Microscopic Process Modelling for Efficient Aircraft Turnaround Management

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Abstract—**While the current turnaround handling shows potential for prediction and reliability improvement, the turnaround management approach (GMAN) of the Department of Air Traffic Technology and Logistics at TU Dresden describes a scientific foundation using a stochastic approach for process description and delay modeling. Based on recent air traffic network and delay analysis, new delay input data could be derived for European airports. In a first step to integrate open and closed-loop process control for higher automation levels in turnaround management, the sub-processes of aircraft cleaning and boarding have been modeled and implemented, showing great potential of minimizing aircraft ground time in case of disturbances. Further enhancements to the turnaround model include the integration of the processes pushback and deicing, which by definition are not a part of the turnaround, but can significantly contribute to aircraft delay and therefore need to be considered for airport ground operations.**

Keywords-aircraft turnaround management, closed-loop control theory, automation

I. INTRODUCTION

The Aircraft Turnaround, connecting two flight legs of an aircraft, has been found crucial for keeping up to tight schedules and economic productivity. This does not only apply to airlines but also to ground handling companies and airport operators, all of them trying to maximize the utilization of their respective resources. Unlike the en-route segment of a flight, the turnaround is more complex in terms of involved parties and given restrictions due to technical, legal and operational aspects. Close process dependencies and restrictions also make this "flight" segment vulnerable to process disruptions and disturbances, which will be carried onto the next flight leg and therefore affect the whole air traffic system. This was also recognized by the future ATM research programs, SESAR in Europe and NextGen in the USA, by integrating turnaround operations into the Shared Business 4D-Trajectory (SBT) of a flight. Consequently, the aircraft trajectory on ground does not change spatially but advances in time. The Airport Collaborative Decision Making (A-CDM) initiative shall enable a further increase of predictability in ground operations by introducing multiple milestones for a flight and sharing information between all involved participants of the turnaround.

The aim of our research is to provide airline or ground handlers with an optimum time and place of intervention (using control theory approaches) in case of deviations from the actual planned turnaround. Nowadays this happens by experience of ground handling or airline company's staff, which is more of a best guess method by operators than an objective and valid process strategy granting the propagated target times. Our proposed stochastic model allows the transition from today's commonly used buffer strategies to automated environments by using intelligent prediction and controlling strategies. All important aircraft ground handling processes in the aircraft turnaround are scheduled against the scheduled time of arrival (STA) or the on-block times at the assigned gate (Scheduled In Block Time – SIBT). Deviations to the STA will increase the criticality of the underlying requirements regarding to reliability, high service quality, and punctuality.

Over the past years, our research group at the Department of Air Traffic Technology and Logistics at TU Dresden studied various influences on aircraft ground operations. A study in cooperation with an aircraft manufacturer was carried out to understand reliability enhancements in the aircraft turnaround on a long time period on different German airports. Several technical deficiencies in aircraft design were found, which contributed to uncertainty in turnaround operations. Also, based on representative interviews with ground handling experts, individual impact effects were linked to detailed aspects showing significant potential for improvement on the turnaround reliability for future aircraft design [1].

Analysis of field data gathered as part of our previous research activities has indicated that the delay of incoming aircraft (arrival delay) has a significant influence on the turnaround time. It has also been previously observed that airlines established dynamic buffers strategies to mitigate the disruptive impact of significant deviations in aircraft turnaround time (TTT) and therefore ensure the integrity of their flight schedule. However, no systematic pattern of buffer strategies was found and its efficiency relies mostly again on the operator's experience and available information at the time the disturbance occurs [2].

A detailed analysis regarding to the influence of airport categories (regular hub, non-hub, and supply-base) points out additional variations of turnaround processes [3]. Finally, the varying level of staff skills due to different training principles and expertise was identified as a further major reason for distinct process characteristic [4]. Beside these major findings, several studies focused on our stochastic approach aiming at the detailed characteristics of the turnaround sub-processes such as boarding, fuelling and cleaning [5-7].

II. TURNAROUND

Within the air-to-air process the turnaround has the potential to compensate incoming delay. All actions concerning processes, information, staff and equipment steering within the turnaround can be unified to the so called turnaround management. The ambition of our research activities is, to develop a reliable turnaround management system (GMAN) which integrates all essential knowledge and logic required by turnaround operations on both operational and strategic/tactical levels. Our prior research activities cope with establishing a valid database for turnaround processes, developing a mathematical model to handle stochastic uncertainties and basic delay modeling. This section points out new findings at the delay evaluation of airports, process buffers, and fundamentals for implementing additional ground processes to our model (pushback, deicing).

A. Delay Statistics

Prior research results points out the high influence of flight delays to the turnaround process [1], detailed investigations points out significant influences of the following parameters at the arrival delay:

- Arrival and destination airport,
- Airport category (network function, e.g. hub, non-hub, supply base),
- Time of day, week, month, season, and
- Airline.

To derive a valid arrival delay distribution for better turnaround prediction we use empirical data sets and identify characteristic delay patterns for specific time periods. This analysis is done for four different airports; representing different airport categories (central hub (e.g. Frankfurt, Munich), airline-hub (e.g. Düsseldorf for Airberlin), and non-hub). Observation of specific patterns over time, e.g. high delay at peaks at hub airports, is also accounted for in the delay modeling. In close cooperation with the Center for Air Transportation Research at George Mason University, we extend our database of turnaround process times (based on European airport operations) with delay data from American airports focusing our airport categorization [8]. This step was necessary, because of the unavailability of detailed delay data from European airports. As an example, the histogram in fig.1 shows the distribution of gate arrival delay with respect to scheduled (blue) and flight plan predicted (red) gate arrival times for Atlanta airport (ATL) as an typical example for the delay characteristic. The dotted vertical lines of the corresponding colors represent the mean for both the cases, i.e. 12.16 minutes and 8.59 minutes respectively.

During the last two years we stepwise establish a database, which currently holds more than 60 Mio. flights. One flight entry contains information of flight id, scheduled arrival and departure, arrival and departure delay, aircraft, and code shares. The database was primarily initiated to evaluate the performance of different airline networks, and will be a valid source for the delay statistics.

