Improving Aircraft Turn Around Reliability

Specific Aircraft Body Design Parts hamper Ground Handling and Airport Performance

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The Airport, and specifically the turn around time (TAT) of aircraft at the gate or a remote position from the terminal have been recognized as crucial element to ATM system performance. Currently, the TAT ranges around 30 min for short/medium range aircraft. For the 2020 Single European Sky, SESAR claims as performance target for a cut down to 15 min while also increasing process reliability. There are several reasons, why the turn around is still remarkably uncertain, mainly caused by shared responsibility for the individual ground handling processes, a frequent distortion of gate occupancy schemes at the airport and still deficient interfaces with the aircraft body. All this leads to only a limited predictability of the "Earliest Off Block Time", this being an important time constant to trigger the departure and consequently the arrival sequence. This paper reveals the current data quality as found during a large field study at German Airports, derives the reasons for largely varying process times both on the technical and procedural level and shows the potential for improved TAT reliability through aircraft interface optimization.

Aircraft Turn Around, Aircraft Body, Ground Handling, Boarding, Critical Path, Monte Carlo Simulation

I. INTRODUCTION

The Turn Around Time (TAT) of aircraft has been defined by IATA's Aircraft Handling Manual (AHM) 810 [1] as the time period an aircraft occupies a stand or a gate at the airport. More specifically this period is framed by two activities: The positioning and removal of the aircraft wheel chocks, respectively named as On and Off Block Time. As this time is directly impacting the airport / terminal capacity, there is a vital interest in predicting exactly the Gate Occupancy Time (GOT) by means of stable ground handling processes from the Airport Operator's point of view and a similar one in minimizing that time from an Airline's perspective since block time is commercially lost time. The GOT has therefore become a central planning parameter for Airport / Apron Terminal Design Processes [4]. The largest component during on block is the boarding and de-boarding of passengers, as field measurements clearly show [2]. Hence, it could also be learned, that ground handling events are characterized by a remarkable diversity in processes, occurrence of such processes and their service depth, making every aircraft turnaround somehow a unique procedure in terms of required times, interfacing and services. Our referred field study was performed in summer 2006, to learn about these constraints and to gather relevant data with the aim to exploring ways how to improve the reliability of and also shorten the time needed for a Turn Around. This with SESAR's performance target in view, to cut down the TAT for domestic flights to 15 min, and 30 min for international flights [5].

Chapter II presents the results of that field study; chapter III discusses the management of the gathered data in a relational database to allow systematic analysis and dissemination of the results to the various stake holders. Chapter IV reveals the statistical data modeling to determine the level of reliability in today's Turn Around operations by means of Monte Carlo (MC) Simulations, Chapter V creates an improved aircraft interface scenario and derives the expected increase in Turn Around reliability, again by applying MC modeling.

II. CURRENT TURN AROUND PRACTICE

A. Overview

The Turn Around has been described in several studies such as [6], many of them putting emphasis on the boarding and de-boarding processes, [7], [8], [9] and is also part of many standard documents such as the *Aircraft Characteristics For Airport Planning Manual* of any modern aircraft [3]. It is generally represented as a bunch of processes, from which a subgroup may run in parallel, and others are required to run sequentially, e.g. due to legal or logistical requirements such as limited space around the aircraft, tool availability, or legal constraints such as to prohibit Fueling with Passengers onboard.

The collection of sequential processes consuming the maximum time during turn around is called its *critical path*. As stated, typical process members of the critical path are boarding, de-boarding, fueling, loading, unloading and service processes such as cleaning or catering [2], [3].

The following picture depicts the typical process and dependencies:

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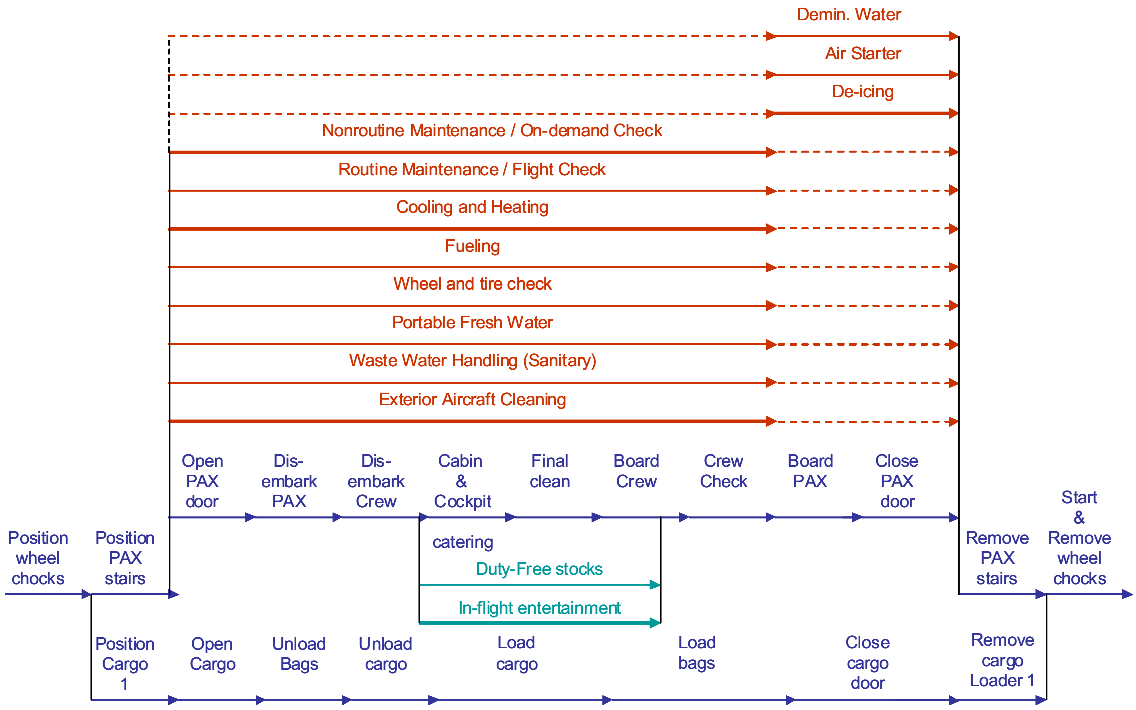

