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Effects of Pushback Accuracy On Static Apron Capacity

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The static apron capacity for aircraft with a wingspan higher than 65m is limited at Amsterdam Airport Schiphol (AMS) . With the introduction of new large aircraft with increasing wingspan, such as the B777-9X, Schiphol is faced with the challenge of realizing larger gates. Currently, the taxi wingtip clearance is used for pushback and towing and the goal of this research is to see if it is possible to decrease the wingtip clearance there. Using aircraft transponder data and reproducing the pushback tracks for five gates, it is shown that some room is available to limit clearance and thus increase capacity at some gates, but more capacity could be gained by providing tug drivers with extra guidance through Differential GPS or a 'Follow the Greens' system.

I. Introduction

In October 2016, IATA forecasted that the total passenger air traffic will double over the next 20 years. Airbus (in its Global market Forecast 2016-2035) expects a total demand of 9500 aircraft for twin-aisle, wide bodies like the A350 and the very large A380. Boeing (in its current market outlook 2016-2035) presents a growth of the total number of wide body aircraft from the present 4000 to 10400 in 2035. In particular, the number of medium wide body such as the B777 will grow from 1700 to 3700. These forecasts should not come as a surprise; despite the worldwide financial crisis, passenger air traffic between 2003 and 2016 increased with 6% per year.

Airport capacity is a worldwide issue. NASA e.g. started a five-year project called Airspace Technology Demonstration, a series of demonstrations covering improvements of the terminal, surface and en route segments. Along with the FAA, American Airlines and Delta Airlines have been partners in the program since 2014. As, Lorene Cass, American Airlines' Vice President of the Integrated Operation Center, so aptly put it: 'Surface operations today are the most inefficient phase of the flight.'

In the long term vision approach of Amsterdam Airport Schiphol (AMS) a passenger market growth of 4 to 5 percent per year is also expected. In reaction to this growth Schiphol is designing new and redesigning existing piers[20] to increase its capacity. As apron surface area at Schiphol is restricted, more efficient ways of handling passenger air traffic movements are currently under development to cope with a future capacity problems, besides expanding and rebuilding the apron area. Even with the newly designed piers, the number of gates where wide body aircraft can be handled is limited.

Currently, the taxi wingtip clearance is used for pushback and towing. With accurate pushback movements, these clearances may be reduced and static apron capacity could be increased.

The following research question will be answered: *Is the spread of the analyzed pushback tracks at Schiphol sufficiently small to justify a decrease in wingtip clearance for pushback movements?*

II. Amsterdam Airport Schiphol

Amsterdam airport Schiphol (AMS) has a single roof terminal layout with finger piers, which are characterized by a dense infrastructure. Aircraft are parked nose-in, which requires less space but also requires assistance of a pushback tug when the aircraft wants to leave the gate.

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Aircraft gates at AMS are divided into categories, which are based on the wingspan and the length of the aircraft. The largest, category 9, allows a wingspan between 65m and 80m. Whilst these allow any size of aircraft to be parked, only 2 gates are currently available at Schiphol. For this research the E-pier, shown in Figure 1, which handles only non-schengen traffic, has been chosen as it is a critical pier and representative for all pushbacks that happen at the airport. The E-pier has 1 category 9 gate and 8 category 8 gates, with a wingspan up to 65m. The largest category 8 aircraft, in terms of wingspan, currently operating at AMS are the Boeing B777-300ER and the Airbus A350.

Figure 1: E pier location within terminal AMS

A. Standard operating procedures (SOP) pushback

The pushback manual written by the AAS Airside Operations Department presents the SOP of the pushback movements for Schiphol Airport, for which the goal is to ensure safe operations and adhere to the time schedule. Before pushback aircraft-tug interface is prepared, the clearance of the gate is checked and pushback clearance is obtained from ATC.

Each gate can have a different actual pushback procedure:

- E6: Left. From cat. 5 push-back on taxiway A10 until gate D47
- E7: Right. Until cat. 4 push-back on taxiway A14, from cat. 5 push-pull on taxiway A16
- E8: Left. From cat. 5 push-pull until gate E20
- E20: Left. Push-back on taxiway A12
- E22: Straight backwards. Push-back on taxiway A12

After pushback the nose gear must be positioned in the pushback limit line, the tug disconnected from the aircraft and the crew must be given the all clear signal.

