Hochschule für Angewandte Wissenschaften Hamburg
*Hamburg University of Applied Sciences*

**Master Thesis**

**Department of Automotive and Aeronautical Engineering**

# Ground Handling Simulation with CAST

Author: Sara Sanz de Vicente

Supervisor: Prof. Dr.-Ing. Dieter Scholz, MSME

Delivered: 13.09.2010

# Abstract

Nowadays low cost airlines carriers have grown becoming an important part of the passenger air traffic market. Since they are looking for ground handling operations which would reduce the aircraft costs, a new aircraft can be developed optimizing the turnaround process.

This master thesis is focused on the analysis of ground handling processes and and the description and application of the simulation program Comprehensive Airport Simulation Technology (CAST) Ground Handling. This program enables to obtain a 3D simulation of different service arrangements of a reference aircraft model, including an analysis about involved costs in the turnaround process.

The analysis of ground handling processes is based on the real-time ground handling videos recorded at different airports by ARC Aachen. The videos were analyzed to collect data of ground handling process times and characteristics. The data was summarized in and Excel table in order to be statistically analyzed. Based on the results of the statistical analysis, the turnaround Gantt charts have been created and analysed showing the features of the turnaround scenario with the shortest turnaround time and the smallest ground handling costs.

The conducted simulation shows the ground handling process of a reference aircraft based on the Airbus A320 during a turnaround. The results that have been extracted from the simulation are the ground handling process times and the costs and the visual simulation in 3D of the defined scenario. The simulation program is being developed by ARC Aachen, therefore a discussion of several possible improvements has been proposed.

A theoretical analysis of unconventional configurations has been carried out based on literature research on ground handling processes for these configurations and on a literature research on ground handling improvements showing the compatibility of the box wing and the blended wing body configurations with current airports and ground handling procedures.

All the information presented in this master thesis might be useful when developing an aircraft optimized for ground handling.

DEPARTMENT OF AUTOMOTIVE AND AERONAUTICAL ENGINEERING

# Ground Handling Simulation with CAST

Project work towards a thesis at ETSIA UPM

## Background

Within the joint research project *Aircraft Design for Low Cost Ground Handling* (ALOHA), innovative conventional and unconventional aircraft designs are investigated and evaluated with respect to ground handling operation and their associated ground handling costs, by using the programs CAST Ground Handling and PrADO. The Comprehensive Airport Simulation Tool (CAST) is an in-house development of the research partner Airport Research Center in Aachen (**CAST 2010**). The ground handling part of it has been designed within ALOHA and allows for simulation of different service arrangements of different aircraft models. In order to evaluate aircraft designs out of PrADO (**Heinze 1994**), an interface has been programmed to transfer the three-dimensional geometry of the aircraft into CAST Ground Handling. This allows for ground handling simulation of different aircraft designs that have been predesigned (and evaluated) with PrADO. In this project work, the ground handling simulation shall be conducted with CAST for an aircraft optimized for ground handling that shall be compared, in terms of ground handling performance and associated costs (compare **Crönertz 2008**), with a preselected reference aircraft (i.e. a 150 passenger, twin engine subsonic transport aircraft). If possible, unconventional aircraft such as box wing or blended wing body shall be investigated to gather first aspects of the respective ground handling.

## Task

The tasks of the project are as follows:

- Literature research on ground handling (process) optimization.
- Definition of ground handling scenarios on the basis of real data.
- Creation of standard turnaround Gantt charts on the basis of real data and with respect to the predefined ground handling scenarios.
- Familiarization with the program CAST Ground Handling.
- Ground handling simulation with respect to predefined ground handling scenarios of the reference aircraft and the aircraft optimized for ground handling.
- Comparison and discussion of the results obtained.
- Technology assessment of the aircraft optimized for ground handling.
- If possible, further ground handling simulations of unconventional aircraft such as box wing or blended wing body.

The report has to be written in English based on German or international standards on report writing.

## References


**Heinze 1994** HEINZE, Wolfgang; Zentrum für Luft- und Raumfahrttechnik, Technische Universität Braunschweig: Ein Beitrag zur quantitativen Analyse der technischen und wirtschaftlichen Auslegungsgrenzen verschiedener Flugzeugkonzepte für den Transport großer Nutzlasten. Braunschweig: 1994 (94-01)

**CAST 2010** AIRPORT RESEARCH CENTER: CAST Comprehensive Airport Simulation Tool – CAST Overview. Aachen: Airport Research Center, 2010.– URL: http://www.airport-consultants.com/ (2010-03-15)

**Crönertz 2008** CRÖNERTZ, Oliver: *Prozessorientierte Kalkulation von Flughafenleistungen. Schwerpunkt: Bodenabfertigungsdienste von Passagierflugzeugen*. Saarbrücken : VDM Verlag Dr. Müller, 2008 – ISBN: 978-3-8364-8460-2

# Declaration

This Master Thesis is entirely my own work. Where use has been made of the work of others, it has been totally acknowledged and referenced.

| Date | Signature |
| --- | --- |
| September 13, 2010 | SANZ DE VICENTE, Sara |

