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Impact of Electric Taxi Systems on Airport Apron Operations and Gate Congestion

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Growth in air traffic demand and increasing attention for environmental impact of the air travel industry and airports has spurred the innovation of the Electric Taxi System (ETS). KLM Royal Dutch Airlines and Amsterdam Airport Schiphol (AMS) have instigated research to investigate the impact and potential benefits of the implementation of ETS. This thesis research work continues the exploration of ETS's impact at AMS by posing the following research question: What opportunities does the ETS offer for gate capacity and buffer utilization optimization, and what is the value of the impact of the ETS on apron operations at Amsterdam Airport Schiphol?

I. Introduction

Electric Taxi System (ETS) incorporate an electric motor in the main or nose landing gear of an aircraft, as shown in figure 1, powered by the auxiliary power unit (APU) of the aircraft. The system allows the aircraft to maneuver and taxi without the use of its main engines or a tow truck. Thereby, ETS reduces fuel usage and the environmental impact during the taxi phase of flights. Additionally, the system aims to increase the gate pushback efficiency. ETS eliminates the need for a tow truck during the pushback process as it allows for autonomous pushbacks.

Figure 1: EGTS motor[3]

The studies performed on existing ETS systems (the EGTS[3] and the WheelTug[7] systems)[1,2] indicate that time can be saved with autonomous pushbacks using ETS. This research attempts to draw light on the value of ETS for operations in the apron environment.

With increasing air traffic demand, the gates at Schiphol Airport, illustrated in figure 2, are nearing their maximum dynamic capacity during the airport's peak hours. Therefore, the potential gate capacity enhancement procedures enabled by ETS are explored in detail in this research. Additionally, the value of ETS for the overall apron environment is investigated. The reduction in the need for tow trucks due to ETS implementation also provides benefits for the apron environment.

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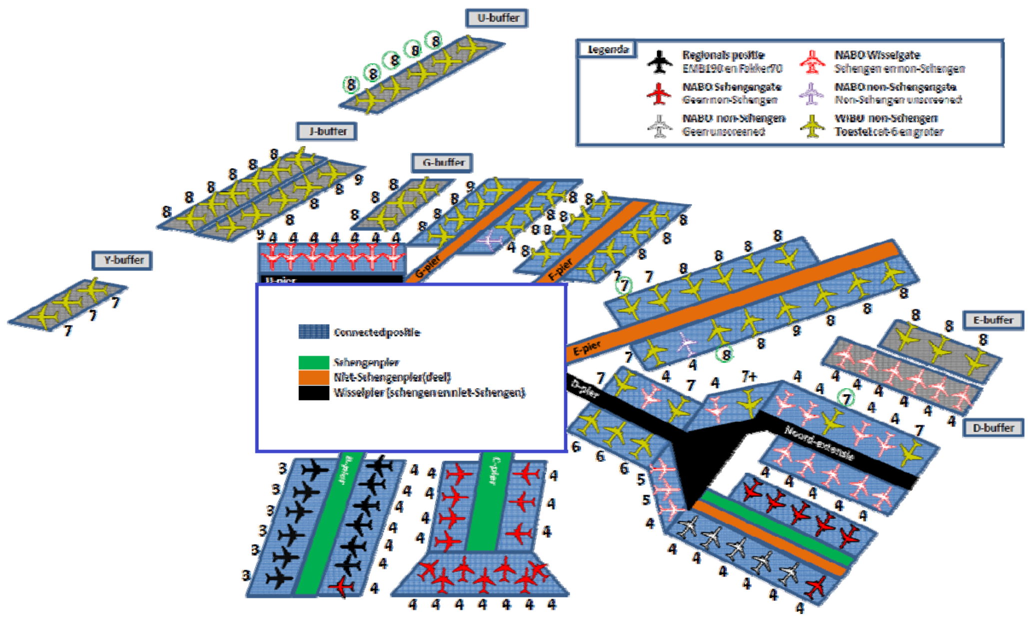

Figure 2: Gates at Amsterdam Airport Schiphol

However, as with any new system, ETS presents some challenges as well. The weight of the system reduces its fuel benefits in flight. Therefore, short ranges and many turn arounds per day are beneficial for the use of ETS. Additionally, the systems currently designed are only available for narrow body aircraft. These, and other challenges posed by the system, need to be investigated and weighed against the benefits of the system in order to determine the potential offered by ETS and whether the system is worth investing in for airlines and airports.