When there is a pushback guidance line present at a gate, the center of the main gear should be directed over the pushback guidance line. Except for gate E19, where the tug should follow the pushback guidance line. The pushback guidance lines and limit lines are only present at some gates. If there is no pushback guidance line or limit line, those parts the of the general ’during pushback SOP’ and ’after pushback SOP’ are based on the expertise and judgment of the driver and his perception of the actual surroundings.

An important factor in the execution of the pushback is the drivers reaction to the environment, which includes making evasive maneuvers to create extra safety margins with adjacent obstacles. Also the situational awareness is reduced when the wingtip or tail cone is turned away when cornering. Additionally, the separation between the wingtips and adjacent buildings is difficult to predict as the wingtips can be up to 50 m away from the tug.

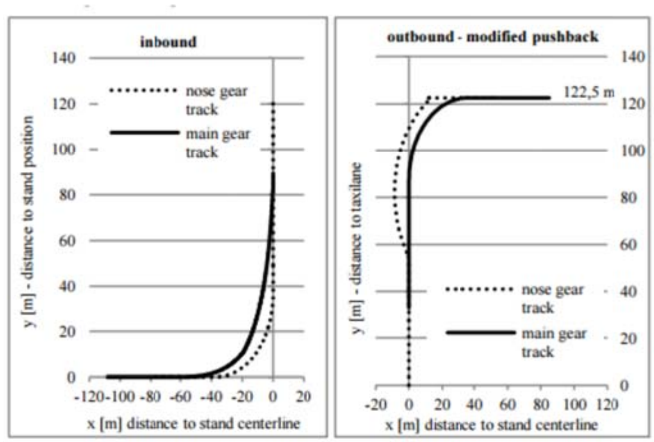

Figure 2: Moving tracks of nose gear and main gear center point of an A340-600

Bad weather conditions and nighttime influence the perception of the surroundings. The pushback limit lines and the pushback guidance lines are not always visible due to bad surface conditions, reflections, water or. Gate specific pushback limit lines can be confused with pushback limit lines from other gates.

Tug drivers will tend to avoid sharp turns and will deviate from the taxi in-line for counter steering in anticipation of the turn to come. The dimensions of the aircraft determine the turning radius of the nose gear and the main gear. A pushback track always consist of two tracks: the track of the nose gear and the track of the main gear. Figure 2 shows that the track of the nose gear is significantly different from the track of the main gear and shows the difference between a taxi in (left plot) and a pushback maneuver (right plot).

The skill of the tug driver to push an aircraft over a line accurately is trained and practiced in the hangars where wingtip clearances can be limited up to 50 centimeters. These very small clearances are achieved by reducing the speed to a minimum, adding human assistance and adding a plummet underneath the fuselage, pointing towards the guidance line. So in a controlled environment, the tug driver can execute a very precise pushback maneuver and the proficiency of the tug driver is not a limiting factor.

B. Static Apron capacity

The E-pier is selected to quantify the possibility of a static apron capacity increase and the required wingtip clearance reduction as it is a critical pier and representative for all pushbacks that happen at the airport. Figure 3 shows the standard pushback directions for every gate. After each gate number, the following characters are used to indicate the pushback type.:

- R right turn (as seen from the push-back vehicle)
- L left turn (as seen from the push-back vehicle)
- \+ push-pull
- push back limit line
- S straight backwards

The static capacity is defined by how many aircraft of a certain category can be parked simultaneously. Therefore, this case focuses on the situation where the gates are all occupied by the aircraft with the maximum allowed wingspan. The gates of the E-pier can accommodate a maximum of thirteen aircraft from category 4 (B737 / A320), up to twelve from category 7 (B787, A330), up to nine from category 8 (A350, B747) and only one from category 9 (A380, B777-9X).

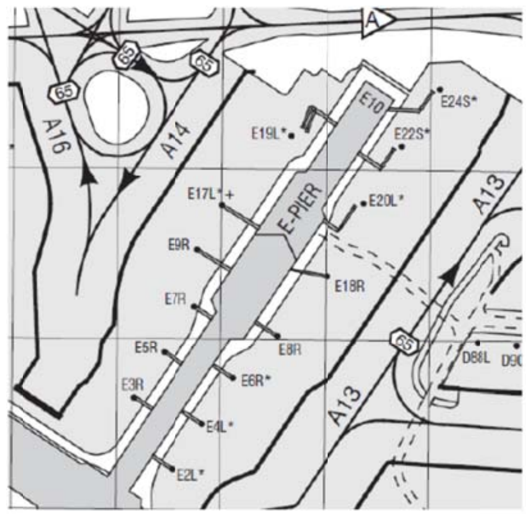

Figure 3: E-pier gates[21]