# Table of Contents

# List of Figures

# List of Tables

# List of Abbreviations

| | |
|---|---|
| Aero | Aircraft Design and Systems Group |
| AFT | After |
| AIBT | Aircraft In Blocks Time |
| ALOHA | Aircraft Design for Low Cost Ground Handling |
| ARC | Airport Research Company GmbH |
| ATC | Air Traffic Control |
| BWB | Blended Wing Body |
| CAST | Comprehensive Airport Simulation Tool |
| DOC | Direct Operating Costs |
| FWD | Forward |
| GH | Ground Handling |
| GPU | Ground Power Unit |
| GSE | Ground Support Equipment |
| HAW | Hoschschule für Angewandte Wissenschaften (University of Applied Sciences) |
| IATA | International Air Transport Association |
| ISO | International Organization for Standardization |
| JAR | Joint Aviation Requirements |
| LCA | Low Cost Airlines |
| MATLAB | MATrix LABoratory |
| OPS | Operations |
| PrADO | Preliminary Aircraft Design and Optimisation |
| PWS | Potable Water Service |
| SUMO | SUrface MOdeling tool for aircraft configurations |
| TBL | Tow Bar Less (Pushback equipment) |
| TMO | Ten Miles Out |
| ULD | Unit Load Device |
| URL | Universal Resource Locator |
| WWS | Waste Water Service |
| WWW | World Wide Web |

# 1 Introduction

## 1.1 Motivation

This Master Thesis is part of the aircraft design research project Aircraft Design for LOw cost ground HAndling (ALOHA).

The project ALOHA investigates and evaluates innovative conventional and unconventional aircraft designs in order to improve the ground handling process and achieve a reduction in Direct Operating Costs (DOC). In particular, ALOHA investigates Low Cost Airlines (LCA), which have been successful in the reduction in ground handling costs. Therefore, the principal aim is the research on improvements to ground handling operations, which reduce turnaround time and ground handling costs and increase aircraft utilization. However, it is necessary to obtain a general over view on the aircraft design and its operation, in order to check if these improvements also reduce DOC, because, in some cases, they can also increase the weight or the price of the aircraft, and thus increase other DOC cost items too.

Low Cost Airlines usually fly short and medium range aircraft like the Airbus A320 or the Boeing 737. These aircraft models were developed before the LCA apparition, so requirements of LCA were not considered, but now aircraft manufactures have announced the successors of both models, in which the requirements of the LCA are more likely to be taken into account during the design. **(Gómez 2009)**

This Thesis, as a part of the ALOHA project, is a research on ground handling operations looking for an aircraft optimized to reduce DOC. Therefore, the ground handling process is analysed and a reference aircraft is investigated in different predefined scenarios and simulated with the CAST Ground Handling program. This last task is not only a theoretical task, because CAST GH is a new program which has been recently developed by ARC. The analysis of CAST Ground Handling is therefore also useful to understand the program and improve it.

## 1.2 Definitions

Ground handling

Ground handling includes all passenger-, cargo- and aircraft related operative processes, procedures, services and personnel, which are necessary to prepare the aircraft for the next flight and take place at the airport during the aircraft. Ground handling includes the processes of (**Stavenhagen 2002**):

- Positioning and removal of passenger bridges or operation of passenger buses
- The supervision of passenger boarding and deboarding and a possible transportation with the passenger bus
- Aircraft servicing such as cabin conditioning, catering or cleaning
- Pre-flight inspections and maintenance performed at the ramp
- Cargo and baggage loading and off-loading
- Refuelling
- Preparation for pushback
- De-/anti-icing

Simulation

The concept of simulation has been defined by **Shannon 1975** as follows:

> *"Simulation is the process of designing a computerized model of a system or a process and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies for the operation of the system"*

A simulation makes it possible to study an experiment with complex internal interactions of a given system and to evaluate the effects which the alteration of certain parameters causes on the model of the system. A detailed observation of the simulated system may lead to a better understanding of the system, but simulations can also be used to experiment with new situations and anticipate behaviours of the variables. **(Adkins 1977)**

CAST

CAST (Comprehensive Airport Simulation Tool) is comprehensive simulation software which provides a virtual 3D environment for integrated simulation of all airport related processes. **(CAST 2010)**

Aircraft design

Aircraft design is the process of supplying the geometrical description of a new flight vehicle estimating masses, performances and requirements for a defined mission. This process is made in two steps, preliminary sizing and conceptual design, and the result is a new aircraft described by a three-view drawing, a fuselage cross-section, a cabin layout and a list of aircraft parameters. **(Scholz 2010)**

Turnaround

A**irbus GH 1995** gives the following definition of turnaround:

> *"Turnaround is the period of time that the aircraft is at the airport ramp, from blocks on at the aircraft arrival to blocks off at the aircraft departure. This includes the positioning of the pushback tractor and tow bar in preparation for the pushback process".*

Direct Operating Costs (DOC)

Direct Operating Costs are the costs that are involved in the operation of the aircraft, including not only ground handling costs, but also depreciation, interest, insurance, fuel costs, maintenance costs, crew costs, landing fees and navigation fees.

Low Cost Airlines (LCA)

Low Cost Airlines are airlines that offer low fares during their flights. They offer a basic flight where the seating comfort is minimal eliminating or cutting down on service elements from the standard products profile and charging for extras such as on-board catering, rebooking options, luggage, priority boarding, seat allocating, etc. (**Gross 2007**)

Critical path

The critical path is the sequence of activities which defines the total time of a project. These mandatory activities must be completed before other activities can commence. In consequence they are critical and any delay in them would increase the total time of the project.