This research explores the potential gate planning optimization procedures enabled by ETS and the overall value of ETS in the airport apron environment, through the use of a gate planning simulation model and a value model based on value operations methodology.

II. Gate usage concepts

ETS presents the possibility for of two gate usage optimization concepts to be implemented more widely, namely; the dispatch towing concept and the pit stop concept.

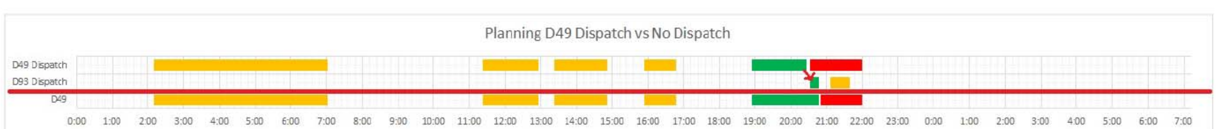

Figure 3. Gate planning with and without dispatch towing.

The dispatch towing concept, as illustrated in figure 3, can help prevent arrival ground delays and last minute gate changes at airports. Aircraft arriving at AMS sometimes have to wait up to 30minutes after landing in order to be able to reach an available gate because the gate is initially still occupied by another (delayed) aircraft. In some cases the aircraft still occupying the gate is fully loaded and ready for take-off, but delayed due to departure slots, en-route slots, arrival destination slots, last minute baggage loading, and/or last minute maintenance. The aircraft does not necessarily need to be occupying the gate anymore. The dispatch towing concept allows the delayed aircraft to be moved to a free buffer position in order to free up the gate for the next arriving aircraft. The concept is currently rarely applied because long distance towing of fully loaded aircraft by tow trucks can cause extra wear to the aircraft nose landing gear. ETS would allow for the fully loaded aircraft to be moved to a buffer position without causing structural damage.

The pit stop concept as illustrated in figure 4, implies that arriving aircraft park at a gate in order to offload passengers and baggage. Subsequently, the aircraft moves to a free buffer for handling and turnaround services, after which the aircraft moves back to a gate for passenger and baggage loading. Therefore, the aircraft is only occupying a gate area when strictly necessary; loading and offloading of passengers. This opens up the gate for other flights to be handled during the turnaround time of the pit stop aircraft on the buffer. In order to perform a pit stop, a minimum turnaround time of 170 minutes is currently required for a narrow body aircraft.

The pit stop concept requires two extra towing and pushback movements. At a congested airport such as AMS, the tow trucks are often busy or, during peak hours, in short supply. Therefore, the pit stop concept is conventionally not used very often. The ETS can change this by eliminating the need for a tow truck. The pit stop with the ETS would, therefore, not put any extra demands on the tow truck resources at the airport. Thus the procedure can be implemented more widely.

Figure 4. Gate planning with and pit stops.

III. Gate planning model

The gate planning models designed in this research explore the potential of the implementation of the pit stop and dispatch towing concepts at AMS. Initially, a gate planning model is designed to graphically present the narrow body gate and buffer plan in Gantt chart format. In doing so the gate and buffer planning schedule for the busiest day at AMS in 2014 is visualized. The pit stop and dispatch towing concepts are then applied to the schedule where possible.

The model consists of a flight scheduling user form. Via this form the user can enter flights and flight data into a schedule. The data entered includes:

- The flight number (of the flight departing from the gate)
- The aircraft registration code
- Whether the aircraft is a narrow body aircraft or a wide body aircraft
- The aircraft category
- The aircraft type
- Whether the aircraft is arriving from (or departing to) a Schengen or non-Schengen destination
- The arrival and departure time of the aircraft

The flights are then assigned to the gates with the following constraints:

