a portion of the airport. For example, the local (LOC) ATCO handles the runways and the taxiways feeding them; the traffic or apron controller oversees the parking areas; and the GND controller manages the taxiways between the parking stands and the runways. These roles may be further divided or merged, depending on the size of the aircraft and the traffic flow. In general, the ATCO must attempt to determine the most fuel-efficient and minimum time required trajectory for each aircraft while avoiding collisions and respecting the aircraft time table. This task requires knowledge of each aircraft's characteristics, initial and final position, and airport operations.

Previous studies have shown that scenario complexity is correlated with workload – more complex and difficult scenarios induce greater workload for the ATCO (e.g., Mogford et al, 1995; Cummings & Tsonis, 2006; Hilburn, 2004). There are multiple sources of complexity. Cummings and Tsonis (2006) describe three general categorical sources within the ATC domain that contribute to cognitive complexity: environmental (traffic demographics and density), operational (airspace properties and ATC principles), and display (information organization). Eurocontrol's Project Complexity and Capacity (Hilburn, 2004), in an extensive review of the literature, identified 108 individual complexity factors in the entirety of air traffic control (including en route and around airport). While there exists a great deal of literature describing factors that would fall under the environmental and display complexity categories, less has been written about operational, particularly for the GND ATCO. Atkin et al. (2010) describe five categories of constraints on the GND controller, such as timing, aircraft movement speeds, and separation constraints. He notes that future airport ground movement problems should account for other airport operations, such as gate assignment.

It is already well-established that the largest contributor to scenario complexity (and as such, taskload) is traffic load (Delahaye & Puechmorel, 2000). The effects due to traffic load are readily apparent; every aircraft must be monitored by the ATCO and each additional aircraft reduces the available space for trajectory options. Additionally, each call to the tower, whether by radio or digital, requires visual, aural, and oral resources. This resource capacity and limit is related to the ATCO's familiarity of the airport, situation awareness, and tools, with the former being the greatest limiting factor.

Indeed, most scenarios in the literature have focused primarily on display complexity, but more so with respect to attempting to minimize it through an interface design or automation. These new systems are then validated under different workloads that have focused primarily on deviations in traffic load (e.g., Verma et al, 2007; Martin et al, 2011). A few projects have included operational complexities such as a configuration change (e.g., Stelzer et al, 2011). The traffic load is also modulated in some cases regarding the type – a mixture of arrivals and departures, or entirely homogeneous.

However, there are other operational events that can also contribute to ATCO taskload and that are also part of routine operations, providing complexity via another dimension than traffic load. Such isolated events can provide opportunity to evaluate the effectiveness of a decision support system, the addition of automation, and the utility of advanced interfaces.

## METHODOLOGY

In addition to a literature review and consultation of airport manuals, this work includes four visits to two airports, observations of four ATCO student training sessions at the Ecole Nationale de l'Aviation Civile (ENAC), and consultation with five active ATCOs who are also instructors at ENAC.

Three of the four visits were to Roissy Charles de Gaulle (CDG) South tower and the fourth was to Toulouse-Blagnac airport (TLS; France). Each visit was 2-5 hours long, with observations of ground operations and listening in on radio communication. Questions regarding operations, specific events, and personal opinion were answered by the ATCO when available. At Blagnac, the GND controller handled the taxiways and the parking stands.

The consultation with subject matter experts were conducted over the course of six months, ranging from 1-2 hours each. Each of these semi-structured interviews began by asking which events, operational procedures, or work factors increased taskload. Follow up questions relating to the specifics of their home airport of the ATCO. Of the five ATCOs, three were from CDG (4 runways), one was from TLS (2), and one from Paris Orly airport (ORY; Paris, France; 3).

## COMPLEXITY-GENERATING GROUND OPERATIONAL EVENTS

While the work was intended specifically for validating modern taxiing techniques at CDG, these types of events can be applied to other airports of varying size. These categories were suggested specifically for the GND ATCO role.