The following activities are likely to be on the critical path.

- Critical activities.
- Activities dependant on critical activities
- Overall engagement times for each activity. **(IATA 2009)**

## 1.3 Objectives

The main objective of this master thesis is the creation of standard turnaround Gantt charts on the basis of real data with respect to the predefined ground handling scenarios and the ground handling simulation with CAST Ground Handling in order to collect results which might be used to improve the aircraft configuration.

The aim of the whole project is to get results of the turnaround process in order to minimise time and costs. Airlines are always looking for new ways to manage their companies in order to maximize incomes, and a good way to do that is maximizing the daily utilization of their fleet. A high daily utilization can be achieved with short turnarounds. However, a short turnaround must not affect the service quality of the flight and must obviously not reduce safety aspects; consequently it requires the consideration of all ground handling aspects. Many factors affect the processes which are performed during a turnaround, so it is not easy to make a real simulation, but it could be achieved by taking into consideration the main variables.

As part of the ALOHA project, the final goal of this thesis is to assist ALOHA in reducing the ground handling costs and turnaround times of the aircraft in order to be able to create an optimised aircraft whose design reduces the total DOC.

## 1.4 Literature

<u>Books</u>

The *Airport Handling Manual"* **IATA 2009** contains recommended industry standards, procedures, equipments and directives aimed to the management and arrangement of the ground handling services at the airport and can be used to study turnaround processes.

**JAR-OPS 2007** *"JAR-OPS 1. Commercial Air Transportation (Aeroplanes)",* describes the requirements during the operation of a commercial aircraft and has been consulted to research on specific directives and specifications of ground handling procedures.

**Gross 2007** *"Handbook of Low Cost Airlines"* has been used to obtain information about low-cost carriers in terms of strategies and business processes.

**Scholz 2010** *"Short Course on Aircraft Design"* and **Crönertz 2008** *"Prozessorientierte Kalkulation von Flughafenleistungen"* have been used for the cost evaluation. **Scholz 2010** gives an insight into the procedures and the multidisciplinary interactions of aircraft conceptual design and defines DOC and different calculation methods. **Crönertz 2008** goes into ground handling services in depth evaluating each GH process at German airports and describing a cost method which depends on the aircraft model, the parking position and other variables.

The features and ground handling characteristics of the Airbus A320 are taken from **Airbus 1995** *"A320 Airplane Characteristics For Airport Planning",* which gives general information about airplane description and performances at the airport.

Thesis and papers

Most of the reports which have been looked up come from the database of the ALOHA project or from the research group AERO (Aircraft Design and Systems Group): papers and thesis written to work, to contribute or to assist ALOHA project and others AERO projects. The most referenced thesis and papers in the context of this thesis are described below. (URL: http://ALOHA.ProfScholz.de; URL: http://bibliothek.ProfScholz.de)

**Krammer 2010a** *"Cost Estimation and Statistical Analysis of Ground Handling Process"* and **Krammer 2010b** *"ICAS 2010: Aircraft Design For Low Cost Ground Handling-The Final Results of the ALOHA Project"* have been consulted since they contain important results about ALOHA project.

The master thesis of **Rico 2009** *"Analysis of Ground Handling Characteristics of Innovative Aircraft Configurations"* has been used to collect more information about what has already been done about ground handling in ALOHA project and to extract an equation which approximates the refuelling process.

The thesis of **Stavenhagen 2002** *"Analysis of the aircraft turn-round for modelling and improving the cabin cleaning process"* describes and analyses the complete turnaround process in general and the turnaround cabin cleaning process in detail which has contributed to the aircraft ground handling information for this thesis.

The research on ground handling process optimization has been based on **Gómez 2009** *"Improvements to ground handling operations and their benefits to direct operating costs"*, the master thesis of **Raes 2008** *"Efficient autonomous pushback and taxiing- a step forward to reducing costs and pollution"* and on the project of **Müller 2009** *"Optimal Boarding Methods for Airline Passengers"*. The first report was created by AERO and investigates possible improvements to ground handling operations and determines their influence on direct operating costs. The thesis **Raes 2008** and the project **Müller 2009** have been used to see the research done on the pushback and the boarding procedures. Also the report **Gomez 2009b** *"Optimized Ground Handling Aircraft"* has contributed to the research on an optimized aircraft since it proposes changes of the aircraft configuration which can improve the ground handling process and evaluates their influence on the others aircraft performances.

For the investigation of the ground handling of unconventional aircraft several reports have been used: **Hortsmeier 2001** *"Influence of ground handling on turn round time of new large aircraft"* for large aircraft and **Frediani 2006** *"The Prandtlplane Aircraft Configuration"* for a box wing configuration For the study of blended wing area the following documents have been consulted: the reports **Leifsson 2009** *"The Blended Wing Body Aircraft"* and **Liebeck 2004** *"Design of the Blended Wing Body Subsonic Transport"* and the presentation of **Scholz 2007a** for EWADE *"A Student Project of a Blended Wing Body"*. Also the master thesis of **Lee 2003** *"Konzeptionelle Untersuchung einer Flying Wing Zweideckkonfiguration"* has also been consulted since it deals with the ground handling of the blended wing body configuration.