- Schengen and Non-Schengen classification matches between the gate and the flight.
- The aircraft type matches that of the aircraft types that can be handled at the gate.
- For the dispatch towing and pits stop procedures only the buffers that are a maximum of 10 minutes taxi time away from the flight's gate are considered. For the narrow body gates in question these buffers include: the A-apron, the D-apron, and the R-apron.
- Aircraft leaving or arriving at two adjacent gates cannot do so at the same time.
- A margin of 20 minutes (10 minutes for the H-pier) is taken between each consecutive departing and arriving aircraft at a gate. This is done in order to be able to handle any short stochastic delays.
- RASAS defines a minimum narrow body turnaround time of 170minutes for a pit stop to be considered.
- Additionally, if the aircraft is towed away from the gate it has to be able to be parked on the buffer for at least 30minutes.
- For dispatch towing, the flights disturbing the planned operations are never favored. This implies that an aircraft will not be dispatch towed from its gate because the next aircraft arrived early. Furthermore, this implies that from the time the gate is planned to become available for the arriving aircraft, the delayed

departing aircraft may be towed to a remote parking place to await its departure. This is only done if the departing aircraft will spend more than 5 minutes on the buffer.

From the visualization of the gate plans with and without ETS enabled concepts, it can be concluded that the pit stop concept increases gate capacity at AMS by approximately six additionally aircraft on the busiest day at the airport in 2014. Furthermore, the dispatch towing concept increases gate planning efficiency and reduces ground arrival delays for six arriving aircraft on the busiest day at the airport in 2014.

The gate planning model is subsequently expanded in order to explore the effect of increased traffic and delays on the gate planning at AMS, and the usage of pit stops and dispatch towing to help increase gate capacity and solve delay conflicts, respectively.

A. Pit stop analysis

The pit stop model (or extra flight model) makes a few assumptions regarding the handling time at the gates and on the buffer. For the narrow body flights arriving at AMS the maximum time taken to offload passenger and luggage (as defined by the aircraft's characteristics for airport planning) is 13 minutes. After these 13 minutes the aircraft can leave the gate and the rest of the handling can be performed on the buffer until the loading of passengers and baggage commences. The flight then spends at least 30 minutes on the buffer. Subsequently, the flight moves back to a gate for the last 20 minutes of its turnaround time. The 20 minutes loading time for passengers and final checks is also based on the narrow body aircraft characteristics for airport planning. For some aircraft the processes may take shorter than 13 or 20 minutes because the aircraft are smaller. However, for the purpose of this model, it is assumed that every pit stop flight spends at least 13 minutes at a gate upon arrival and 20 at a gate upon departure.

To do an analysis on the future benefit of pit stops, a percentage of flights are added to the current peak hour schedule (7:00-9:00 and 18:00-22:00) and the model then tries to allocate them, as illustrated in figure 5.

