Self-Managing Conflict Resolution for Autonomous Taxiing Tugs: An Initial Survey

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***Abstract*—Local conflict resolution, or designating priority to one vehicle over another, is a critical task necessary for managing safe and efficient airport ground movements. Air traffic controllers use a variety of information cues to inform this decision. New technologies such as autonomous taxiing tugs will likely be introduced to the ground operations problem in order to minimize aircraft fuel consummation. The introduction of such vehicles will create situations that have never been seen before, such as conflicts between two autonomous tugs. This research aims to solicit feedback from air traffic controllers on the decision cue strategy for prioritizing between two tugs. An online study featuring 73 different types of scenarios based on five different decision cues was designed. Seventeen participants from Europe and North America reporting evaluating one cue at a time until a decision was made. Results showed that participants typically always chose the tug that was closest to the intersection. If both tugs were of equal distance form the intersection, then participants would likely prioritize the tug with a trailing aircraft over a single tug. If this cue did not discriminate, then the tug that was closest to its parking destination was favored over that which was farther away. However, the order of these cues is not universal and as such, future work should continue investigating this strategy and other decision strategies. Furthermore, future research should account for participants' origins, as slight differences between French and non-French air traffic controllers were observed. No significant changes were determined between participants from small or large airports, or with greater than or less than 15 years of ground controller experience. The results of this research could be applied to the operational policies of a multi-agent system or for decision support.**

I. Introduction

Airport ground traffic management involves efficiently directing incoming and outgoing traffic and resolving potential conflicts by prioritizing one vehicle over another. This prioritization task occurs when a vehicle require use of the same taxiway resources at the same time. The Air Traffic Controller (ATCo) must decide which aircraft yields to the other. This decision is made on different criteria, or decision cues, and often involves various objective functions such as reducing aircraft fuel consumption or meeting flight schedules. The ground prioritization problem has studied as extensively in the literature more as an en-route conflict detection and resolution problem.

Previous research have categorized cues or rules for determining priority between aircraft and airport operational rules and practices have been well established. The general consensus within the literature [1] [2] [3] [4] on the key decision cues is: the taxiing route, the slot time, the ATCo's assigned priority level, arrival/departure constraints; aircraft size category; aircraft ground movement speeds [1]; airline [3]; and variations associated with each airport [4]. Between service vehicles, the intersection is treated like a standard road: generally the vehicle on the right advances before the other. In all cases, a service vehicle must yield to an aircraft. If any confusion should occur, the ATCo should be consulted before proceeding [5].

An increase in ground traffic subsequently leads to greater fuel consumption, noise pollution, and emissions [6]. To meet these challenges, researchers are attempting to offset reliance on the aircraft's main engines for ground taxiing. One proposed solution that is currently being implemented is the using of taxiing tugs. Taxiing tugs, such as Taxibot ™ [7] or SAFETug [8], would have a tractor push the aircraft to and from the runway. Both human-driven and autonomous tugs have been proposed, with the autonomous tugs managing themselves with little ATCo intervention [9]. These concepts would reduce the fuel consumption by avoiding reliance on the aircraft's main engines and instead using the tug. When attached, the tug would be controlled from the pilot's cockpit as if he or she was taxiing normally, or it would be controlled by the tower controller via data link. It would move as quickly as the aircraft it is towing. As with all other aircraft, a tug attached to an aircraft would need to ask for taxiing clearance before beginning its trajectory - effectively, a seamless integration with the aircraft. The impact of an autonomous tug on the ground controllers' and pilots' tasks are currently unknown, as this technology is still relatively new. In fact, the human-driven Taxibot ™ only began operations at Frankfurt airport [10] earlier in 2015. This version tows only departures to the runway [11]. The autonomous tug is under investigation by Project Modern Taxiing [12], which evaluates the inclusion of this technology and others on ground operations. At the current moment, a maximum of 10 tugs are estimated to be added to predicted traffic flows in the south end of Roissy Charles-de-Gaulle. Naturally, the addition of that many vehicles would pose several challenges to the current ATCo role.

Thus, there is little guidance as to how these tugs would operate, in terms of their interactions with the the ATCo. Key questions include:

- Should the tug call for taxiing clearance upon entry of the ground sector/after aircraft detaching?

- What prioritization strategy should be used to resolve potential conflicts between two tugs?
- Who and how should tug reservation and assignment be conducted?
- Who is responsible for tug health maintenance (i.e. monitoring tug power levels)?
- How should the tugs traverse within the ground sector?

This research attempts to address one of these questions, by examining conflict resolution between two autonomous tugs. Namely, the decision cues and utility curve used to determine priority between two non-servicing, or empty, autonomous tugs. A potential application of this research is the development of a decision support system for ATCos or operational rules for a multi-agent system [9]. From this knowledge, prioritization strategies based on actual ATCo preferences can be proposed for further investigation, especially with respect to airport optimization. The next section discusses the methodology and online test used to solicit ATCo input. Results from the test are presented, including a discussion of the significance of these results and future work.