Internet

For a previous study of the software program Comprehensive Airport Simulation Tool (CAST) the information of the **ARC 2010** *"Airport Research Center*: *Main web page"* has been looked up, as well as several subpages, inside the main page of the ARC**,** which describes the CAST tool and the CAST Ground Handling program such as **CAST 2010** and the **CAST GH 2010.**

Also, where appropriate, the WWW has been consulted to find information about simulations, critical path methods and other concepts.

## 1.5 Structure of the work

This thesis is structured in six chapters and one appendix, as follows:

**Chapter 2** Definition of the scenarios, the meaning of the critical path and the statistical analyses of the turnaround process.

**Chapter 3** Explanation of turnaround Gantt charts of the defined scenarios and analysis of the results by comparing them with data found in the aircraft manual *"A320 Airplane Characteristics For Airport Planning"*.

**Chapter 4** Description of a process cost calculation method in Ground Handling.

**Chapter 5** Description and analysis of the computer program CAST Ground Handling and simulation of the turnaround process of the chosen reference aircraft in CAST Ground Handling. With this program the reference aircraft is simulated.

**Chapter 6** Investigation of the possible modifications to optimize the GH processes.

**Chapter 7** Evaluation and discussion of ground handling processes applied to unconventional aircraft configurations.

**Appendix A** Description of the general features and GH characteristics of the Airbus A320.

# 2 Scenarios

## 2.1 Introduction

The air traffic continues growing and airlines must define carefully their turnaround process according to their route structure, schedules, fleet, etc. in order to maximize their fleet utilization and reduce direct operating costs. The turnaround procedure of the aircraft includes sub processes which take place in the aircraft while it is standing at the airport between two successive flights. These include aircraft servicing activities (e.g. fuelling, catering and cabin cleaning), cargo and baggage handling activities and also passenger activities such as passenger boarding and deboarding. **(Stavenhagen 2002)**

The duration of the turnaround can vary depending on the type of the company and on the ground handling services the aircraft receives. These operations are complex and it is difficult to make a unique general ground handling process that summarizes all the whole meaning of a turnaround. The turnaround time mainly depends on the airline business model and the parking position. That is the reason why four different scenarios are defined in this project, and LCA and conventional airlines are studied separately.

In order to minimize costs, low cost airlines especially focus on reducing their operating specifically ground handling costs, since these low ground handling costs are considered the key factor of their business model and their main advantage compared to the traditional airlines. Therefore, LCA are always searching to reduce the ground operations at the airport and have developed new procedures in the turnaround process. **(Gómez 2009)**

As it can be seen in Figure 2.1, LCA usually park at the remote apron at secondary airports, which avoids the airport charges related to air bridges or to main airports. In addition, cleaning and catering services are not always required due to the lower in-flight food consumption and the lower on-board services. LCA usually use the so-called “fuel tankering” technique, making it not necessary to refuel at every stage and since they park on apron in front of the terminal and parallel to the terminal building, they do not need any pushback equipment. Moreover, these secondary airports are quite small and there is no need of passenger buses to carry passengers from or to the aircraft, since they can go walking. Furthermore, as the Figure 2.1 shows, by parking at remote apron, LCA airlines can board through two operative doors and do not need pushback equipment. Integrated ladder and luggage belt can save ground handling costs.