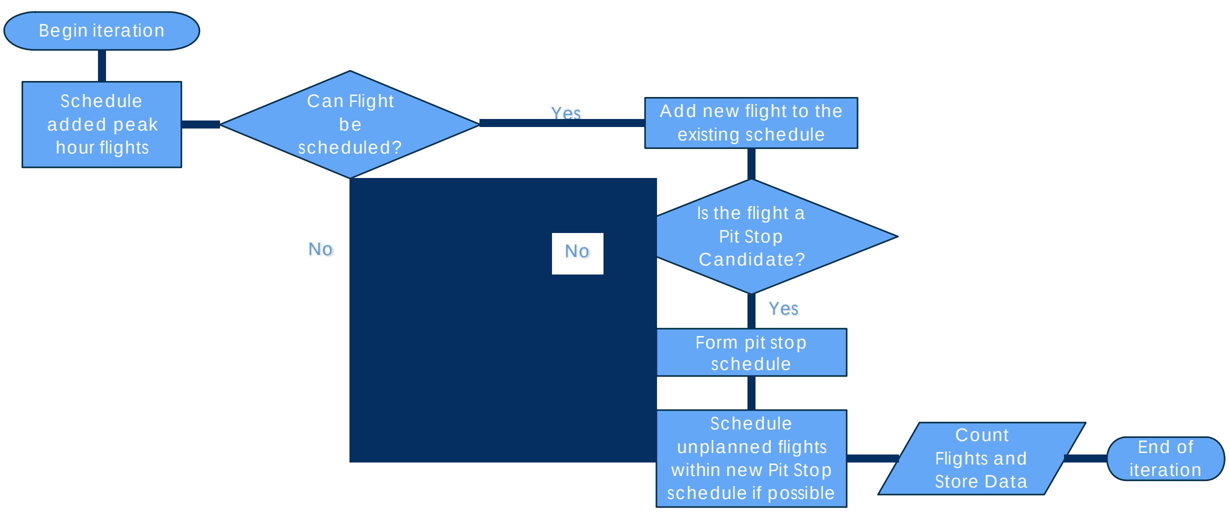

Figure 5. Adding flights for pit stop analysis

Figure 6 shows the results of the pit stop analysis for 10% till 100% more flights. From the graph it can be observed that if up to 30% flights are added to the peak hour schedule, more than 50% of those flights can be scheduled with the use of pit stops. The model results show that a maximum of 25% of added peak hour flights can be rescheduled using the pit stop concept when adding 10% flights. Thus, even with pit stops there is only very little room in the gate schedule for the additional flights.

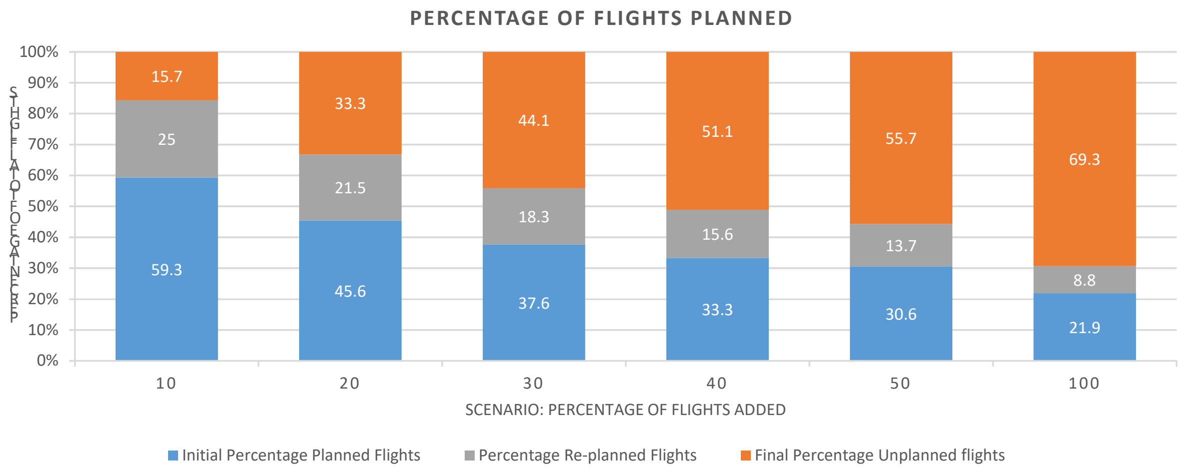

Figure 6. Results of pit stop analysis

Currently, the minimum turnaround time needed for an aircraft to be considered for a pit stop is 170 minutes. However, the turnaround time needed after off-loading passengers and baggage, and before reloading, is only 22 minutes for most narrow body aircraft. Therefore, the turnaround time necessary for a narrow body aircraft to perform pit stop is actually: 13+10+22+10+20=75 minutes. The Pit stop (or extra flights) extended analysis model was run again for each traffic scenario in order to investigate the number of additional peak hour flights that can be handled if pit stops are implemented with an aircraft minimum TAT qualification of 75 minutes. In this case only 10% of the added 10% flights could not be planned, 30.7% where re-planned and 59.3 where planned, showing slight improvement.

From the extended model it becomes apparent that should the number of peak hour flights at AMS increase by 10%, and average of 25% of the additional flights can be scheduled at a gate using the pit stop concept. Should the number of peak hour flights double, an average of 8.8% of the additional peak hour flights (corresponding to 12 flights) can be scheduled using the pit stop concept.

B. Dispatch towing analysis

The extended dispatch towing model (or delayed flights model), shown in in figure 7, also applies some additional constraints and Assumptions. It is assumed that dispatch towing candidate flights are delayed by 25 minutes on average. This is based on data regarding dispatch towing candidate flights over 2014. Additionally, the flights are assumed to be delayed a minimum of 5 minutes in order for the delay to be considered significant. Therefore, the overlap with the succeeding flight also has to be more 5 minutes in order for the delay caused to the succeeding flight to be considered significant.