Figure 1. Parallel and sequentiel Turn Around Processes

B. *Set up of the Field Study*

To identify possibilities to reduce individual process times and their expected remarkable variance in time especially on the critical path, the field investigation aimed at exploring potential changes to the aircraft-design and arguments for innovative technologies to be installed in the aircraft or applied on ground in order to smoothen and accelerate the ground services resulting in shorter turnaround times with increased reliability.

This activity shall be seen in concert with e.g. the physical implementation of supervision technologies such as process scanning and tracing devices or e.g. data networking at the apron, as e.g. [6] is calling for, and modification of current legal regulations (see Chapter III).

The datasets collected had to cover nearly all models and types of Airbus-manufactured aircraft and at least some representative Boeing aircraft. It was further anticipated to consider different airport types, such as the Hub-Airport Munich (MUC) and mid size airports such as Leipzig/Halle (LEJ) and Dresden (DRS) in Saxony. The data gathered also covered interviews with ground handling staff as well as detailed time sequence measurements to allow determination of specific process indicators (fuel quantity, passenger rates, etc., see TABLE I.). Further, process interruptions due to limited or distorted logistics were noted.

These data did form the platform for various process analyses looking at optimization potential. Based on the Aircraft Handling Manual [1] providing a detailed framework on how to cluster and categorize ground handling services, then extended for the boarding related activities, the following collections of services were gathered (see also Figure 1.):

- Aircraft Servicing (covering exterior services, such as water and lavatory service, e.g. attachment of stairs and passenger bridges);
- Loading and Unloading (on- and offloading of belly payload, container and bulk);
- De-boarding (differentiating in remote and gate positions as well as number of doors used);
- Catering (Handling at Ramp);
- Interior Cleaning (including cabin and crew rest compartment cleaning);
- Crew Change and Cabin Preparation (including duties to be performed by cabin crew);
- Boarding (hence without distinguishing into different boarding procedures, this later recognized as important data and being subject to further studies at TUD); and
- Fueling (number and location of fuel valves used).

Based on that structuring, the measurements performed in the field did include timestamps assigned at the lowest observable level, so linked to a process, task or element as respective sub-processes. A distinct process start and end was required to be observed. As such, those timestamps were tested on their traceability and practicability before they were implemented into the process templates (see Figure 2.).

The field studies needed for this research were kindly supported by Airbus Deutschland, Dresden, Leipzig/Halle and Munich Airport, and the Ground Handling Agents Mucground and Port Ground.

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At some processes, intermediate timestamps were defined in order to allow gathering information about process interruption times, waiting times or other intermediate points (milestones). Besides collecting time sequences, the sampling of the following additional information affecting the turnaround was performed:

- Manpower (amount of personnel performing a specific process, task or element)
- The equipment types used;
- The equipment quantities;
- Load figures (e.g. Passenger figures, Seating, Baggage-, Cargo-, Mail-figures etc.);
- Aircraft layout information (if possible: amount of lavatories, galleys, etc.);
- Transfer volumes (e. g. fuel quantity figures).