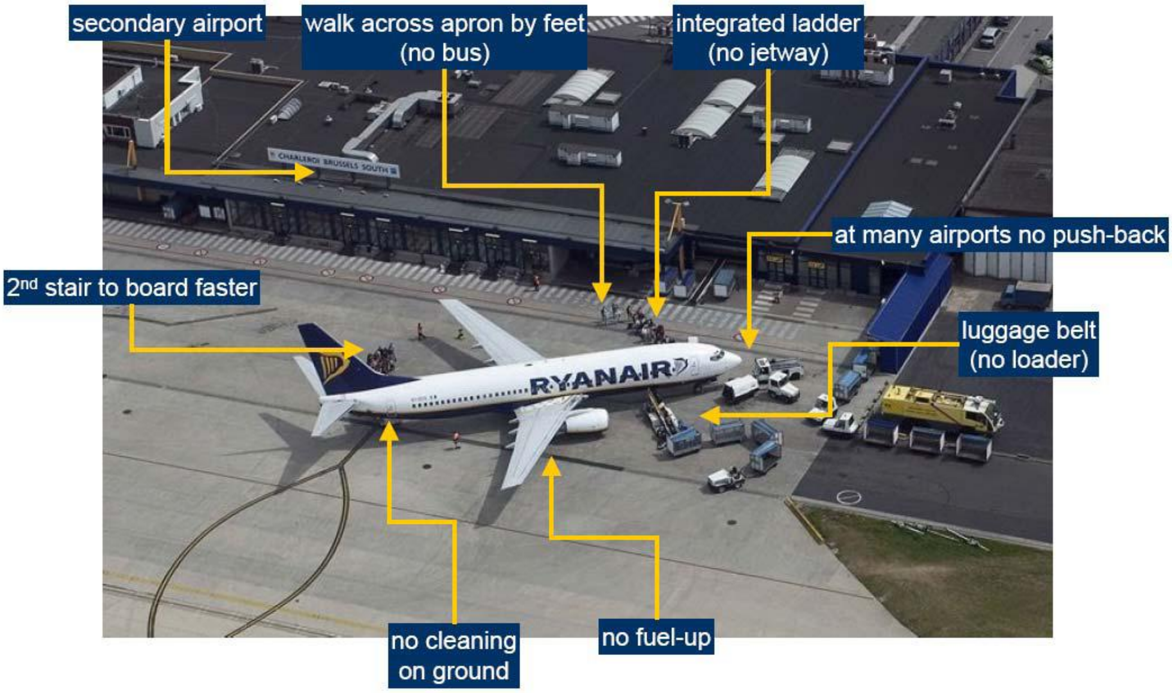



**Figure 2.1** LCA Turnaround Characteristics **(Tesch 2007)**

ARC installed cameras at many aprons at different airports in Germany to analyse in real time the ground handling process of different airlines. Most of the studied flights belonged to LCA and the considered aircrafts were in the short to medium range segment. The results have been collected in an Excel table in order to be evaluated and obtain each sub process of the turnaround and other statistics values by a Matlab program. These results are required for the subsequent definition of the turnaround process.

## 2.2 Scenarios definition

In this Master Thesis, four scenarios are studied in order to calculate the turnaround time and draw the Gantt Charts of each one and compare them.

These four scenarios are all defined for a determined aircraft mission and a reference aircraft with the next features:

- 150 passenger, twin engine subsonic transport aircraft
- design range 4800 km
- cruise speed Mach 0.78
- powered by two turbofan engines with 98 kN static thrust
- Max. take-of mass 70 tons

- Operating empty mass 37 tons
- Fuel mass (for design range) 37 tons incl. domestic reserves

Table 2.1 shows the features of each scenario:

**Table 2.1** Definition of ground handling scenarios: conventional vs. low cost airline business model / terminal vs. remote apron position

| Scenario | I | II | III | IV |
|---|---|---|---|---|
| airline business model | Conventional | | low cost | |
| no. of passengers | according to utilization of the conventional company | | according to utilization of LCA | |
| fuel | according to DOC mission (range = 500 nm, 3011.768 kg) | | | |
| catering | two catering trucks: 1 AFT, 1 FWD | | one catering truck: 1 AFT | |
| potable water service | 200 litres (100% refilled) | | | |
| waste water service | 200 litres (100% emptied-refilled) | | | |
| parking position | terminal | apron | terminal | apron |
| cargo (type and amount) | 4 ULDs (3 AFT, 1 FWD) | 4 ULDs(3 AFT, 1 FWD) | 100 bags (bulk cargo) | 100 bags (bulk cargo) |
| ground power | from PBB[1] | from GPU | from PBB[1] | from GPU |
| cleaning | yes | yes | yes | yes |
| pushback | Towbarless (TBL) | n/a(remote apron) | conventional | n/a(remote apron) |

[1] PBB = passenger boarding bridge

Due to the complexity of the process and the different options to give service to an aircraft, these four scenarios are defined offering full service to a plane. Nevertheless, as LCA do not cleaning and change the catering at every flight, two examples of half service are shown.

As shown in Table 2.1, the four scenarios have been chosen separating conventional airlines (scenarios I and II) and low cost airlines (scenarios III and IV), because of the different performances at the airport and their different aims. Moreover, embarking and disembarking are investigated separately for the cases with bridge or in remote apron, since they make necessary several ground handling equipments, obtaining in each case a different turnaround. An aircraft which parks at the remote apron needs a GPU during its turnaround but does not need pushback equipment. On the other hand, an aircraft which parks at the terminal can have the disembarking through a passenger boarding bridge which the electrical power can be supplied to the aircraft through.

Since the airlines do not always use containers, but it depends on the company management, the loading equipment is different in the scenarios. Scenarios I and II are loading containers and scenario III and IV are loading bags. Loading containers allows to carry a lot of bags in a Unit Load Device (ULD) which is more expensive because of the necessary equipment and must be previously packed but can save time of the turnaround and reduce the ground handling personal. On the other hand loading bags is a simpler process but it entails more handling equipments and staff and delays are more likely to happen.

## 2.3 Turnaround Process Analysis

The 168 videos collected by ARC have been analysed by ALOHA at HAW Hamburg and turnaround data has been collected in an Excel table. In order to study statistically each ground handling process, a Matlab program was specifically developed by **Rico (2009)**, which analyses input data, and allows the following results:

- Regression Analysis
- Measures of Central Tendency and Dispersion
- Statistical figures density probability distribution
- Statistical figures cumulative probability distribution
- Distribution fitting tool

This Matlab program is explained in **Rico 2010** but since it has been used for this thesis it is described here in short.

The Excel table with the turnaround data can be imported into the program either by importing the data directly: selecting *"File"* -> *"Import Data…"* or creating a cell array and copying the Excel data into it. The cell array must be named DATA_AIRP.

Then, a different subroutine can be activated in the main subroutine, depending on the parameters to be obtained. For the tasks of this project, the used subroutines were the necessary ones to obtain the measures of central tendency, the dispersion and the statistical figures of density probability distribution and cumulative probability distribution.