It should be noted that visibility is often cited in the literature as a factor in operations complexity (ICAO, 1986). However, its influence on the GND ATCO is limited. Most ground controllers use the ground radar screen as their primary source of information, with the window as backup or confirmation for an aircraft's actual location. Additionally, low visibility procedures limit traffic density and lower the maximum taxiing speed, thus translating to less active taxiing aircraft and a greater time horizon for decision making. Nevertheless, LOC controllers are affected by visibility, as it impedes their ability to perceive arriving and departing aircraft.

Additionally, if the GND and LOC positions are combined, the GND must respect the required separation between Light, Medium, and Heavy aircraft necessary for takeoff. Subsequently, this constraint may factor into the routes given to departing aircraft, particularly when attempting to optimize runway usage. However, should the GND and LOC roles be handled by different people, the separation constraint factors considerably less on the GND controller than the LOC. Nevertheless, the GND ATCO should always account for aircraft sizes, particularly for taxiing power and wake turbulences (FAA, 2014), and for reducing the taskload of her colleague.

We identified seven possible operational events that can serve as adding to the ATCO taskload and individual decision events. The frequency listed with each event is an approximation and varies based on the airport. The common point on these operational events is the uncertainty that they add to the activity. They are unpredictable to the ATCO and require executive control and risky decision-making under temporal pressure. Facing uncertainty, it is necessary to reestablish executive control over more automatic and effortless process linked with the routine work. This reestablishment requires an increased endogenous attentional control to apply new task rules, which has been notably associated with dorsolateral prefrontal cortex activations (Brodmann's areas 9/46/8) (Kübler, Dixon, & Garavan, 2006), a brain region that plays a crucial role in executive functioning and non-automatic behavior (MacPherson, Phillips, & Sala, 2002). In addition, these events cause a multitasking situation: ATCO has to process them while they still have to continuously monitor the rest of the other aircrafts. The scenarios can be even more complex, if two events occur at the same time with each demanding the ATCO's attention.

### Configuration Change (once per day, depending on wind)

A configuration change is defined as when the directional usage of the runway is reversed. There is a short period when the runway is closed (i.e., a pause in the arrival sequence) and the departures begin lining up for the new orientation. The ATCO must coordinate with the local controller on which departure is the last to use the runway prior to closure, reroute departures as necessary, recall the changes in traffic flow on certain taxiways, and the position of aircraft that are still taxiing within the previous configuration. However, since there is a break in the arrival sequence, there are less active aircraft that he must manage. Almost every ATCO, from all three airports, felt that a configuration change significantly contributed to taskload.

### Closed Taxiway (some part every day for large airports)

A taxiway may be closed for an indefinite period of time, due to airport procedures, the taxiway state, or aircraft operations. In general, the ATCO must be conscious of this blockage and come up with alternate routes, even going against the normal direction of traffic. She may have to coordinate more with the other controllers, especially if aircraft are entering the other zones via a non-typical taxiway. If the taxiway is closed due to aircraft operations (mechanical problem, waiting for a parking stand), more communication is necessary between the ATCO and the pilot.

The effect of this factor depends on where the closure occurs. Hot spots, or airport-specific locations noted for higher risk of collision, will perturb operations more than less-frequently used taxiways. Closures of taxiways that do not have a parallel or alternate route are also more difficult to manage than others. Similarly, two parallel taxiways that only have one or two intersection points would pose more difficulty than those with more. Naturally, the closure of an intersection would interfere with multiple taxiways.

**Deicing Operations (based on airport location)**
Snow and ice must be cleared off of departing aircraft before takeoff. Deicing stations are usually located right by the runway entry ramp, often near airport hot spots. The time required for deicing is proportional to the size of the aircraft and the rate of precipitation during the operation. Additionally, the deicing procedure may take so much time that the aircraft requires an additional deicing cycle. The ATCO must manage the demand of these resources i.e. the deicing station and the associated taxiways. Indeed, when considering a trajectory, she must predict which deicing stations would be available at time-of-arrival and/or provide additional routing instructions as the aircraft draws closer to the designated spot.