The various data collection templates designed for the field activity are depicted in the following figure e.g. for the loading case[1]:

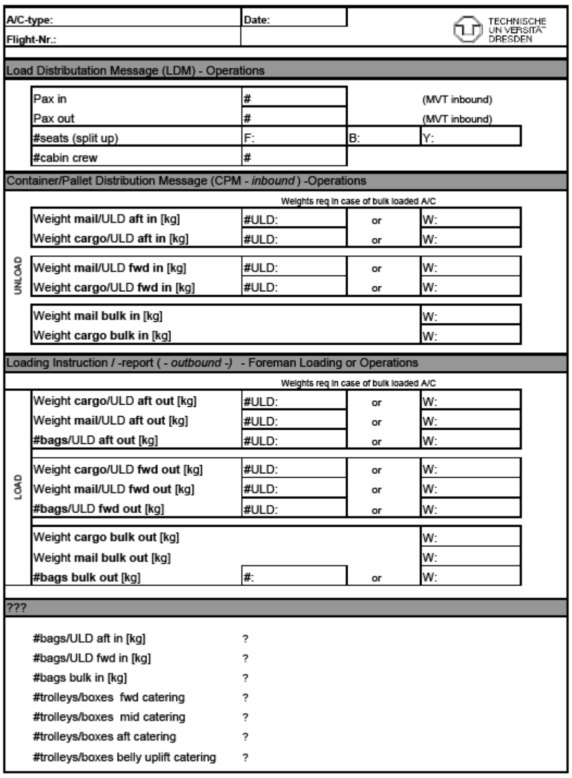

Figure 2. Data collection template, the loading case

C. The Collected Data: A Web Application

To allow efficient handling of the remarkable amount of data collected, a relational MYSQL Database was implemented. Further a PHP application was designed so forming a powerful web application to create easy access to the data, and providing a clear structure and documentation platform:

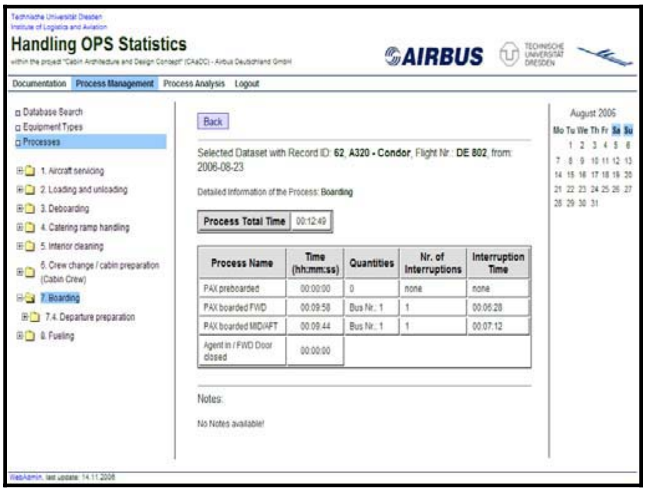

Figure 3. Web Front end to access data of Turn Around Database

D. Data preparation for Turn Around comparison means

For each of the analyzed processes, and sub-processes, dedicated values were derived from the field measurements in order to allow comparing the individual turnarounds. The following parameters were defined for the individual processes [2]:

TABLE I. SPECIFIC PROCESS PARAMETER

Specific Process Data generated (extract)	
Process	***Value Subhead***
(De-)Boarding	A/C (De-)Boarding Rate [PAX/min]
	A/C (De-)Boarding Time [min]
	Avg. Boarding Flow Interruption Time [min]
Catering	Catering Time Split up AFT Galley [%]
	Catering Time Split up FWD Galley [%]
	Total Catering Vehicle retention time [min]
Cleaning	Cleaning rate [per seat]
	Cleaning Time Cabin, Lavatory, Galley [min]
Fueling	Average Fuel Flow rate [l/min]
	Starboard/Portside Fueling Split up [%]
	Tanker-Dispenser Split Up [%]
(Un-)Loading	(Un-)Loading AFT/FWD [ULD/min]
	(Un-)Loading Bulk [kg/min]
Servicing	A/C Service Vehicle Retention Time [min]
	Pushback Waiting and Standby Time [min]
	A/C Servicing Equipment Split up [%]

These specific data could be sampled for <u>over 120</u> complete turn around events, measured at the three sites MUC, DRS and LEJ.

[1] ULD = Unit Load Device, Standard cargo container. Typical dimension: 317cm length, 243 cm width, 299 cm height. Various subclasses do exist according to IATA coding definitions.

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III. Statistical Process Data Analysis

A. Legal and Procedural constraints

In accordance with ICAO Doc 9626, the Manual on the Regulation of International Air Transport [10], ground handling consists of those processes as listed previously and implemented in our database. Further, the ICAO Doc 9562 Airports Economics Manual [11] separates ground-handling services into terminal handling (passenger check-in, baggage and freight handling, flight plan processing) and ramp handling (aircraft handling, cleaning and servicing). For all of these processes, operational interdependencies do exist, limiting the parallelizing of these processes, as the area around the aircraft is very limited in light of the various service equipment used during ground handling. Further, legal requirement call for granted maneuvering capability for the fire brigade on one side (typically located right hand to the aircraft) and passenger related activities (stairs typically installed left hand).

Obviously, Airlines and Ground handling companies are permanently investigating into possibilities to reduce process constraints, since further parallelizing of processes besides mainly fueling, catering, cleaning and servicing nowadays as found during the field study and shown in Figure 4. is seen as mandatory to substantially reduce the TAT. This aspect will be focused in subsequent papers.