First of all the conditional parameters must be set and then the type of values will be analysed. All the parameters must be named like in the Excel table imported in the array DATA_AIRP. For example, typing *'A319','A320'*, *'CONV'* and *'t FUEL', 't FUEL POS'*, studies the time of refuelling and the time of positioning the fuel truck for the aircraft models A319 and A320.

After that, the different subroutines are called and results are obtained and automatically written in ASCII files. Nevertheless, the user must save the resulting plots and change the name of the file before starting a new application.

The results which were created for the ground handling analysis in collaboration with Aero group are included in **Krammer 2010a**.

After getting the results of the program, the user obtains different statistical approximations of the behaviour of each process. The figures of the probability density distributions and the probability cumulative distributions must be checked in order to choose which distribution fits more precisely with the real process. Results in this case show that most of the processes are exhibiting a log normal distribution or a normal distribution.

The normal distribution is described by the probability density function:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \tag{2.1}$$

Where $\mu$ is the mean of the distribution and $\sigma^2$ is the standard deviation which is a measure of the dispersion of the data.

As shown in Figure 2.1 the function *f(x)* is symmetric around the mean $\mu$ which is at the same time the mode of the distribution. The standard deviation is defined by the inflection points of the curve.

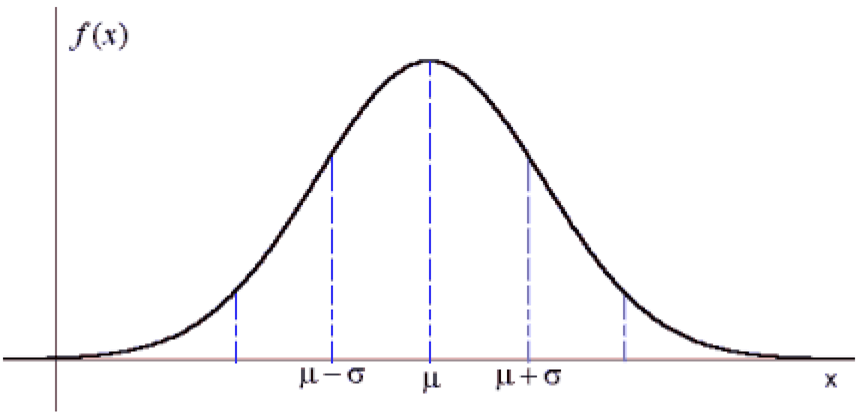



**Figure 2.2** Normal distribution

On the other hand, a variable $X$ is said to be log-normally distributed if log($X$) is normally distributed.

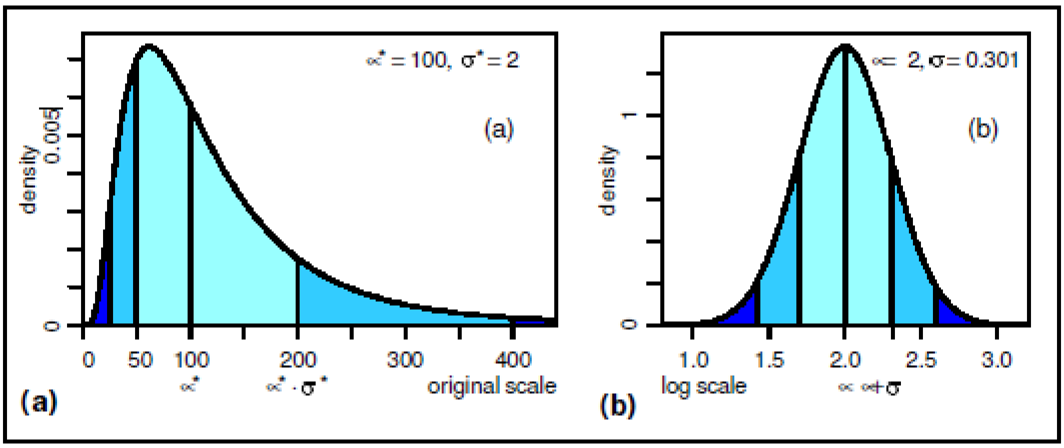



**Figure 2.3** A lognormal distribution with original scale (a) and with logarithmic scale (b) **(Limpert 2001)**

The probability density function of the lognormal distribution has the following form:

$$y = \frac{1}{x\sigma\sqrt{2\pi}} e^{\frac{-(Log(x)-\mu)^2}{2\sigma^2}} \tag{2.2}$$

Where $\mu$ and $\sigma^2$ are the mean and the standard deviation of the variable natural logarithm.

As shown in the graphics of each distribution (Figures 2.2 and 2.3), the normal distribution is symmetrical around the mean while the lognormal distribution is skewed to the right. Since not all the processes have a symmetrical density distribution, processes are more likely to have a lognormal distribution.

