MEET YOU AT THE CROSSROADS: THE SIMULATION ANALYSIS OF AN AIRPORT FOR IDENTIFYING POTENTIAL PROBLEMS

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ABSTRACT

The aeronautical industry is still under expansion in spite of the problems it is facing due to the increase in oil prices, limited capacity, and novel regulations. For this reason, it is necessary to have tools that help during the process of an expansion project, or during planning phases of new aeronautical infrastructures. For the particular case of a new airport project there are many variables to consider in order to minimize the risk of high costs or even serious problems during the operation of a new airport. The article presents a methodology that combines two simulation approaches that complement each other applied to the problem of the development of a new airport in The Netherlands. The use of the methodology gives light to the future problems that might be faced by the managers of the airport. One model focuses in the operative of the airport from a high-level angle taking into account the configurations that might be in place once the airport is under operation. The second model put focus in other technical aspects of the operation for challenging the feasibility of the proposed configurations and for identifying other issues that cannot be perceived with the first model. With the use of the methodology different problems and performance indicators can be foreseen and act in consequence. The combination of both approaches is a powerful one in which the overlapping of solutions will save a lot of money to the airport operators and/or airport developers.

Keywords: expansion, apron, configuration, performance, Lelystad.

INTRODUCTION

The air mode carries out most part of the global transport, in 2014, the number of flights in Europe has increased by 1.7% compared to 2013 [6] and the number of passengers grew by 5,4% compared to 2013 reaching 3,3 billion of passengers [8].

According to these trends, an increment in volume of flights and number of passengers for the next coming years is expected. This situation is translated into a massive use of resources of both air and ground; therefore, in the future it is likely to encounter congestion in many airports worldwide.

In order to avoid as much as possible congestion problems, the improvement of capacity has become a hard challenge to deal with; therefore many factors must be taken into account during the planning phase of new or improved facilities. In particular, Airports have been reported as the main bottleneck of air transportation [2], when the system is at the edge of congestion.

Since aviation is an industry where safety is put as priority, it is the typical one where decision makers are not able to experiment in-situ because this experimentation can put in risk the operation which is costly and in the worst cases the safety of the aircraft involved.

For the previous reasons it is important to have decision-support tools that allows the stakeholders and decision makers evaluate novel configurations of the system or new technology without having at stake the operational procedures of the airport. Simulation is a methodology that is gaining more and more importance since it is the only technique that allows to incorporate different characteristics of the systems in a single model that other techniques fall short in the modelling of systems such as synchrony, parallelism, cause-effect relationships, and most importantly the uncertainty inherent in any dynamic system and in particular in the aviation one. All these characteristics are also implicitly dependent on the time dimension which is the variable common to all the different simulation approaches used in this field such as discrete event systems, system dynamics, agent-based technology, cellular automata among others.

When dealing with a simulation study, the level of abstraction is one of the fundamental questions that arise. In the best situations, this question is answered by the experience of the analyst or the modeller and in the worst ones the analysts just take any simulation tool and apply it to the problem under study [10]. However, for making a thorough analysis and reducing the risks of a particular case, it is desirable to approach to it in different angles and sometimes with different techniques besides simulation in order to get as much knowledge from the system as possible without interfering with it. In this work, we present a methodology applied in the study of a regional airport that will be developed in the Netherlands as a result of intensive studies performed by the government [3]. The methodology combines two simulation approaches at different abstraction levels in order to get as much insight as possible about the new facility. By applying this approach, it is possible to get a better understanding of the potential issues that will be faced by the airport during the different phases of the development and to obtain initial performance indicators of the future infrastructure with the correspondent reduction of risk of failure in the investment.