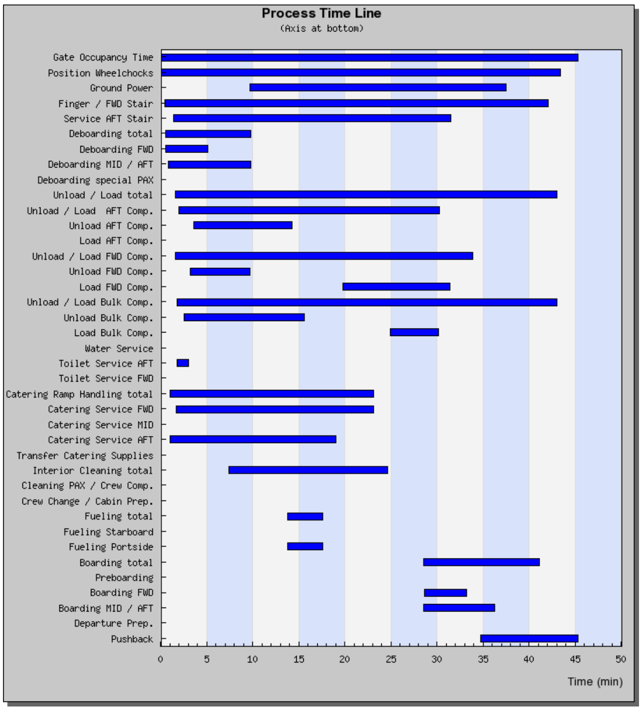

Figure 4. Sample Paralel Processing during turnaround – field study

Candidates for (increased) parallelized processing so remain

- loading/unloading and
- fueling.

Further,

- shortening and
- increasing the reliability of the boarding and de-boarding time

do represent a second field for improvement, being subject of this paper. Investigation was consequently directed into the technical aspects of these processes in the field for getting a clear picture of all operational requirements and systematic deficiencies linked to them, presented in the next section.

B. Technical constraints

Based on the interviews done with ground handling personnel in the field and observations gathered during the monitoring phase, the following representative process distortion cases were found [2]:

TABLE II. Technical Deficiencies at Turnaround

Technical Deficiencies at Turnaround (extract)	
Process	***Deficiency***
(De-)Boarding	Installation of second passenger bridge on gate position does not result in the time saving of the two passenger stairs on remote position due to the marginal distance between the two doors.
Boarding	Boarding is influenced by the mutual obstructions of the passengers.
Catering	The catering door is opened by the purser after all passengers left the aircraft and the catering vehicle arrived on position. Usually, the employee signalized his arrival by knocking at the door which is occasionally not realized by the crew and result to a delay of the beginning of the process.
	Leaving of the vehicle affected by obstructions because of loading equipment especially on smaller aircraft with bulk load.
Cleaning	High quantity of waste produced because of in-flight services. The lack of disposal units leads to defilement of the aircraft and time consuming removal by the cleaning staff.
Fueling	Obstructions between the service vehicles result to delayed start of the fueling process and a non-compliance of the safety requirements
	Simultaneous fueling on both wings enhances the flow rate not to the double of a single side fueling
	The fuel computer has problems calculating the exact filling quantity due to temperature variations. So, the centre tank is opened too late and fuelled with a flow rate lower than for the other tanks.
(Un-)Loading	Cargo Door: Panel for opening hatches of the A300, A330 and A340 attached to high to be reached manually by all personnel
	Conveyer belts used for (un)loading bulk. Height of aircraft influenced by the current weight of Payload and Fuel. Permanent Altitude adaptation needed inducing repositioning of the equipment
Servicing	Cockpit misses the information about the removal of the GPU by the loading crew. However, clear commitment necessary before disconnection.
	Reasoned by weight of the adapter, negative effects can occur for the employee by attaching the unit as well as for the holding of the plug connection itself.

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Figure 5. Physical Deficiencies : Displaced Control Panel for cargo door (left) / Manual positioning of load compartment (right)

To conclude, quite a bunch of technical deficiencies were found during the field study that effectively hamper the manual and also partly automated activities during Turnaround in terms of delays and consequently reduced reliability for process times.

The following section looks into the turnaround database and determines the statistical behavior of the processes.

C. *Determination of Process Stability*

To determine the nature of the generated process descriptors as listed in TABLE I. typical density distributions were compared to the data. Since the data has a non normal distribution character, a WEIBULL density function f(x) with α and β as shape parameter was finally selected for probing the data fitting, since it is most commonly used in life data analysis and due to its flexibility. It can mimic the behavior of other statistical distributions such as the normal and the exponential. A Weibull distribution may generally written in the form

$$f(x,\alpha,\beta) = \frac{\alpha}{\beta^{\alpha}} x^{\beta-1} e^{-(x/\beta)^{\alpha}} \qquad (1)$$

Where x >= 0 and f(x) = 0 for x < 0
x to substituted by (x += x_offset)
α = scale parameter
β = shape parameter

