Final Project Report WP-E.02 24 MOdern TAxiing

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Abstract

The final report of the MoTa project provides a publishable summary of the results obtained during the project. In addition it lists all deliverables, dissemination activities, eligible costs, deviations, bills and lessons learned.

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Intellectual Property Rights (foreground)

This deliverable consists of SJU foreground.

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Publishable Summary

Project Modern Taxiing (MoTa) studies the impact of future taxiing technologies such as Datalink and autonomous taxiing tugs on airport taxiing operations and air traffic controller workload.

Aircraft traffic is increasing not only in the air but also on the ground at airports that already are close to saturation. As a consequence, collision risk, time delays, pollution, and stress for the air traffic control officer (ATCO) are rising. However, new automated techniques are being developed, aiming at saving fuel during the ground taxiing phase. Although the environmental benefit would be interesting on its own, technologies such as the TaxiBot© system may also increase the number of ground movements, or the throughput. Project MoTa deals with providing ground ATCOs a tool that will help with managing increased traffic and taking advantage of modern aircraft taxiing techniques when available. The tool consists of an integrated ground control interface featuring the latest progress in modern taxiing methods and multi-agent algorithms for enhanced ground automation while still supporting current and conventional ground control procedures during the transition period. In addition to the new integrated ground control interface, autonomous taxiing tugs (inspired by the TaxiBot system) were simulated. The concept is to use the tugs to continue towing the aircraft after pushback, along the taxiways until the runway holding point, thus saving fuel since aircraft engines would be started later in the taxiing sequence. In that manner, a departure aircraft would be handled as usual by ground control, but when the tug is detached from the aircraft after depositing it at the runway, the empty tug would return to the parking areas via the same taxiways as the rest of the traffic. It was assumed that no other infrastructure would be built to support the tugs. As the taxiing tug is still a concept and deployed at only a few airports, different assumptions had to be made on the future operational procedures. Since one objective of the project is to ensure that proposed solutions are robust and compatible with the ATCO's workload, the most constraining assumptions were retained.

The Ground Control Working Position

The interface is based on the AVISO (the ground radar image currently in use at Paris Charles De Gaulle (CDG)) but it was enriched to include information from the paper flight strips that are still used in France, thus capable of replacing the paper strips entirely. Together, these two technologies provide the minimum information required to manage today's ground taxiing operations.

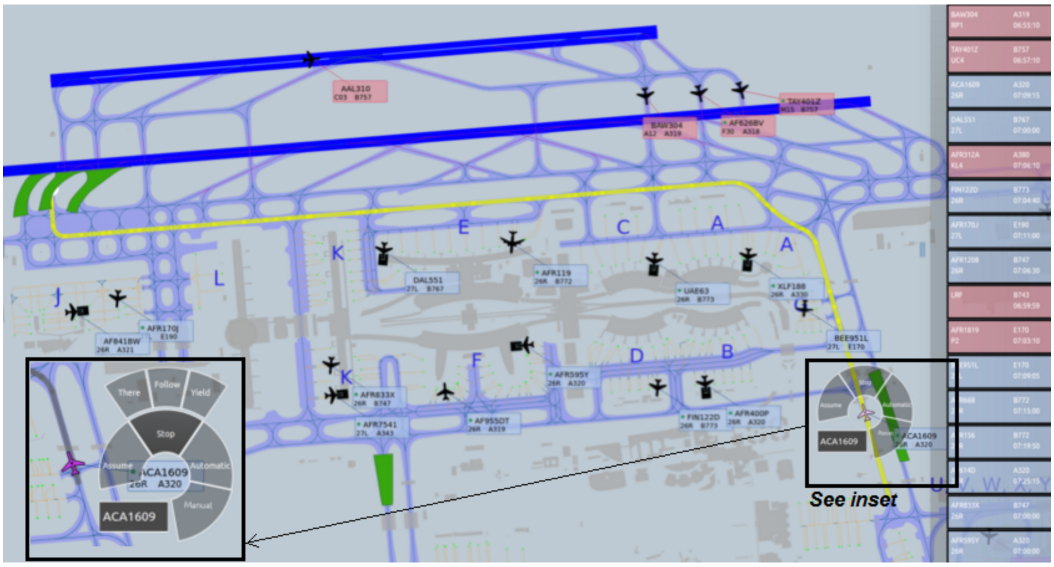

Illustration 1: MoTa ground controller interface prototype, as in use for the South ground sector at CDG.