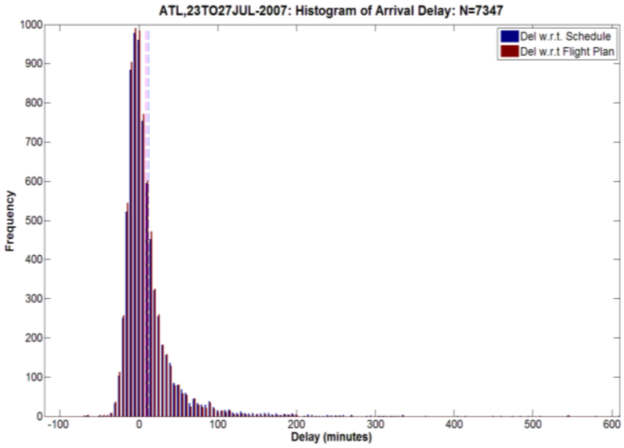

Figure 1. Distribution of Arrival Delay at ATL [8]

With the focus to the airport categories, the database contains a complete set of a 6 year history for the following airports (tab. I).

TABLE I. AIRPORTS IN THE DATABASE

Airport Size (<= Mio. Pax per year)	Airports per Category	Airports (IATA)
1	0	-
2	2	DRS, FMO
4	2	LEJ, BRE
8	10	LYS, MRS, SXF, LED, VLC, HAJ, IBZ, SVQ, BSL, NUE
16	12	OAK, SVO, LIS, TXL, HEL, HAM, GVA, CGN, LPA, STR, LHX, TFS
32	18	PVG, BOS, ORY, IST, MXP, STN, PMI, MAN, CPH, ZRH, OSL, VIE, DME, ARN, BRU, DUS, AYT, ATH
64	14	LAX, CDG, FRA, PEK, MAD, AMS, JFK, BKK, SFO, LGW, DXB, MUC, FCO, BCN
128	1	LHR

The selection of airports was extended to allow for a comparison of "airport-twins" (comparable location, capacity, traffic) and to fill the gap in the traffic characteristic (see fig. 2).

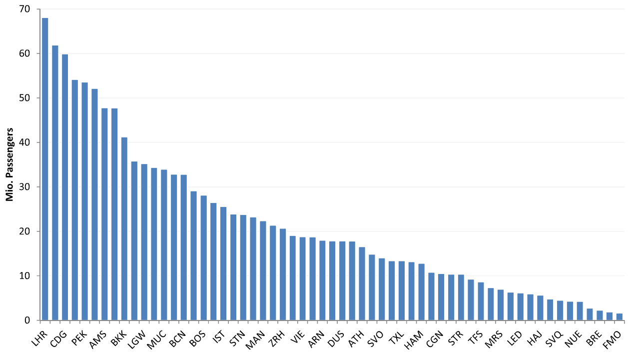

Figure 2. Overview of stored airports

For the delay statistics in the context of the proposed turnaround research, three levels of details are relevant to cover the different view of the system (operational, tactical, strategic). To cover the increasing aggregation demand the arrival delay is analyzed in detail on an intra-day, inter-day (week) and yearly level (season).

The following examples are based on the Munich Airport (MUC) in the time period from 1.1.2011 - 31.11.2011. The dataset contains 192,427 arriving flights, where 162,988 (84.7%) were on time (delay < 15min), 23,469 (12.2 %) delayed flights (delay ≥ 15min), 3,864 (2 %) were not associated with a timestamp and 2,106 (1.1 %) flights were canceled. In comparison to the official 193,899 movements (statistical information of Munich airport) the overall data coverage reaches a level of 99.2 %. In fig. 3 the process of the delay is shown against the daily operations (6:00 to 22:00). This figure does not contain information on canceled flights, because these flights are not assigned to a specific time stamp. It is obvious, that the amount of on-time flights is higher in morning hours than at noon or in the evening section. MUC as a typical air traffic hub possesses the multi peak characteristic over the day.

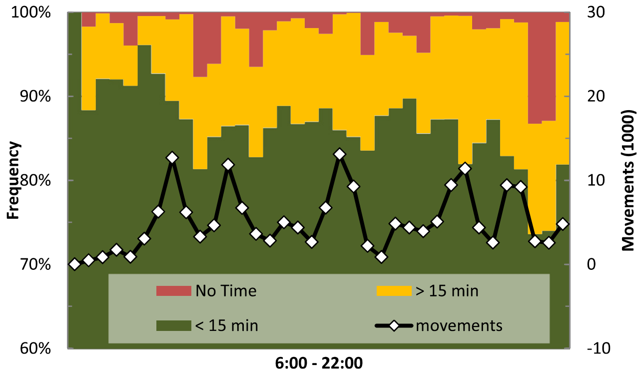

Figure 3. Intra-day delay analysis of MUC 2011

To emphasize both the correlation of time of day vs. delay and arrival movements vs. delay two analyses are shown in fig. 4 and fig. 5. As fig. 4 points out, the correlation coefficient R^2 has a value of 0.542, so more than the half of the delay can be explained by time of the day effects (cumulating delays caused by increasing flight legs).

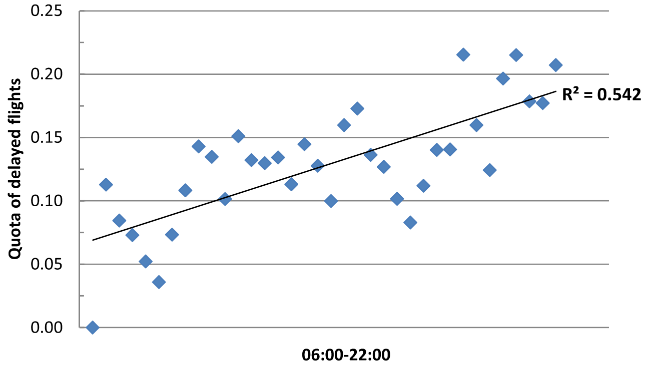

Figure 4. Correlation of time of the day vs. delayed flights of MUC 2011

There is also a significant correlation between the amount of arriving aircraft and the delay (see fig. 5) with $R^2 = 0.24$.