II. Methodology

Since this technology is still in its infancy and no ATCo has worked with an autonomous vehicle, a small test was used to simulate the autonomous tug interactions and to solicit the types of strategies and cues that drive this type of a decision. While a general discussion and a questionnaire would provide a substantial amount of feedback, there were concerns regarding the subjective nature of such data and the open interpretation of the questions. A simulated exercise of the prioritization event and extraction of the strategy and cues used from the recorded performance would provide more objectivity and impose more consistency between participants with respect to the scenarios presented and the autonomous tug characteristics. Additionally, using quantitative data could better achieve the research goal of finding a general cue usage strategy amongst participants.

To prepare the scenarios for this test, a review of the literature and informal discussions with various ATCOs unveiled a plethora of individual aircraft taxiing criteria, or cues. These cues were further reduced to those appropriate for the autonomous tug prioritization problem based on current assumptions on future tug implementation. For example, the flight status is not a relevant cue in this context. Concerns regarding the potential blockage immediately at the runway exits for tug attachment has established a working assumption that the tugs will only tow departures (more maneuverability in the parking areas). Tug velocity was also not a concern, as it is assumed that empty tugs will taxi at a constant velocity. In the end, five cues were used in this scenario, with low and high values in parentheses:

- Position relative to the intersection (PosRel; Closer, Farther)
- Path after intersection (PathAfter; Turn, Straight)
- Estimated time of arrival at Destination (ETA; +2 mins, +10)
- Taxi time prior to intersection (TaxiPrior; -10 mins, -5)
- Number of other aircraft around intersection (NAC; 0 aircraft, 1)

The estimated time of arrival at destination could be considered as the proximity of the tug to its parking area (arrival). For simplicity, the rest of this paper shall refer to this cue as ETA, to correspond with the high and low level values of this cue. The taxi time prior to the intersection is the amount of time the tug has been in the ground sector prior to the intersection. It is unknown how this information is stored in memory, but likely that if considered, participants use relative qualitative quantifiers ("long time") or a sense of the passage of time. Numbers were used due to implementation limitations.

These cues describe each tug and its taxiing status and some combination of cues are used to guide the prioritization process between tugs. It is acknowledged by the ATCos that the combination of cues may change depending on the context. Most likely, these cue combinations will also evolve with respect to the deployment and experience with the autonomous tug's physical characteristics and governing behavior. There may be other influencing factors such as airport operations policy, the size of the airport, or the country of the airport. To minimize these noise factors, all parking areas presented were from either A, B, C, or D. Thus, it is not evident if the example airport is relatively small or just a portion of a larger airport.

An 81-run fractional factorial design was used that incorporates all five criteria. This design of experiments described the differences between each of the tugs for each of the criterion. There are three levels: 0 (both tugs are at the low level); 1 (one tug is at the high level, the other is at the low level); and 2 (both tugs are at the high level). This design is derived from the work of Xu (2004) [13] and is a resolution V design.

There were certain assumptions made about the autonomous tug. First, as previously stated, empty tugs were assumed to operate at a constant velocity. Second, the tugs are assumed to be equipped with data link and the ATCo can interact with them using an interactive tablet. There is no radio communication with the tugs as there is no human driver on board. Third, the participants were told that stopping an aircraft via an interface would require several steps: click on the *icon of the yielding aircraft - Yield to - icon of the preceding aircraft*, all of which would take a few seconds. Fourth, participants were taught that message transfer via data link was effectively instantaneous, whereas in reality it takes around 25 seconds for the transmission and the closing transmission correspondence [14]. Since the detected conflict between the two vehicles would come to a head in about 10 seconds, this assumption was made to avoid a major contradiction in the scenario design.

In each scenario, two tugs were displayed: the reference and the challenger. In this study, the reference tug was that which always retained the low value when the challenger held the high value (level 1 in the design of experiment 3-level codification). As such, the design of effectively resulted in the description of when the challenger differed from the reference tug. This test was created as an online questionnaire using Google Forms [15]. The questionnaire was provided in both English and French. The first part introduced the problem, described the autonomous tug and data link systems, explained the symbols and information provided, and provided three practice tests: one with full text descriptions of each tug (as to reinforce the symbology) and two without text (the actual format of the test). Participants were also asked to follow four rules:

1) Please do not spend more than 5 seconds in selecting a vehicle.
2) All of these situations occur in the middle of the airport taxiways. NONE are near the runway.
3) Please select 'either' ONLY if the two tugs are equal to you. Do not choose a tug according to its position (e.g., do not, by default, choose the tug on the right if the two are equal - instead, select 'either').
4) You are not obligated to use all of the information presented.