As seen in Illustration 1, flight information is displayed on the aircraft label and in a flight list in a concealable side panel. The standard path suggestion for an aircraft can be retrieved by selecting its icon or label (i.e. a stylus touch). As seen in the Figure 1 inset, ACA1609 is departing on runway 26R and the ATCO can validate the suggested path (marked in yellow) by clicking on one of the 3 holding points to the runway (represented by the large green zones on the runway threshold).

The aircraft context menu can also be opened by clicking on the label in addition to the icon. This helps in selecting the correct aircraft in dense traffic. The ATCO can manage the frequency status by assuming or transferring the vehicle, to inputting a non-standard route using the “Automatic [path completion]” or “Manual [path completion]” options, or using path input shortcuts such as “Follow [another aircraft]” which is quicker than inputting the same route again.

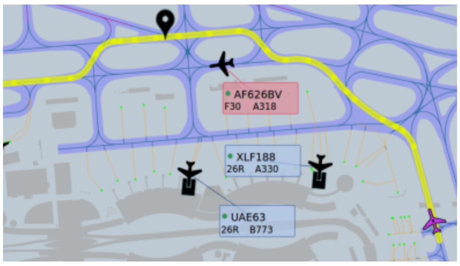

Illustration 2: standard route modification using waypoints

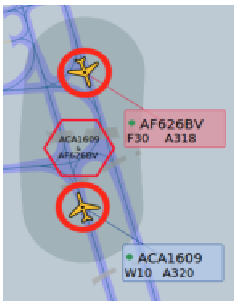

Illustration 3: conflict representation.

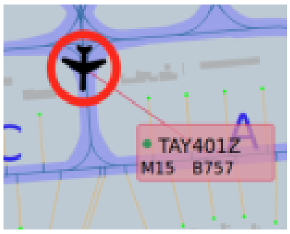

Illustration 4: warning representation.

A non-standard route can be defined by adding waypoints on the path. In Illustration 2, a point has been added to force the aircraft to avoid AF626BV which is stopped on the taxiway. The difference between the automatic and manual modes is the completion of the route. The automatic mode will complete the suggestion to the final destination whereas the manual mode stops the route on the last added waypoint, hence allowing definition of partial routes that stop at any point along the taxiway.

Illustration 3 and 4 shows the conflict and warning visualizations. In Illustration 3, two aircraft are highlighted because of a potential crossover. AF626BV has been instructed to turn right while ACA1609 is going straight ahead and neither of them has been told to give way to the other. In Illustration4, TAY401Z is circled in red to alert the ATCO that it has stopped for more than 10 seconds. The ATCO must determine if the aircraft has a technical problem, is momentarily paused, or requires transfer to the next sector

Evolutions

Illustration 5: Partial and conditional clearances (stop, yield, follow)

Illustration 6: Runway holding points load estimation

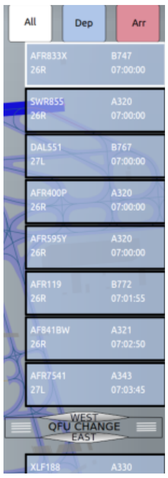

Illustration 7: Precise runway config. change insertion

Multi-Agent System modelling of the platform

The developed Multi Agent System optimizes aircraft ground trajectories in a decentralized manner and also manages autonomous tugs movements. Taxiways and vehicles (autonomous, service, and aircraft) are represented in this environment as agents. A taxiway agent manages resource usage (whether it is employed or not by another vehicle) and maintains a schedule of future aircraft passages. Vehicle agents asynchronously explore (i.e., independently of the others) and express their intentions with respect to resource usage by communicating with the taxiways every second. These vehicles schedule their usage of the taxiways as needed.