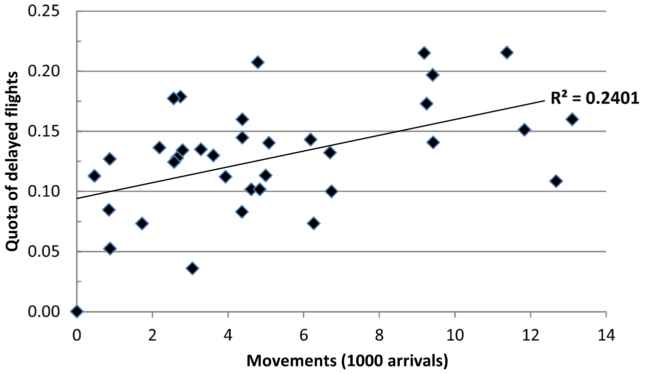

Figure 5. Correlation of arrival movements vs. delayed flights of MUC 2011

As a next step, the inter-day delay characteristics will be focused (see fig. 6). Since the amount of traffic ranges between 23,860 (Saturday) and 29,033 (Wednesday) the amount of delays significantly varies between comparable days (Monday, Tuesday, Wednesday).

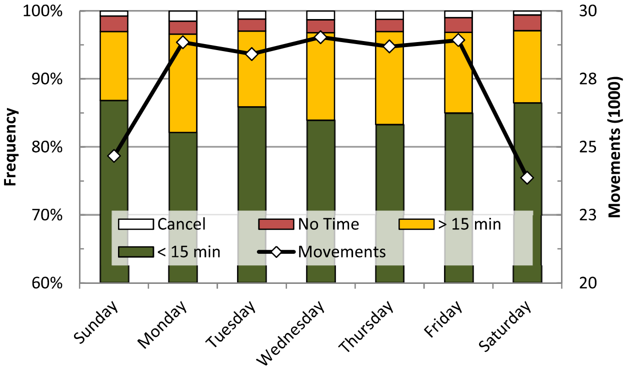

Figure 6. Inter-day analysis of MUC 2011

The comparison of day of week against the amount of delayed flight (fig. 7) reaches the same order of magnitude than the correlation of delay to the time of the day (cf. fig. 4)

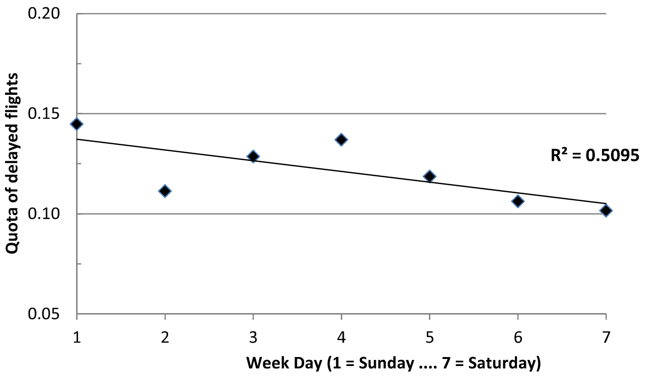

Figure 7. Correlation of week day and amount out of MUC 2011

Finally, the entire year 2011 will be plotted to expose seasonal effects. As fig. 8 points out, a higher amount of delayed flights during the winter period is evident. In the timeframe between 1.1.-28.2.2011 an average of 17.4 % of the flights were delayed or canceled. In the spring, summer period this quota drops to 10.7 % (1.3.-31.8.2011). In the following autumn/winter period (1.3.-31.8.2011) the quota increases by 4.2 % to a level of 14.9 %.

The evaluation of MUC points out the high value of the database for testing the turnaround model against realistic scenarios.

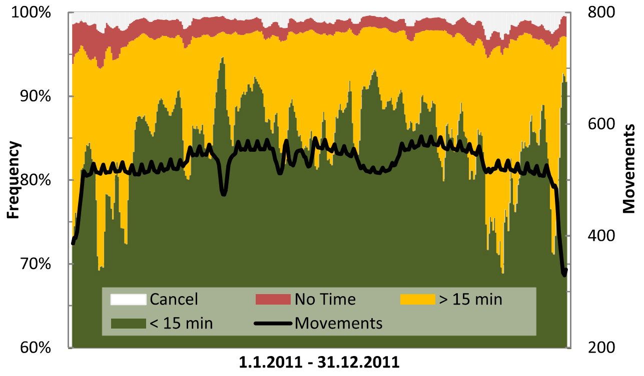

Figure 8. Yearly analysis of MUC 2011

B. *Delay Compensation*

To evaluate the potential of delay compensation strategies, we transferred the empirical findings to our already developed stochastic model [1]. This model copes with the process staring times and the process duration. Contrary to the common understanding that all processes start immediately after deboarding, our analysis clearly showed that a significant time shift is found between the end of the boarding and the beginning of the following ground processes. This time shift behaves like a buffer, which decreases with higher arrival delay and compensate a specific amount of the delay.

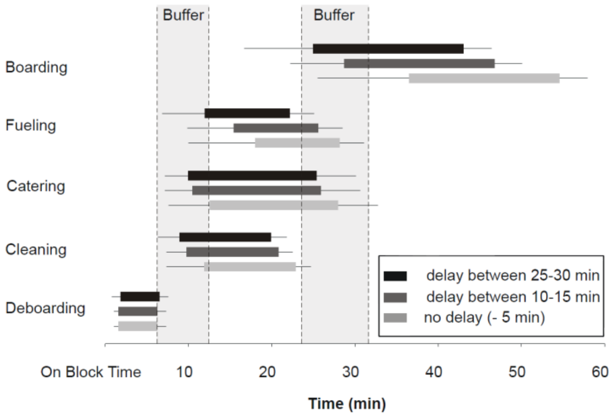

Figure 9. Process shift of turnaround processes with increasing delay [1]

Fig. 10 shows the characteristic shape of the time buffer after the de-boarding. Since the subsequently following processes can only start if the preceded processes are finished, the number of interactions (the following process have to wait) consequently increase with reduced buffer times (see left side of the figure). This effect significantly reduces the impact of planned buffer times. If the delay increases, the buffer compensates the delay only by one-third [1]. This additional compensation effect has a comparable characteristic (but slightly higher magnitude) the buffer between cleaning/catering/fueling and boarding and for the buffer between deboarding and cleaning/catering/fueling (fig. 11).