The Netherlands airport system

Amsterdam Schiphol (AMS) is the main airport in the Netherlands and it was the fifth busiest airport in Europe in 2014 in terms of passenger traffic [1]. Furthermore, AMS is also the main hub for KLM, which provided 54% of the seats available at the airport in 2013, and a major airport for the SkyTeam alliance, whose members – including KLM – are responsible for 66.3% of the airport traffic in terms of ATM [15]. Its role as a hub is central to the airport strategy, especially considering the small size of the domestic market in the Netherlands and the airport's role as economic engine for the region. Due to environmental reasons, the capacity at AMS is limited to 500,000 air traffic movements (ATM) per year. In 2014 there were 438,296 movements at the airport, 86% of the imposed cap. Since the operation is approaching to its limit, Schiphol Group, the airport owner and operator, would like to support the Hub strategy by redistributing traffic that has low positive impact to the Hub to other airports in the Netherlands in order to relieve capacity at Schiphol. The preferred alternative is to upgrade Lelystad Airport (LEY) to attract flights to European cities and regions, putting focus on tourist destinations.

Lelystad is the largest airport for general aviation traffic in the Netherlands. It is located 56 km from central Amsterdam, about 45 minutes by car to the east. The airport is fully owned by the Schiphol Group, which also owns Rotterdam airport (RTM) and a 51% stake in the Eindhoven airport (EIN), both will be part together with Lelystad and Schiphol of what has been called the Amsterdam Multi-Airport System (see Figure 1).

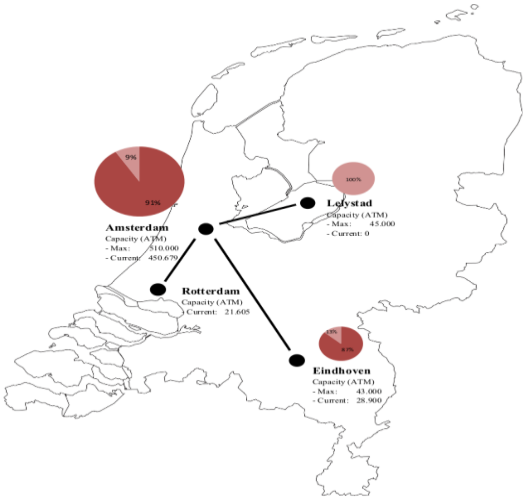

Figure 1. The multi-airport system of The Netherlands.

The ambition to divert short haul traffic "with focus on tourism destinations", to Lelystad implies a stronger focus on the airlines that are able to deliver such type of traffic. The low-cost carriers (LCCs) have been identified as the type of traffic that most likely would use the airport facilities. At Lelystad the availability of slots can be hampered by the remaining general aviation traffic after the upgrading has been finalized and the possible conflicts with air traffic in approach and departure trajectories at Schiphol. For this reason, short turnaround times (TAT) will be important to achieve in order to attract the right traffic otherwise there is high risk of ending with another unsuccessful project of a European airport [7].

The aim of the current work is to have a better insight about the future facility, identify what the requirements are in terms of apron configuration, TATs, and what potential issues might rise once the operation is in place. This should be achieved time in advance to the construction in order to reduce the risk of failure or mitigate potential disruptions that might appear during the operation.

METHODOLOGY

Nowadays, simulation techniques are used in industry to deal with the decision-making activity by searching optimal or feasible solutions to real problems. The use of simulation techniques for analysis facilitates the design and assessment of strategies reducing the risk of poor outcomes. In addition, simulation models have proved to be useful for examining the performance of different system configurations and/or alternative operating procedures for complex logistic or manufacturing systems, among many applications [9]. However, its use in the aviation industry is not common practice but it is an approach that some players and researchers are actively exploring [10, 12, 17].

The advantages and potential of simulation techniques are increasingly recognized in a wide range of activities. Basically, simulation provides a virtual environment for studying the dynamic behaviour of a system when stochasticity plays an important role in the outcome of the system under study. Simulation approaches range from continuous, discrete to hybrid models to represent the actual system [4].

