33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

INFLUENCE OF DEMAND PATTERN ON RELATION BETWEEN OVERALL TURNAROUND TIME AND AVERAGE GATE OCCUPATION DEPENDING ON AVAILABLE RESOURCES

Lothar Christoffels[1], Olga Gluchshenko[1]

[1]Institute of Flight Guidance, German Aerospace Center (DLR), Braunschweig, Germany

Abstract

It is of strategic and economic importance for airports to know the required deployment of resources needed to efficiently handle aircraft turnarounds while ensuring high customer satisfaction even with considerably varying traffic volumes [1]. This case study, based on traffic data from a mid-sized international European Airport, presents an investigation of relation between the occupation of the boarding and deboarding facility (e.g. passenger gate), which represent the key resource and the overall turnaround time depending on other available necessary resources for some given demand list and its numerous variations. The case study includes extensive simulation results and analysis of resources needed for the turnaround process in various traffic densities and the availability of ground handling resources. The main finding of the simulation data analysis is, that power functions provide very well fitting for the relation between the overall turnaround durations and their related average gate occupations for different considered availabilities of ground handling resources and traffic demands (for the same list of flights). Moreover, to approximate the resource limits for reasonable overall turnaround durations which are comparable to the values gained at the simulations with unlimited resources, it is sufficient to use the median values of the maximal numbers of utilized resources. The method and findings of this study might be valuable to estimate a reasonable utilization of ground handling resources and to calculate the layout of gates for planned or expanding airports to satisfy an expected traffic demand.

Keywords: Airport Capacity; ATM Operation; Air Transport System Efficiency; Gate Occupation; Turnaround

1. Introduction

Efficient handling of aircraft turnaround time even with heavy varying traffic and high customer satisfaction rate require the deployment of various types of resources. Planning of these resources is of strategic and economic importance for airports. This case study is focused on mid-sized international European airports. Traffic data of this airport is investigated to identify relation between the occupation of the boarding and deboarding facilities (e.g. passenger gate), which represent the key resource and the overall turnaround time. This time depends on other available resources necessary for a given demand list with its numerous variations. As the demand of the airport is dominated by short-haul flights executed by aircrafts of the Airbus A320 family, the study concentrates on the turnaround procedures of the short-haul flights. Extensive simulations were carried out and analyzed to determine the required amount of resources involved in the turnaround process for different traffic densities and availabilities of ground handling resources.

2. Methods and Setup

The relevant ground handling processes and procedures at an airport which are applied during the turnaround of an aircraft were modelled for a simulation. The characteristics of the involved processes and their dependencies have been implemented in a discrete eventful simulation environment. Results of simulations with numerous runs with traffic scenarios of different densities were examined by a sensitivity analysis for gaining knowledge of the interdependencies of process durations and resource [1].

2.1 Modelled Turnaround Processes

In the simulations, an aircraft can arrive or depart as a short-haul flight or it can leave the over-night parking position before becoming in-block for ground handling or it can stay over-night after becoming off-block. Due to the different possible turnaround procedures, it is necessary to model dedicated process chains for each of situational combinations. The modelled turnaround procedure starts with opening the passenger and cargo doors shortly after the aircraft is in-block. Water and lavatory services and the unloading of baggage and cargo start in parallel with the deboarding of passengers. Cleaning, catering and refueling will be processed between deboarding and boarding. After finishing boarding, water and lavatory services, loading of baggage and cargo, the doors will

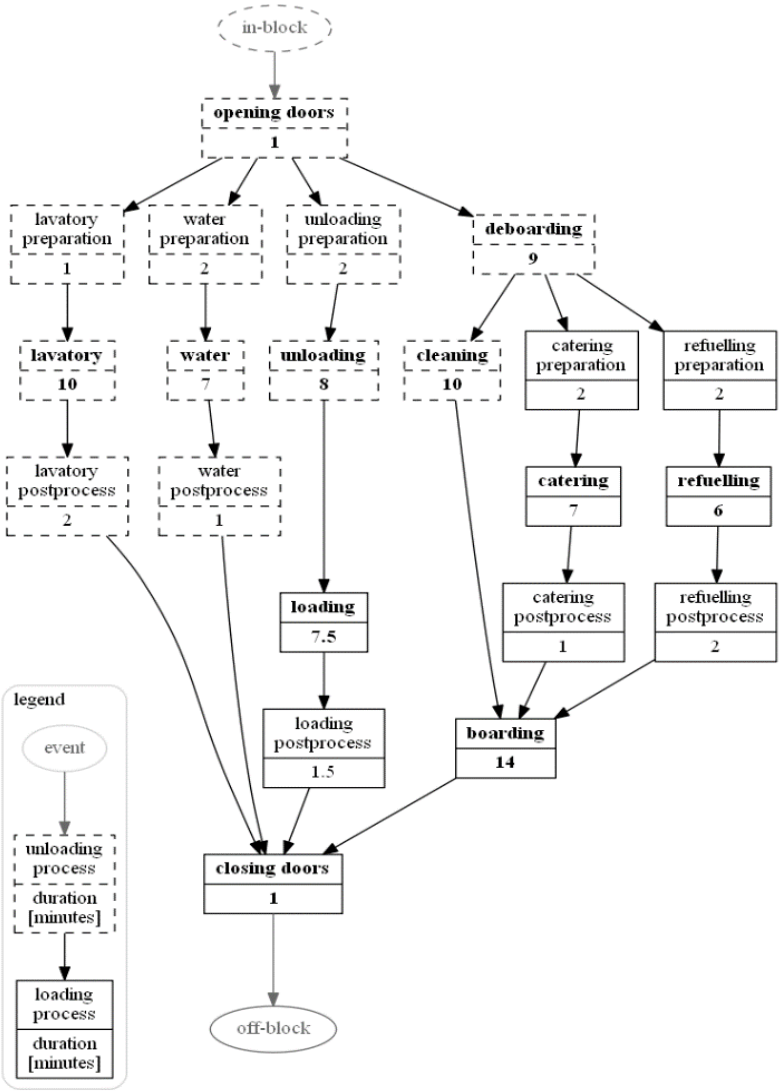

Figure 1 – Process chain of an in- and outbound turnaround

be closed and the aircraft is ready for becoming off-block (Figure 1).

Depending on a potential overnight stay, some processes dedicated to inbound or outbound are skipped resulting in different process chains [2]. The durations for the turnaround process used in this simulation were derived from a specification by Airbus for an aircraft of type A320 with deboarding and boarding via an avio bridge [3]. The turnaround time (TAT) is defined as the period during which an aircraft occupies an apron or a gate position [4][5] and is determined by the critical path of the process chain [6]. A complete turnaround process of a short haul flight has a mean duration of 35 minutes, while inbound only lasts 26 minutes and outbound only can be processed in 30 minutes under the condition that all required resources are available in time.