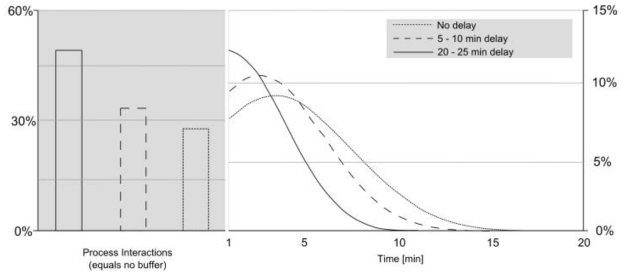

Figure 10. Buffer characteristics deboaring - cleaning/catering/fueling

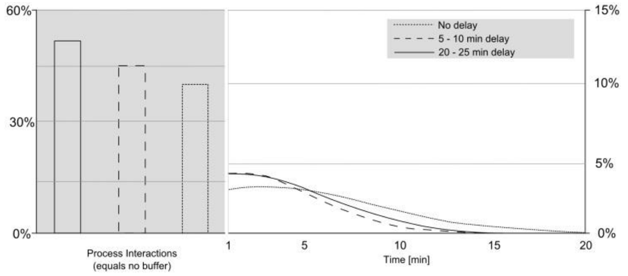

Figure 11. Buffer characteristics cleaning/catering/fueling - boarding

To understand how a single ground process can influence the overall turnaround performance, its individual contribution to the critical path has to be known. Due to the fact that the boarding process is always on the critical path, only the remaining handling processes need to be analyzed consequently. To extend our developed stochastic ground handling model, we will additionally add the handling processes pushback, deicing/anti-icing, and unloading/loading to the process chain. The ground handling model (GMAN) now covers a broad range of significant ground processes, except transfers and taxiing. This will be considered on a more general level by deterministic look up tables, which hold average transfer times for a given traffic scenario [22].

We will stepwise overcome the aggregated view of the delay compensation by modeling each process on a microscopic level (section III/IV). So, some turnaround sub-processes hold the potential to be significant shortened, e.g. by using different boarding strategies or adaptive cleaning procedures.

C. *Extended TA - Pushback*

Evaluating potential bottlenecks at the apron, limited capacities can be identified regarding to aircraft parking stands, apron space, or taxiway layout. To cope with the final take-off sequence planning and to ensure a high reliability of the planned chronological sequence, one significant optimization strategy will most probably be applied to the push-back planning. Even if the pushback defined as subsequent following process of the turnaround, we will include the push-back in our future turnaround model to consider crucial interdependencies and to ensure valid optimization strategies. Therefore will integrate an intern research project which focus on safe and reliable pushback strategies in our turnaround research activities [10, 11].

An aircraft pushback is required if an aircraft is unable to leave its stand by its own power because of the stand design at an apron. Then the aircraft is pushed out by a tug from the stand to a position on the taxiway or to a safe area at the apron. According to the actual standard procedure and used technologies, the pushback process of an aircraft inevitably holds potentials of optimization, and so far is executed with very limited automation support. We are convinced that our detailed pushback analyzes ensure both a significant process optimization and a reliable risk mitigation methodology (adequate collision prevention system for the tug operator). As an example for the pushback process time modeling, fig. 12 shows the classified, empirical times for pushback operations, collected at the German airport Dresden (DRS).

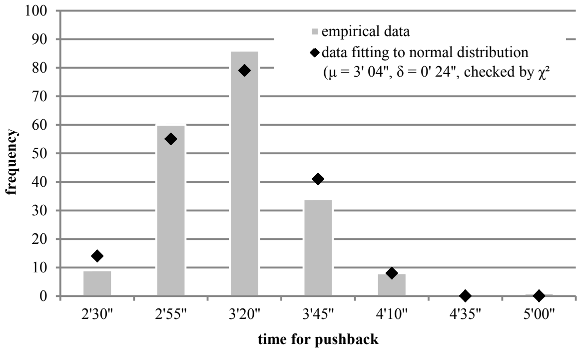

Figure 12. Standard pushback process at Airport Dresden [11]

The pushback operation time is defined therefor from start of the manoeuver up to the moment of visual confirmation of the ground given hand signal by the cockpit crew. On average a pushback at DRS needs 3 minutes for the operation, the disconnection of the tug/towbar, clearing the aircraft (final check, disconnect communication) and the final hand signal.

D. Extended TA - Deicing

Winter conditions crucially result in de-icing/anti-icing processes. Following the Airport CDM Implementation Manual [12] several process requirements are directly impact the turnaround, e.g.:

- Increases communication and coordination between parties and the de-icing companies involved, or
- Bottlenecks regarding to staff and equipment availability, caused by additional de-icing operation.

At winter conditions the surfaces of the aircraft need to be free of ice or solid water. The conditions are temperatures below 4°C and narrows to the dew point and/or solid precipitation. The process can be separated to deicing (removing of ice and snow etc.) and anti-icing, where a special liquid is used to prevent the development of a new coat of ice for a certain time (hold over time). These two processes can be conduct in one or two steps. The liquids have to be applied with special vehicles either on stand or remote on special deicing pads. The anti-icing, de-icing process significantly holds potential of process interference on the apron (e.g. taxi, push back, or gate occupancy times).

In close cooperation with airlines, airports and ground handling agents, we use our expertise in gathering data from field trials. The measurements are consequently transferred to a mathematical description and can be directly implemented in our stochastic turnaround environment. Because the data are subject of non-disclosure agreements, the data are qualitatively shown at fig. 13 considering the deicing duration at three different airports. Quantitative varieties are caused by local specifics, but the characteristics of the standard deviation points out a good consistency between the airports.