There are different modelling approaches such as system dynamics, agent technology or discrete-event systems (DES). The former is used in systems in which the state variables change continuously in time such as the level in a tank, agent technology is a relatively novel approach in which the power of computers are used to calculate independent behaviour of the entities within a system [5], while DES are suitable for analysing systems in which the state variables change at particular instants of time like in the aviation systems in which the evolution of events in the system depend on the traffic which follows a particular schedule and all the operations have a dependence on the operation of the aircraft. In addition, there are combinations of approaches in commercial tools in which some phenomena are modelled by DES while other phenomena within the model are characterized by system dynamics or agent-based logic.

Aviation systems have different operations that can be studied by using different abstraction levels such as high-level strategic analysis to high-detailed passenger-level operation. For this reason, we propose a methodology which uses a combination of operational-level with high-detailed analysis. The combination of both approaches allows identifying diverse particularities of the future system enabling the decision makers to give more informed advises on the future operation of the airport.

The Figure 2 illustrates the interrelation of both approaches in the methodology in which some output information from one model is the input for the other one thus making it a virtual circle of simulation-based improvement. In the current work, the initial iteration is presented for the study of LEY, but it gives light on what is the next configuration to evaluate so that the models are progressively improved and understood which might be result in a powerful approach for analysing the development of future facilities.

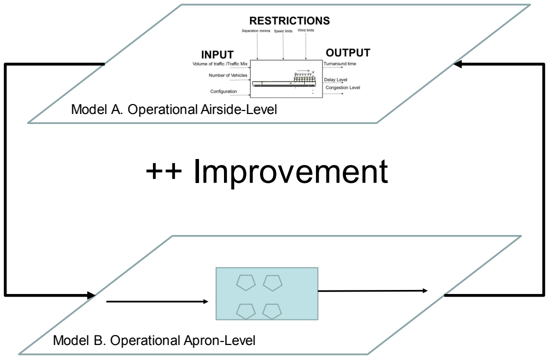

Figure 2. The simulation-based virtual circle approach.

In this methodology, the model A is developed first by using the DES approach incorporating different elements of the tactical operations such as traffic, landing, take off, taxiing and the general configurations of the apron. Some of the output and information is used by model B which is a lower level which uses a hybrid simulation approach. The model A is developed with a commercial general purpose simulator called SIMIO and the model B is developed by using a specific-purpose simulator called AEROTURN. By using the two tools the results complement each other and can interact in a virtual circle generating a powerful approach for the analysis of aviation systems. The circle starts with model A and produces some performance indicators and it reveals potential issues at tactical level, then with model B we identify low-level issues that can be used for improving model A and then the circle moves on reducing some risks and potential issues with the model B. By following the circle, the analysis is progressively improved. The previous approach has been put in practice in the analysis of the future airport of Lelystad.

Model A Characteristics

For the study of the case of LEY, a DES simulation model developed in SIMIO was adopted since it allows developing through a bottom-up approach a dynamic model. The developed model has the characteristic that is dynamic, stochastic, and asynchronous. These features allow identifying the potential problems of the future airside of the airport as well as the so-called emergent dynamics.

In order to understand the potential problems for the airport in the future, we analysed the response for the different inputs (internal and external). Among different parameters and configurations, a particular focus was put on two configurations, one which is linear in which the aircraft park perpendicular to the taxiways (Nose In configuration) and the other in which the aircraft parking positions are located parallel to the taxiway. This configuration has the advantage that in theory it makes the TAT short since the aircraft uses its own engines to perform the taxi-in and out to the apron see Figure 3.

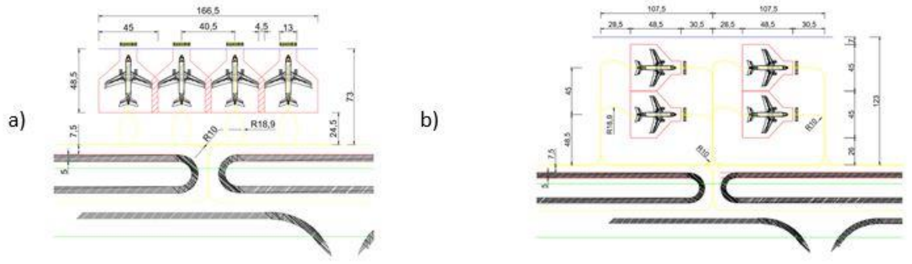

Figure 3. Partial view of the linear lay out configuration: a) Nose In b) Parallel Parking.