**Insufficient Parking Stands (a few times a day)**
Occasionally, an arrival cannot go directly to the parking stand as it is in use by a delayed aircraft or there is not enough parking for the current influx of aircraft. The ATCO must decide to place the affected arrival somewhere in the airport, often on an infrequently used taxiway. This decision point requires coordination with other ATCOs and minimizing the degree of disruption on other aircraft. Resting an aircraft somewhere effectively closes the taxiway, with the ground ATCO responsible for redirecting the aircraft to the final parking stand – the pilot does not have direct contact with the other ATCOs during this time.

**Pilot Error (more frequent at large airports)**
Pilots, especially those who are unfamiliar with the airport, occasionally make route errors around the airport, resulting in an inefficient taxiing trajectory. In the worst case, they may find themselves face-to-face with another aircraft. The ATCO must monitor, recognize, and identify this type of path deviation and determine a possible solution. Depending on where this path deviation occurs, the ATCO may need to stop both aircraft and reroute one, or direct a tractor to tow the offending aircraft out of the taxiway. The latter may introduce yet another operational complexity of a slow-moving towed aircraft.

**Restricted Areas (on permanent basis)**
Certain aircraft are forbidden to access specific taxiways due to wingspan or weight restrictions. Temporary taxiway closures to a type of aircraft also fall into this category. The ground controller must recall and recognize which aircraft are affected and reroute as necessary, an exercise that may be more difficult if the situation is temporary. Coordination with the other ATCOs is necessary to avoid confusion or surprise in unexpected aircraft behavior.

**Towed Aircraft (several times a day, even once an hour)**
Occasionally, an aircraft must be towed from one point to another. While modern tractors move at a relatively quick towing velocity, some tractors currently in use move at ~50% of the aircraft taxiing velocity. Such a tractor can retard the progress of other aircraft taxiing behind it. This effect becomes even more pronounced if the tractor is taking a taxiway that has no parallel pathway. The ATCO must judge which aircraft should have priority, the towed or the non-towed aircraft, including an understanding of each aircraft's situation. She must also consider if re-routing an aircraft is possible and where the redirection should take place. Depending on the airport, this event may occur as frequently as once every 15 minutes.

## SCENARIO DEFINITION

Two scenarios, based on the identified ground operational event complexities, were developed for the validation campaign of Project Modern Taxiing (MoTa, Chua et al, 2014), which aims to improve taxiing operations through the use of advanced taxiing technologies such as tactile interfaces, intelligent algorithms, and autonomous taxiing robots. These scenarios, Average and Hard, originated from exercises used to train the ground controller specifically at CDG (Roissy CDG, 2014). The original exercises gave the traffic load, the sequence, and the call sign, parking stand and taxiway for each aircraft but did not include the operational events. These events were added based on the observations and interviews regarding scenario complexity. Figure 1 presents a map of CDG and a representative timeline of each aircraft's call to the tower.

Of the seven event categories that generate cognitive complexity, only five were chosen to be represented in the scenarios. The decision to include these five – towed aircraft, pilot error, restricted zone, closed taxiway, configuration change – were chosen based on simulation capabilities, validation aims, and participants expertise. We considered using ATCO students as participants and worked closely with their instructors to develop scenarios that would be challenging enough without introducing a ceiling effect (i.e. misleading results indicating a false utility of the MoTa platform). It was determined that deicing operations would be too complicated to introduce in a 35 minute scenario, as it is not taught in the early years of the French ATCO students. The same issue exists with a configuration change, but since one-third of the scenario would feature less traffic and occurs more regularly than a deicing scenario, a configuration change was kept in the scenario design. Insufficient parking stands were not considered.