Of the 81 trials, there were 71 unique cases where the tugs differed by at least one criterion. Two of the equality scenarios were included as a "litmus" test to determine if participants followed Rule 3, with a final count of 73 scenarios presented. The 73 scenarios were presented in randomized order, but the order was same between participants. The structure of the Google Forms circa April 2015 did not permit the order of the questions to be randomly assigned. Pre-tests indicated there was no apparent fatigue factor, meaning there was no change in performance between the first and last trials. It was not evident that one of the two vehicles was always the same. While the participants were asked to respond to each scenario in 5 s, the questions did not automatically advance (an option not available on Google Forms). Participants were to indicate their choice: the Left tug, the Right tug, or either tug (equal prioritization). The left and right tugs were not with respect to the relative position, but rather to the columns of information (Figure 1). This orientation was conveyed to the participants during the practice session.

Figure 1 is an example of the types of potential conflicts presented to the participants. In this figure, the tug on the left, Taxibot 1, has been taxiing for 5 minutes prior to this moment. It is expected to arrive at parking A08 in 2 minutes after making this last turn. The tug on the right, Taxibot 4, has been taxiing longer (10 minutes) and will be at parking D15 in another 10 minutes. Taxibot 4 is followed by an aircraft and will be turning straight. Neither parking area is presented within the image and there is no particular correlation between the parking area and the ETA. Both tugs are moving at the same velocity as evidenced by the equal spacing of the comet tails behind each tug.

At the end of the 73 trials, they were asked to select which of the following statements best matched their prioritization approach ("Looked at the criteria of each aircraft and picked the aircraft that seemed to be globally 'better"' or "Chose between aircraft based on one criterion, if they were equal, used another criterion until I found one 'better' than the other"). These strategies correspond to Take-the-Best (TTB) and Weighted ADDitive strategies, respectively. Additionally, they were asked to check all cues that they used, with an option of noting others that were not already on the list. Overall, the training and the main task took about 25 minutes to complete.

There were twenty-nine anonymous online participants in this study, representing France (18), other European countries (8) and the United States of America (4). Of the twenty-nine participants, 16 participants clearly marked off that they used the TTB strategy, 12 used the WADD, and one participant stated they used a mixed of the two. Those that used TTB in any way were retained for further investigation in this study. Of these 17 participants, five came from either Roissy Charles-de-Gaulle (Paris, France; 3) or Marseille Provence Airport (France; 3). The other participants represent 9 different airports. The average number of years of experience working as a ground controller was 15.3 ($\sigma = 9.27, [4, 32]$).

The final 17 responses were re-codified as to match whether the chosen aircraft corresponded to the reference vehicle (-1), the challenger (1), or either (0). Depending on the analysis, either a linear multivariate regression model (Equation 1) with logical variables was performed on each participant's session, a One-way Kruskal-Wallis ANOVA, or a Mann-Whitney Wilcoxon rank-sum test) was used. The regression treated all of the participants' data together and noted the significance and contribution to each term in Equation 1 to the choice of either -1,0, or 1. What is lost in this analysis, however, is the range of cue importance as denoted by the participants. The One-way Kruskal-Wallis ANOVA on the beta values of individual regressions supplies this missing information and allows for comparison between groups. The Mann-Whitney Wilcoxon rank-sum test was used to directly compare between different groups, such as by experience, runways, or country.

$$\begin{aligned} y \;=\; & \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_5 x_5 + \beta_{12}(x_1 \vee x_2) \\ & + \beta_{13}(x_1 \vee x_3) + \ldots + \beta_{45}(x_4 \vee x_5) \\ & + \beta_{16} x_{\text{exp}} + \beta_{17} x_{\text{runways}} \end{aligned} \quad (1)$$

The first five betas were for describing each variable and the next ten variables described the two-way interactions. As the TTB strategy looks only at the sameness between options with respect to a given variable, a logical regression was chosen to reflect this concept. Hence, the 81-run fractional factorial design by Xu (2004) [13] can be recodified to 1s and 0s: 1 (TRUE) if there is a difference between the two vehicles, and 0 (FALSE) if there is not a difference (i.e., 0 and 2 are treated as the same value). The two way interactions therefore are modulo-2 addition: 1 (TRUE) when either x_i **or** x_j are TRUE; 0 (FALSE) when x_i **and** x_j are both TRUE or both FALSE. Thus, the interactions should give some indicator as to what follow-up cue is used when the first cue does not discriminate.