2.2 Deployed Scenarios

The scenarios used in the simulation were based on the real operational data from a mid-sized international airport in Europe consisting of 104 independent airplanes of type A320 distributed in 72 in- and outbounds, 17 inbound only and 15 outbound only flights. Based on the 17.2 hours lasting original Scenario 1, two compressed scenarios Scenario 2 and Scenario 3 (compression factors 2 and 3.5) with approx. durations of 9 and 5.5 hours were derived, which makes a total of three scenarios with different traffic densities.

The scheduled in-block time (SIBT) and scheduled off-block time (SOBT) were assigned as follows: The original scheduled time is taken as SOBT for departures. Since our goal is to estimate the impact of demand variations on the duration of turnaround process, there is no buffer in the corresponding turnaround time to compensate deviations from SIBT and SOBT. Therefore, the associated SIBT is equal to SOBT minus the specified above corresponding turnaround time. The SIBT and SOBT of all flights result in demands which are illustrated for each traffic scenario in Figure 2.

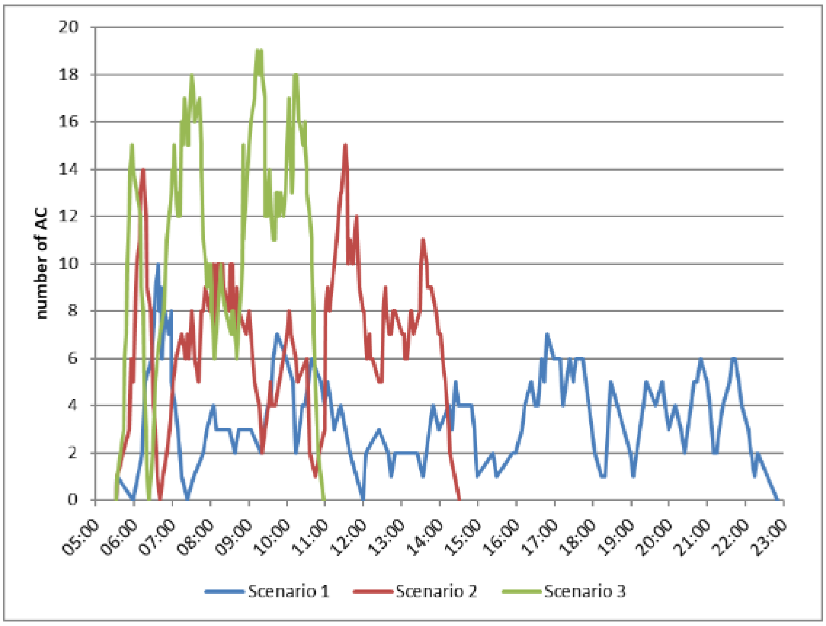

Figure 2 – Demand in original Scenario 1, 2-times compressed Scenario 2 and 3.5-times compressed Scenario 3

3. Simulation Description

The resource passenger gate appears to be a connecting intermediate element between demand and other available resources. Therefore, it is crucial to investigate relation of turnaround duration for given demand and average gate occupation depending on availability of resources that are necessary for the turnaround process. Hence, the performed simulations had the following goals:

I. to study the amount of resources which are necessary or even sufficient for the turnaround of the given scenarios;

II. to estimate limits on resources to have acceptable compromise between rational turnaround time and amount of resources needed for it;

III. to investigate relation between average passenger gate occupation and overall turnaround time depending on the number of available resources.

The overall turnaround time denoted as duration TA is defined as the time between the beginning of the turnaround for the first aircraft and the end of the turnaround for the last aircraft in the considered demand scenario (Figure 3). The average gate occupation, avio mean, is calculated so that both – the times a gate or a parking place is occupied by an aircraft or is free – were considered. In such a way, the periods without utilization of available capacity, like the period $j = 3$ in Figure 3, were also included, because they influence the average gate occupation during the demand processing.

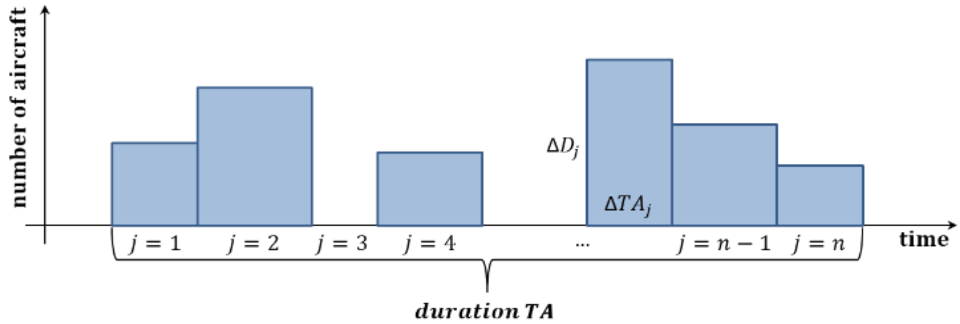

Figure 3 – Turnaround periods and overall turnaround time

Let us denote n the number of periods between changed gate occupation, i.e. between time moments where some aircraft goes in-block or off-block. If ΔTA_j is the duration of the j-th turnaround period, where $j = 1, \dots, n$ and ΔD_j is the number of aircraft undergoing turnaround procedure during the period ΔTA_j, then

$$duration\,TA = \sum_{j=1}^{n} \Delta TA_j$$

and

$$avio\ mean = \frac{\sum_{j=1}^{n} \Delta D_j \Delta TA_j}{duration\,TA}.$$

When the total number of aircraft in the demand is equal to D, then the part of the demand at the j-th period is equal to

$$\Delta D_j = \sum_{i=1}^{j} D_i^+ - \sum_{i=1}^{j} D_i^-,$$

where ΔD_i^+ and ΔD_i^- is the number of aircraft that start and end the turnaround at the beginning of time period $i = 1, \dots, n$. Therefore, the total demand is equal to

$$D = \sum_{i=1}^{n} D_i^+ = \sum_{i=2}^{n+1} D_i^-$$

and the average gate occupation can be calculated as

$$avio\ mean = \frac{\sum_{j=1}^{n} (\sum_{i=1}^{j} D_i^+ - \sum_{i=1}^{j} D_i^-) \Delta TA_j}{duration\,TA}.$$