For all processes found to be timely critical during today's turn around (see Figure 4), data distributions were analyzed, statistically tested on its significance against chi-square. The probing procedure is shown exemplarily for the de-boarding process, referring to the process parameter passenger rate per door [PAX/min] to allow normalizing of the varying seat load factors. It may be noticed that for some processes, an offset is required to adopt the data range to the Weibull distribution by *x_offset*. For the sample case presented below, this offset is at 10 PAX/min:

De-boarding:

x-Offset:	10 [PAX/min]
Number of counts:	97
Minimum flow rate:	4,1 PAX / min
Maximum flow rate:	38,9 PAX / min
Number of classes:	10 (see TABLE III)
Class with:	4 [PAX/min]

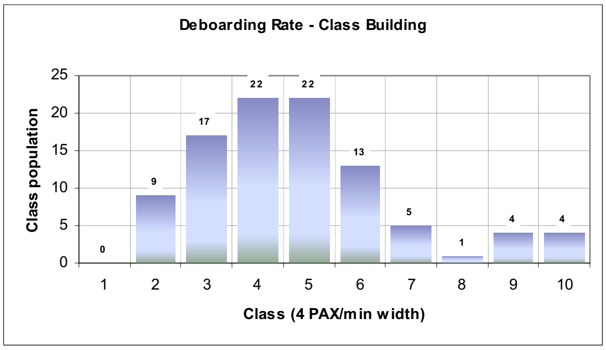

Figure 6. Class Building for the De-Boarding Case

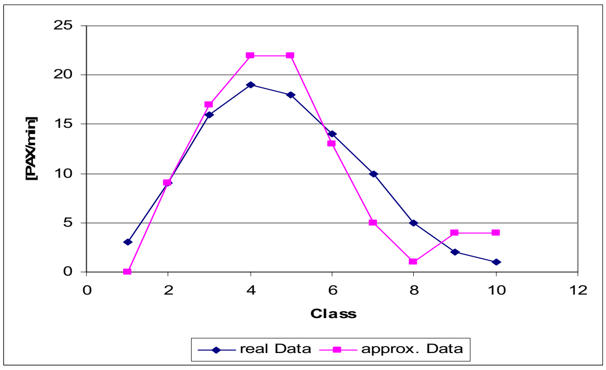

Figure 7. Approximated versus Real Data Distribution – De-boarding case

TABLE III. STATISTICAL FIT AND PROOF DATA – DE-BOARDING CASE

Statistical Fit and Proof Data	
(De-)Boarding [PAX / min]	***Value***
Class number logic	5 log(number of counts)
α	2.23619
β	19.2339
x offset	10
Mean	17,0354
Standard Variation	7.92729
Variance	0.465343
Density (Weibull)	$0.0030067\ e^{(-0.00134457\ x2.23619)}\ x^{1.23619}$
Distribution	$1 - e^{(-0.00134457\ x2.23619)}$
Chi²	10,3228
a	0,05
Proof	12,5916
Pass Status	TRUE

For some other timely critical processes, the following distributions are depicted below, showing the remarkable magnitude in the distribution variations:

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TABLE IV. REAL DISTRIBUTIONS – CRITICAL TA PROCESSES

Real Distributions – Critical TA Processes	
(De-)Boarding [PAX / min]	***Value***
α	2.23619
β	19.2339
x offset	10
Boarding [PAX / min]	
α	2.29263
β	19.5224
x offset	0
loading AFT&FWD [bags / min]	
α	3.13022
β	165.289
x offset	0
Unloading AFT&FWD [bags/ min]	
α	4.05691
β	215.208
x offset	0

These parameter sets do allow sorting the processes against their stability, as with α (scale parameter) tending to smaller values and β (shape parameter) tending to larger values do express increasing variance of the distribution. It comes to the following ranking:

1. Unloading
2. Loading
3. Boarding
4. De-boarding

As observations did further show, the reason for this inter-process uncertainty trend refers to the varying standardization and automation level of the individual processes as well as the quality of technical support means, as described above.

IV. UNCERTAINTY EFFECT ON THE TURN AROUND

When accumulating the critical processes along the line, the agglomeration of all partial process uncertainties will obviously induce a total uncertainty for the turn around. To determine the magnitude of that total variation, analytically modeling was replaced in favor of statistical random probing. This was achieved by applying the Monte Carlo method, relying on repeated random sampling of all critical processes, using the calibrated distributions as found above. The results are presented in the next section.

