# Simulating Air Traffic Control Ground Operations:Preliminary Results from Project Modern Taxiing

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Zarrin K. Chua*, Mathieu Cousy†, Fabien Andre† and Mickaël Causse*

*Centre Aéronautique et Spatial
Institut Supérieur de l'Aéronautique et l'Espace (Toulouse France)
{zarrin.chua, mickael.causse}@isae.fr

†École Nationale de l'Aviation Civile
Toulouse, France
{mathieu.cousy,fabien.andre}@enac.fr

*Abstract*—Automated technology is one of many solution that can help meet the growing air traffic demand at busy airports by assisting air traffic controller officers maintain efficient and safe operations. In particular, ground air traffic controllers can benefit from the services of an automated decision support system that can provide taxiing path suggestion and conflict detection. Fuel consumption can be minimized with the use of automated aids such as path suggestion for the most fuel-optimal trajectory, robotic taxiing tractors, or electric taxiing systems. Project MoTa - Modern Taxiing promises these capabilities and assists in the transition from current technology by developing a human-centered user platform. Nevertheless, developing such a system requires a simulated air traffic control environment, both for testing new concepts and for validation. To this end, we have built an environment and begun evaluating taxiing performance for the ground operations in the south end of Paris Charles de Gaulle airport. Results from the initial sessions indicate the modeled scenarios are representative and solutions have been found to account for the experience gap with ATCO participants not from Charles de Gaulle. This paper presents these results and discusses the solutions for the modeling and simulation challenges encountered during the development process.

## I. INTRODUCTION

The demand for increased air traffic control (ATC) efficiency provides an excellent opportunity to introduce automated systems and decision support aids to air traffic controller officers (ATCOs). Such technology would enable the controller to perform his or her responsibilities fluidly without much additional workload, while still meeting the increasing demand. Furthermore, alternative taxiing techniques that rely on a power source other than aircraft's main engines (e.g., TaxiBots [1], a tractor that tows aircraft during taxiing, and eTaxi [2], an electric in-cockpit taxiing system) and intelligent algorithms for conflict detection and path suggestion, can reduce taxiing time, fuel savings, and improve overall airport capacity. However, while all of these concepts are in various stages of development and maturity, one challenge that is often forgotten is the transition period from today's technology to tomorrow's. Additionally, the inclusion of these technologies transforms the ATCO's overall task - care must be taken to ensure that these future taxiing operations do not surpass the limits of either automation or human performance.

The purpose of Project Modern Taxiing (MoTa) is to develop a ground control interface which would not only enable varying levels of automated assistance, but also support the transition period during which the ATCO would be able to gradually take advantage of the algorithms and automation in a non-intrusive manner. This transition-centered design adapts to the controller's evolving and dynamic needs and while ensuring effective and efficient performance to a wide variety of working environments. The premise of this concept is the use of a ground radar image of taxiing aircraft and an intelligent multi-agent algorithm. This coupled system promises the capacity to manage different layers of information, display suggested aircraft trajectories, detect and identify potential collisions, and allow for ATCO interactions (e.g., modification of proposed path, highlighted blocked or restricted areas). The algorithm would account for such inputs and adjust to the constraints and goals of the ATCO. This concept would allow for intuitive, quick, and efficient communication between the ATCO and the pilot, thus facilitating and meeting the need of expanding ground operations. Touch sensitive technology insures familiarity with existing pen-and-paper technology, in a comprehensive and cost-free manner.

In order to test the effectiveness of this ground control interface and the intelligent algorithms, an ATC simulation is needed. As it is not feasible to validate the interface in a real-time working conditions and use of existing ATC simulators are often restricted, it became necessary to develop a realistic ATC microworld. The process of developing this simulation also helps in understanding the shortcomings of the current system and allows for iterative development of Project MoTa. This paper presents a brief overview of the modeling and simulation of ATC operations necessary for Projet MoTa, including a generalized discussion of airport ground control operations, the proposed interface validation plan, and preliminary results of the initial sessions. We conclude this paper with a discussion of the knowledge gained from these results, simulation challenges and how they were overcome, and future work.
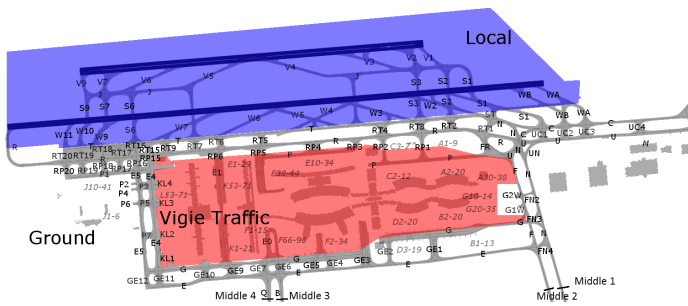
Fig. 1. **ATC at Charles de Gaulle Airport**. The sector in blue is managed by the Local controller. The red sector is managed by the Apron controller (unique to CDG). The rest of the airport is managed by the Ground controller. During peak hours, this sector may be managed by two controllers (Ground West, Ground East). In this project, we only simulate one controller, regardless of the workload.