In addition, the no use of push-back trucks implies that the aeronautical charges would also be less than in an airport that uses the pushback trucks in the operation. The next figure illustrates the approach for evaluating the model response.

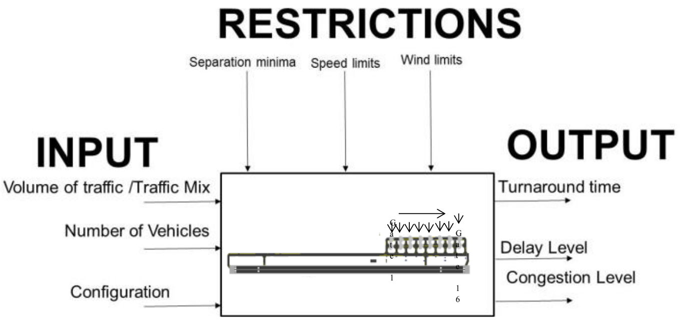

Figure 4. Linear with parallel parking positions model.

In this case we evaluated different performance parameters the configurations under the reported expected traffic figures: 45 k annual movements [15].

Different combinations of the number of ground handling vehicles were used for evaluating the capacity limitations of the future facilities. In the case of the ground handling operations, the vehicles that were included for performing the TAT were:

- 1 fuelling truck
- 1 bus boarding
- 1 bus for deboarding
- 2 stairs (for dual boarding)
- 1 water truck
- 1 cleaning truck
- 1 baggage cart for baggage in and out

The simulation module was developed under a bottom-up approach in which different elements were developed independently and then at some point put together and synchronized so that the final model worked as one model. The following is the example of the module developed for the operations at the stand in particular all related to the turnaround process.

Stand Module

The stand module simulates the ground operations performed at any stand in the airport. For the particular case of this airport only some operations from the ones that are common to perform in a full-service carrier will be performed, namely fuelling, passenger boarding/deboarding, baggage loading/unloading, water service, cleaning. Figure 3 illustrates the physical aspect of the module used for the stand.

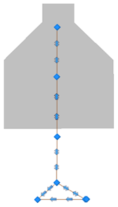

Figure 5. Module of the operations at the stands.

The different nodes in the figure are the nodes of the route that the aircraft must follow. All the logic for the turnaround is implemented in the module and it has been done general enough to adapt it for a different configuration and/or type of aircraft.

Network Module

Once the first module is developed it is necessary to connect all the instances of the model through a network that represents the taxiways and the runway. Figure 6 illustrates the network that is used for modelling the airside of the airport.

Figure 6. Final Airport model: Linear with parallel parking positions.

The model is composed by 16 instantiations of the stand model. The network represents the runway and also the taxi-ways. For the analysis, also the ground service vehicles are included; the depot of those vehicles is located in the north-west location of the apron (not depicted in the figure). So, as it can be perceived, the model is an integral one that includes the apron, runway, vehicles and taxiway.

Assumptions

For this model, some assumptions have been done; the most relevant ones are enlisted as follows:

- The turnaround processes start as soon as the aircraft has blocked in.
- The vehicles that perform the ground operations are located in depots at one extreme of the apron.
- The engines jets are neglected at the Apron operation.
- The exact dimension is not considered in the operation, just an approximation that allows a smooth approach to the parking positions is considered.
- The different operations at the parking positions follow the probability distributions reported in literature [14].

For a more detailed description of the construction of Model A we refer the reader to the work of [14]. In this article, a thorough description of the probabilities distributions and main results can be found; they were not included in this paper since the description of the model is beyond the scope of the current work.

Model B Characteristics

The model B was developed using a specific purpose simulator called AEROTURN 5.0 [16] which uses a combination of physical characteristics and the interaction of the layout for modelling at lower level than model A. The model developed was used for evaluating in higher detail the two potential configurations of the apron already mentioned.