Three experiments were conducted to validate two different levels of this technology across two different types of scenarios. The Modern Taxiing platform was designed based on Roissy Charles-de-Gaulle airport in Paris, France, and was simulated at the Ecole Nationale de l'Aviation Civile with 18 air traffic controller instructors with experience from airports around Europe. Four of the 18 participated in all three experiments, whereas 2 out of the 18 participated in just two experiments. The other twelve participated in one experiment. The first experiment was conducted in the fall of 2014 and the second and third experiments were conducted in the fall of 2015.

Each participant performed two 35-minute ground taxiing scenarios, Medium and Hard, which were both simulated in each of the three experiments. Both scenarios varied by the number of aircraft and different operational events (restricted zone, pilot errors, closed taxiway, change in configuration, towed aircraft). In experiments 2 and 3, a percentage of the aircraft fleet was equipped with data link, and in experiment 3, a fleet of autonomous taxiing tractors based on the tug system was introduced. The first experiment provided a reference point with respect to performance with current technology. The second experiment evaluated the use of the interface alone (interface includes the tactile screen, the path suggestion, and the decision support system unless otherwise noted). The third experiment evaluated the inclusion of the tugs in addition to the technology of the second experiment. The second experiment represents technology that could be used in the near future, whereas the technology of the third experiment is farther along the line.

Results

Operational results

The results of the entire experiment campaign show that the Modern Taxiing platform can increase the overall performance of ground taxiing, with greater throughput and less time in the ground sector. The use of the tugs appears to reduce the technology gains, with the greatest performance occurring when using only the interface, without the tugs. However, the advantages due to technology also come at a price, with an increase in perceived workload although the physiological response does not significantly vary. The technology is still currently too immature for accepted use by the air traffic controllers, but comments made during debriefing suggest that with improvements, the participants would be accepting of this new technology in an operational context. The technology also appears to assist participants during some operational events, namely, in managing the impact of a towed aircraft, a change in configuration, and a pilot error.

Globally, the current MoTa platform performs well in nominal conditions but is less robust to off-nominal behaviour (e.g. misplacement of hands, stylus, or misclicks; major trajectory modifications). Participants struggled with modifying trajectories due to ergonomic problems or path suggestion algorithm inconsistencies. This problem was particularly compounded when a change in configuration was planned, as suggested paths could not be varied with different configurations for each aircraft. Additionally, participants commented on a mistrust of the tugs, particularly when they entered the ground sector autonomously. Inappropriate or unimportant alerts were raised due to the tugs, which added to the decreased sense of awareness regarding the situation and possibly increased workload (division of attention, information decluttering). Nevertheless, no participant completely distrusted the automation (lowest score was 2.33/6) and several participants (both from CDG and not) said that with this interface they would use the data link system if available at their home airport. Additionally, experience with the interface improves acceptability. Several participants stated that they were more at ease with the platform towards the end of their sessions than at the beginning.

However, there are some limitations to this study. The run order may be confounded with the experiment run order and the gains in performance and self-reported workload may be due to learning effects and not the technology. The change in configuration due to the change in winds was simulated differently between Experiments 1 and 2, 3, with less rerouting of aircraft towards the end of their original trajectories in the latter two experiments. This change may have contributed to improved performance in the hard scenario. The small sample size, especially of controllers who have experience with CDG, limits the conclusions that can be drawn from this study.

The ATCOs interviews during the simulation sessions provided different enhancement suggestions. Some of them were actually implemented, such as an easier way to input a partial clearance that would replace the full manual mode which was identified as a weakness, some pie menu and a/c labels design upgrades and an interaction to set precisely after which departing a/c the runway configuration change would actually occur. Other enhancement propositions were of interest but would need more time to be implemented, for example the possibility to define magnifier windows to monitor more closely specific congested areas or the representation of a workflow for each aircraft (i.e. next action for the ATCO on an aircraft with a time estimate).