## II. AIR TRAFFIC CONTROL OPERATIONS

The primary airport of Project MoTa is Charles de Gaulle (CDG; Paris, France), chosen for its complexity and accessibility to the researchers. The size of CDG is sufficiently large that there are multiple ATCOs for different aspects of the airport [3]. In this project, we focus specifically on the south ground control position (Fig. 1). Unlike the local ATCO (in blue, who handles two runways and the taxiways immediately next to them) or the Apron ATCO (in red, parking areas except for Areas G and M, which are under the ground sector), the ground controller handles all intermediary taxiing routes. Simply, this task includes directing aircraft to and from their respective parking stands to the necessary runway, while minimizing taxiing time, avoiding collisions, and respecting the fixed departure timetable from the Central Flow Management Unit [4]. In cases of heavy traffic, two ground ATCOs may manage this sector (thus splitting the south end of the airport into south-east and south-west). The south local, south Apron, north local, and north ground ATCO are automated for this project. The south ground controller only interacts with the pilots, which are managed by two or more pseudo-pilots working in the backroom of the simulator.

Generally, the ground ATCO communicates with the pilot at least twice: once during initial contact of the tower for the taxiing route; the second time during the transfer, when the ground controller gives the radio frequency to communicate to the other ATCOs. Additional calls may occur for modifications to the original route, clarifications, or warnings. In the case of departures from parking areas within the ground sector (in this project we only simulate G and M as managed by ground), the exchange of calls is much greater, to account for pushback and parking area taxiing just until the ground sector is reached.

## III. OVERALL VALIDATION PLAN

The success of Project MoTa is defined by the achievement of several main goals. The tool must demonstrate improvement in operations in current and future operations of ground traffic control through the use of a new human machine interface and automated taxiing techniques. As with any new human-machine interface system, the tool must appeal to ATCOs for use in current and future ground operations and support a sufficient range of operational environments and ATCO cognitive complexities. In order to validate the platform and to provide iterative input and feedback on the system, three main experiments and several smaller working sessions are planned.

Each of these three main experiments will reflect the maturity of the MoTa platform. The first experiment is focused on capturing baseline data on ATCO performance with current ATC technology (i.e., the paper flight strips). The second experiment measures the effectiveness and the changes in ATCO performance with just the interface. This interface will replace the paper strips with the label interaction and also provide additional functions to the ATCO, including information management and the decision support system (path suggestion, conflict detection). These paper strips will not be replaced by digital strips; rather, the same information is transformed to labels that are visually linked to the aircraft's current position within the airport. The third and final experiment validates the entire MoTa platform. In this experiment, the interface and automation will modeled (i.e., the Taxibots, the eTaxis, the decision support system). The three experiments are planned for October 2014, January 2015, and October 2015 respectively. Each participant session will last two hours, consisting of a practice session (for familiarity with the airport, the rules, and the simulator) and the two Medium and Hard scenarios (in randomized order). They will be asked to provide feedback on the scenarios and suggestions for improvement on the interface. The dependent variables include operational (e.g., taxiing time, fuel consumption, throughput) which are measured in real-time during the experiment or calculated *post-hoc*; subjective (workload, situation awareness, trust in the automation); neuro-physiological (cerebral activity, heart rate, and ocular movements); and behavioral (i.e., number of actions, controller attitude).

### A. Participants

The participant pool consists of instructors and students in the Air Traffic Control program at ENAC and active ATCOs from French airports. About fifteen participants are planned for each experiment, for a total of 45 individuals (repetitions will be avoided). Simplifications have been made to the scenarios to accommodate for the inexperience of the students and unfamiliarity with CDG. For example, CDG has twelve parking areas in the south end of the airport. Each of these twelve parking areas has multiple one-way entry and exit taxiways, depending on the specific parking stand. The experiment scenarios only consider nine unique parking areas, with one unique entry and exit taxiway each. The individual parking stands are not considered. The airline companies represented in the scenario are limited to the most well-known European and international carriers. Both French and English is spoken, as is the current practice in airports in France.
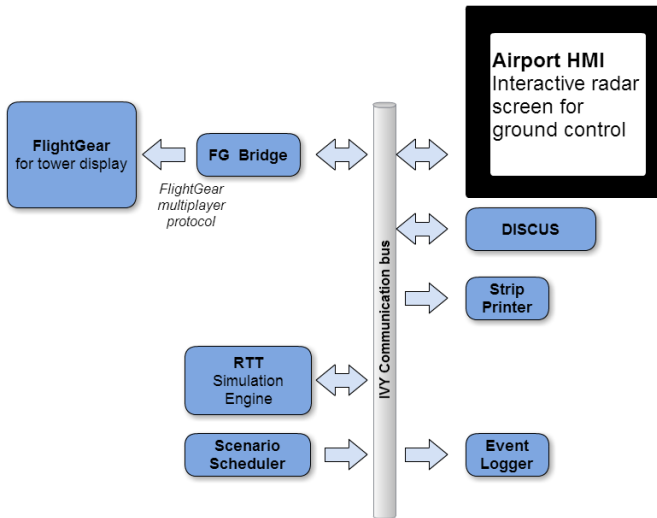
Fig. 3. **Project MoTa Simulation Platform**.