For all the cases of model B, the apron with four parking positions were analysed even though the apron under study has more parking positions (16 parking positions); but this approach allows us to identify problems related to the manoeuvres that might be faced by the aircraft once it is operational.

For the development of the model B, we took into consideration more specific requirements such as the minimum security margins for the taxiways and the size of apron according to ICAO regulations. Some variations were analysed, in total 12, in which the main differences were the inclusion or not of the engine jet at two different speeds in the analysis, the type of the aircraft, whether the margin limits in the Nose in configuration were independent or not and the use of two types of aircraft (the two main that are expected to operate at the airport). In this case the model input-output can be depicted by the following figure.

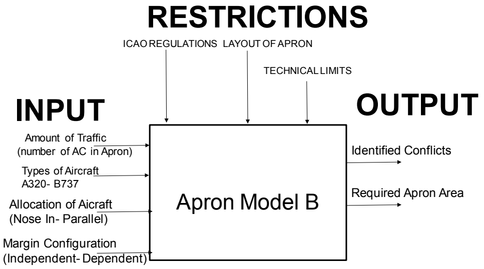

Figure 7. Apron model.

Assumptions

The following assumptions are considered for the development of the model:

For the scenario with push back trucks (Nose-in configuration):

- The taxing manoeuvres are made in an autonomous way with the engines in the slow speed regime.
- The taxing out manoeuvres are made with push back truck until the aircraft is aligned with the taxiway that get access to the parking positions.

For the scenario with lineal configuration with parking positions in parallel:

- The taxiing manoeuvres towards the parking positions are made in an autonomous way with the engines in the slow speed regime.
- The taxiing out manoeuvres are made in an autonomous way, with the engines in start-up mode for the first 10 meters and then in the regime of slow speed for the remaining of the manoeuvre.

In both cases, the turn radius and the types of turns (anticipated, exact or past) are defined in accordance with the performance of each aircraft, and following the requirement that they should be aligned with the central axis of their respective parking position.

For the jet engines, the critical admissible speed in the area of manoeuvres is 56 km/hr as advised by ICAO. The aircrafts considered in the study were the B737-800 (w/winglets) and the A320-200 (sharklet).

Experimental Design

The experimental design was developed to get insight about the future performance of the airport under these configurations which have been considered by Schiphol group; and also, to identify what the potential problems would be once it is at its operational phase.

The following table illustrates the different scenarios that were analysed for the two models.

Input	Description	Assumptions
Airside configuration	A) Linear with Nose In apron configuration. 16 stands. B) Linear with taxi-in taxi-out apron configuration. Parallel parking stands.	Scenarios created, accordingly to the latest *Ondernemingsplan* [15].
Traffic mix	a) 737 series + A320 series (narrow-body). b) 737 series + A320 series (narrow-body).	Schedule developed based on Eindhoven operations.
Vehicle numbers	Base number reduced to evaluate the capacity limits of the ground operations.	1. 6 vehicle sets for each operation 1. 5 vehicle sets for each operation 1. 4 vehicle sets for each operation 1. 3 vehicle sets for each operation 1. 2 vehicle sets for each operation
Traffic limit	2. Neutral scenario 45,000 flight movements annually.	1. Based on the *Ondernemingsplan* [15].
Stand Allocation	Allocation 1. Left-right 2. Centre- Out	The allocation is performed from left to right based on the dominant RWY use or Centre -Right.

Table 1. Experimental Design Model A.