On the other hand, there are D aircraft denoted AC_k, $k = 1, \dots, D$ with the corresponding turnaround times TA_k, $k = 1, \dots, D$. Therefore, the blue area in Figure 3 consists of D blocks $1 * TA_k$ and as a result

$$avio\ mean = (duration\,TA)^{-1} \sum_{k=1}^{D} TA_k. \tag{1}$$

To estimate the resources requirement for different variations of available demand containing the exact same 104 aircraft, actual in-block time (AIBT) of the reference scenarios was varied by means of triangle distribution. This distribution appears to be sufficient to model wide demand variations between the available reference Scenario 1 to Scenario 3. Since one of the simulation goals was to investigate the spectrum from small deviations up to a big variance of AIBT for the same demand list compare to SIBT at the reference scenario, there were six cases of triangle distribution with the corresponding maximal possible deviations from scheduled in block time: (-15min, +30 min), (-30min, +1h), (-1h, +2h), (-2h, +2h), (-3.5h, +3.5h), (-5h, +5h). The first two represent realistic deviations for the given reference scenarios, the last four were used to create a wide range of demand variations between three reference scenarios. To estimate the resources utilization, there were 51 simulations with unlimited resources for each scenario perturbation case by means of mentioned triangle distributions. As a result, rational limits on resource sets for each simulation series were found. Then there were again 51 simulations per triangle distribution and per resource limits for each of the three scenarios. Since the constructed scenarios have three different densities of demand, resource limits for less dense scenarios were also used in simulations with higher density to investigate the influence of these limitations on the turnaround process.

The specified simulation approach was done for two turnaround models: Model 1: "arrived-serviced-departed" and Model 2: "arrived-serviced-waited-departed". Model 1 is necessary to get the Pareto-efficient front that provides the lower bound for the possible relations between turnaround duration and average gate occupation for the considered demand. The described various combinations of input parameters have resulted in a total of 2452 simulation runs.

4. Simulation Results

4.1 Reference turnaround with undisturbed demand and unlimited resources

For calculation of reference values, there was a simulation for each scenario with undisturbed demand (i.e. AIBT=scheduled in-block time) and with unlimited resources. In this case scheduled off-block time (SOBT) can be hold, i.e. AOBT=SOBT. Table 1 summarizes in the first three lines *duration TA* for each scenario in hours, *avio mean* in number of aircraft and the maximal number of required resources. The last two lines illustrate the ratio between considered values of the compressed scenarios Scenario 2, Scenario 3 and the corresponding values of original Scenario 1.

Table 1 - Reference turnaround for Scenarios 1, 2, 3 and resources ratio

	duration TA (h)	*avio mean* (#AC)	max number of required resources						
			avio	belt-loader	cargo-loader	water truck	galley truck	tank truck	lavatory truck
Scenario 1	17.2667	3.3832	10	6	12	4	8	5	4
Scenario 2	8.96667	6.5149	15	8	16	7	7	7	7
Scenario 3	5.41667	10.7846	19	13	26	9	13	9	9
Scenario 2/Scenario 1		1.93	1.5	1.3(3)	1.3(3)	1.75	0.875	1.4	1.75
Scenario 3/Scenario 1		3.19	1.9	2.16(6)	2.16(6)	2.25	1.625	1.8	2.25

The ratios in Table 1 show that for 2-times compressed Scenario 2 the maximal number of required resources increases between 0.875 and 1.75 times. For the 3.5-times compressed Scenario 3 the growth rate on required resources is between 1.625 and 2.25 times compare to Scenario 1. The lowest increase is for the resource galley truck and the highest increase is by water truck and by lavatory truck in both compression cases. It should be noted that the resource galley truck with the lowest increase of the maximum is on the critical path for aircraft that arrives and departs on the same operational day and for departures that have stayed overnight. The resources with the highest increase – water truck and lavatory truck – are not on the critical path with exception of the small number of arrivals that stay overnight, where lavatory truck is on the critical path. The maximal need of the resource galley truck at the simulation was higher for the original Scenario 1 than for the 2-times compressed Scenario 2.

4.2 Turnaround Model 1

For each turnaround model, there were two series of simulations. In the first one, the goal was to estimate how many resources are required to service each of the scenarios in the case of various perturbations of AIBT. Hence, the simulations were performed with unlimited resources. The second series analyses the turnaround process with perturbations of AIBT and with the resource limits obtained at the first one. The perturbations were performed by means of six triangle distributions described above.

4.2.1 Perturbed demand and unlimited resources

Demand in Scenario 1 to Scenario 3 consists of the same 104 flights, which arrive with different density and scheduled time. Therefore, the results of all three simulation can be merged and then analyzed together. Figure 4 shows the dependence between avio mean and $duration\ TA$ for all 153 simulations with unlimited resources in the case of turnaround Model 1. Each point in Figure 4 corresponds to one particular simulation run. Since the resources are unlimited, the corresponding turnaround time TA_k, $k = 1, \ldots, 104$ is equal to the planned turnaround time and does not vary. Hence, the sum $\sum_{k=1}^{104} TA_k \approx 58.417\ h$ stays constant for each demand scenario consisting of 104 aircraft and, according to (1), the average gate occupation avio mean is an inverse function of $duration\ TA$. Therefore, as shown in Figure 4, there is the perfect correlation between avio mean and duration TA for Model 1 in the case of unlimited resources. Using this correlation, one can indicate the overall turnaround time for some known average gate occupation and vice versa. The correlation curve provides the lower bound – Pareto front – for possible relations between the average avio bridge occupation and the turnaround time for the different combinations of the considered demand.

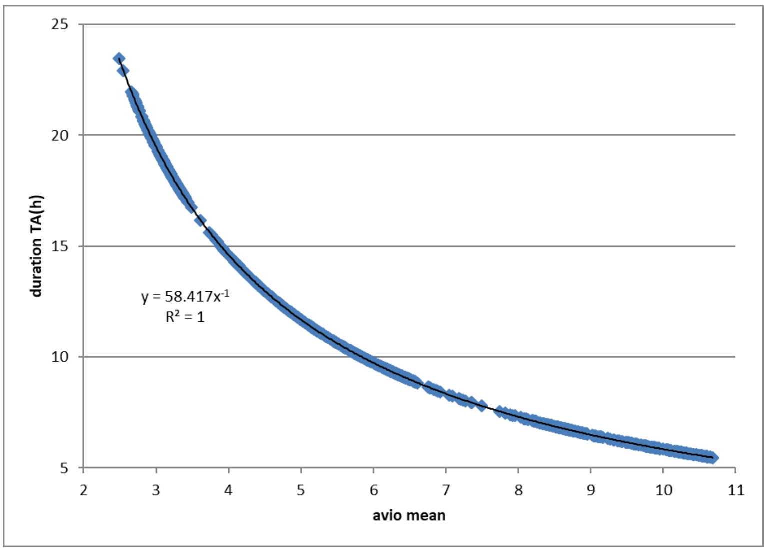

Figure 4 – Fitting curve for all three scenarios with turnaround Model 1 with unlimited resources