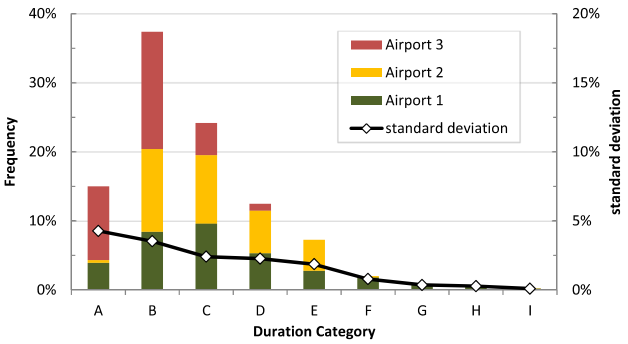

Figure 13. Deicing times at different airports

III. METHODOLOGY – MICROSCOPIC VIEW

The possibility to modify a planned turnaround process exists basically for every (sub-)process. Due to logistical, technical and organizationally reasons two possible changing strategies are available: open-loop control and closed-loop control. While an open-loop control can only adjust process parameters before the start of the process, a closed-loop control monitor changes and there ongoing effects and adjust parameters and properties during process execution. Possible control options comprise of a change in used equipment (e.g. vehicles, doors), change in amount of staff assigned or a change in the conducting of process parts (e.g. cutting out sub-processes and reduce scope of work to “best-fit”). Hence, the turnaround management needs specific information on specific times to change process durations properly to achieve nonstandard target times. In the following section, all main TA processes are analyzed for possible control options. Therefore each process is separated into single sub-processes representing tasks on a microscopic level. Basically there is a core turnaround process, which can be parted into individual tasks. This section describes the processes in a more detailed way, where the following section presents the actual state of our turnaround research. So, the processes of boarding and cleaning are modeled and implemented on a microscopic level. These implementations allows for a detailed process evaluation, optimization and control.

A. Deboarding/ Boarding

The deboarding is the first considered turnaround processes after the aircraft arrives the assigned apron/gate position and contains of no relevant control procedures (individual passenger behavior). In contrast, the passenger boarding, as the final turnaround process, possesses a higher potential for optimization. The process chain of deboarding can be idealized to:

- allocation and positioning of equipment,
- preparation of deboarding (opening doors, clear ways),
- deboarding the aircraft, and
- disembarking special passengers (e.g. wheelchairs).

The boarding process follows the reverse procedure. Boarding and deboarding are mainly influenced by the nature of human interactions and physical possibilities (e.g. walking, stowing items) and the amount of used aircraft doors, which is possesses the highest influence of the process duration [27, 28, 31]. This comes with a certain cost. The allocation, positioning and repositioning of necessary equipment (jetways, stairs, stand positions remote or on gate) requires time and planning effort.

B. Catering

The Catering process includes all handling activities to supply a flight with meals, drinks and service utilities for passenger supplied by the airline. Due to the location of galleys near to the exits, the accessibility is only given, if service personnel vacate this area. The galleys are located at the front and rear exits and additionally next to center exits in a widebody aircraft. Depending on the amount of catering containers one or more catering vehicles at one or more exits can be used. To further allow access to the aircraft via jetway or stairs, the doors on the opposite side of the aircraft are used. The following sub-process can be observed during the catering:

- positioning of equipment (catering vehicle),
- preparation of catering (opening doors, clear ways),
- catering (remove used containers and boxes, restock new containers and boxes),
- post-processing of catering, and
- repositioning of equipment (catering vehicle).

Controlling the catering process is limited by the available aircraft entries and associated with the number of used catering vehicles. The duration of the core processes of changing containers and boxes is constrained by their amount. As a *fast* catering method some airlines use prepared snack packs for short range flights, which are picked up by the crew. In this case, the planned full catering service will be canceled.

C. Fueling

The process of fueling includes all activities on the ramp to refuel the aircraft with jet fuel. It can be transferred from one or both sides of the aircraft. The duration for the core process directly correlates with the fuel amount and therefore with the flight distance. The total fuelling process can be separated into the following steps:

- positioning of equipment,
- preparation (connecting electrical grounding, hoses, determination fuel amount),
- fueling,
- post-processing (remove electrical grounding, hoses, paperwork), and
- repositioning of equipment (fueling, dispenser vehicle).

Due to the fact that the fuel amount is set, controlling is only possible by the number of used vehicles, if the aircraft is equipped with multiple inlets

D. Cleaning

The cleaning of the aircraft interior is separated in different stages and sub tasks. Depending on the airline and turnaround time these are connected to different cleaning service products offered by the ground handler. The following process chain includes activities for common turnaround cleaning, that means further and deeper cleaning tasks can be conducted but mainly at the end of a day – but for this no turnaround management is necessary:

- allocation and positioning of staff & equipment,
- parallel sub-processes, mainly contain remove rubbish, cleaning, restock items, rearrange seatbelts and wipe the seats, lavatories, galley, crew rest, and vacuuming,
- rubbish removing,
- post-processing (paperwork), and
- repositioning of equipment.

Considering the individual demands of the airlines (low cost vs. full service airlines) and the operational requirements (minimum turnaround vs. overnight) a different set of sub-processes and number of staff can be used. Due to the fact that the cleaning activities are mainly done manually only consequent process standardization will allow to control these sub-processes and allowing changes during the cleaning progress.

IV. APPLICATION OF MICROSCOPIC PROCESS MODELS

In contrast to the aggregated system view reasoned by the prior introduced system measurements (delay characteristics, process start times and duration) this section will focus on a more detailed (microscopic) model of the turnaround processes. For this purpose the boarding and the cleaning processes are used as distinguished examples.

A. Passenger Boarding

In contrast to the mixed integer linear program approach [23] or the multi-parameter discrete random process [24], our favored simulation model is based on the asymmetric simple exclusion process (ASEP). The ASEP was successfully used for road traffic investigations. In a close analogy, the boarding can also be described as a stochastic, forward directed, one dimensional, and discrete (time and space) process [25-28, 31]. For this purpose the seat layout (see fig. 14) is transferred into a regular grid consists of equal cells with a size of 0.4 x 0.4 m, whereas a cell can either be empty or contain exactly one passenger. During the boarding process a passenger enters an empty cell on his way to the seat. If the cell in front of the passenger is occupied the passenger has to wait (probability to overtake passengers is set to zero, comparable to the assumption of a one-dimensional transition process). Assuming a maximum speed of 0.8 ms^{-1} at the aisle (60% of maximum passenger speed) [28], the time step has a width of 0.5s. At each time step during the simulation run the position of all passengers is updated via a shuffled sequential update strategy [29, 30]. In the next paragraphs we will provide a highly aggregated view on the microscopic boarding model and its implementation. Closer details about the model and its application are given at [27, 28, 31].