Apron Configuration	Type of Aircraft	Analysis	Independent Margins	Dependent Margins
Lineal Nose-In	A320- 200 (sharklet)	No Engine Jet	The apron uses A320s without including the jet in the analysis and the apron is minimized.	The apron uses A320s without jet in the analysis and the apron is bigger minimizing conflicts.
		With Engine Jet	The apron uses A320s including the jet in the analysis and the apron is minimized.	The apron uses A320s with jet in the analysis and the apron is bigger minimizing conflicts.
	B737-800 (winglet)	No Engine Jet	Similar but using B737s.	Similar but using B737s.
		With Engine Jet	Similar but using B737s.	Similar but using B737s.
Lineal w/parallel parking	A320- 200 (sharklet)	No Engine Jet		The configuration assumes only A320s without the Jet in the analysis.
		With Engine Jet		The configuration assumes only A320s including the Jet in the analysis.
	B737-800 (winglet)	No Engine Jet		Similar but with B737s.
		With Engine Jet		Similar but with B737s.

Table 2. Experimental Design Model B.

After verifying the models, several replications were performed for the model A and model B in order to get as much information as possible; as it has been mentioned the main objective at this stage was to identify the potential problems or conflicts that might raise and to get insight about the operation performance and special interest was put on the TATs.

RESULTS

Model A

The simulation was run and some of the most relevant results obtained can be summarized in the following table. For the following results, we used 8 sets of vehicles for performing the TAT.

Configuration	Performance Indicator	Statistics			
Lineal Nose IN		**Average (minutes)**	**Min (minutes)**	**Max (minutes)**	**Half Width**
Left-Right Parking allocation	Turnaround time	30.75	27.86	33.9	1.43
	Expected Delay	2.42	2.09	2.88	0.19
Centre-Out Parking allocation	Turnaround time	30.95	28.86	33.83	1.16
	Expected Delay	3.56	2.13	7.89	1.45
Lineal w/Parallel Parking positions					
Left-Right Parking allocation	Turnaround time	30.40	27.85	34.19	1.75
	Expected Delay	2.18	1.97	2.50	0.16
Centre-Out Parking allocation	Turnaround time	29.66	27.31	33.06	1.37
	Expected Delay	2.17	1.83	2.83	0.32

Table 3. Experimental Results Model A (min).

Besides turnaround time, by running the simulations, we could evaluate the amount of vehicles that are required for having a smooth operation and also the turning point when the behaviour became unstable (exponential delay). Figure 5 provides an example for the configuration with parallel parking positions in which approximately 3 or 4 is the threshold for this behaviour.

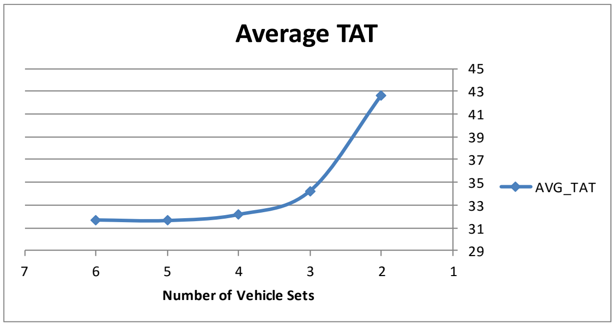

Figure 8. Average TAT for parallel parking positions.

In the figure, it can be appreciated that the system is able to manage the operation with 4 sets of vehicles giving an average of total gate time of less the 33 minutes.

Model B

Based on the analysis performed with the simulation model of the apron we could identify potential conflicts such as the ones illustrated in Figure 9 which partially determined the optimum size of the apron.

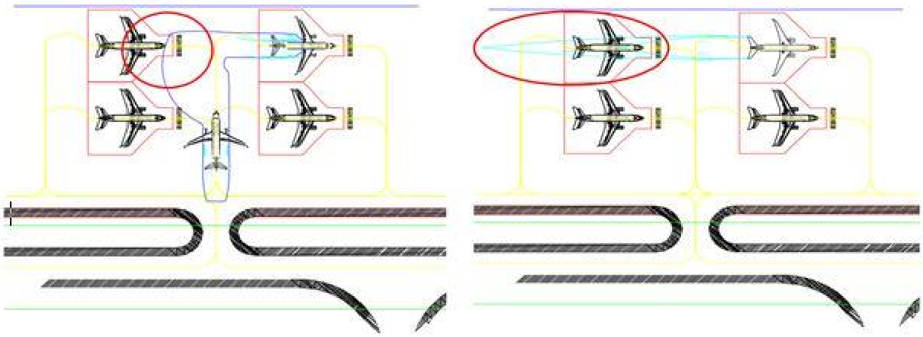

Figure 9. Example of identified conflicting situations.