### B. Simulation Hardware

The ATC simulator is located at École Nationale de l'Aviation Civile (ENAC) in Toulouse, France. The simulator (Fig. 2) consists of a three-screen display used to project an external view from the ATC tower; an additional rear view screen; a radio communication system between the pilots and ATCO; an ATCO workspace with a desk, a paper strip printer, a strip board, a ground radar screen, the Déport d'Information de Supervision et de Clairance pour les Utilisateurs dans les approcheS (DISCUS) flight manager - a list of planned and active flights; and the Tower Supervisor desk. Additionally, in the same facility, there is a station for two or more pseudo-pilots, including interactive tablets to direct aircraft and individual radio systems. The participants are also equipped with neuro-physiological sensors, with a small desk containing the supplementary operational equipment (i.e., another computer workstation).

The external tower view from the south end of CDG is based on FlightGear, an open-source software [5]. The two south runways (26R/08L, 26L/08R), the aircraft including size and airline company, and weather are all simulated. The viewing angle is $225°$ of the $360°$ with the height of the tower included in the projected image.

### C. Software

The MoTa platform is centered around ivy bus [6] [7], text-based communication bus, the central hub with which all components send and receive data. This bus is frequently used in the platforms and tools developed at ENAC, thus facilitating the integration of existing tools. Fig 3 illustrates the types of program components and the communication links.

There are three main components of the platform: Ready To Taxi (RTT, the simulation engine), Scenario Scheduler, and Airport Human-Machine Interface (HMI). The **RTT** component sends updates of radar tracks positions at a frequency of

1 Hz and provides flight plan information when requested by the user. This component provides the reference simulation time that synchronizes all other components. The RTT also traces all aircraft trajectories, regardless of its source (pre-defined within the scenario files for planned events such as arrivals, or user-generated via the tactile interface). These trajectories are based on an aircraft dynamics contributed by Airbus which accounts for the on-ground characteristics of every aircraft type, such as taxiing and take-off speeds. The **Scenario Scheduler** reads an input file that describes all of the desired events during the scenario and sends a message via the ivy bus to all the agents concerned so that the appropriate function is executed. For example, the printer prints the paper paper flight strips according to the departure and arrival schedule and the Route Validator generates the take off and landing trajectories. The **Airport HMI** generates the simulated radar image that provides the physical location of all vehicles with respect to the airport map. This component, the DISCUS, external view, and the strip printer are the only components seen by the participant.

### D. Subjective and Neuro-physiological Collection Methods

Workload, situation awareness, and trust in automation were measured using the NASA Task Load Index (TLX) [8], the Situation Awareness Rating Technique (SART) [9], and SHAPE (Solutions for Human Automation Partnerships in European ATM) Automation Trust Index (SATI) [10], respectively. This paper, however, focuses strictly on a preliminary session conducted to prepare for the first experiment.

An electrocardiogram (ECG) was used to collect the participants' cardiac activity at a sampling rate of 2048 Hz with the ProComp Infinity system (Thought Technology, Montreal). We applied three electrodes connected to an extender cable to the participant's chest using Uni-Gel to enhance the quality of the signal. The BioGraph Infiniti software was used to export the heart rate (HR) derived from the interbeat interval. Baseline HR was derived from a three minute resting session prior to the scenario. Artifact correction was performed based on visual inspection with Kubios HRV software Version 2.2 [11]. In this paper we only present the preliminary cardiac results.