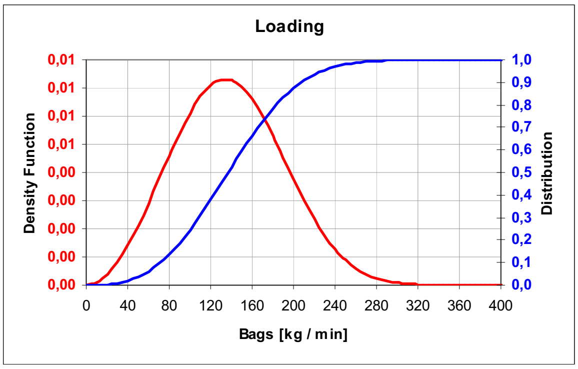
A. MC Simulation for overall turnaround uncertainty determination

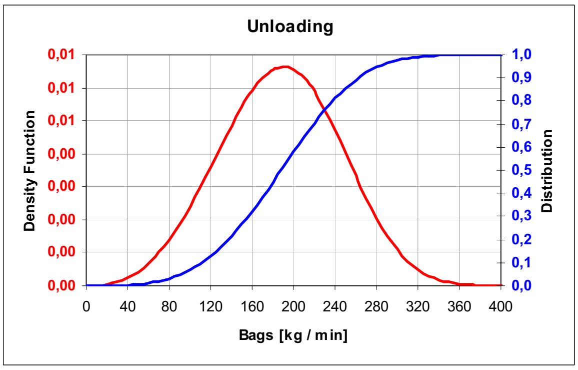
The processes

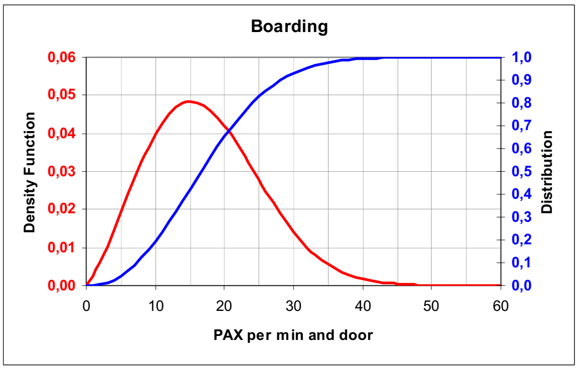
- boarding, including the emphasis on the door closing procedure after the last Passenger did board, de-boarding, obviously running in sequence;
- loading and unloading, obviously running in sequence, too, and
- either fueling, catering or cleaning, all running in parallel

have been identified as critical processes according to Figure 4. Concerning the fueling process, process interruptions were recorded on a regular basis, resulting from the fact, that fueling is generally initiated by the responsible personnel without knowing the exact quantity beforehand, to be ordered by the cockpit crew. So a typical volume is being fueled in a first step, than for most of the tracked cases, a break occurs within which communication takes place and the exact quantity will be told. This effect was also included in the process modeling.

The following density and distribution shapes do result from functional fitting as presented in Chapter III, reflecting also the x offset applied to the de-boarding case:







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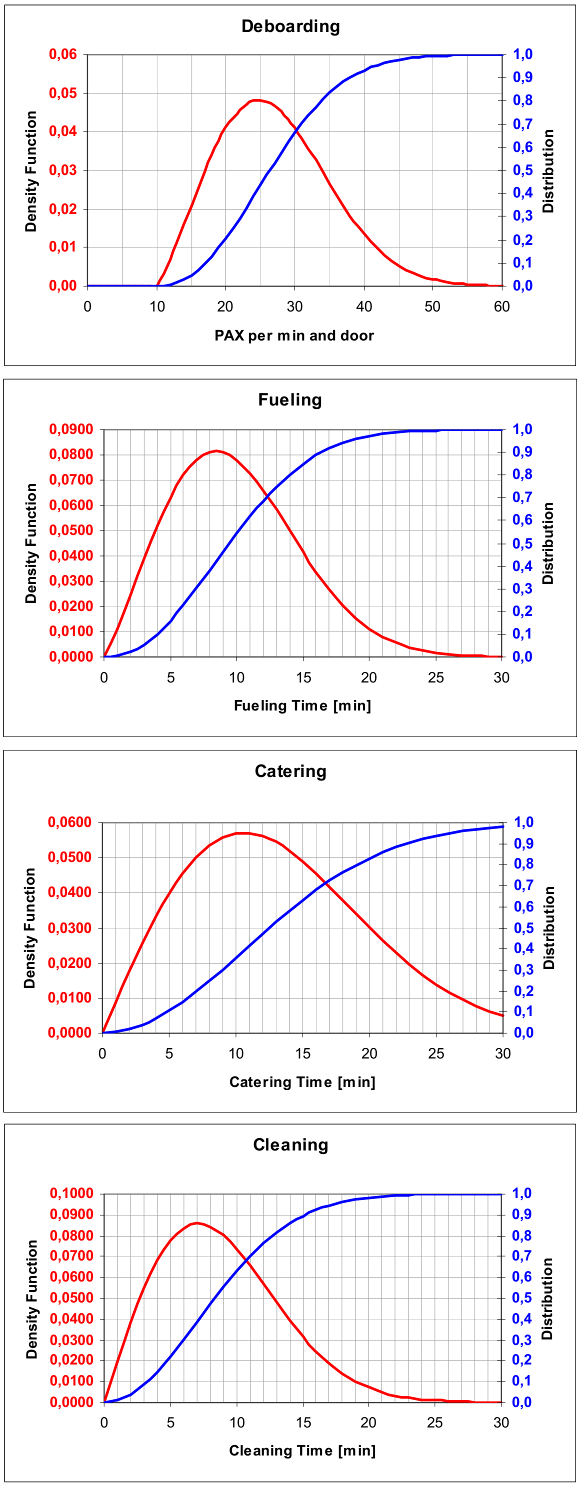