The absolute value of the betas indicates the contribution of

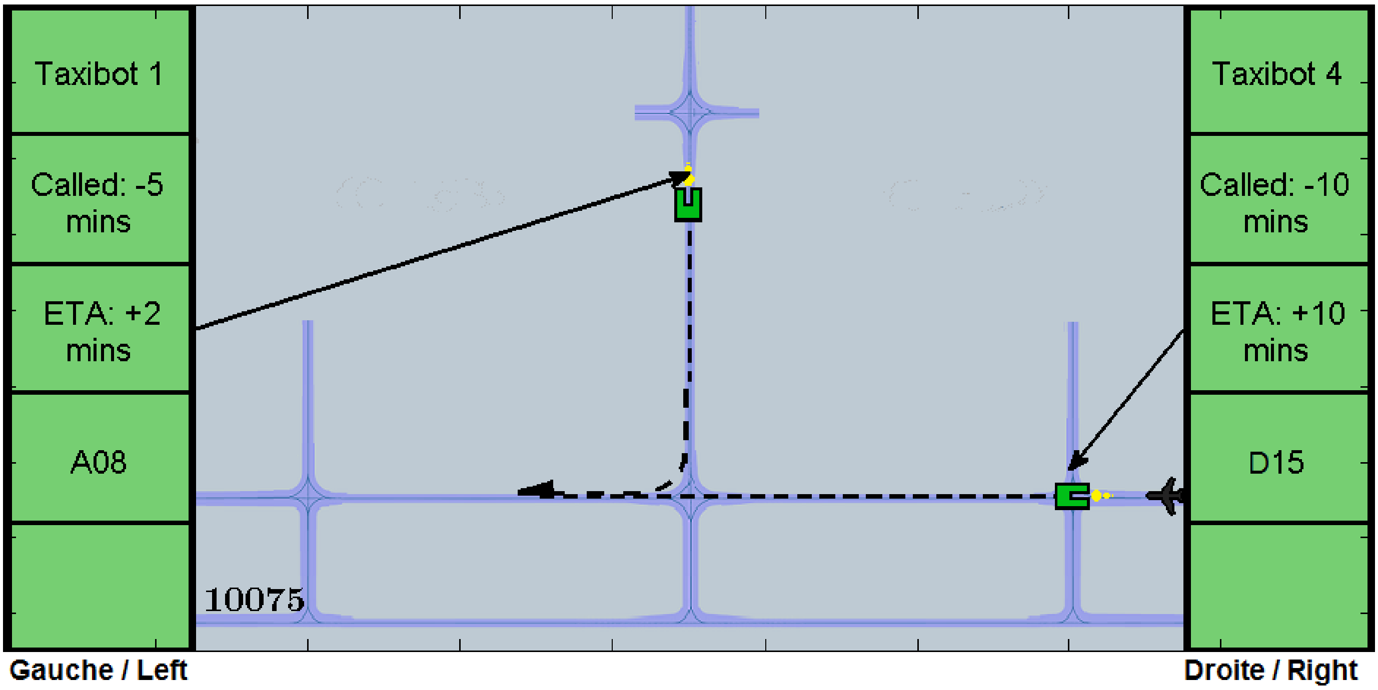

Fig. 1. Example Prioritization Scenario. In this example, the reference tug is to the left. For this particular question, 2 participants chose the tug on the left and 15 chose the tug on the left.

that particular variable to the response. A larger beta would imply a large overall contribution. The sign of the beta values indicates the direction of the preference, with negative betas implying a contribution to choosing the reference vehicle and positive betas for the challenger.

III. Results

The results were first analyzed to determine the validity of the collected performance, as to whether participants truly behaved in the manner assumed for this analysis. Participant responses and results were also compared to determine the level of agreement between self-reported and extracted decision cue usage. Finally, an analysis of the decision cue usage was completed.

A. Calibration

A Mann-Whitney Wilcoxon rank-sum test (main factor: whether the two tugs were deliberately equal or not) showed that participants did respect Rule 3 and only selected a tug for a known reason ($U = 0, Z = -2.4129, p < 0.0000, r = 0.585, \widetilde{x}_{\text{No Ties}} = 4, \widetilde{x}_{\text{Ties}} = 14.5$).

As seen in Figure 2, the individual betas of each participant were plotted (black x's) against the cues they self-reported (red circles) using during the experiment. For clarity, the top two greatest betas were plotted as well (blue circles). It is evident that while most participants' reported cues match their performance, almost $1/3$ of the participants had a mismatch. Participants did not use any cues that were not specifically included in this study.

B. Cue usage

A logical linear regression on the global data (all 17 participants together) demonstrated that certain cues were used more frequently than others. Table I lists the beta value for each coefficient and the p-value. The results indicate that four cues were significant factors to prioritizing between the the tugs, two interactions were significant, and that the number of runways (i.e. airport size) and years of experience as an ATCo are significant to the choice. The four significant cues were PosRel, ETA, TaxiPrior, and NAC. The two significant interactions were the PosRel*NAC and PathAfter*NAC. Figure 4 illustrates the interactions.

These results mostly corresponded with a Kruskal-Wallis One-way ANOVA on the absolute value of the betas from the individual linear regressions. The results showed that there was a significance difference between the values ($\chi^2(14) = 37.81, p < 0.0006$). As seen in Figure 3, PosRel, NAC, and ETA have the largest absolute beta coefficients, with average values of 0.841, 0.382, and 0.297, respectively. However, post-hoc tests using the Dunn-Sidak correction indicate that the PosRel cue is significantly different from all other coefficients ($p = [0.0000, 0.0164]$) except for NAC and ETA*NAC. However, no contrasts involving either of these coefficients are significantly from the others. Table I summaries the distribution of beta signs and magnitudes (three-bin histogram of $< 0.2; [0.2, 0.7]; > 0.7$).