### E. Scenario Definition

In all three experiments, the ATCO is asked to oversee ground operations at CDG in two different scenarios of varying complexity: Medium and Hard. The Medium scenario represents the normal working day of an air traffic controller, with a rate of $40 - 50$ movements per hour (mvts/hr). The Hard scenario pushes slightly beyond the ATCO current work capacity with 80 mvts/hr and includes a configuration change. Both scenarios are based on exercises in the ATC simulator used during ATCO training at CDG and have been modified to fit the specific needs of Project MoTa. In addition to directing all aircraft as they enter the ground sector, the ATCO must also manage other activity, or smaller events. These events were developed with the assistance of an active ATCO at CDG and under consultation with other ATCOs to reflect the experience
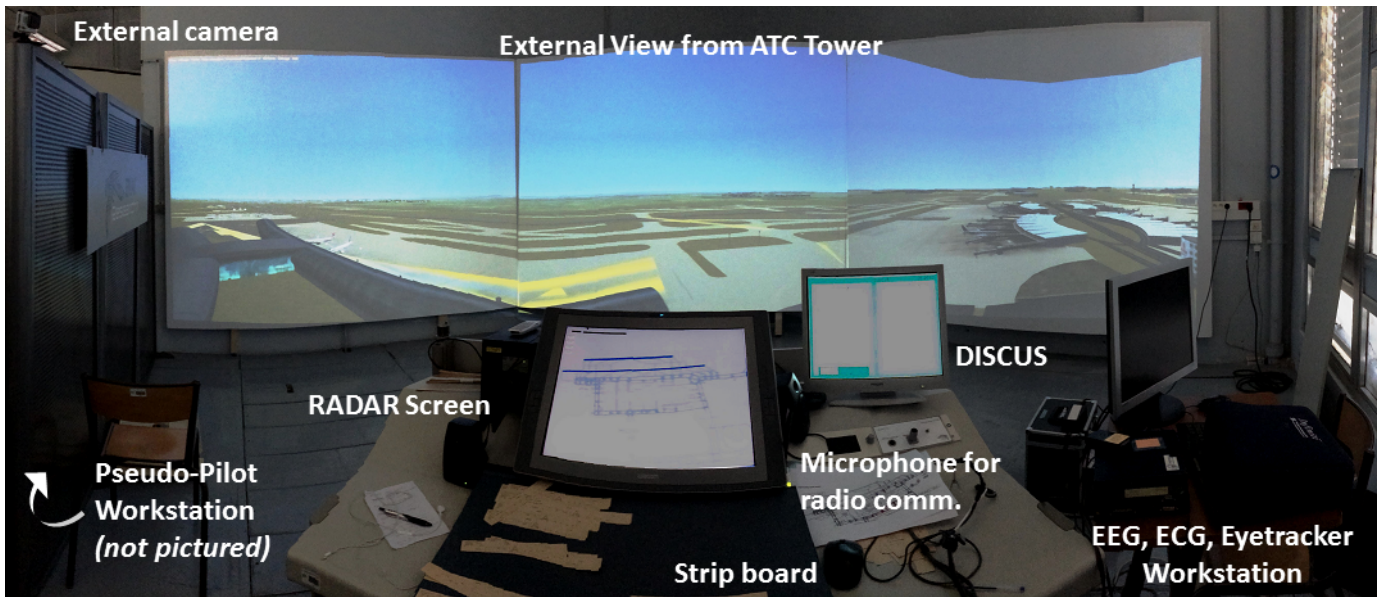
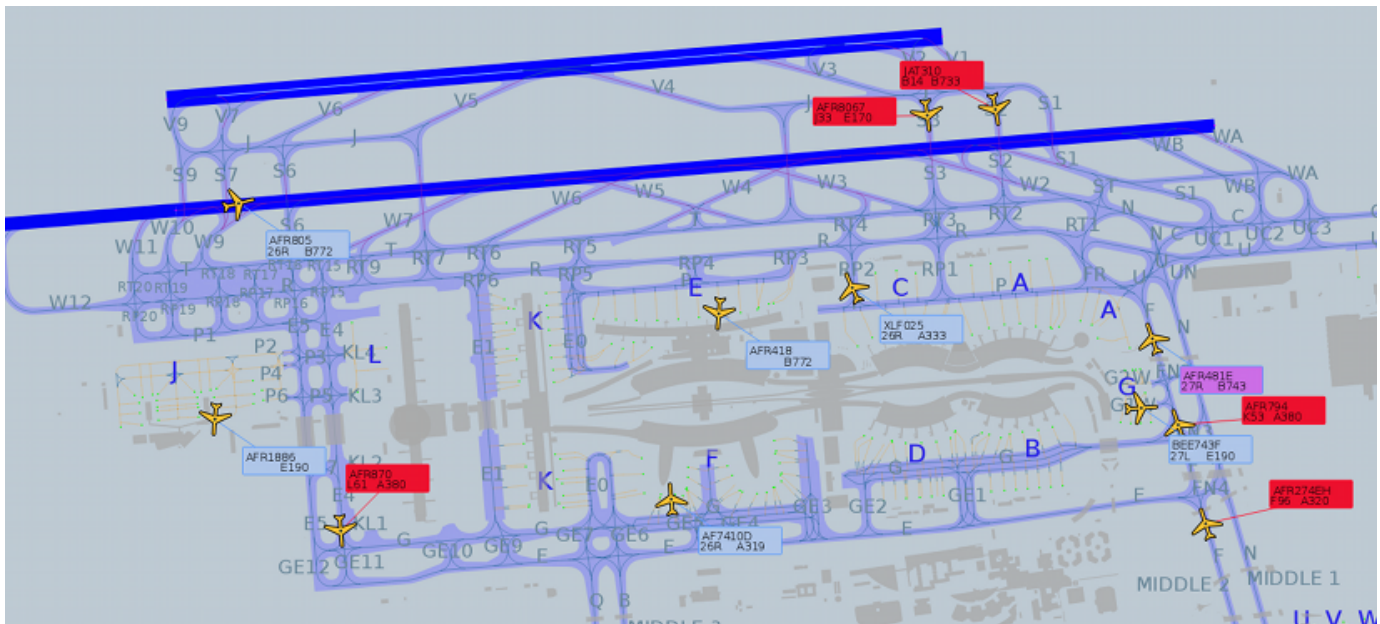Fig. 2. Panorama of the ATC simulator at ENAC (Toulouse, France).