The Average and Hard scenarios represented the range of controller taskload that would benefit the most from the MoTa platform. These scenarios were designed to be used specifically for the south end of CDG and are designed to be 35 minutes long. Both scenarios included some simplifications from the full set of GND responsibilities at CDG. For example, the parking stand number was ignored. Participants only had to send the arrival to one entry taxiway per parking area. Similarly, departures always left from one exit taxiway per parking area. At CDG, some parking areas have several entry/exit taxiways and aircraft enter and exit depending on the parking stand. Ignoring the parking stand numbers reduced the GND's responsibilities for this project. Pushback at stands A30-33 was not required in the scenario (DGAC, 2008). Some parking areas were also merged and treated as one: A and C were combined (used the same entry/exit) and B and D.

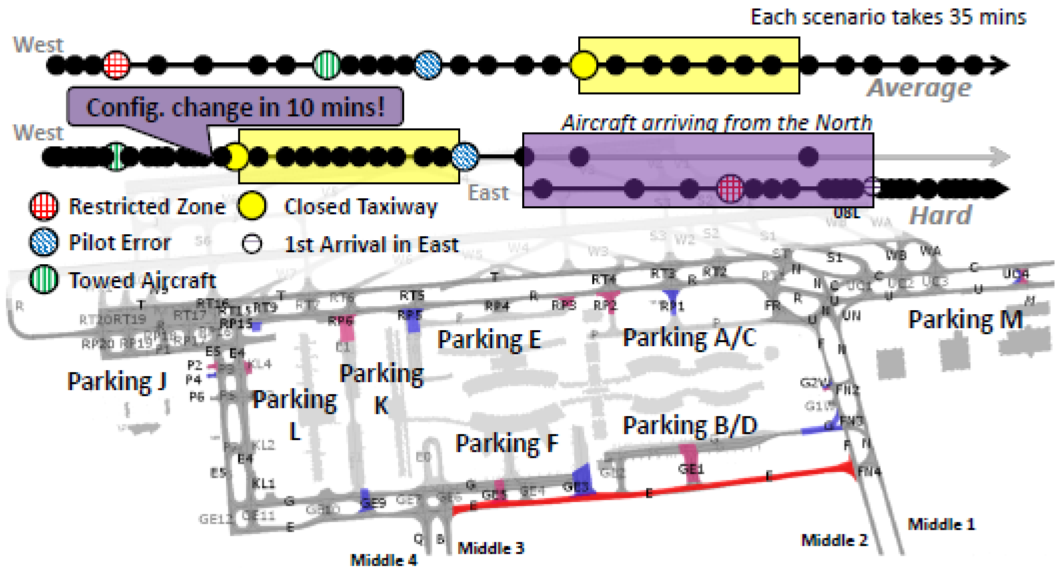


**Figure 1. Map of the South end of Roissy Charles-de-Gaulle Airport (Paris, France) and Representative Scenario Event Timeline.** Taxiway E, in red, is forbidden to A380 due to weight constraints. Taxiways colored magenta and blue represent entry and exit taxiways, respectively, for that parking area. Each dot on the timeline represents an aircraft calling the tower.

**Table 1. Definition of Average and Hard Scenarios for use in Project MoTa (Roissy Charles-de-Gaulle, Paris, France).**

| | Traffic Characteristics | | | | Operational Events | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Load (mvt/h)** | **N° Arr.** [†] | **N° Dep.** [†] | **M : H a/c** | **Config. Change** | **Closed Taxiway *** | **Pilot Error** | **Restricted Area** | **Towed Aircraft** |
| Average | ~ 54 | 17 | 14 | 22 : 9 | -- | Dep. from F, stuck on RP15 | Dep. from G, takes F instead of N | A380 Arr. from North, going to L | From North, to J |
| Hard | ~ 90 | 13 / 7[¥] | 18 / 13[¥] | 29 : 22 | W to E, T+15 mins | Dep. from J, stuck on RP15 | Arr. from North, takes F instead of N | A380 Arr. from North, going to L | From North, to M |

[†] in a 35 min scenario [¥] in the East configuration * closed for five minutes, unknown to participant

Taxiway E was selected as the only area with a restriction. Both scenarios assume that there was good visibility. The traffic was composed of major international airlines and was approximately half francophone.