Figure 4 illustrates the two significant interactions, including a histogram of the choices made with respect to each individual case. As evident through this Figure and Table I, the effect of these interactions is quite small relative to the other factors.

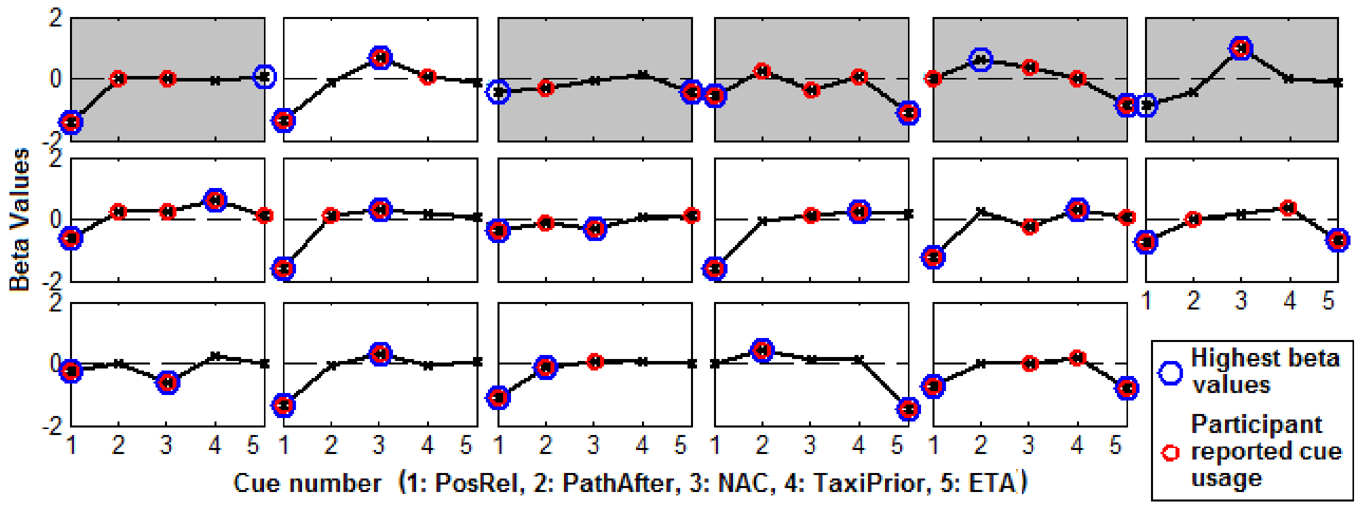

Fig. 2. Participants' individual betas (black x's) plotted with against self-reported cues (red circles). The top two largest beta magnitudes are plotted in blue circles.

TABLE I
BETA VALUES FOR THE GLOBAL LINEAR REGRESSION.

	Global			# of Participants				
Variable	β**-value**	p**-value**	**Sig.**	$\lvert\beta\rvert \leq 0.2$	$0.2 < \lvert\beta\rvert \leq 0.7$	$0.7 < \lvert\beta\rvert$	$\beta < 0$	$\beta > 0$
(1) PosRel	-0.8366	0.0000	**	3	4	10	15	2
(2) PathAfter	0.0343	0.4900		13	4	0	11	6
(3) NAC	0.1054	0.0341	**	11	5	1	7	10
(4) TaxiPrior	0.1413	0.0045	**	15	2	0	3	14
(5) ETA	-0.2908	0.0000	**	11	2	4	10	7
($1 \vee 2$) PosRel*PathAfter	0.0252	0.5559		17	0	0	8	9
($1 \vee 3$) PosRel*NAC	0.0913	0.0327	**	11	6	0	6	11
($1 \vee 4$) PosRel*TaxiPrior	0.0080	0.8514		16	1	0	10	7
($1 \vee 5$) PosRel*ETA	-0.0239	0.5765		13	4	0	9	8
($2 \vee 3$) PathAfter*NAC	0.1305	0.0023	**	13	4	0	2	15
($2 \vee 4$) PathAfter*TaxiPrior	0.0325	0.4467		16	1	0	7	10
($2 \vee 5$) PathAfter*ETA	0.0154	0.7193		16	1	0	9	8
($3 \vee 4$) NAC*TaxiPrior	0.0399	0.3508		16	1	0	9	8
($3 \vee 5$) NAC*ETA	-0.0655	0.1252		17	0	0	12	5
($4 \vee 5$) TaxiPrior*ETA	0.0570	0.1821		14	3	0	9	8
(6) Number of Runways	-0.0543	0.0000	**	–	-	–	–	–
(7) Years of experience	0.0109	0.0000	**	–	-	–	–	–

Indeed, the trend for PosRel*NAC is in the opposite direction. As such, the interactions do not give a direct indicator as to the order of cues used during the TTB strategy.