Fig. 4. **MoTa Interface**. For clarity, only a portion of CDG is shown. The interface presents the entire airport and the user may choose to zoom in and out of a particular location.

of the participant pool and the limitations of the simulation engine. They occur in both scenarios and only once during the scenario.

- **Restricted Area**: Participants are told that due to weight restrictions, A380s cannot enter taxiway E. An A380 will arrive in the ground sector on one end of E, with the intended parking on the other side, resulting in the shortest route going through E. The participant must remember and recognize the restriction against this aircraft type.
- **Towed Aircraft**: A towed aircraft moves, in some cases,

half as fast as an untowed aircraft. The participant must send the towed aircraft to the correct parking destination without causing bottlenecks in the ground operations.
- **Closed Taxiways**: Mechanical difficulties or construction may stop the taxiing process of an aircraft. The scenarios are designed to simulate mechanical difficulties of a departure. The participant must redirect aircraft around this disturbance (unknown to the controller, closed for 5-7 minutes).
- **Pilot Error**: A pilot makes a wrong turn down a taxiway and goes against the flow of traffic. The participant must
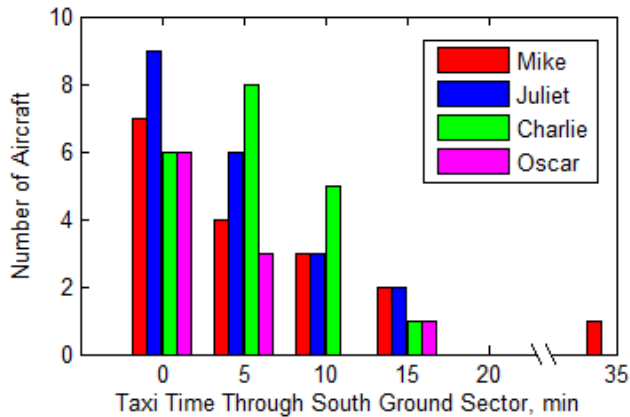
Fig. 5. **Taxiing Time Through the South Ground sector**. These values do not include taxiing time within the South/North Local, South/North Apron, or North Ground sectors.



Fig. 6. **Time History of Number of Active Aircraft.**

recognize the pilot's error and correct the situation.

## IV. PRELIMINARY RESULTS

The design of the Medium scenario of the ground operations were refined with four ATCO instructors at ENAC. The Hard scenario will be validated and refined at a later date. This pre-session provides an indication of the type of performance expected during the October 2014 session, including estimations on the dependent variables. All four instructors were from French airports and had at least a year of experience with their home airport. The ATC students were not available during this pre-session. Each participant performed the scenario for 40 minutes, seeing the prescribed rate of traffic during the entire session. However, in terms of data analysis, only thirty minutes were counted. The additional 10 minutes were to allow for aircraft sent at the end of the 30 minute window to finish taxiing and to verify that the participant had correctly transferred the aircraft to the proceeding sector. Participants were not told when the scenario would finish, or given any indicator that the session would be completed soon. On average, 5.07 minutes were needed to traverse the south ground sector (defined in Section II) This taxiing time does not account for time spent in the Apron, Local, or North sectors of the airport. Fig. 5 presents the distribution of taxiing time between participants. For clarity within the results, the participants have been given anonymous identifiers - Charlie, Juliet, Mike, Oscar.

The Medium scenario was originally designed to have a fixed rate of arrivals and departures, but individual performance plays a significant role in how many aircraft are active at one time. Longer routes extend the required aircraft monitoring time. Delays can cascade through the schedule, reducing the number of aircraft active within the ground sector. Generally no more than 7 aircraft were active at a time, with an average of 2.64 (2-3 aircraft).