4.2.2 Perturbed demand and resources limited by median values calculated for demand with unlimited resources

One of our aims was to study how much resources are necessary or even sufficient for the turnaround of real and constructed scenarios. Moreover, the limits on resources should be investigated in order to have acceptable compromise between rational turnaround and amount of resources needed for it. In the simulations with perturbed demand and unlimited resources, the maximal numbers of utilized resources over all simulations were analyzed. It turned out that the median values of the maximal numbers of utilized resources are appropriate to use as resource limits to get overall turnaround time comparable to the simulations with unlimited resources. Figure 5 summarizes all median values for Model 1: "arrived-serviced-departed". Here MED1, MED2 and MED3 are the sets of median values of the corresponding resource limits for Scenario 1, 2 and 3 accordingly to investigated perturbations of demand by means of six triangle distributions. As one can see the values grow as well as relation between resources limits changes with growing scenario density.

Since the assessed resource limits MED1, MED2 and MED3 are adjusted to the corresponding scenario with the particular density, the limits MED1 can be used as stricter limits for Scenario 2 and Scenario 3, and the limits MED2 for Scenario 3, respectively. So, they are appropriate to investigate the influence of insufficient resources on the turnaround process.

As shown in Figure 5, the median values for the corresponding scenarios and for the corresponding resources vary mostly on one unit or stay constant. For instance, a closer look on the values MED1 regarding Scenario 1 (the first subblock in each of six distribution blocks) shows that the limit of the resource avio bridge grows on one unit for the perturbations dr3.5h.3.5h and dr5h.5h compare to the perturbations with smaller variations.

4.3 Turnaround Model 2

The turnaround Model 2: "arrived-serviced-waited-departed" was also explored with two series of simulations. The first one estimates how many resources are required to service Scenario 1 to Scenario 3 in the case of various perturbations of AIBT. The second series analyze the turnaround process with the resource limits obtained at the first one under perturbations of AIBT by means of six described triangle distributions.

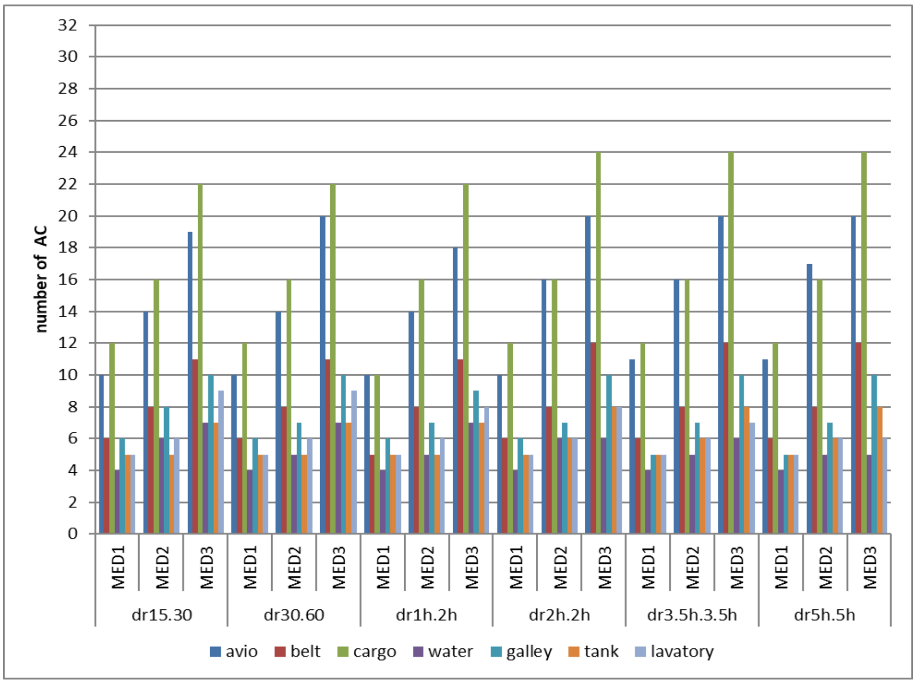

Figure 5 – Median values (MED1, MED2, MED3) representing resources limits for all scenarios and all explored distributions in turnaround Model 1

4.3.1 Perturbed demand and unlimited resources

Figures 6 to 8 illustrate the relation between duration TA and the average gate occupation avio mean for Scenario 1 to Scenario 3. Each point corresponds to one particular simulation run, where the color of the point is given accordingly to the applied triangle distribution. White rhombus in figures represents the reference value for each undisturbed scenario with unlimited resources. It should be noted, that there were no simulations with a better turnaround time compared to the reference turnarounds.

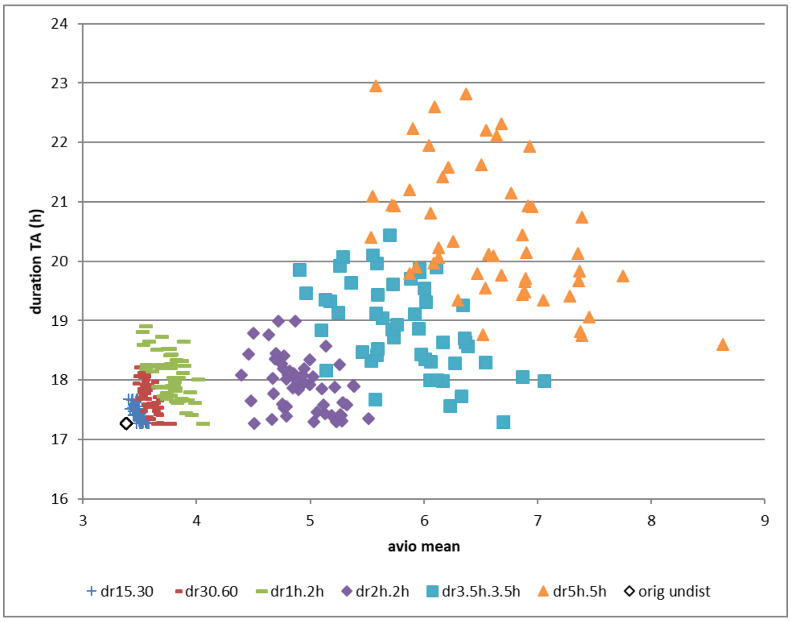

Figure 6 – Relation between duration TA and avio mean for Scenario 1 with turnaround Model 2 with unlimited resources