Environnmental impact

Current results indicate that the taxi times and fuel consumption are reduced with the implementation of the MoTa interface and the TaxiBot-like tugs, especially with dense traffic scenarios (-17% with the interface, -21% with the interface and the tugs).

It shall be noted that the present analysis was conducted based on a simulation of one part of CDG. It would be advised to conduct additional studies on a whole airport to confirm this trend.

CO_2 emissions are directly derived from fuel consumption reductions. As an order of magnitude, it is considered that every kg of fuel burnt corresponds to an emission of 3.15 kg of CO_2.

Conclusion

Key indicators

	Exp 1 (radar image + paper strips)	Exp 2 (tactile interface)	Exp 3 (interface + autonomous tugs)
Percentage of Aircraft Correctly Treated	81,75% (~55 ac/h)	94% (~65 ac/h)	87,5% (~59 ac/h)
Deviation from Ideal Trajectory (in minutes)	1,9675	0,705	1,52
Normalized Taxi Time	1,9675	1,305	1,6
Number of Stop and Go	1,0125	0,43	0,45
Workload (TLX score)	4,585	3,33	4,67
Average Fuel Consumption per movement (in kg)	138	127 (-8%)	120 (-13%)

The new ground control working position noticeably increases the platform throughput, and the taxiing time are a bit lower. In addition, the number of stop and gos is also reduced which can have an impact on the fuel consumption.

The ATCO workload is improved when introducing the tactile interface, although the monitoring of autonomous tugs raises it again.

On average 68 % of the aircraft were given a route electronically during the exercises (maximum is 90 % in medium scenario and 85% in hard). It has to be noted that it was not an objective given to the ATCOs, they were asked to manage the traffic as a priority and using the tool as much as they could.

Route input time is 6.75 seconds on average. This may include an undetermined decision making time during the input process.

Future work

Future work should consider improving on the design of the MoTa platform, both in terms of information representation and algorithm definition. Potential avenues of research could be determining the maximum performance achievable with the MoTa platform, coordinating several actors of the airport (either all the same platform or with slight variations), integrating an Arrival/Departure manager, and incorporating in real-time human input to improve suggested solutions over time with respect to ATCO preferences.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to:

- Summarise the technical results and conclusions of the project (Publishable Summary);
- Provide a complete overview of all deliverables;
- Provide a complete overview of all dissemination activities (past and in progress). Where appropriate, provide feedback from presentations. Describe exploitation plans.
- Provide a complete overview of the billing status, eligible costs, planned and actual effort (incl. an explanation of the discrepancies).
- Analyse the lessons learnt at project level.

1.2 Intended readership

Airport stakeholders (airports authorities, ANSP, airlines) for the potentialities of enhanced collaborative decision making.

Scientific communities of human factors, HMI and multi agent systems, for practical instance of multidisciplinary approach.

Air Traffic Controllers trade unions, for social impacts of new tools design.

Training institutions for the benefits that could be derived for training purposes.

1.3 Glossary of terms

Term	Definition
ATC	Air Traffic Control
ATCO	Air Traffic Control officer
ATM	Air Traffic Management
CDG	Roissy Charles de Gaulle Airport
CTOT	Computed Take Off Time
DIT	Deviation from ideal trajectory
E-ATMS	European Air Traffic Management System
GND / SOL	GROUND: ATC controlling position in charge of all the a/c from the block or gate to the runway and backwards
HRV	Heart Rate Variability
LF/HF	Low Frequency/High Frequency
MoTa	Modern Taxiing
NSG	Number of Stop and Gos

Term	Definition
NTT	Normalized taxiing time
SA	Situation Awareness
SART	Situation Awareness Rating Technique
Tug	An aircraft tractor controlled by the pilot from the cockpit or fully automated that pulls aircraft on ground without using aircraft's engine power.
NASA TLX	NASA Task Load Index
PAC	Percentage of aircraft correctly treated
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.