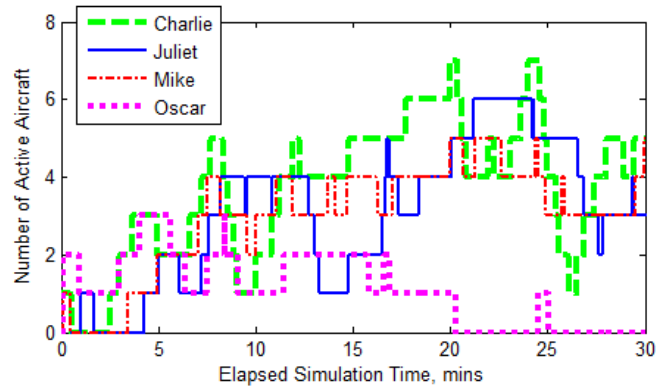Additionally, the developmental state of the simulator meant the sessions were more for exploration (of the possible partic-ipant performance) than for evaluation. There was still a great deal of scenario variability between participants (i.e., the same aircraft was active at different times within the scenario; some events were not rendered, etc). While much of this variability can be naturally attributed to individualistic differences and participant errors, the simulated ground operations were not consistent between participants. Subsequently, the throughput, or the number of aircraft successfully managed needed to be adjusted. Throughput is calculated as the *percentage* of aircraft successfully managed, rather than the absolute count value. An aircraft is considered successfully managed if, in addition to giving the initial taxiing commands, the ATCO has orally transferred the aircraft to the next sector. This transfer consists of radioing the pilot and passing the radio frequency of either apron, south local, or north ground (i.e., "Speedbird 3-0-1, contact Apron at frequency 1-1-9 decimal 5, goodbye.") Usually, this transfer occurs right before the aircraft has reached the holding point between each sector. There is only data for participants Charlie, Juliet, and Mike, as this definition for throughput was not yet finalized for the session with Oscar. Tbl. I summarizes the throughput of these three participants.

The questionnaires for workload, situation awareness, and trust in automation were all administered on 7-point scales. Ideally, in terms of workload, the Medium scenario would be considered 4 and the Hard scenario would be at least a 6 (7 being very high). In general, the TLX score was 3.79 (range of 3.33-4.5, Charlie and Mike respectively). The average SART score was 4.7 (range of 4.5-5.4, Oscar and Mike respectively), with 1 being low situation awareness and 7 being high. The average trust in automation score was 4.58 (range of 2.5-5.66, 0 representing low confidence, 6 high, Juliet and Mike, respectively). Participants were asked to grade their confidence in today's ATC system (paper flight strips, RADAR screen, DISCUS, external view from tower), and not the simulation itself.

Literature [12]–[14] has shown that the change in heart rate (HR) to be a useful proxy for workload. The average HR was 77.79 bpm ($\sigma = 4.71$), with an average change in HR of 2.47 bpm ($\sigma = 1.41$). Histograms of individual's change in HR are

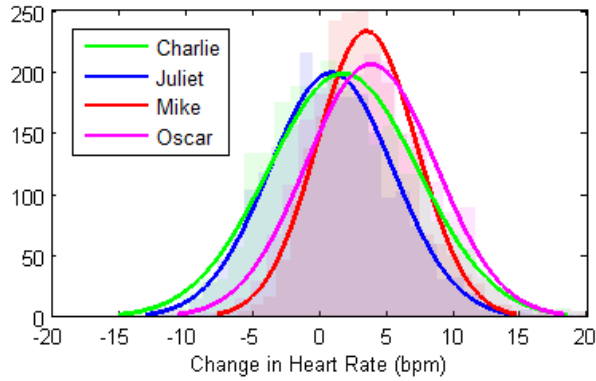| ATCO | # of Aircraft that Contacted (rate, mins/ac) | # of Aircraft Successfully Managed (%) |
|---|---|---|
| Charlie | 23 (1.30) | 22 (96%) |
| Juliet | 20 (1.50) | 19 (95%) |
| Mike | 17 (1.76) | 8 (47%) |



Fig. 7. **Participant Change in Heart Rate during the Medium Scenario.** The change in HR for each participant was as follows: Oscar: +3.81 bpm, Mike: +3.48 bpm, Juliet: +0.86 bpm, Charlie: +1.74 bpm

presented in Fig. 7. Within this small sample size, only a weak correlation was found between workload and change in HR, and this correlation is not significant.

Additionally, each participant's change in HR was plotted with respect to time (Fig. 8). The Kubios-filtered data is represented by thin lines and the moving change in HR average is represented by the thick line. This moving average was calculated by averaging a minute's worth of data at increments of ten seconds. Future sessions will include markers denoting the events discussed in III to evaluate any potential change in workload. These events were not rendered for each participant, based on the simulator development and the cascading effects of participant performance on the scenario timeline. Ideally, the MoTa platform should minimize the amount of stress induced such events, although this effect is not intended to be captured in the baseline experiment.

## V. DISCUSSION

The initial sessions provided an opportunity to assess the realism of the Medium scenario and to obtain feedback on how to prepare for the future experiments, especially for the variety of experience. Additionally, these sessions helped shed light on problems that were not originally foreseen.