Mathematical regressions of each main process are also obtained by the program. In order to see the goodness of fit of the correlation, this is how well the regression line approximates the real data points, the coefficient of determination $R^2$ has been calculated according to:

$$R^2 = 1 - \frac{\sum_i (y_i - fi)}{\sum_i (y_i - \bar{y})} \tag{2.3}$$

$$\bar{y} = \frac{1}{n}\sum_i y_i \tag{2.4}$$

Where:

- $y_i$ Observed values
- $f_i$ Predicted values
- $\bar{y}$ Mean of the observed data
- $n$ Number of observations

A coefficient of determination $R^2$ of 1.0 indicates that the regression line perfectly fits the data; on the other hand an $R^2$ near to 0 indicates a poor model fit. Values of $R^2$ outside the range 0 to 1 mean that there is an error between the modelled and real values. Thus, the mathematical regressions with values of $R^2$ between 0.6 and 1 are considered correct and regressions with values of $R^2$ lower than 0.6 are not considered. In these cases the mode of the data is used, since it is the value that is most probable to occur.

Making this statistical evaluation and putting into practice this goodness of fit rule show that only a few processes correlate linearly and some processes have a high standard deviation. This is due to the fact that the collected data are much dispersed, since many activities are involved in the whole ground handling process and they depend on various parameters that are hard to consider. Moreover, there are few data of some processes, and the results for them are not so reliable. **(Krammer 2010b)**

The information collected with the program is used to calculate individual process times according to the operational parameters, to obtain reference values for individual aircraft or different ways of ground handling and to simulate real turnaround examples with CAST GH.

Nevertheless, for the case of refuelling, since it is a process which depends directly on the volume of fuel that is going to be loaded, an equation will be used. This following equation was developed by **Rico (2009)**, according to the A320 equipment.

$$t_f = \frac{1}{-0.036} \cdot Ln\left(1 + \frac{V_f \cdot (-0.036)}{1475}\right) \tag{2.5}$$

Where:

- $t_f$ Refuelling time [min]
- $V_f$ Volume of fuel loaded [litre]

The volume of fuel which is needed to be loaded was calculated with PrADO according to the reference mission.

By evaluating the results extracted from the program, it has been noticed that most of the processes do not show a linear behaviour, even there are not mathematical regression in many cases, but they are exhibiting a log-normal or a normal distribution characteristic.

In consequence, the value of the mode is taken as the process time for the cases which have not a linear behaviour or a normal distribution characteristic. Since the mode is the most probably value to occur it is supposed that the scenarios will represent similar situations as the analysed situations. In cases with a linear behaviour, the process time is calculated with the equation which results with the program. In case of a normal distribution the process time is the mean which matches up with the mode.

Nevertheless, the range of variation of each process will be calculated by using the mean and the standard deviation of the process, in order to see the deviation of the chosen value regarding the mean and have a view of the chosen value in keeping with reality.

The table 2.2 summarises the chosen value for each process and equipment

**Table 2.2** Times of Ground Handling Processes

| Process | Equipment | Chosen value | Total process time (min) |
|---|---|---|---|
| Disembarking | Bridge (150 pax) | Linear equation | 7.003 |
| | 2 Stairs(150 pax) | Mode | 4.097 |
| Embarking | Bridge (150 pax) | Mode | 8.271 |
| | 2 Stairs (150 pax) | Mode | 5.848 |

| Process | Equipment | Chosen value | Total process time (min) |
|---|---|---|---|
| Offloading | Cont. Loader (3AFT) | Linear equation | 6.601 |
| | Cont. Loader (1FWD) | Linear equation | 3.311 |
| | Belt Loader (100 bags) | Quadratic polynomial | 9.272 |
| Loading | Cont. Loader (3AFT) | Linear equation | 6.206 |
| | Cont. Loader (1FWD) | Linear equation | 3.07 |
| | Belt Loader (100 bags) | Mode | 6.73 |
| Refuelling | 3837 l | Equation (2.5) | 2.731 |
| Cleaning | - | Mode | 7.542 |
| Catering | 1-2 trolleys | Mode | 5.18 |
| PWS | 200 l | Mode | 1.53 |
| WWS | 200 l | Mode | 3.54 |
| Ground Power | GP Bridge | Mode | 0.806[1] |
| | GPU | Mode | 0.806[1] |
| Pushback | TBL | Mode | 1.103 |
| | conventional | Mode | 1.47 |

[1]% of utilization of the total turnaround

The table reflects that the time of most of the processes is defined by the mode, which means that in some cases it will not be possible to make the process depending on a specified parameter. For example, the time for loading with a belt loader is defined by the mode of the distribution, which leads to loose the information about the number of the bags.

## 2.4 Critical path

> *"Critical path is a term used in the field of project management to define a sequence of tasks in a project wherein none of the tasks can be delayed without affecting the final project end time."* ***(Aguanno 2002)***

Since these tasks which are on the critical path add up the longest overall duration, additional management techniques can be applied to the tasks on the critical path sequence to reduce the time of each of this task and consequently the overall project time. **(Aguanno 2002)**

The determination of aircraft ground times requires the establishment of the critical path of the ground handling process. Since the critical path is the activity or combination of direct dependent activities that take the greatest time to complete, both, prioritizing these activities for the effective management and shortening the planned critical path will allow to obtain a lower turnaround time and therefore to reduce the involved costs.