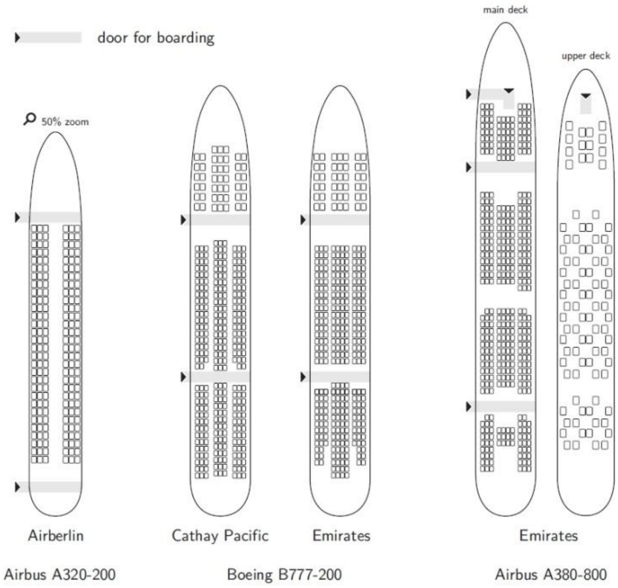

Figure 14. Aircraft seat layout of A320, B777, and A380

The boarding progress consists of a simple set of rules: a) passengers enter the aircraft at the assigned door (based on the current scenario), b) they move from cell to cell along the aisle until they reach the assigned seat row, and c) they store their baggage (block the aisle) and take their seat. Whereas the movement process is only dependent on the next cell state, the storage of the baggage is a stochastic process considering the individual amount of baggage pieces and the seating process has to take into account the occupied state of the associated seat row. In fig. 15 the distribution of the time to store the baggage is shown, considering the amount of baggage and the necessary time effort.

Figure 15. Time to store baggage, depending on amount

In order to speed up the boarding process, it seems obvious to eliminate the required interactions of the seat replacements using defined boarding calls, and three different strategies were evaluated and used for the turnaround optimization: *random* (no special order, benchmark process), *outside-in* (window seats first, aisle seats at the end, see fig. 16, top), and *block* boarding, where the seat rows are summarized to a block. An example of the proposed block classification with 6 blocks is given at the following figure (fig. 16, bottom).

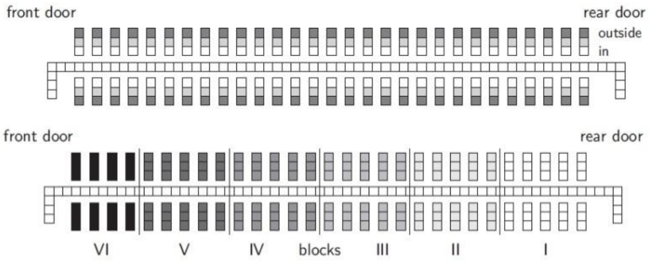

Figure 16. *Outside-in* and *block* seat layout

To allow a reliable and significant statistical analysis of the efficiency of the simulation results, each boarding scenario consists of 10^4 simulation runs. The evaluation of the boarding strategies considered the common parameters conformance rate of boarding strategy (CR), seat load factor (SLF), the passenger arrival rate (PR), the amount of available boarding doors as well as the specific parameters for the *block* boarding: block size and sequence. During the evaluation the proposed layouts of A320, B777, and A380 are evaluated using the following parameter bandwidth:

- SLF and CR ranging from 20% - 100% (default: 85%),
- AR ranging from 1 to 40 passengers per minute (default: 14 at A320 and 28 at twin aisle aircraft B777, A380),
- boarding strategies, and
- One and two door configuration (default: one door).

During the boarding progress the number of seated passengers characteristically increases. In fig. 17 the center line represents the expected time embedded by the corresponding quantiles ($Q_{0.1}$, $Q_{0.25}$, $Q_{0.75}$, $Q_{0.9}$). Depending on the proposed stochastic model the boarding time using the default boarding parameters varies between ± 9% and ± 5% for $Q_{0.1}/Q_{0.9}$ and for $Q_{0.25}/Q_{0.75}$ respectively. The statistic evaluation of the boarding time suggest a normal distributed behavior which is confirmed by a chi-square test using a standard deviation of $\sigma = 7\%$ for the expected boarding time ($\mu = 100\%$).

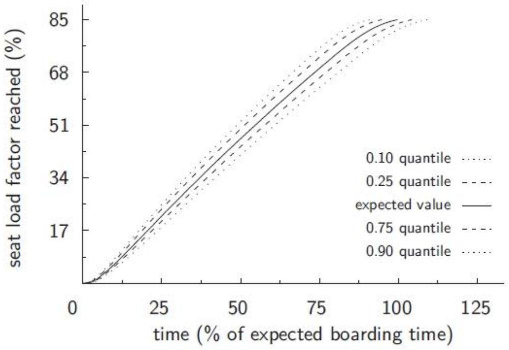

Figure 17. Boarding progress using the default boarding parameters

The detailed analysis points out, that different seat configurations at the B777 (2-5-2, 3-3-3, or 3-4-3) only have a minor influence on the expected boarding time (1-3%) against the time savings due the implementation of boarding strategies (10-15%) or the use of a two door configuration (20-25%), which could be verified at all aircraft. Tab. II contains the results of the boarding analysis. As the boarding is on the critical path of the turnaround, the proposed time savings will be directly shorten the overall turnaround process.