Overall, as seen through the TLX scores, the participants found the workload challenging, but not excessively. Individual remarks, however, differed between participants. For example, while participant Charlie found the scenario ecologically valid, Mike believed the task to be too difficult. The individual performance and change in HR attest to that statement, with Mike's throughput at a 47% success rate (Tbl I and a larger change in HR than Charlie. Throughout the experiment, this participant was observed to occasionally misidentify aircraft and give incorrect taxiing routes. The inefficiency of the taxiing commands led to delays in the sequence, with only 17 aircraft presented. Also, there were many aircraft that were not properly transferred to the local, apron, or north ATCOs (all automated in the simulation) although this observation may be due to the fact that the local and ground roles are often combined in smaller airports. Participant Mike also gave scores of 7 (very high) to the "Concentration of Attention" and "Division of Attention" dimensions of SART.

On the contrary, participant Charlie was effective in the commands given and had a 96% success rate with over 23 aircraft seen. This number would have likely been higher, had it not been for the limiting pace of the simulation. Even with this success, his HR slowly increased during the simulation, at points reaching a maximum change of HR of 6.59 bpm. This value is likely correlated with the number of active aircraft in the ground sector, as that value increased correspondingly as the scenario progressed. Nevertheless, each individual has differing reactions. The number of active aircraft for Juliet and Mike also increased with respect to simulation time, but neither participant's change in HR does appears to proportionally increase. Since these sessions, the simulation has been modified to include more information on the RADAR map (arrows noting the traffic flow, the radio frequencies of the other sectors), additional training has been included during the practice session, and the simulation is now capable of distributing more aircraft. These modifications should provide sufficient accommodations for ATCO that are unfamiliar with CDG. Additional practice with the layout of CDG will also have an influence on performance, leading to a possible learning bias. To counter this, the order in which the scenarios are presented will be randomized. The participants are also sent a small description of the project and a layout of CDG, including the direction of traffic, prior to their individual sessions.

The trust in automation scores were relatively high, except for the scores of one participant (Juliet), who gave scores of 1s and 3s (out of 6) across all dimensions of the questionnaire. It is possible that this participant may have graded the simulation itself, rather that his experience with the equipment at his home airport. However, the scores may reflect reality. Informal discussions with ATCOs outside of these four revealed discontent with the RADAR image and the visual representation of information. Further studies will be conducted to accurately quantify trust in today's ATC systems within this particular framework.

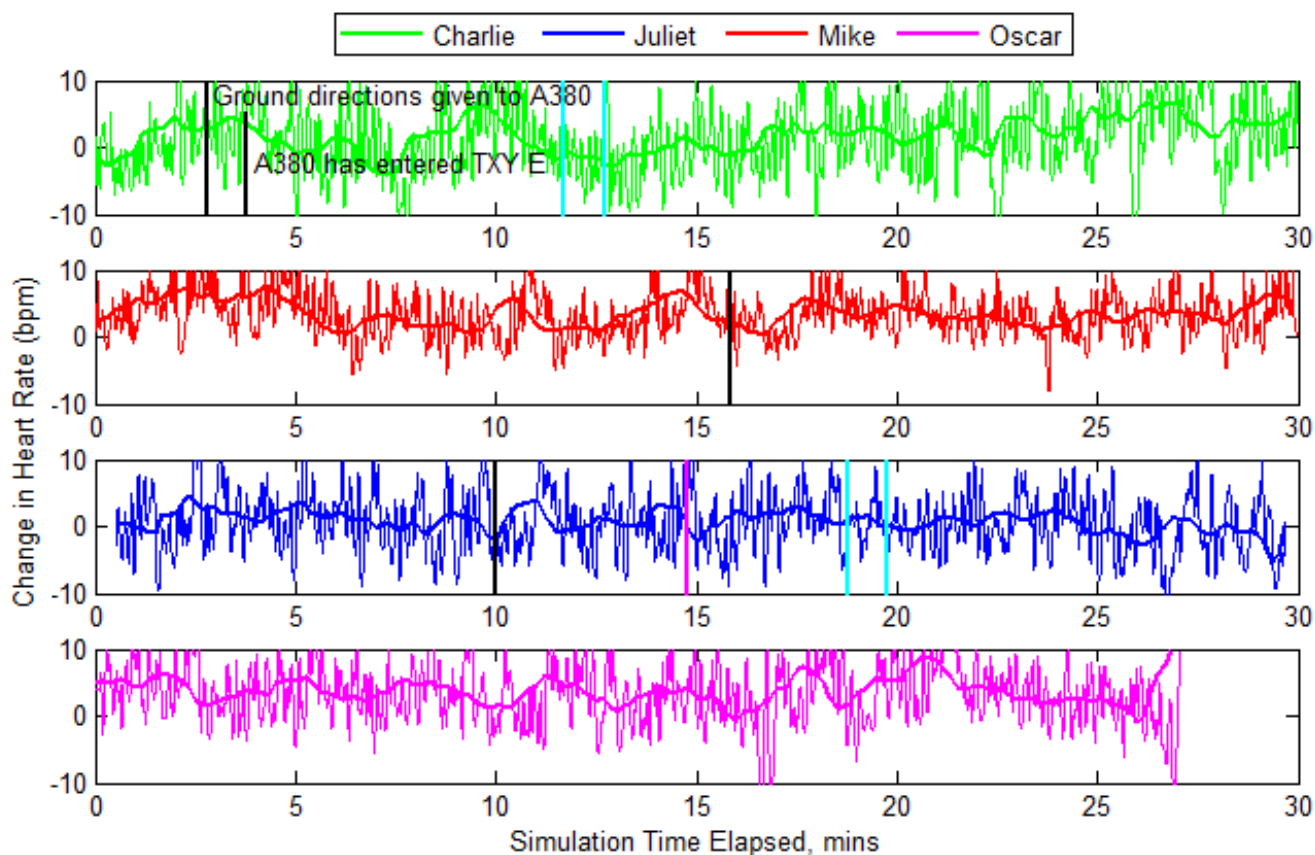A major challenge of the simulation was ensuring the