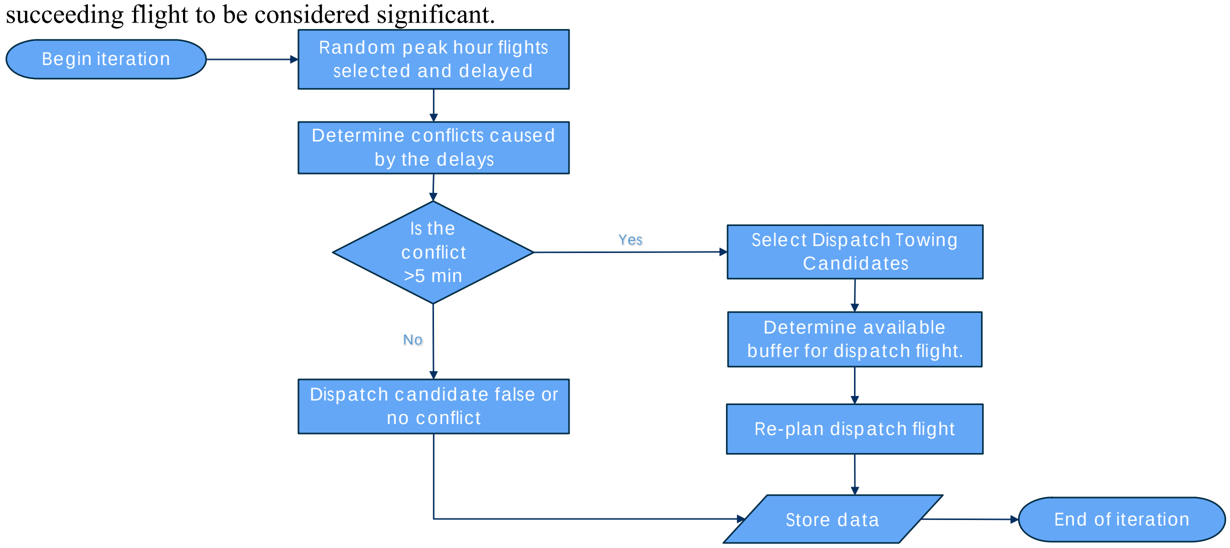

Figure 7. Delaying flights for dispatch towing analysis

Furthermore, the model assumes that the total delay has to be at least 9 minutes for the dispatch tow to be worthwhile. The model assumes that any total delay less than 14 minutes will be towed to a buffer no more than 5 minutes away from the gate. For all the flights with a total delay of more than 14 minutes, a buffer less than 10minutes away is designated (conforming to the rules set by AMS).

After determining the peak hour flights, the percentage of peak hour flights to be delayed is indicated at the start of the iteration runs. Based on this percentage, a number of randomly selected peak hour flights are delayed. The amount (in minutes) by which the flights are delayed is determined by a random number according to a normal distribution with a minimum of 5 minutes, a maximum of 180 minutes, a mean of 25 minutes, and a standard deviation of 10 minutes. The mean of 25 minutes is based on delay data and information obtained from KLM for dispatch towing candidates over 2014.

The model assesses whether a conflict with the next flight was caused and the extent of the conflict caused in minutes overlap with the next flight. Should the overlap caused be greater than 5 minutes and the entire delay of the flight be greater than 9 minutes (5 minutes taxying, 4 minutes on buffer), the flight qualifies as a dispatch towing flight.