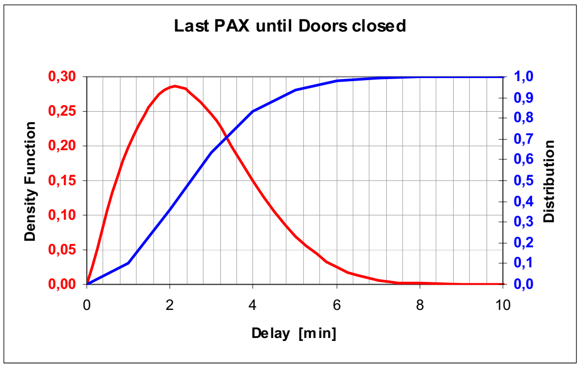

Figure 8. Modeled distributions for all time critical processes

The MC method is then applied to the collection of these processes, linked according the prescribed constraints, and executed for 10^4 simulation runs. It comes to the following TAT distribution:

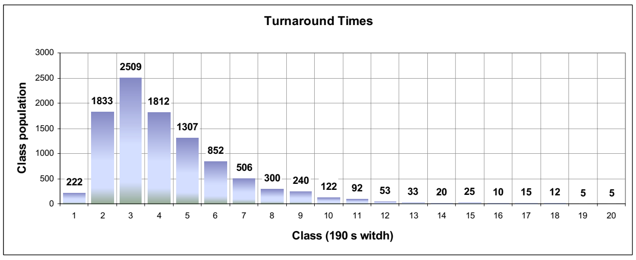

Figure 9. Turn Around Time Distribution

The shape of the TAT Distribution so follows again a WEIBULL behavior with the following over all process characteristics:

- Minimum Time: 1135 s (19 min)
- Maximum Time: 12486 s
- Mean: 1872 s (31,2 min)
- Standard Deviation: 23 s

Obviously, the central limit theorem according to which under certain conditions such as referring to independent and identically-distributed data with finite variance, the sum of a large number of random variables is approximately normally distributed, may not applied without inacceptable errors for this data case.

Instead, it is shown, that all type of optimization of single (and critical) processes does lead to a turn around time distribution with Weibull character. This to be proven by the different spot case analyzed in chapter V.

The 3 critical processes running in parallel in between de-boarding/boarding and unloading/loading were limiting with the following distribution, based on 10^4 simulation runs, too:

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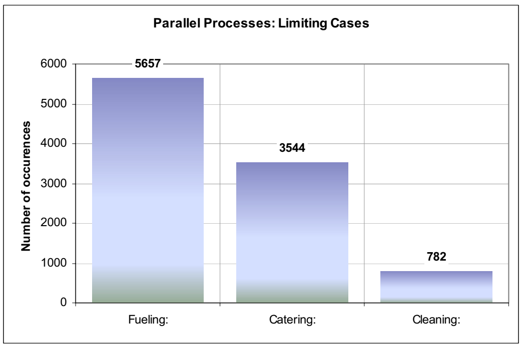

Figure 10. Distribution of limiting process linking de- boarding and boarding

So fueling was the limiting process out of the parallel processes for most of the cases (56%), followed by catering (36%).

V. POTENTIALS TO INCREASE TA RELIABILITY

The field study has shown a set of technical deficiencies which lead to uncertain, non standard processing in many cases. Based on representative interviews with ground handling personnel, individual impact effects were affiliated to the specific aspects. These have to be transferred into adopted process shape distributions, those in turn being subject of further MC simulations to derive the overall potential gain on the turnaround.

A. *Addressing time burden to technical deficiencies*

With reference to TABLE II, the following potential for reducing the impact effect to uncertainty of the individual deficiencies was found to be applicable according to expert judgment in the field (bold values mean consideration for the following MC simulations as time critical processes):

TABLE V. ADDRESSED TIME EFFECTS TO TECHNICAL DEFICIENCIES

Fighting Technical Deficiencies at Turnaround		
Process	***Deficiency counter measure***	***Judged Variance reduction potential***
(De-)Boarding	Second passenger bridge on gate position	**10%**
Boarding	Innovative Boarding Concept / New seat arrangement.	**20%**
Catering	Catering door signaling technically supported	10%
	Enhanced vehicle logistics lowering obstruction effects	15%
Cleaning	Reduced waste produced	25%
Fueling	Enhanced vehicle logistics lowering obstruction effects	15%
	Optimized Simultaneous fueling on both wings	20%
	fuel computer upgrade to calculate FOB precisely	5%
(Un-)Loading	Optimized Cargo Door: Panel	**10%**
	Auto adjustment for Conveyer belts & equipment	**30%**
Servicing	Cockpit Info granted about GPU removal	10%
	Light-weight adapter for GPU	10%

It shall be noticed that the expected gains shown in the above table may be seen as (realistic) indicators only, and subject of alteration when performing interviews at other airports. Nonetheless, the following section will clearly show how optimization potential and TA reliability do correlate.