2 Technical Project Deliverables

Number	Title	Short Description	Approval status
D0.0	PMP	Project plan including dissemination	Approved
D0.9	Final report	Final report	Under review
D1.1	Definition Phase Report	High level overview of the operational methodology	Approved
D1.2	Modern Taxiing Techniques Dynamic Model	Aircraft performances table used in the simulator	Approved
D1.3	Simulation Platform	Description of the tower control simulator	Approved
D2.1	Functional HMI0	This document describes the development and execution of the first of three experiments for the validation campaign	Approved
D2.2	Functional HMI1	This document describes the design of a ground controller position that facilitates the input of a variety of clearances and the collaboration with autonomous vehicles.	Approved
D3.1	Experimental process definition	This document details the experiment plan for the validation of Project MoTa.	Approved
D3.2	Benefits and Performance evaluation	This document describes the analysis of the three experiments for the Project Modern Taxiing (MoTa) on an operational point of view.	Under review
D3.3	Final Evaluation	This document describes the execution and the analysis of the three experiments for the Project Modern Taxiing (MoTa) validation campaign.	Resubmitted
D4.1	AMAS Opt ATC use case adaptation INITIAL	This document details the decision support system (DSS) developed in the MoTa platform to help the ground controller with path suggestion and conflict detection.	Approved
D4.2	AMAS Opt ATC use case adaptation FINAL	This document details a decision support system and an autonomous tugs controller for ground taxiing operation based on a decentralized multi-agent approach.	Approved

D5.1	dissemination + SID participation	First year dissemination activities wrap up	Approved
D5.2	dissemination + SID participation	Second year dissemination activities wrap up	Approved
D5.3	dissemination + SID participation	Third year dissemination activities wrap up	Approved

Table 1 - List of Project Deliverables

3 Dissemination Activities

3.1 Presentations/publications at ATM conferences/journals

- *“Self-Managing Conflict Resolution for Autonomous Taxiing Tugs: An Initial Survey” [1]*
- *“Development of an ATC Tower Simulator to Simulate Ground Operations” [3]*
- *“Simulating Air Traffic Control Ground Operations: Preliminary Results from Project Modern Taxiing” [4]*
- *“Initial Impact of Modern Taxiing Techniques on Airport Ground Control” [6]*

3.2 Presentations/publications at other conferences/journals

- “Modulating Workload for Air Traffic Controllers during Airport Ground Operations” [2]
- “Human-in-the-loop Multi-Agent Approach for Airport Taxiing Operations” [5]
- *“Initial Impact of Modern Taxiing Techniques on Airport Ground Control” [6]*
- “Adaptive route suggestion for ATC combining previous decisions and eye movement data” [7]

3.3 Web presence

- Project website: http://www.recherche.enac.fr/ihm/index.php?article2/modern-taxiing
  - Project description.
  - Video explanations of interface and algorithms.
  - Listing of publications.
- Film presentation on aeronewstv.com: http://www.aeronewstv.com/fr/industrie/recherche-innovation-aeronautiques/2955-comment-concilier-transport-aerien-et-developpement-durable.html
  - MoTa was shown during the “Journée du développement durable aéronautique” and a webTV presented the project.

3.4 Demonstrations

Project MoTa has been demonstrated at the following events:

- *Journée de la Recherche (20/02/2014): http://jre2014.sciencesconf.org/*
- *Assise du développement durable (18/11/2015): http://fonds.enac.fr/index.php/8-actualites/28-1eres-assises-de-l-aeronautique-et-du-developpement-durable-de-l-enac*
- *World ATC Congress Madrid 2015 / 2016 on DGAC stand*
- *Sesar Innovation Days 2014 / 2015*
- *ISAE Euro GNC (13 - 15/04/2016) : http://eurognc2015.onera.fr/*
- *Aerospace Valley DAS SSTA seminar (10/11/2015) : http://www.aerospace-valley.com/das/s%C3%A9curit%C3%A9-et-s%C3%BBret%C3%A9-du-transport-a%C3%A9rien*
- *ATACCS 2015 (30/09 – 02/10/2015): https://www.irit.fr/recherches/ICS/events/conferences/ataccs/ataccs2015/*