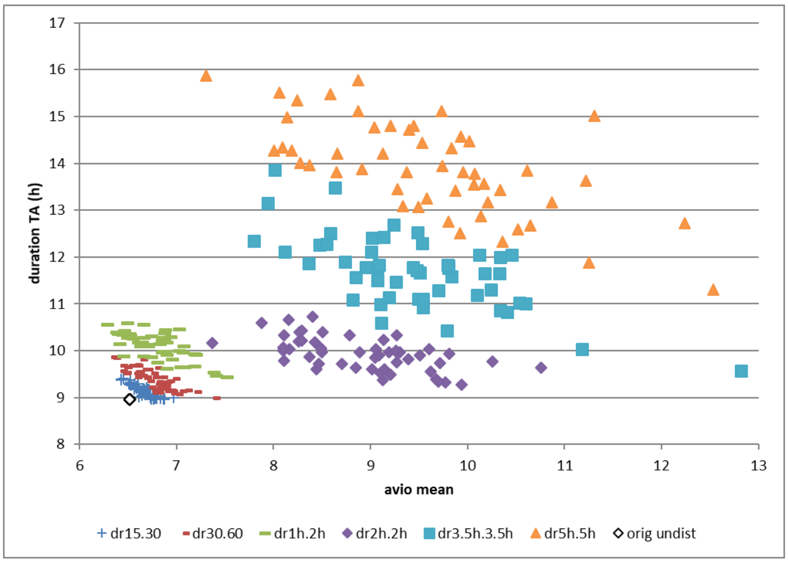

Figure 7 – Relation between duration TA and avio mean for Scenario 2 with turnaround Model 2 with unlimited resources

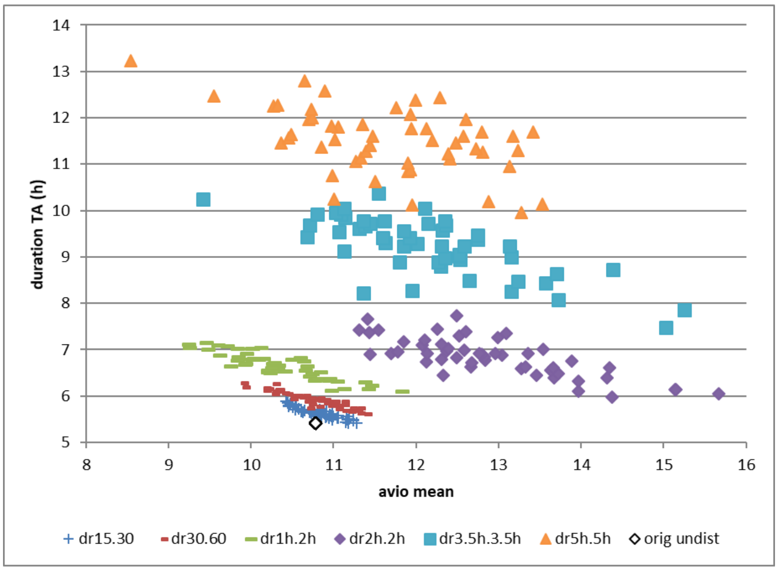

Figure 8 – Relation between duration TA and avio mean for Scenario 3 with turnaround Model 2 with unlimited resources

Comparing the results of Model 1 and Model 2 for Scenario 1 to Scenario 3, one can see their wide distributions and lack of correlation between avio mean and duration TA for Model 2. The relation points in each scenario migrate in the increasing direction of duration TA and/or avio mean. Since the considered scenarios consist again of the same 104 flights, the results for them are unified in Figure 9. Unlike Model 1, a fit with a power function for all scenarios and all considered perturbations is not suitable for Model 2.

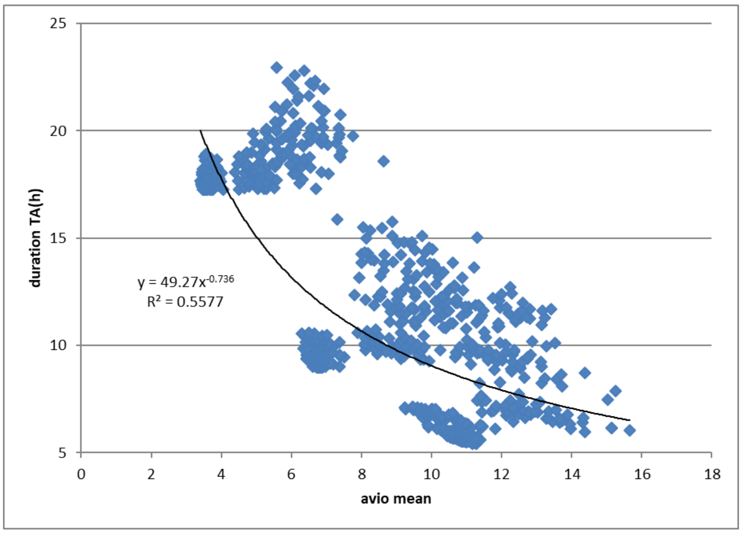

Figure 9 – Fitting curve for all three scenarios with turnaround Model 2 with unlimited resources

4.3.2 Perturbed demand and resources limited by median values calculated in Subsection 4.3.1

Similar to the case of turnaround Model 1, Figure 10 summarizes all median values for Model 2. Here, MED1, MED2 and MED3 are the sets of corresponding limits for Scenario 1, 2 and 3 accordingly to investigate perturbations of demand. The median values grow as well as relation between resource limits changes with growing scenario density. Analogous to Model 1, the limits MED1 and MED2 can be used as stricter limits for Scenario 2, Scenario 3, and for Scenario 3, respectively. So, they are also appropriate to investigate the influence of insufficient resources on the turnaround process.