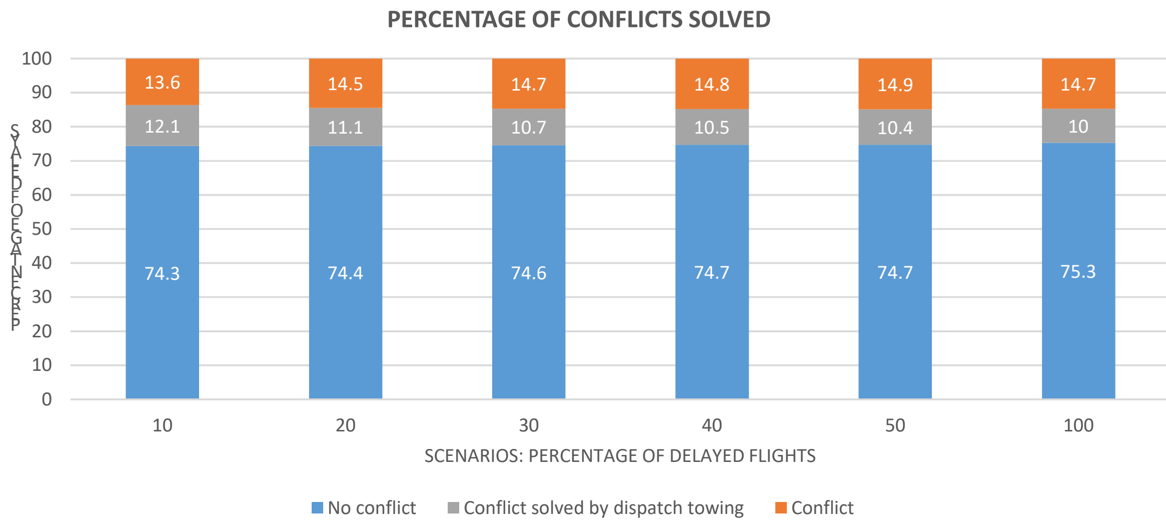

Figure 8. Results of dispatch towing analysis

The results in figure 8 show that for each scenario approximately 25% of the delayed flights cause conflicts. This does not mean that the same number of conflicts is caused in each scenario but merely that the percentage of delayed flights causing a conflict is nearly the same for each scenario. This implies that the usefulness of the dispatch towing concept does not diminish if more flights are delayed; approximately the same percentage of delay conflicts can still be solved through the use of dispatch towing. Thus, approximately 85-86% of peak hour flights can either be delayed without causing a conflict or dispatch towed to avoid a conflict. 10-12% of the peak hour flights delayed will cause conflicts which can be solved through dispatch towing.

The average amount of delay time saved for arriving flights is between 16 and 17 minutes. This means that, on average, with the random delay sequence applied, the next arriving flights would have had to wait 16 to 17 minutes for their planned gates to become available. This time is saved through the application of dispatch towing, allowing the arriving aircraft to taxi to its gate without any delays.

IV. Value model

The gate planning models have indicated the potential of the pit stop and dispatch towing concepts enabled by ETS for gate planning efficiency and capacity at AMS. However, the implementation of ETS influences many key performance indicators (KPIs) of the apron area. In order to explore the value of ETS on the apron area, a value model is developed. The value model is based on the value operations methodology (VOM). In the VOM, stakeholder values are investigated and weighed for importance in order to determine whether a design (or in this case ETS) adds or reduces value for the environment in question (in this case the apron area).

The coefficient (or weight) values of the KPIs (objectives) and the ETS objective attributes can be determined in multiple ways as they are dependent on the main stakeholders involved and the extent of the influence of each attribute on the overall system. Based on a combination of past research performed by Bennebroek[5], Curran[6],Wijnterp[1], and Sillekens[2], a suggestion for the KPI coefficients is made.

Table 1: Valuemodel objective: Emissions. Overview of objective attribute scores.

Objective	Qualitative Analysis Attribute Score		Quantitative Analysis Attribute Score	
	Initial	Potential (long term)	Initial	Potential (long term)
Safety				
Elimination Tow Truck incidents	-	- - -	-3 incidents/month	-16 incidents/month
Communication Efficiency	0	++	N/A	N/A
Situational Awareness	- -	0	N/A	N/A
Objective: Capacity, Efficiency				
Pit Stops	+ + +	+ + +	6 gate slots/day Peak hour traffic increase of 10%: 3 additional peak hour flights	See initial impact
Dispatch Towing	+ + +	+ + +	Avg 17.2min time saved per delayed AC 10.8% peak hour flight delay conflictsSolved	See initial impact
Pushback Time reduction	- -	- -	-1:50 min/pushback	See initial impact
Costs				
Tow Truck Maintenance and fuel costs	- -	- - -	-978,549.-$/yr	-4,595,786.-$/yr
Personnel Costs	- -	- -	-163,520.-$/yr	-490,560.-$/yr
FOD costs	-	-	Unknown	-32,730.-$/yr
Ground delay costs	-	- -	-516.-$ per peak hour dispatch tow	See initial impact. More dispatch tows possible if more aircraft have an ETS
ETS and APU maintenance costs	+	+	15,000.-$/year	See initial impact
Emissions				
Pit Stop Extra Fuel usage	++	++	Extra Fuel used: 260.4kg Fuel costs: 198.9$ per 6 pit stops: 12 extra taxi movements	See initial impact
Dispatch Towing FuelSaving	- -	-	Fuel saved: 80kg Fuel costs: 61.10$ per dispatch tow	FuelSaved: 13kg Fuel costs: 9.93 per dispatch tow
Pushback Fuel Saving	- -	- -	FuelSaved: 9,227 kg Fuel costs: 7,046.50$ per year	See initial impact
Apron Noise Reduction	- -	- -	-69%	See initial impact