Table 1 describes the specifics of each scenario, including traffic characteristics (load with respect to movements/hour, number of arrivals and departures, the ratio of Medium to Heavy aircraft) and employed operational events. The **Average** scenario used four operational events to create uncertainty and complexity: Closed Taxiway, Pilot Error, Restricted Area, and Towed Aircraft. The **Hard** scenario used the same four but included a fifth, a Configuration Change. There were several assumptions made for both scenarios: the towed aircraft was assumed to move at 10 kts; the pilot route error causes a potential head-to-head collision that does not require another tractor; the cause for the closed taxiway was always a mechanical error.

The Hard scenario represents one of the most difficult scenarios within nominal operations for the ATCO. The traffic load is about its maximum for a single person. Normally, there would be two ATCOs managing the South end (split between East and West). This traffic load is representative of future traffic loads and we are interested in seeing if our platform can sufficiently assist the ATCO. The scenario begins in the West configuration (26R/26L). Participants receive an oral notification from the Tower Supervisor five minutes after the start of the scenario that a configuration change will occur in ten more minutes. It is stated that this change is caused by significant winds. Fifteen minutes into the scenario, the arrivals are momentarily stopped as the simulated LOC reroutes arrivals. For the next ten minutes, there are aircraft still finishing their taxiing routes in the West configuration as departures are preparing for takeoff in the East configuration. Depending on the participant's performance up to that point, some departures must be rerouted from West to East. The last ten minutes are completed in the new configuration.

## INITIAL VALIDATION

These scenarios were used in a human subject experiment involving ATCO technology currently in use in France (e.g., paper flight strips (Letondal et al, 2013)). As of time of submission, ten ATCOs participated in this experiment (one retired, eight active ATCOs and instructors at ENAC, one active ATCO, non-instructor). Six participants were from airports around Europe and four were from CDG. The run order between Average and Hard was randomized. Participants were

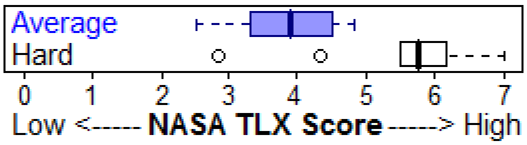


**Figure 2. Changes in Workload due to Scenario.**

asked to complete the NASA Task Load Index (TLX) after each run (1: low workload; 7 high). Inter-dimensional ranking was not performed.

In general, the Average scenario had a median score of 3.92 (about moderate workload) and the Hard scenario had a median of 5.75. The Wilcoxon Signed-Ranks test was used with an alpha value of 0.05 to determine significance. Scenario was shown to have a significant main effect on the TLX score among all participants, $W = 0$, $Z = -2.81$, $p < 0.002$, $r = 0.63$. This result indicates that the Average and Hard scenario evoke sufficiently different workloads. Figure 2 illustrates a boxplot of these results. This change in difficulty was further confirmed by the workload. Scenario was determined to have a significant effect on the percentage of aircraft treated in each scenario, $W = 0$, $Z = -2.80$, $p < 0.002$, $r = 0.63$ (medians for Average and Hard are 95.5% and 64.0%, respectively). This result demonstrates that performance has declined due to the complexity of each scenario.

## CONCLUSION

Developing sufficiently complex scenarios that can differentiate potential workload gains due to proposed technology is critical for system validation. In addition to traffic load, airport taxiing operational events can be used to modulate scenario complexity and create individual decision events for further analysis. Seven operational events were determined from interviews and tower observations of air traffic controllers. Five of these seven were used to create two scenarios, Average and Hard, for Charles de Gaulle Airport. These scenarios were validated with ten air traffic controllers, showing that NASA Task Load Index scores and performance significantly changed between scenarios.

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