B. *Conversion into Adopted Distributions*

This potential is to be transformed into process distribution behavior, respectively the modeling of reduced process uncertainty to be modeled through

- α (scale parameter) tending to larger values, and
- β (shape parameter) tending to smaller values.

The approximation for the new shape and scale parameter follows the following relationship between the function parameters α, β, and the variance, using the Gamma Function Γ:

$$\Gamma = \int_0^\infty t^{x-1} e^{-t} dt \qquad (2)$$

$$Var(x) = \alpha^{-2/\beta} \left(\Gamma(\frac{2}{\beta}+1) - \Gamma(\frac{1}{\beta}+1)^2 \right) \qquad (3)$$

This leads us to the following adopted shape parameters for the time critical processes:

TABLE VI. ADOPTED DISTRIBUTIONS – CRITICAL TA PROCESSES

Adopted Distributions – Critical TA Processes	
(De-)Boarding [PAX / min]	***Value***
α	2,534656
β	19,193186
x offset	10
Boarding [PAX / min]	
α	3,4680421
β	19,23082
x offset	0
loading AFT&FWD [bags / min]	
α	3,252597
β	154,5100
x offset	0
Unloading AFT&FWD [bags/ min]	
α	4,047813
β	206,81878
x offset	0

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These adopted distributions are now being re-applied to the MC simulation set up to explore the effect of every single counter-measure on the turn around time. With another 10^5 simulation runs, it comes to the following distribution:

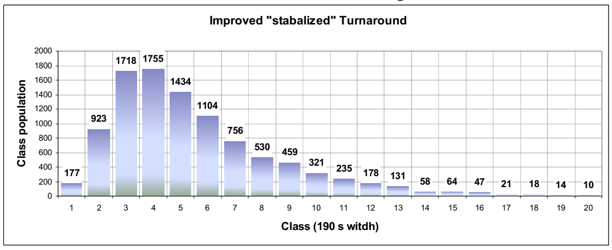

Figure 11. Improved “stabalized” Turn Around Time Distribution

The shape of the improved TAT distribution now follows the over all process characteristics:

- Minimum Time: 1.222 s (20 min)
- Maximum Time: 7.790 s
- Mean: 1.784 s (29,7 min)
- Standard Deviation: 19s

When comparing both scenarios, the following table depicts the potential for stability increase of the turn around:

TABLE VII. POTENTIAL FOR INCREASED PROCESS RELIABILITY

Expected Benefits of technical counter measures for increased process reliability			
Figure	***Baseline***	***Optimized***	***Gain / Loss***
min	1135 s	1222 s	7,67%
max	12486 s	7790 s	-37,61%
mean	1872 s	1784 s	-4,70%
Variance	535 s²	395 s²	**-26,17%**
SD	23 s	19 s	**-17,4 %**

The 3 critical processes running in parallel for this improved case follow the distribution as depicted below:

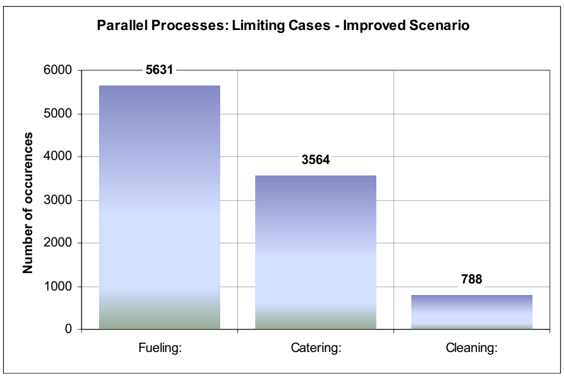

Figure 12. Distribution of limiting process linking – improved scenario

So equal to the baseline scenario, fueling did constrain the parallel processes for 56%, followed again by catering (36%).

C. Reduced process uncertainty affecting TA reliability

Two effects can be noticed when comparing the reference scenario with the improved: Although the mean of the TA time is only decreasing by roughly 4% its stability, indicated by the variance is increasing by roughly 25%. So obviously, installing efficient technical upgrades at the aircraft for the sample case only would significantly improve the turn around reliability achieved through stable (deterministic) processes.

TABLE VII indicates a potential for increasing the turn reliability by roughly 25% when retrofitting the aircraft body accordingly, and optimizing the manual procedures for the processing. This is seen as an important contribution which obviously is worse to be investigated further.

Hence, it also came clear that this type of counter measures will in no way allow complying with the SESAR performance targets for the turn around. This one can so only be achieved by parallelizing Fueling and hereafter catering with the critical processes (de-)boarding and (un-)loading.

For the boarding processes, an in-depth study has recently been completed at TUD, exploring the effects of different strategies (random, inside-out..) onto the process time.

ACKNOWLEDGMENT

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