The subjects were further grouped with respect to airport size (i.e. number of runways), ground controller experience, and nationality, to determine the effect of these variables. For this analysis, there were two airport sizes used: large (3 or more runways; 7 participants) and small (2 or less; 10). Two different groups of years of experience were created based on whether the participant fell above or below the mean (15 years): above (range of 2-15 years; 9 participants) and below (15-32; 8). The participants were separated by whether their airport was in France (10), or Not (7).

A Mann-Whitney Wilcoxon rank-sum test was applied to each each group of airport sizes within each cue, with a Bonferroni correction ($0.05/n$ where $n = 5$ comparisons). No comparisons were significant. This same analysis was applied

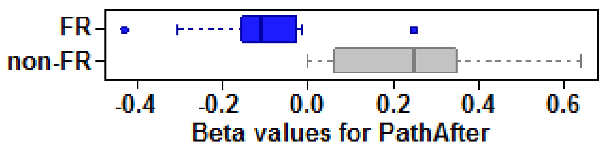

Fig. 5. Differences in betas for the PathAfter cue between French and non-French ATCos.

to the two groups separated based on years of experience and for the nationality, to determine if there were changes in cues used. Only one comparison was significant, within the beta value of PathAfter, between the non-French and French ATCos ($U = 66, Z = 3.0365, p < 0.001, r = 0.734$). The medians of the betas were 0.250 and -0.111, respectively (Figure 5).

In order to determine the next differentiating cue, only the cases where PosRel was 0 (both tugs were equally distant) was examined. A one-way Kruskal-Wallis ANOVA on the

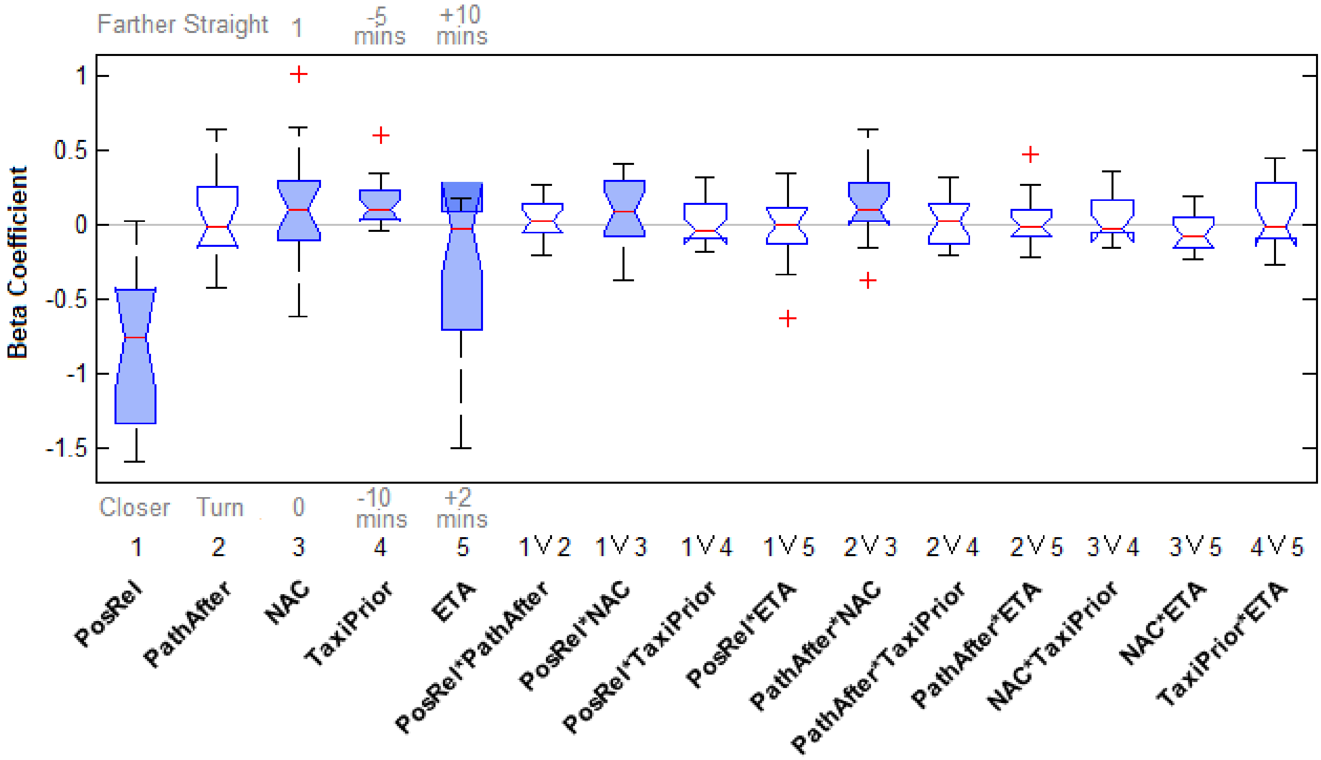

Fig. 3. Boxplots of betas for each of the 5 cues and their interactions. The red line marks the median.

absolute value of the betas (main effects only, no interactions) showed that there was no significant difference between the main effects ($\chi^2(3) = 5.71, p < 0.1264$). Both NAC and ETA had the greatest mean absolute betas (0.5049 and 0.4902, respectively, compared to values 0.2761 and 0.2712). However, the preference direction is not as well defined, with average beta values of 0.2164 and -0.2827, respectively. Furthermore, multiple Mann-Whitney Wilcoxon rank sum tests with a Bonferonni correction showed that the betas did not change with respect to the actual of PosRel, i.e., whether both were equally “Closer” or “Farther” (cf. Section II) from the intersection.