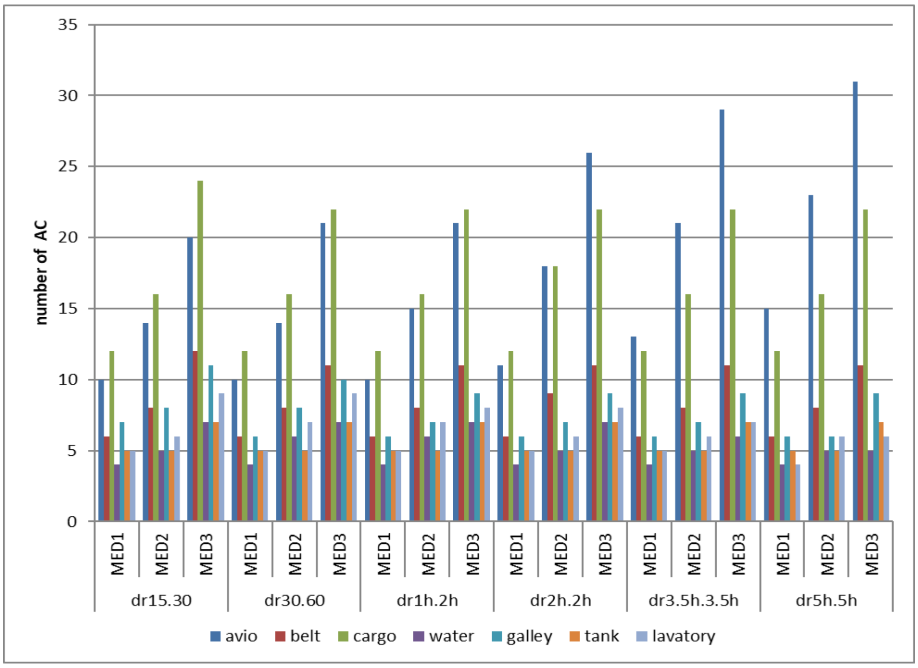

Figure 10 – Median values representing resources limits for all scenarios and all explored distributions in turnaround Model 2

4.4 Model 1 versus Model 2

4.4.1 Resources

Figure 11 illustrates the difference between the corresponding resource limits calculated for Model 2 and Model 1. As it was to expect the biggest difference by growing deviation from the scheduled time provides the resource avio bridge (dark blue bars in Figure 11).

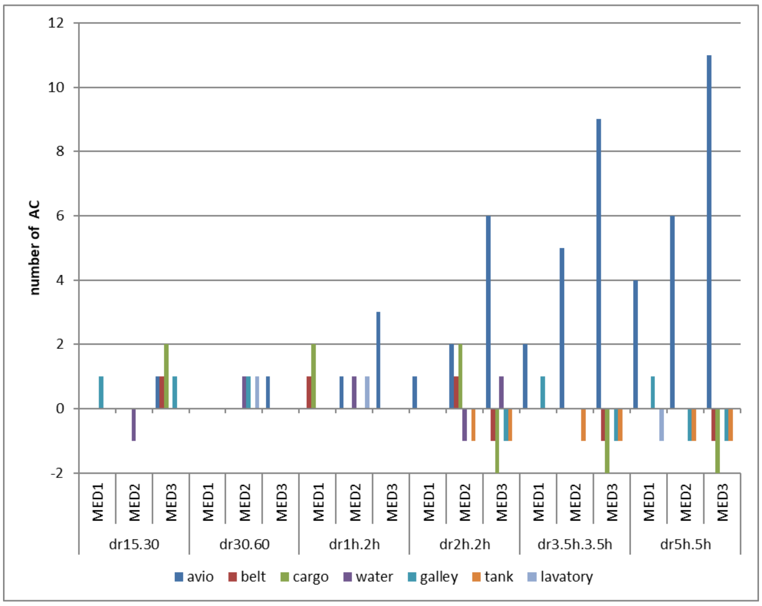

Figure 11 – Difference of resources limits between Model 2 and Model 1

By the scenarios with deviations up to one hour to be earlier to 2 hours to be late from the reference scenario (left part of Figure 11) there is the grows of needed resources in the amount of 1-2 units. For the large possible deviations from the scheduled time at the reference scenario (right part of Figure 11) the amount of needed resources is even decreasing by 1-2 units. That is because the applied distributions smooth the demand peaks shown in Figure 2.

4.4.2 Relation between turnaround duration and average gate occupation with different resources limits

As illustrated in Figure 9, a power function is not suitable to fit the results of all simulations for Model 2. However, when the results are clustered with respect to the possible deviation from the scheduled time, a power function appears to deliver a good estimation of relation between the turnaround duration and the average gate occupation.

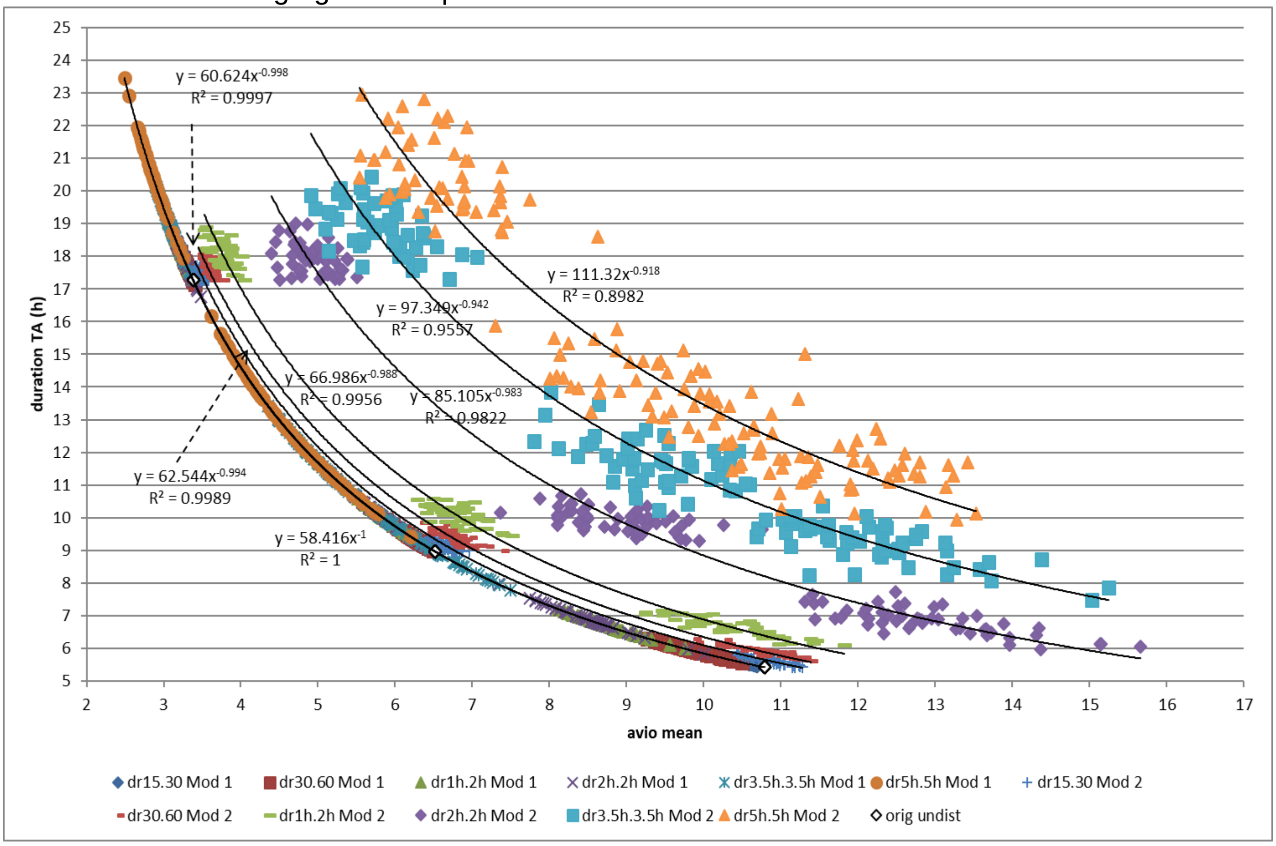

Figure 12 – Simulation results by unlimited resources: relation between overall turnaround duration

and average gate occupation depending on availability of resources that are necessary for the turnaround process of the considered scenarios. Six used colors present simulation results of scenarios constructed by applied distributions

Figure 12 summarizes clustering for both Model 1 and Model 2 for the case of unlimited resources. Acronyms "Mod 1" and "Mod 2" at the end of the cluster names represent relation with the corresponding model.