The main stakeholders involved in the implementation of ETS are KLM and AMS. Based on these stakeholders, four main KPIs or objectives are identified for the apron area, namely; Safety, capacity/efficiency, costs, and the environment.

The attributes of ETS influencing the four identified objectives are explored in detail and assessed qualitatively as well as quantitatively where possible. Each attribute pertaining to an objective is weighed against the other attributes pertaining to that objective for importance. Finally, each objective in the model is also assigned a weight according to its importance to the value of the apron environment. Apron area safety was identified is the most important objective for the stakeholders. ETS increases the apron area and overall airport safety by reducing (and eventually eliminating) the need for tow trucks. This reduces the number of two truck incidents as well as the amount of foreign object damage (FOD). Additionally, the pushback safety may be increased by increasing the communication chain efficiency during the pushback process. However, autonomous pushbacks present a serious situational awareness problem for pilots.

When navigating the aircraft backwards, pilots need the assistance of a marshaller or additional technology to help them avoid objects behind the aircraft or next to the aircraft.

The capacity and efficiency objective can be enhanced by ETS through the implementation of pit stops and dispatch towing. Additionally, the system reduces the pushback time by up to 1minute and 50 seconds.

Operational costs are also influenced by ETS. Due to the reduction in the use (or elimination) of tow trucks, the tow truck maintenance, fuel, and personnel costs can be reduced. Furthermore, FOD and collision costs can be reduced and, through the implementation of dispatch towing, delay costs can also be avoided. It should be noted, however, that the APU and ETS maintenance costs will increase due to the extra load of ETS. It is estimated that ETS and extra APU maintenance costs amount to 15,000$/year.

ETS also influences the airport environment. During ETS pushback, fuel can be saved through the elimination of tow trucks. Additionally, noise on the apron is reduced to only APU noise, as opposed to APU and engine idle noise. The dispatch towing concept also allows for a reduction in fuel usage and, subsequently, emissions by reducing the time arriving aircraft need to wait with their engines still running. Due to the extra maneuvering necessary for the pit stop concept, fuel usage is increased slightly, though not as significantly as when the concept is applied with the use of tow trucks to maneuver the aircraft.

The qualitative and quantitative attribute results for the value model are shown in table 1.

Conclusions

ETS not only influences the taxi-phase of a flight, but it also has an influence on the apron and pushback procedures. ETS presents the opportunity for more extensive use of the dispatch towing and pit stop concepts. These concepts aim to improve the efficiency of the apron operations, reduce delays, and enhance gate capacity. Even though both are existing concepts, neither is commonly used at AMS. ETS may offer the opportunity to implement the concepts more widely.

From the pit stop extended analysis model it can be concluded that, with a pit stop candidate aith a turnaround time of at least 170 minutes, a maximum of 25% of the added flights can be scheduled. The more flights that are added to the schedule, the lower the percentage of flights that can be allocated with pit stops becomes. This is due to the saturation of the gate schedule.

The value model qualitative assessment indicates that ETS can enhance the safety, capacity, and efficiency of the airport apron environment, while reducing the costs and environmental impact of the apron area operations. The results of the models and the research performed can be further analyzed and developed by KLM and AMS in order to assist in the development of electric taxi systems and, eventually, enhance their competitive position within the aviation industry.

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