This research attempts to address one of these questions, by examining conflict resolution between two autonomous tugs. Namely, the decision cues and utility curve used to determine priority between two non-servicing, or empty, autonomous tugs. From this knowledge, prioritization strategies based on ATCo preferences can be proposed for further investigation, especially with respect to airport optimization. The next section discusses the methodology and online test used to solicit ATCo input. Results from the test are presented, including a discussion of the significance of these results and future work.

IV. Discussion

This study was conducted to start examining the changes on airport ground control with the introduction of autonomous tugs. In particular, conflict resolution between two tugs, when one tug must be prioritized over another. Since no autonomous vehicles currently traverse on airport taxiways, a small test was designed to solicit the decision cues and utility curves based on ATCo performance in a variety of potential scenarios. The results of the analysis demonstrated that globally, there is one deciding cue that almost all ATCOs use, but when this cue does not differentiate between vehicles, the there is mixed opinion on the next best cue. Additionally, there appears to be some difference in cue usage between French and non-French ATCOs, implying that future research in this area, especially when determining airport operations policies, should account for cultural differences.

Overall, four out of five cues were significant to the choice between the two tugs. The path of each tug after the intersection was not significantly used to inform this decision. Of the four significant cues, almost all participants employed the relative position of each tug to the intersection as the primary cue. This result is not surprising, as both tugs move at the same velocity and it goes against reason to stop a tug that is closer to the intersection just to allow passage of one tug that is farther away.

However, if the two tugs were of equal distance from the intersection, there seems to be no universal consensus on what cue should be used to determine priority. There was no change in response with respect to whether the two tugs were both close or both far from the intersection. Both the number of trailing aircraft and the estimated time of arrival cues had the greatest mean absolute betas, implying that participants frequently used those cues than the others (the path of each tug after the intersection, the taxiing time prior to

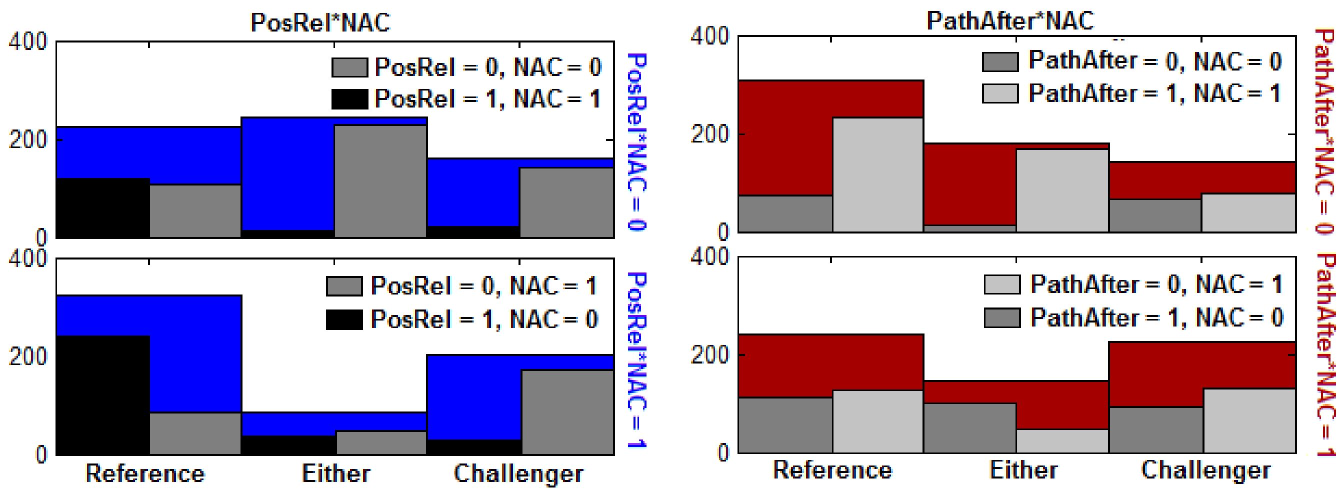

Fig. 4. Histograms of choices for the significant interactions.

the intersection). Participants favored the tug that had a trailing aircraft and favored the tug that was closest to its destination. The ETA cue having the same significance as the NAC cue is surprising, given the discussions conducted prior to the study. The use of NAC as a dominant cue is logical, as stopping the preceding tug would require stopping the following aircraft, thus expending more fuel. One could argue that proximity to the destination may indicate that the conflict is occurring near the runway, where it is of greater priority to avoid an influx of vehicles (which could lead to an increase in potential runway incursions). The participants were clearly told during training, however, that none of the conflicts occurred near the runway. Participants may have believed that a delay with the destination so close by may have a greater impact than when experienced earlier on in the trajectory.