Taking all into consideration, we could define the required characteristics of the apron for avoiding those situations. Table 4 summarizes the results obtained from the simulation for the linear Nose-In configuration while Table 5 summarizes the requirements for the linear with parallel parking positions.

Physical characteristics of the Apron	**Linear configuration with Nose-In parking stands**	
	Minimum distances according to regulation	
	Independent Margins	**Dependent Margins**
Parking position (long)	48.5 m	48.5 m
Parking Position (max. width)	45.0 m	45.0 m
Separation between central axis in parking positions	45.0 m	40.5 m
Distance between the axis of the taxi entrance to the parking position and the security line	24.5 m	24.5 m
Distance between the taxiway to the parking position and the service road	73.0 m	73.0 m
Required length for the parking positions (total width)	180.0 m	166.5 m
Approx. Apron area (4 positions)	13,140 m2	12,154 m2

Table 4. Experimental Results Model B: linear Nose-In configuration.

In this configuration, the minimum distances according to regulations match the distances obtained from the ones calculating the engine jets. While in the second configuration (as it can be seen in Table 5) the minimum distances need to be adjusted for the engine jets in order to avoid the interaction between the different parking positions.

Physical characteristics of the Apron	**Lineal Configuration with Parallel Parking positions**		
	Minimum distances according to regulations	**Distances according to nodules of A320-200 (Sharklet)**	**Distances according to nodules of B737-800 (winglets)**
Parking Positions (Length)	48.5 m	48.5 m	48.5 m
Parking Positions (Max. Width)	45.0 m	45.0 m	45.0 m
Separation between parking positions central axis	45.0 m	45.0 m	45.0 m
Distances between axis of taxiway to parking positions and security lines	24.5 m	28.5 m	72.5 m
Distance between taxiways axis in apron and security line	26.0 m	26.0 m	26.0 m
Distance between taxiway axis in apron and service path	118.0 m	123.0 m	123.0 m
Separation between taxiways axis towards parking positions	97.5 m	107.5 m	193.5 m
Total Length Required for the parking positions (total width)	195.0 m	215.0 m	387.0 m
Approx. Apron Area (4 positions)	23,010 m2	26,445 m2	47,601 m2

Table 5. Experimental Results Model B: linear with parallel parking positions.

As it can be seen in this case the size of the apron for the positions studied reveal that by doing this configuration, the aircraft can perform the operation with their own engines, however the impact in the size of the apron is significant. The area of the apron that needs to be selected is the one that allows the use of the B-737s and the A320, which in this case is the biggest one of 47,601 m2 (for four positions).

DISCUSSION

The analysis performed allows to give light to different issues that might rise in the development of the new airport. On the case of model A, as it has been mentioned by the authors is possible to obtain short turnaround times if the variability of the allocation and the utilization of the apron is optimized. On the other hand, when we performed the analysis of the particularities of the operation at the Apron, other situations raised. In particular the dimension of the apron is drastically affected by the configuration of the Apron and by the type of aircraft used. Since the engine jet from the B-737 is more powerful, it affects the area required or holding 4 parking positions and in particular it has a significant effect in the size (and in the cost of construction) of the Apron.

After applied the methodology for the first iteration, we could get insight of the requirements, issues and potential performance indicators. This has been done just by analysing public information of the airport; the second iteration will include in Model A the results of Model B: add the dimension of the Apron, increase the detail of the turns, and verify the impact of the Nose-In configuration in case of the independent and dependent margins. After updating model A then it will be the turn of model B and so on. This work is currently under development.