Project MoTa has also been demonstrated to industrial and end-users

- *Airbus Defense and Space – Airport division*
- *Cuong Pham Quang from Nanyang Technological University / School of Mechanical & Aerospace Engineering: 09/12/2014 and 15/01/2016, aiming at adapting Rapid-Exploring Random Trees algorithm to the MoTa routing problem.*
- *Roissy-CDG ground and apron ATCOs (01/02/2016), during a visit to work on potential continuation on cooperative work.*

3.5 Exploitation plans

On the ENAC perspective, the project MoTa allowed to structure the research on airport activities. The next steps to be considered could be extending the interface to other control positions, the apron manager for instance would benefit of an integrated tool that could ease the coordination with ground control. In addition, a result of the project is that the interface helped more ATCOs who were not familiar with Roissy CDG platform. Hence an evolution of project MoTa could be oriented towards the training phase of new comers to the platform. Otherwise, the MoTa concept can be pushed in a new context, that of remote tower. In this specific domain, the MoTa HMI could be a valuable mean to support and capture ATCO's activity and take advantage of the possibilities offered by a remote tower. Finally, the general notion of "high performance airport" could benefit from the availability of an HMI such as MoTa's to build upon, using this tool as a node to interconnect information systems from different actors (airport, ATC and airlines as a minimum).

The project MOTA was an opportunity for Airbus Group Innovations to improve its knowledge on ATM systems. This gained knowledge will allow for contributing to future projects with a broader vision than an aircraft-centric view. This project has also highlighted interest in the use of dynamic human-in-the-loop decision support systems. The experience acquired for building such systems can benefit other fields (e.g. manufacturing). This project should also benefit the multi-agent research community by applying multi-agent technics in a real application (airport taxiing operations).

Automated technology (e.g. path suggestions via interface, autonomous taxiing systems) is one of many solutions that can help meet the growing air traffic demand at busy airports by assisting air traffic controller officers maintain efficient and safe operations. Yet, proposed solutions have to be acceptable and robust to the ATCO's workload. In this sense, ISAE's implication in MOTA project was an invaluable opportunity to fully deploy a neuroergonomics approach to evaluate the impact of the transition from current technology in the safety-critical ATC domain. To this end, we have performed various human factors evaluations and the results highlighted the advantages of the introduction of automation and taxiing autonomous tractors on human performance, subjective feelings (e.g. felt mental workload, confidence in the system) and brain activity. This human factor evaluation also put forward several pitfalls that should be avoided. Relatively to the neuroergonomics domain, the collection of subjective, behavioral and physiological data in such a realistic setting helps to develop new analysis technique, (e.g. signal filtering), for example resilient to body movements. That type of experiments paves the way to the deployment of objective measurements of the operator "in the wild".

On Airbus side, the MoTa project was an opportunity to test Air Traffic controllers' reactions and opinion on future taxiing methods such as TaxiBot.

Finally, project MoTa started a collaboration between ENAC and ISAE that leads to the co-financing (French CPER – Contrat Plan Etat Région) of an Aeronautical Computer Human Interface Lab in ENAC and ISAE premises.

4 Total Eligible Costs

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
27/02/2014	*D0.0, D0.1, D1.1*	*25 923,30 €*	*0 €*	*Paid*
14/11/2014	*D0.2, D0.3, D1.2, D1.3, D5.1*	*40 822,17 €*	*7400,99 €*	*Paid*
16/12/2014	*D0.4, D1.3, D4.1*	*178 528,69 €*	*0 €*	*Paid*
22/12/2015	*D0.5, D0.6, D0.7, D2.1, D2.2, D5.2*	*94 931,40 €*	*28 850,12 €*	*Billed*
TBD	*D0.8, D0.9, D3.2, D3.3, D4.2, D5.3*	*171 310,93 €*	*3934,82 €*	*Incoming*
GRAND TOTAL		*511 426,23 €*	*40 185,93 €*	*To be confirmed*