Fig. 8. **Participant Heart Rate Variability over Time.**. The filtered data (thin lines) and the moving HRV average (thick line) are presented.

appearance of the mini-events (Section III). Originally, these events were linked to specific aircraft within the scenario (i.e., the pilot of FIN946P would make a wrong turn). While it is still the case for some of the events (notably, the towed aircraft and the restriction of A380s on taxiway E), the pilot error and taxiway closure proved to be difficult render within the 30 minute simulation time frame. Subsequently, the focus has shifted to ensuring the appearance of an event within a specific point during the scenario, regardless of the aircraft affected. The pseudo-pilots are trained to identify potentially interesting problems for the participant and the simulation has been modified to accept incidents outside of the original scenario input files (e.g., "create a face-to-face conflict by performing a wrong turn on taxi N instead of F, around 15 minutes from the start of the scenario").

Simulation of ground operations, particularly the pseudo-pilots, has proven to be a significant challenge to the project. Informal discussions with controllers at CDG have confirmed that this issue is also a problem even with the training simulations at CDG, particularly for problems outside of the standardized training program (e.g., only one runway available at each end of the airport, instead of the standard two). The pseudo-pilots oversee 10-15 aircraft each. In addition to following the commands given by the participant, they must

conduct landing, takeoff, pushback, and taxiing through the parking areas. The specialized vocabulary has also been difficult for pseudo-pilots who do not have actual pilot training. To counter these problems, we have attempted to automate as many of the maneuvers as possible (i.e., pushback and landing of the first few aircraft that are not linked to participant performance are all automated) and provided dialogue scripts depending on the pseudo-pilot's experience with this role. For example, pseudo-pilots can opt for different versions of the dialogue script, ranging from full (phonetic alphabet completely spelled out "Jersey 2-4-0 on taxiway Golf-Echo-5, requesting taxi"; complete and exact phrasing in French and English depending on the aircraft; timelines for when pushback, apron taxi, and tower calls should occur; common routes to aide in repeating the ATCO's commands) to minimalist ("BEE240 on GE5"; timelines just for the expected departures; no suggested routes).

The pseudo-pilot version of the simulation also includes a SmartPilot utility that allows the pseudo-pilot to select an aircraft from a list (of only those that he is managing) instead of clicking on the actual location of the aircraft at that moment in time. The SmartPilot also indicates unusual aircraft behavior and automatically stops aircraft if one is facing another or behind a braked aircraft. Future versions of the pseudo-pilot

simulation will include voice recognition [**?**]. When the ATCO calls for a specific aircraft over the radio, the simulation will highlight the corresponding aircraft on the corresponding pseudo-pilot's screen and propose a "Wilco" (will comply) if the order has been recognized. Automated reminders are also in place to help the pseudo-pilot, in addition to the capability to "resume original trajectory" should the pilot be asked to stop mid-course. Nevertheless, the most effective tool has been training sessions for the pseudo-pilots. Around six to eight 45 minute sessions have been noted to be necessary in order to reach competency. There are about seven people in the pseudo-pilots pool, to avoid overload.

## VI. CONCLUSION

Project MoTa proposes an interactive ground controller interface equipment with an intelligent algorithm that can propose taxiing routes and detect conflicts. Additionally, the ATCO can dynamically add, modify, and remove information elements that the algorithm actively takes into account. Such a system promises more efficient taxiing operations, with time and fuel savings, while improving the safety around busy airports. An ATC simulator was developed to test the interface and to provide an ecologically valid microworld to validate the proposed concept. Two scenarios representing Medium and Hard working conditions at CDG have been developed. Three experiments have been designed to validate specific aspects of the project and to allow for ATCO input on the design process. Results from the initial sessions have shown that the Medium scenario for CDG is a sufficient representation, but there will be large individualistic variations, depending on the participant's familiarity with thi particular airport. Modifications have been made to account for this gap, such as additional training. Additionally, several challenges have been encountered during this process and creative solutions have been employed to overcome these obstacles. Next steps include refining the Hard scenario and conducting the Baseline experiment, planned for October 2014.

## ACKNOWLEDGMENT

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