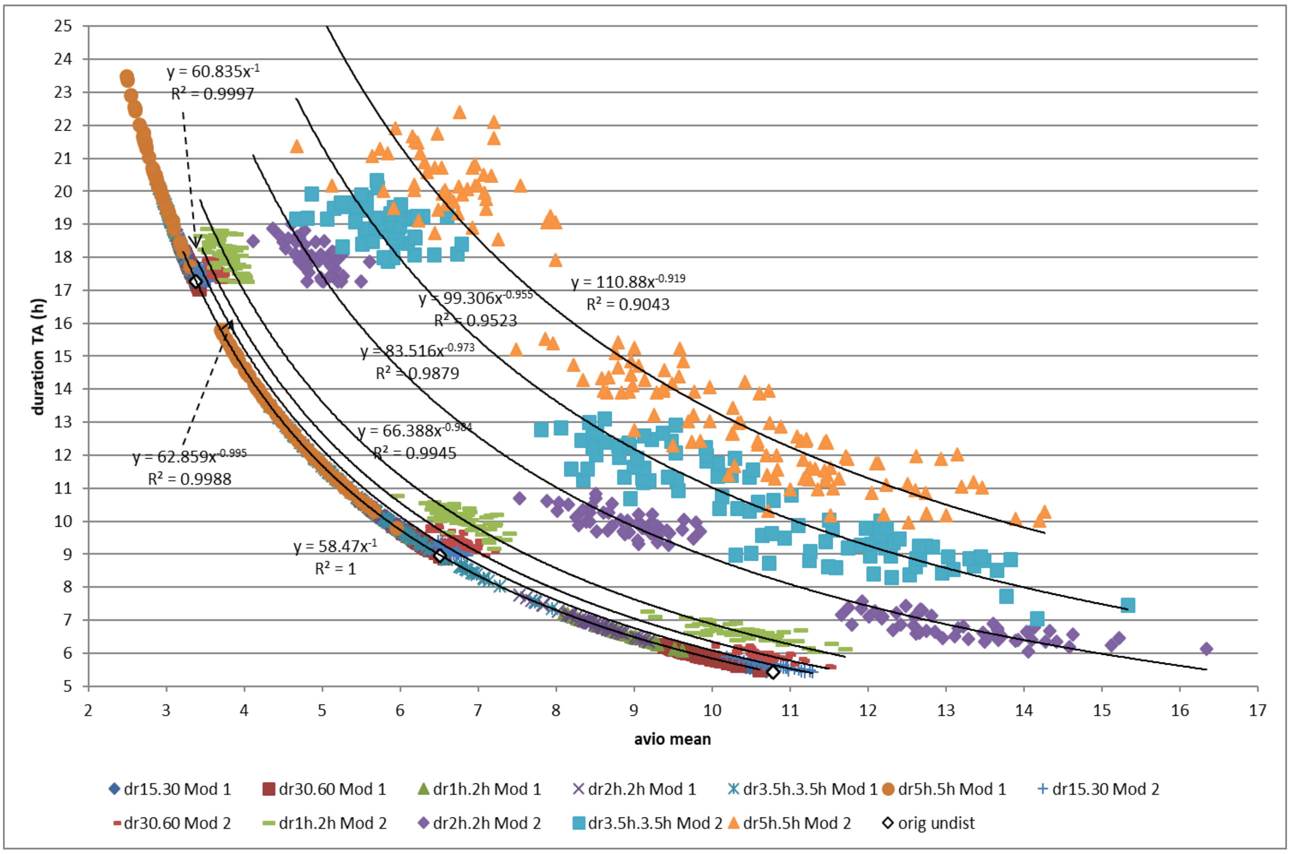

Figure 13 – Simulation results by resources limited by corresponding median: relation between overall turnaround duration and average gate occupation depending on availability of resources that are necessary for the turnaround process of the considered scenarios. Six used colors present simulation results of scenarios constructed by applied distributions

It was already shown in Figure 4, that all six clusters for Model 1 have a perfect correlation and can be fitted by the same power function (Figure 12). This fitting function provides the lower bound for all possible ratios between the turnaround duration and the average gate occupation for the considered demand list. As one can see in Figure 12, each cluster corresponding to Model 2 can be fitted by a power function so that the coefficient and the power of the function grows with growing possible deviation from the scheduled time. The correlation coefficient become smaller, however its value 0.8982 remains high. The coefficient of the power function provides an approximation of the sum of all turnaround times for the considered demand.

Very similar results in the case of corresponding maximal resource bounds by means of median values are illustrated in Figure 13.

As already mentioned, limits MED1 and MED2 were also used in the simulations as stricter limits for Scenario 2, Scenario 3, and for Scenario 3, respectively. Surprisingly, the clustering of all simulation results with respect to the maximal possible deviation from the scheduled time with resources – unlimited, limited by the corresponding median value and limited by the stricter value from less dense scenario – brings again the possibility to fit them with a power function. The fitting functions are shown in Figure 14. They are very close to the fitting functions even for the unlimited case (Figure 12), though with a little smaller correlation coefficient.