Table 2 Overview of Billing (information are to be confirmed after last bill on travel expenses after closure meeting)

Company	Planned man-days	Actual man-days	Total Cost	Total Contribution	Reason for Deviation
ENAC	680	*681,26*	*264 752,05 €*	*220 503,89 €*	*Actual man-day cost was higher than planned cost*
ISAE	427	*427*	*277 646 €*	123 934, 89 €	*ISAE involvement started sooner in the project than what was planned*
Airbus Group Innovation	348	348	350 006 €	175 003, 00 €	
Airbus	80	80	69 120 €	32 690, 00 €	Actual hourly cost higher than expected initially
GRAND TOTAL	1535	1536,26	961 524,05 €	552 131, 78 €	

Table 3 Overview of Effort and Costs per project participant (information are to be confirmed after last bill on travel expenses after closure meeting)

5 Project Lessons Learnt

What worked well?
Collocation of all the partners in Toulouse allowed for better communication and facilitated the integration of the different developments.
The short iterations and frequent meetings allowed us to adjust rapidly the project plan to the encountered issues.
Building the exercises and simulator with ATCOs resulted in an acceptable level of realism to keep ATCOs concentrated on 35 min exercises. Shorter exercises might have been quicker to build and we may have tested more design and interface features. On the other hand, long exercises were required to measure the integration of TaxiBots.
Working on open source simulation environment, entirely modifiable, allowed us to easily add or simulate features that were not planned at the beginning. For instance, during the project definition phase, the important place of datalink was not foreseen but it has been easily implemented (partially in fact, just enough to fake it from the ATCO's point of view).
The project constantly had to balance the work between development of new features, stabilization of the platform and indicators measurements implementation for analysis of the exercises.
What should be improved?
The balance between building a representative simulated environment and the addition of innovative functions.
Collaboration with other SESAR projects would have been better with an easier communication between teams.
It was difficult to obtain reproducible exercise scenarios on 35 min simulation sessions that are highly dynamic and dependent on subject actions and reactions.
Training sessions were too short. Simulation exercises were already quite long and it was not possible to require a longer participation time of the ATCOs, in addition longer sessions would have cause problems of fatigue for the subjects.
The number of runs was uneven between the 3 exercises. We could have reduced the numbers of subjects overall (for instance 5 per exercise) but then the statistical analysis would have been less powerful. *ENAC should have provided more ATCOs but the planning has been difficult to manage.*

Table 4 - Project Lessons Learned

6 References

[1] Z.K. Chua, "Self-Managing Conflict Resolution for Autonomous Taxiing Tugs: An Initial Survey". 2015 SESAR Innovation Days, Bologna, Italy. 1-3 December 2015. - Schaefer, Dirk (Editor) Proceedings of the SESAR Innovation Days (2015) EUROCONTROL. ISSN 0770-1268

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[3] Z.K. Chua, F. Andre, M. Cousy, "Development of an ATC Tower Simulator to Simulate Ground Operations". Proceedings of the 2015 AIAA Modeling and Simulation Technologies Conference. Dallas, Texas, USA. 22-26 June 2015.

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[5] F. Lancelot, M. Causse, N. Schneider, M. Mongeau, "Human-in-the-loop Multi-Agent Approach for Airport Taxiing Operations". PAAMS 2015

[6] Z. Chua, M. Cousy, M. Causse, F. Lancelot, "Initial Impact of Modern Taxiing Techniques on Airport Ground Control". HCI-Aero 2016 International Conference on Human-Computer Interaction in Aerospace. Under review

[7] F.Lancelot, M.Causse, N.Schneider, "Adaptive route suggestion for ATC combining previous decisions and eye movement data". HCI-Aero 2016 International Conference on Human-Computer Interaction in Aerospace. Under review