CONCLUSIONS

In this work, we have introduced a model-based virtual circle methodology for analysing the performance of an airport in The Netherlands that will be constructed in the near future. The methodology makes use of two simulation models (model A and model B) with two different levels of abstraction. Model A is more tactical in which we provide high-level input such as the expected traffic, lay-out of different apron configurations and the expected amount of ground handling vehicles. With that model, we were able to have an initial insight about operational performance indicators without putting focus into low-level interactions. By using some information, we also constructed model B which differs from the previous one in the level of abstraction. This one is low-level and we analysed the interactions of the different aircraft at the apron. With this analysis, we were able to raise other potential conflicts that did not reveal model A and we could came up with the initial requirements of the apron size which depends directly in the configuration and expected traffic.

In the second iteration of the methodology we will use the results of model B into model A in order to be more accurate in the expected performance indicators of the future airport under study and reduce drastically the risk of failure in the development of the real facility.

By applying this methodology the planners are able to reduce the risk of over dimensioning or not fulfilling the demand of the expected traffic. Furthermore, it might be useful for avoiding a potential failure in the investments done in the expansion project or in the development of a new airport. The authors strongly encourage the use of this methodology or at least the use of Simulation in one of the planning phases of critical infrastructures such as Airports.

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REFERENCES

[1] ACI, “www.aci-europe.org/component/content/article/29-article/103-world-airport- traffic-data.html”, 2014.

[2] Airport Council International, “A Vision for European aviation”, 2005.

[3] Alders H., “Presentatie en toelichting van de in het MER te onderzoeken routevarianten”, Informatiebijeenkomst voor bewoners in de regio Gelderland/Overijssel en bewoners van Flevoland 13 en 15 januari 2014.

[4] Banks, J., Carson J.S., Nelson, B., Nicol, D.M., “Discrete-Even system Simulation”, 5th edition, Pearson, 2010.

[5] Becu,N.,Bousquet, F.,Barreteau, O.,Perez, P.,Walker, A., “A methodology for eliciting and modelling stakeholders’ representations with agent based modeling., Multi-Agent-Based Simulation III, Springer”. 2003.

[6] Eurocontrol, Industry monitor, Issue N.169, 30/01/15. 2015.

[7] European Court of Auditors, “EU-funded airport infrastructure: poor value for money”, pursuant to art287 (4), 2014.

[8] IATA, Fact sheet: Industry Statistics. December 2014.

[9] Longo F., “On the short period production planning in Industrial Plants: A real Case Study, International Journal of Simulation & Process Modelling”, vol. 8, p.p. 17-28, 2013.

[10] Mujica, M.M., “Check-in allocation improvements through the use of a simulation–optimization approach”, Transportation Research Part A, vol.77, p.p. 320-335, 2015.

[11] Mujica, M.M., “Flaws and Pitfalls using Simulation in the Analysis of Aviation Capacity Problems”, in Proc. of the Airport Development Conference (AIRDEV), Bangalore, India, 2015.

[12] Mujica, M. M., Scala, P., Boosten, G., “Simulation-based capacity analysis for a future airport”, Computer Aided System Engineering (APCASE), 2014.

[13] Asia-Pacific Conference, pp. 97-101. IEEE. February 10-12, Bali, Indonesia.

[14] Mujica, M.M., Boosten G., DeBock, N., Jimenez, E., Pinho de Souza, (2017), “Simulation-Based Turnaround Evaluation for Lelystad Airport, Journal of Air Transport Management, article in Press Schiphol Magazine”, “http://trafficreview2014.schipholmagazines.nl/air transportmovements.html#atmmainairlinesa”, 2014.

[15] Schiphol Group, “Ondernemingsplan Lelystad Airport”, 2014.

[16] Transoft Solutions, Aeroturn 5.0, “http://www.transoftsolutions2015.com/aeroturnpro”, 2017.

[17] Zuniga C., Delahaye D., Piera M., “Integrating and Sequencing Flows in Terminal Maneuvering Area by Evolutionary Algorithms”, DASC 2011, 30th IEEE/AIAA Digital Avionics Systems Conference, Seattle: United States, 2011.