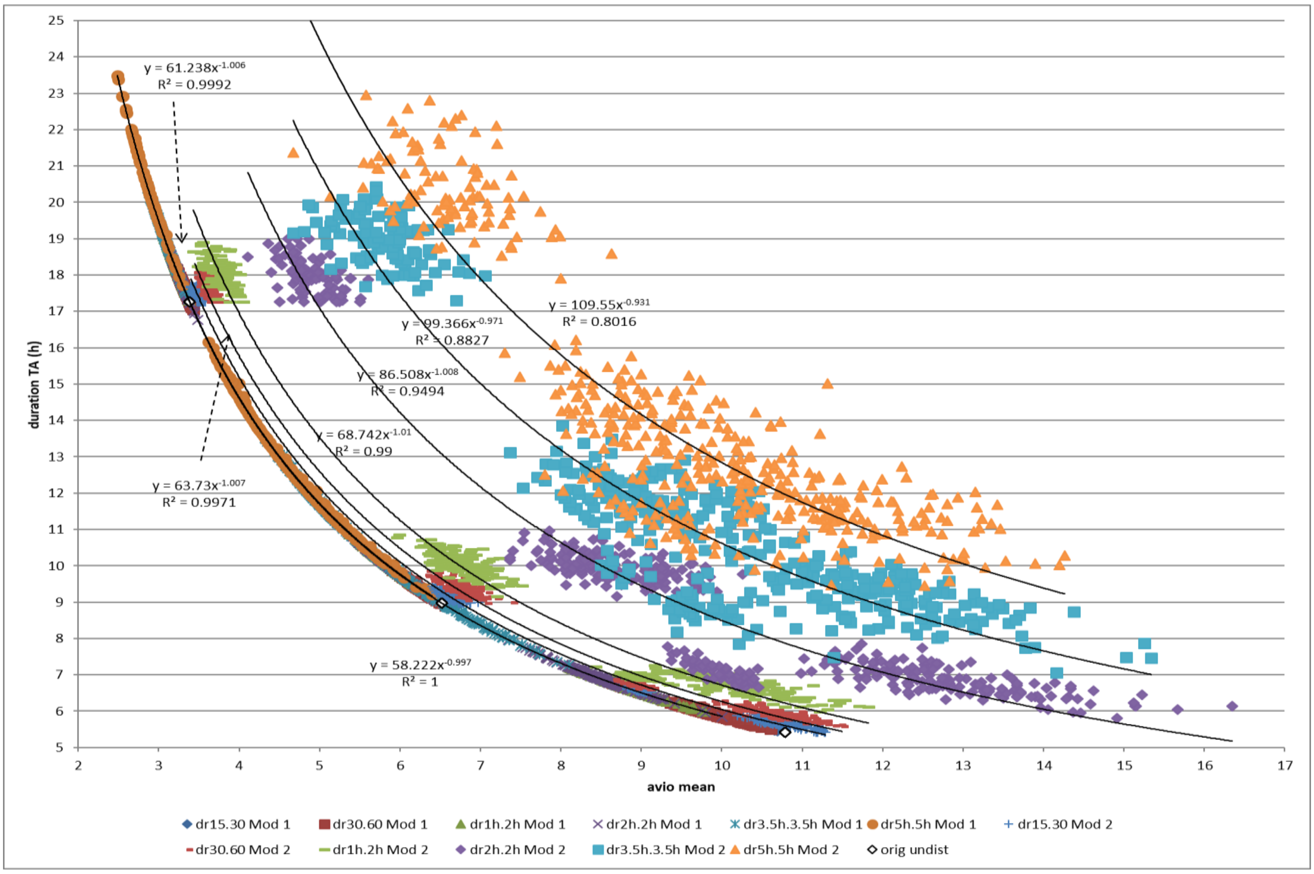

Figure 14 – Aggregated simulation results: relation between overall turnaround duration and average gate occupation depending on availability of resources that are necessary for the turnaround process of the considered scenarios. Six used colors present simulation results of scenarios constructed by applied distributions

5. Conclusion and Outlook

To approximate the resource limits for reasonable overall turnaround durations which are comparable to the simulations with unlimited resources, it is sufficient to use the median values of the maximal numbers of utilized resources.

The data analysis of extensive simulation runs revealed, that the fitting curves for the relation between the overall turnaround durations and their related average gate occupations for different considered availabilities of ground handling resources and traffic demands (for the same list of flights) can be expressed by power functions. Moreover, to approximate the resource limits for reasonable overall turnaround durations which are comparable to the values gained at the simulations with unlimited resources, it is sufficient to use the median values of the maximal numbers of utilized resources over all corresponding scenarios.

As result, fitting curves, which are illustrated in Figure 14, for the relation between overall scenario turnaround durations and their related average gate occupations were found for all six used distributions of demand in Scenario 1 to Scenario 3. Moreover, based on the analysis, quantitative recommendations were made for a reasonable provision of ground handling resources that can cope with different traffic densities. The findings of this study might be valuable to estimate a reasonable utilization of ground handling resources and to calculate the layout of gates for planned or expanding airports to satisfy an expected traffic demand.

It might be of interest for further investigation, what influence on the parameters of the fitting functions would be raised by using specific turnaround models. For example, the distribution of actual in-block time deviations used in the simulations could be replaced by Weibull distributions which might consider airport specific delay patterns [7][8][9]. In addition, the different flight operations (short haul vs. long haul, low budget vs. regular flight) and the characteristics of aircraft types motivate further studies on the subject due to their individual turnaround processing chains.

6. Contact Author Email Address

Lothar.Christoffels@dlr.de

7. Copyright Statement

References

[1] L. Budd and I. Stephen, Air Transport Management: An International Perspective. *Taylor & Francis,* 2016

[2] L. Christoffels and O. Gluchshenko, Sensitivity Analysis to determine the Optimisation Potential of Airport Turnaround Processes for Short-haul Aircrafts, *DLRK 2017 Deutscher Luft- und Raumfahrtkongress*, Germany, 2017.

[3] AIRBUS, A320, Aircraft Characteristics Airport and Maintenance Planning, Revision No. 29 - May 01/15.

[4] H. Ali, Y. Guleria, S. Alam, V. Duong and M. Schultz, Impact of stochastic delays, turnaround time and connection time on missed connections at low cost airports. *Proc. 13th USA/Eur. Air Traffic Manage. R&D Seminar*. 2019.

[5] IATA, *Airport Handling Manual AHM 810*, 2003.

[6] T. Kunze, K Schultz and H. Fricke, Aircraft Turnaround Management in a highly automated 4D flight operations environment, *International Conference on Application and Theory of Automation in Command and Control Systems (ATACCS)* , 2012.

[7] H. Fricke and M. Schultz, Delay impacts onto turnaround performance. *ATM Seminar*, 2009.

[8] B. Oreschko, T. Kunze, M. Schultz, H. Fricke, V. Kumar and L. Sherry, Turnaround prediction with stochastic process times and airport specific delay pattern. *International Conference on Research in Airport Transportation (ICRAT),* Berkeley, 2012.

[9] T. Kunze, M. Schultz, and H. Fricke, An approach for efficient aircraft turnaround operations using automated decision support. *ATACCS. 3rd International Conference on Application and Theory of Automation in Command and Control Systems*. Neapel: ATACCS. 2013.