TABLE II. EVALUATION OF BOARDING PROCEDURES

Aircraft	**Doors**	**Procedure**	**Time (%)**	**Deviation (%)**
A320	1	Random	100.0	7.1
		Block	96.1	6.1
		outside-in	80.9	5.5
	2	Random	74.1	4.7
		Block	75.4	4.9
		outside-in	63.9	3.0
B777	1	Random	100.0	2.9
		Block	91.0	2.7
		outside-in	86.0	2.1
	2	Random	73.8	2.2
		Block	76.4	2.1
		outside-in	67.1	1.7
B380	1	Random	100.0	5.9
		Block	95.9	5.3
		outside-in	85.9	4.3
	2	Random	81.4	3.7
		Block	79.1	3.2
		outside-in	73.7	2.3

B. Cleaning

As already described in section III.B the cleaning processes during the turnaround mainly contains four common sub-steps: 1) remove rubbish, 2) cleaning, 3) restock items, 4) rearrange or wipe for seats). This aggregated sub-step model can be applied for all relevant cleaning processes for seats, lavatories, galleys, and crew rests.

In fig. 18 the standard cleaning procedure is marked in green, an approach to fasten the cleaning process is marked in yellow, and the low cost procedure is marked in orange. As the low cost cleaning procedure points out, the seat cleaning only contains the steps remove and restock, which obviously has to result in faster cleaning times. Also the vacuum and the galley cleaning are not executed at the low cost scenario. As a matter of fact, low cost carriers demand the crew of performing the cleaning process to ensure sustainable cost savings, which results in three available persons for the cleaning service. The standard cleaning process is usually executed by four staff members of the specific handling agent. These assumptions lead to a microscopic and appropriate simplified cleaning model.

The *standard* cleaning procedure is additional adapted to a *fast* cleaning procedure by using a limited seat cleaning service (see *low cost* procedure) and the cancelation of the vacuuming. To complete the model of the cleaning procedure the assignments of activities to the specific team member and the timing (process sequences) have to be defined (fig. 19).

Figure 18. Sub-steps for the aircraft cleaning process

The parallel cleaning of lavatories and galleys followed by the seat cleaning ensures a cleaning duration at the same order of magnitude as the low cost clearing procedure (but with one additional staff member).

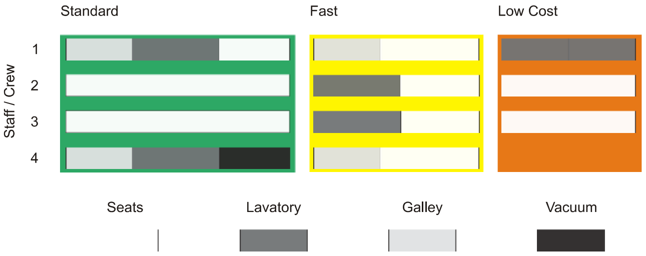

Figure 19. Boarding progress using the default boarding parameters

To stochastically model the cleaning process, two ways to calculated the cleaning duration are chosen: a) an analytical approach and b) a numerical calculation model. Both ways have to provide the ability to handle the progress status of each sub-process (e.g. 40% of the seats are cleaned) a normally distributed behavior of the process duration will be assumed, since the convolution of independent, normally distributed values results also in a Normal-distribution N(μ, σ), with the expected value μ and standard deviation σ.

$$\mu = \sum_i \mu_i \quad \text{and} \quad \sigma = \sqrt{\sum_i \sigma_i^2}\ . \tag{1}$$

This behavior allows to breakdown each cleaning step into elementary progress states and a linear combination of these intermediate results. A separation into n parts results according to (1) in $\mu_i = \mu/n$ and $\sigma_i^2 = \sigma^2/n$. Using the cleaning process as an example with n = 6, μ = 4.1 s per seat and cleaner, σ = 1.4 s, 1 cleaner, and 150 seats to clean, the stochastic distribution of the process time at each corresponding readiness level is shown at fig. 20.

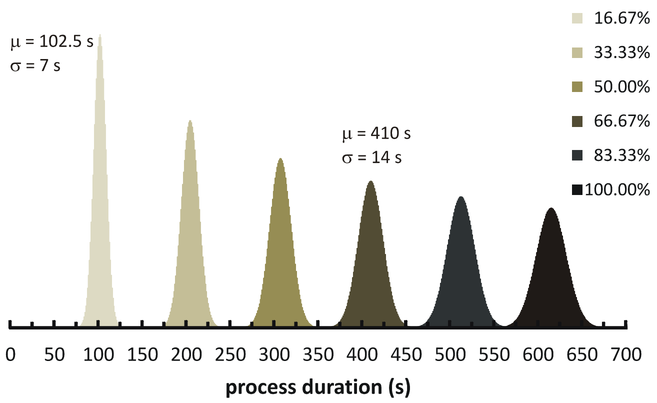

Figure 20. Seat cleaning progress time using 6 readiness levels

This stochastic approach allows for considering provided timestamps at each progress level and is able to continue the real timestamps with the underlying stochastic data set. As fig. 21 points out, the progress of the cleaning can be stochastically anticipated. At each delivered time stamp (coming from the real process) the stochastic model updates the process duration resulting in a continuously enhanced accuracy. If the deviation from the planned progress exceeds a given value, the responsible operator can influence the progress by e.g. resource requests and he will simultaneously increase the update rate of the monitoring system (prioritization). On the other side, a process with a clear tendency to meet or deceed the target time, may detached of the interest of the controller (lower update rate).

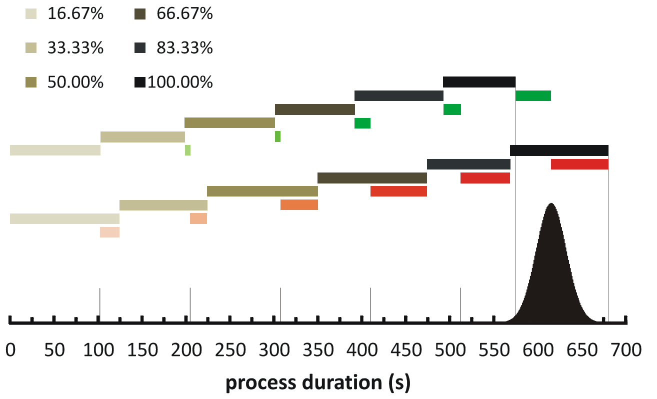

Figure 21. Comparisson of two different seat cleaning progresses

The update rate of the progress duration exhibit a minimum, which is caused by the assumption, that a reached system status cannot be withdrawn by the next update. Since the Normal distribution is not limited to positive values, the expected value μ and the standard deviation σ are used to define the following constraint:

$$0 \geq \mu - 3\sigma \;. \qquad (2)$$

According to (2), only 0.135% values will be smaller than zero (3σ environment), which is defined as an acceptable limitation. So, for each time step the corresponding values for μ and σ for the time range of the next update have to check against (2).