Table 1: Wingtip clearances as a function of aircraft types at pier E

	Gate	E7		E9		E17		E19
Current	Aircraft type	B777-300ER		B777-300ER		B777-300ER		B777-300ER
	Wingtip clearance [m]		8.2		8.2		15.9	
Case 1	Aircraft type	B777-9X		B777-300ER		B777-9X		B777-300ER
	Wingtip clearance [m]		4.7		4.7		12.4	
Case 2	Aircraft type	B777-300ER		B777-9X		B777-300ER		B777-300ER
	Wingtip clearance [m]		4.7		4.7		15.9	
Case 3	Aircraft type	B777-9X		B777-9X		B777-9X		B777-300ER
	Wingtip clearance [m]		1.2		1.2		12.4	

	Gate	E8		E18		E20		E22		E22
Current	Aircraft type	B777-300ER		A380		B777-300ER		B777-300ER		B777-300ER
	Wingtip clearance [m]		8.7		11.7		10.4		10.5	
Case 1	Aircraft type	B777-300ER		A380		B777-300ER		B777-9X		B777-300ER
	Wingtip clearance [m]		8.7		11.7		6.9		7	
Case 2	Aircraft type	B777-300ER		A380		B777-9X		B777-300ER		B777-300ER
	Wingtip clearance [m]		8.7		8.2		6.9		10.5	
Case 3	Aircraft type	B777-9X		A380		B777-9X		B777-9X		B777-300ER
	Wingtip clearance [m]		5.2		8.2		3.4		7	

The capacity of the E-pier would be increased if it would be possible to park a category 9 aircraft at a category 8 gate. The largest category 8 aircraft that is currently using the E-pier is the B777-300ERof which the wingspan is 65m, which is exactly the limit for a category 8 gate. The minimum distance between the taxi-in lines for a category 8 gate is 72.5m. So the minimum wingtip clearance for the largest category 8 aircraft is 7.5m. Table 1 shows some examples of combinations that would be possible if clearances could be reduced to below 7.5 m (orange) or even 3.5 m (red).

III. Data analysis

Using each flights transponder data points, which contain measurement and rounding errors, a cubic spline is fitted to average out the errors and take into account the expected behavior of the movement. This behavior includes curves, straight segments and more subtle heading changes for corrections. Gaps with large velocity increments and alternating data points which indicate rapid heading changes are filtered out.

Figure 3 shows the constructed splines at gate E20 for different aircraft movements, where the blue dots are the aircraft transponder data points, the red lines indicate the constructed spline of individual pushbacks and the black vertical dashed lines are the x-locations of the knots, which is where the curves are connected.

It can be observed that all constructed curves are smooth. The knots are initially located at equal distances for all pushbacks and additional knots are placed where needed. This can be when more curvature is needed, such as in plot E20#2 which has an extra knot at the right extreme compared to plot E20#2.

Gaps limit the possibility to add more knots and additionally can indicate unexpected large velocity increments. Rapid heading changes and large velocity increments are not captured by the spline. One example is for E20 #1, which shows a large shift after the second knot which would indicate a velocity of 9.4m/s, while the expected maximum is 4m/s.

Combined all splines into one plot for every gate, allows a clear comparison of all the pushbacks. Figure 4 shows the result for gate E20. All individual pushback tracks are different. The starting points vary from [460;600] to [470;490] as position information is not very accurate when the velocity is zero, so the starting location is slightly different for all tracks. The same goes for the end points, where the tug is disconnected.