Between the NAC and the ETA cue, the NAC cue may be more favored as the second determining factor if both tugs are equally distant. The interaction PosRel*NAC was significant and as Figure 4 showed, when PosRel was 0, NAC was a discriminant. Contrastingly, when PosRel and NAC were both equal to 0 (both tugs equally distant from the intersection and both with or without aircraft), there were a greater number of ties, meaning that most participants considered just these two cues. Another interaction was determined significant, PathAfter*NAC. While PathAfter is not significant on its own, when a turning single tug is pitted against a tug going straight followed by an aircraft, the former will be selected.

Two covariates, the airport size and years of experience, were determined to a significant effect on the selection of a tug. ATCos from airports with more runways have a minor tendency to choose the reference vehicle, whereas ATCos with greater experience were more likely to choose the challenger tug. However, these effects are very minor and are more dominated by the environmental cues. Indeed, follow-up tests showed that airport size (large, small) and experience (less than 15 years, more than 15 years) had no impact on the cue usage or importance of the cue.

Interestingly, there is a change in the utility curve for the path after intersection cue between ATCos from France and from outside of France. On average, French ATCos were more likely to prefer the aircraft turning over that going straight, and non-French ATCos were more likely to choose aircraft going straight over those turning. There seems to be no evident explanation for this preference but rather highlights the need to account for cultural backgrounds in this type of study.

This study has shown that there is no clear singular strategy for resolving conflicts between autonomous tugs. However, in general, the tug that is closest to the intersection should have priority. If both tugs are equally distant, then the tug with more aircraft trailing it should be selected. If that cue does not discriminate, than the tug that is closest to its final destination should be selected. The sequence of cues may be alternated, with the ETA cue used prior to the NAC. The use of performance data from a small test of various comparisons has shown to be more reliable than asking ATCOs directly, especially when dealing with technology that is still in the conceptual stage. Nevertheless, this study has its limitations. First, this study is not presented in a way that corresponds to how ATCos truly evaluate the decision making event. Cues such as proximity to destination and prior taxi time are likely not retained in working memory as digits, nor are they represented in any way in the ATCo's work environment. Second, this study only used a sample of different cue values. For example, there may be a difference in strategy if the tugs were followed by other tugs, rather than other aircraft. Decision priorities may change if the prior taxi time or estimated time to arrival values were different. Third, this study has only evaluated one type of decision making strategy, TTB. As seen in the initial results, 11 other participants chose to integrate all cues at once rather than once at a time. Focus was placed more on the TTB approach as it can be easier to implement, especially when certain pieces of information are difficult to extract (e.g.

trajectory after the intersection). Fourth, information that does not directly affect the autonomous tugs but rather their charges, such as information from the departure manager, should be considered.

It is clear that the operational policies of autonomous tugs is still in its infancy and future work should examine local optimization strategies and other factors. Such strategies should be validated through fast-time simulations and human-in-the-loop evaluations to determine their effectiveness. However, this research gives initial insight into ATCo opinions on conflict resolution between empty tugs and proposes a basic prioritization strategy that could be used in a multi-agent system or in the implementation of a decision support system.

V. Conclusion

The introduction of autonomous tugs to the dynamic task of airport ground operations creates conflicts that have never been seen. Autonomous tugs that can self-manage themselves at busy intersections should determine priorities based on the practices of air traffic controllers, as to present choices that are similar to what the controller would do himself. Instead of only collecting subjective qualitative feedback, a small study was conducted to determine more objective quantitative data from participant performance. An online study evaluating 73 possible conflicts between autonomous tugs was sent to air traffic controllers from Europe and North America. Seventeen participants reported using a take-the-best strategy, where one cue is evaluated a time until a tug meets the desired criterion. Results showed that almost all participants used proximity relative to the intersection as the first cue, and either proximity to tug destination or number of aircraft trailing the tug. While it is not clear regarding the order of importance of the latter two priorities, results imply that number of aircraft trailing the tug may be more critical than the proximity to tug destination. Regardless, there is no unanimity with respect to which strategy should be used. There is no significant change in the employment of cues between ATCos from large or small airports, with greater than or less than 15 years of ground controller experience, but there is a slight difference in cue preference between French and non-French controllers. French air traffic controllers seem to prefer aircraft turning over those going straight, and non-French controllers prefer the inverse. Nevertheless, the general priority of cues rests equal between both groups.

The results of this study provide the ground foundation for furthering understanding of the intricate decision rules and heuristics that are used during autonomous tug prioritization. Future work should consider examining value threshold for each variable and improving the coherence between the study framework and the actual task.

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