To provide a solid basis, field measurements are done and the data are statistically analyzed focusing the requirements of model. The process times for each sub-step during the cleaning are listed in tab. III. and will be used for the following test implementation. Each process duration will be equally assigned the process sub-steps (remove, clean, restock, rearrange).

TABLE III. PROCESS TIMES FOR CLEANING

Process	**Duration (s)** μ	**Standard Deviation (s)** σ
Seat cleaning	4.1 (per seat)	1.4
Lavatory cleaning	115	17
Galley cleaning	149	45
Vacuum	120	36

C. Test Implementation of Microscopic Cleaning Model,

Since the boarding model was already applied and demonstrate its capabilities to the optimize the turnaround duration, the cleaning model will now implemented. The progress of the cleaning for the standard procedure (see fig. 18/ 19) is shown in fig. 22 using the measurements of tab. III on A320 with 180 seats. One cleaner starts at the front galley and the lavatory, and one cleaner start at the end of the aircraft with galley and lavatory. The other two simultaneously begin to clean the seats. If the cleaner at the front is finishing he changes to seat cleaning, whereas the other cleaner continues with the vacuuming. This task change occurs at 71.5% of readiness level of the seat cleaning. The dotted line at fig. 22 emphasize the speedup of the seat cleaning by the additional cleaner.

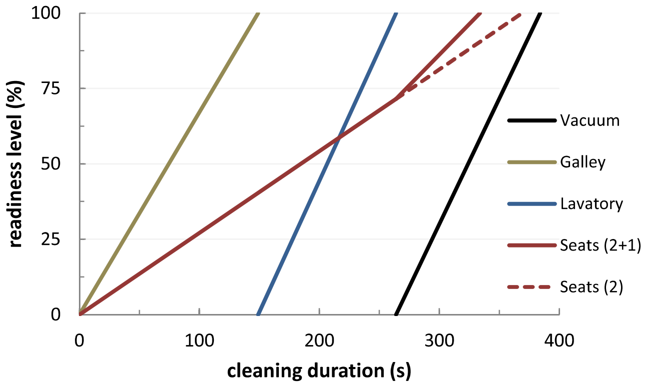

Figure 22. Readiness level for each sub process of cleaning using the standard cleaning procedure (expected values are plotted)

In accordance with the assumption of a stochastic approach with normally distributed durations the expected values have to be seen in association with the corresponding standard deviations. To determine the end of the cleaning process the maximum of duration of the seat cleaning ($\mu = 334$ s, $\sigma = 19.4$) and the end of the vacuuming ($\mu = 393.4$ s, $\sigma = 47.9$ s) has to be taken (see fig. 23).

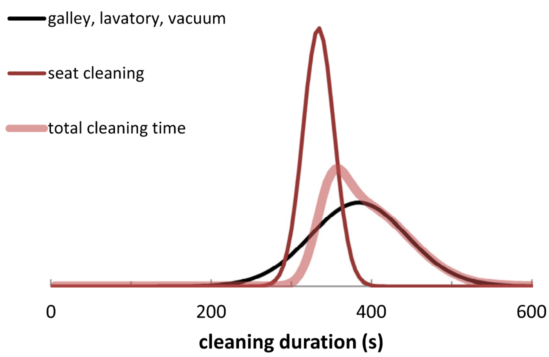

Figure 23. Characteristic of the cleaning simulated with 10^5 simualation runs

Finally, the impact of the shortened processes on the turnaround has been evaluated (fig. 24 and fig. 25) . Since the *outside-in* boarding already reduces the boarding time, the *fast* cleaning procedures holds also a high potential to reduce arrival delays.

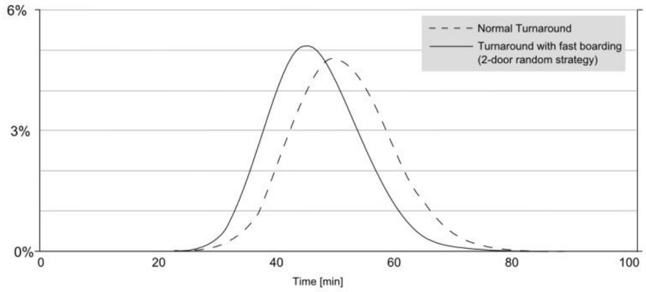

Figure 24. Progress of turnaround using faster boarding procedures

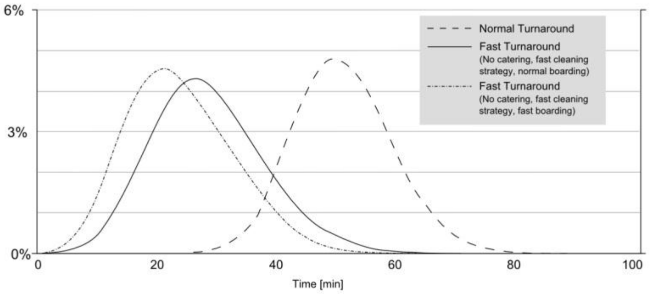

Figure 25. Progress of turnaround using faster boarding and cleaning procedures in association with a no-catering policy

V. OUTLOOK

Single parts of our turnaround management system GMAN were already validated in field. The next logical step is to show the proposed key features of TTT prediction by stochastic process descriptions and basic control options in a live airport environment. Therefore two projects with a small and a hub airport are in progress – giving the opportunity to validate the system in different environments. The GMANs stochastic process descriptions will be respectively adjusted by local data. Running in a shadow mode the TTT prediction will be validated by comparing it with the timestamps generated in live airport operations. Control options will be extended beyond the two presented processes and control strategies based on cost functions will be developed, allowing an automated decision support for finding the optimal intervention option by means of delay and cost minimization. Furthermore the ongoing research in delay and network management will be intensified with other academic institutions and enterprises.

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