To quantify the difference, the shortest distances of the set of coordinates of the individual splines to the reference spline are determined. These distances are ordered in a histogram and the spread is derived in terms of the standard deviation. The reference spline is then

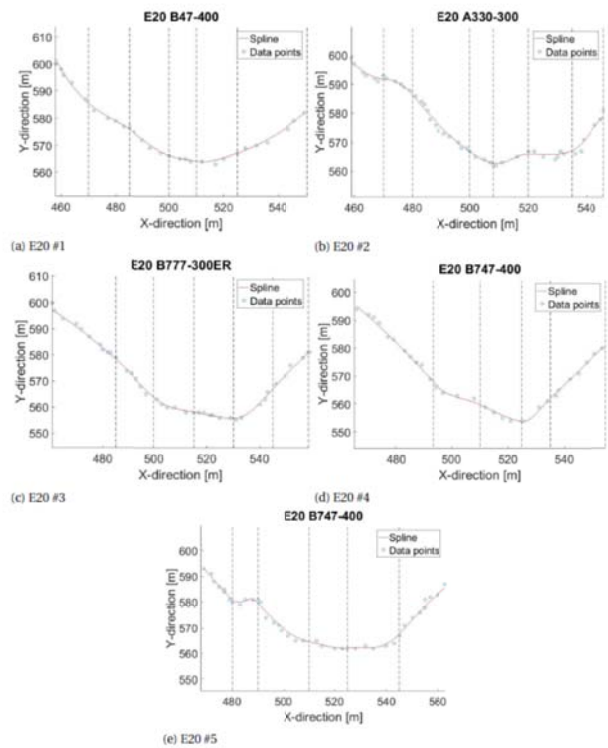

Figure 4: Individual pushback splines for gate E20

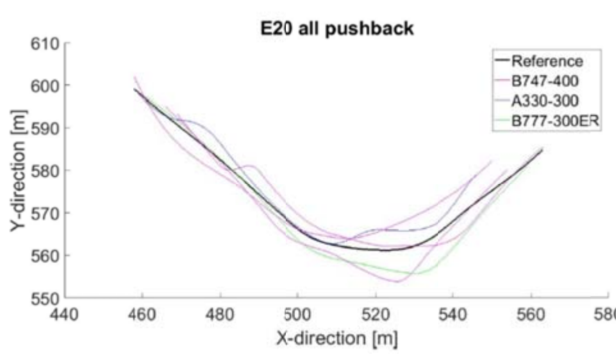

Figure 5: All splines for E20

constructed so that it is the average track where the mean distance of the set of coordinates of the individual splines to the set of coordinates of the reference splines is zero. As the reference is the average of all pushbacks, the reference spline lies at zero deviation according to the constructed histograms.

At gate E6 and E20, a left turn is required to complete the pushback up to the taxi lane. Gate E7 requires a right turn and E6, E8 and E22 is a straight backwards pushback. E6 and E22 have to perform a slight curve, whilst E8 is straight until the point where all the tracks coincide.

Table 1 shows the standard deviations per gate, which vary from 1.5m for E6 S up to 3.5m for gate E8. The straight pushbacks, E6 S and E8, show the smallest and the largest deviation. As the clearances are only important when the aircraft are parked at the gate, the spread is also derived for the straight part of the pushback, before the aircraft initiates the turn and crosses red clearance line. The standard deviation is lower before the red clearance line than for the total pushback for all gates, which is what we would expect.

Table 2: Standard deviation for pushback movements per gate in total and before the red clearance line

Gate	Total STD [m]	STD before line [m]
E6 S	1.5	1.1
E6 L	3	2.9
E7	2.3	1.8
E8	3.5	2.2
E20	3	1.9
E22	2.2	1.9

Table 3: Acceptable clearance (99.73%) per gate

Gate	Total [m]	Before line [m]
E6 straight	4.5	3.3
E6 turn	9	8.7
E7	6.9	5.4
E8	10.5	6.6
E20	9	5.7
E22	6.6	5.7

The standard deviation is used to measure the spread of the pushback tracks per gate. To determine a minimum wingtip clearance, AAS defines an acceptable level of safety, which is met when 99.73% of all apron movements have a spread that is smaller than the wingtip clearance. As the distribution of the measurements follows a normal distribution, so, 99.73% of all measurements fall in a spread that is three times the standard deviation, which is then calculated in table 2.

The wingtip clearance between E20 and E22 reduces to 6.7m, which is 0.7m below the minimum. The spread of the pushback tracks resulted in an acceptable level of safety of 5.7m for gates E20 and E22. So the spread of the tracks is 1m lower than the reduced wingtip clearance. When the B777-9X is simulated on gate E22, the wingtip clearances reduce to 6.7m and 6.8m. As the acceptable level of safety is below these distances, E22 could be upgraded. So, the spread of the pushback tracks at gate E20 and gate E22 are sufficiently small to justify an upgrade of either E20 or E22 to accommodate a category 9 B777-9X. The remaining options show a larger spread that do not allow for an increase in wingspan.

IV. Pushback Guidance Concepts

The data analysis shows that the spread of the total pushback maneuvers is larger than the minimum wingtip clearance for 50% of the gates. In these cases, a wingtip clearance reduction for the pushback is not feasible. Accurate and consistent maneuvers are essential before wingtip clearances can be reduced.

Exist tools for an accurate pushback maneuver are wing walkers, marshals and pushback guidance lines. Schiphol has used wing walkers and marshal assistance in the past and still has guidance line at several gates, but human assistance is not preferred on the ramp as this brings extra safety risks and costs to those persons. Also, to keep the pushback time below acceptable limits, the pushbacks should be conducted with a speed of 15 km/h. is also not recommended to install any extra equipment on the aircraft.

Simulations define a specific track for each type of aircraft, but the tug driver is unaware of these desired tracks as they are not described in the SOP or indicated on the apron surface so to execute a pushback according to the track prescribed in the simulation, the tug driver needs an extra form of guidance, which could be a system on the apron, integrated into the existing infrastructure, or a system in the tug. It is not deemed practical to install extra equipment on the aircraft.

One of the concepts is called ’Follow the Greens’, where lights on the taxiway are used to indicate the path for each aircraft. When the aircraft receives clearance from the air traffic controller to precede from the taxiway towards the runway, or from the runway to the gate, a certain route is given. This route consists of a sequence of taxiways to follow. As large airports have dozens of kilometers of taxiways with many crossings and stopbars, installing this system is an expensive and time consuming task. This method may also be applicable for pushback movements and could consist of a grid of lights in the apron surface, which would then precisely illuminate the pushback track for a particular type of aircraft.

A solution for in the tug is based on the collision prevention system for pushback movements by IFL Dresden[4] and is illustrated in figure 6. The tug driver sees the position of the aircraft with respect to the tug, the desired track and the static obstacles. By giving real time position information of the aircraft and the tug, the situational awareness is enlarged. The aircraft types and dimensions with corresponding optimum pushbacks track are available in a database per gate, which can be updated with temporary SOPs.

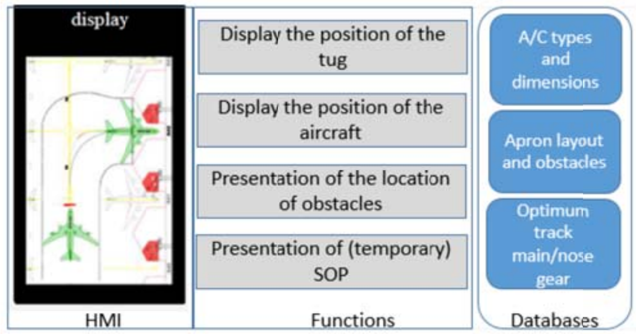

Figure 6: Architecture pushback guidance system[4]

One challenge with tug based system, is that is needs accurate position data. This could be achieved using Differential GPS and Light Detection and Ranging (LiDAR) to determine the position of the tug and the aircraft with respect to the tug.

V. Conclusions and recommentation

General observations of the analysis of the pushback tracks are that all pushbacks are executed differently, the deviation until the red clearance line is smaller than when looking at the total pushback and the tug drivers deviate from the straight taxi-in line by counter-steering in anticipation of the turn ahead.

The spread of the pushback before the red clearance line is lower than the current 7.5 m limit for most of the observed gates. Only E6, which requires a turn, has a safe wingtip clearance that is greater than the minimum clearance. For the total pushback, the 7.5m clearance is exceeded for 50% of the gates.

The static apron capacity for aircraft with a wingspan higher than 65m is limited at AAS. With the introduction of new large aircraft such as the B777-9X Schiphol is faced with the challenge to realize more gates. The E-pier has been chosen to examine the static apron capacity. At the moment, only E18 can handle a B777-9X. By reducing the clearance to 4.5 meters, three 777-9X aircraft could be parked at gates which can now only go up to the 777-300, however, only the acceptable level of safety of gates E20 and E22 are lower than the reduced wingtip clearance for a B777-9X.

Pushback accuracy could possibly be further increased by implementing a follow the greens like concept on the apron or a system in the tug, using differential GPS and LiDAR. It is recommended to do more research into these guidance system and maybe even research the possibility of automatic pushback vehicles, not just on the apron but on the entire airport surface.

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