In most instances, the critical path consists of the passenger and aircraft cabin activities (i.e. passenger disembarkation, cabin cleaning and passenger embarkation), some of them cannot be carried out at the same time like disembarking and embarking but in other instances, the critical path is also caused because of safety regulations (e.g. refuelling cannot start until the end of disembarking and embarking cannot start until the end of refuelling). There are also some circumstances when other operations may become the critical path, due to the fuel load or the capacity of the cargo loader. Other activities, such as water service, can normally be performed without impact on or from the critical path.

The Figure 2.4 is an example of a typical turnaround process and the independence between different activities.

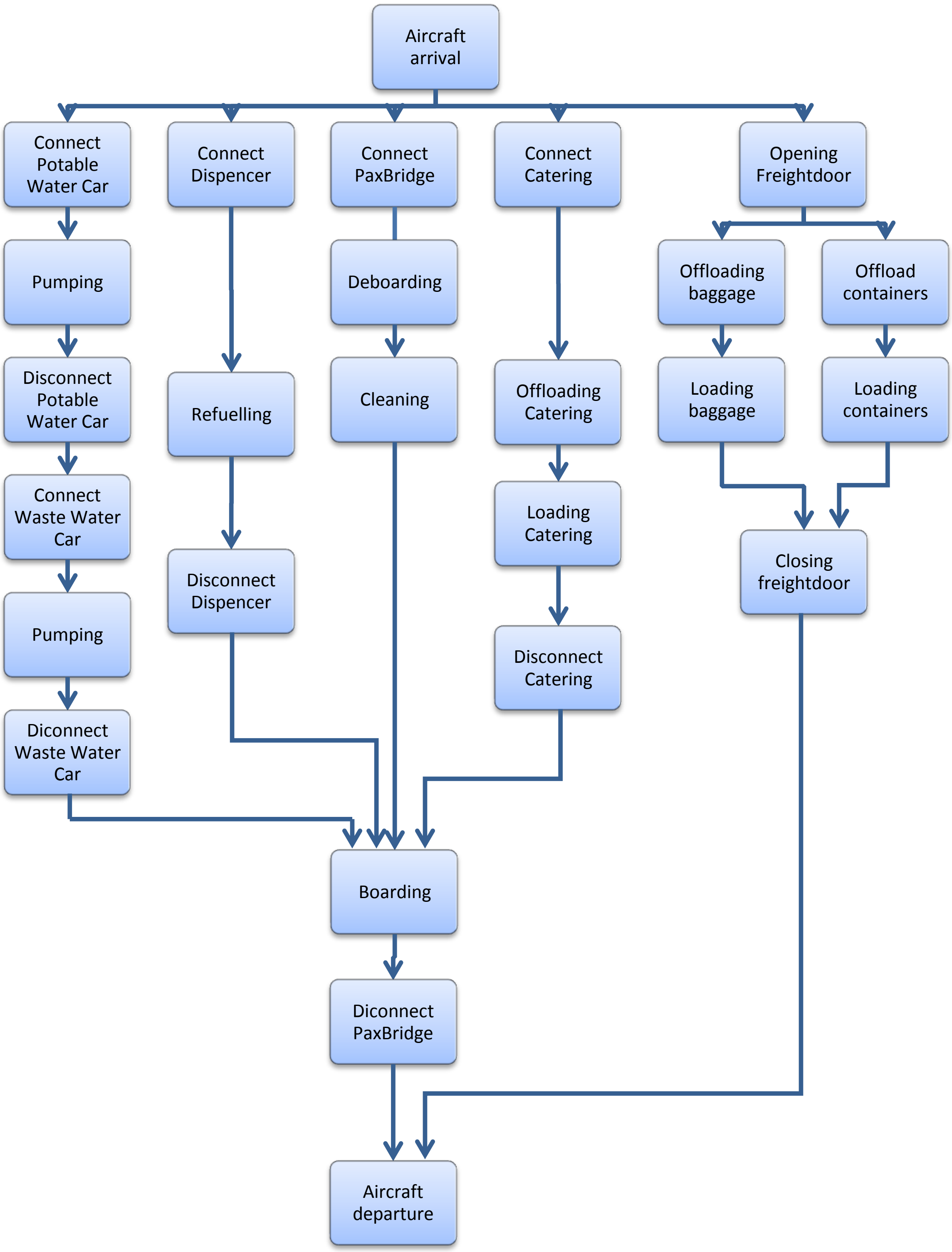



**Figure 2.4** Example of aircraft turnaround diagram (based on **Hortsmeier 2001)**

As the above figure reflects, there are processes which must not begin until others end. Due to these restrictions, these processes are susceptible to become the critical path and an increase in their times can consequently increase the total turnaround time.

In the next chapter, the critical path for each scenario is studied, but some considerations, which are reflected in Figure 2.4, can be made in advance.

The refuelling procedure cannot begin until the disembarking has ended, as well as boarding cannot begin until refuelling has finished due to safety regulations **(JAR-OPS-1)**. This process can be on the critical path because it is performed by only one truck and its process normally takes a long period of time. Although, in this project, the reference mission is short-haul, so refuelling is not going to take a lot of time. In addition, sometimes these low cost airlines only refuel at their own base airport, so they do not need to refuel in all their flights.

Water services and catering process usually are not on the critical path, because they are short processes, but it has to be taken into account that they cannot be carried out until all passengers have deboarded in order not to disturb passengers' comfort. Furthermore, waste water service must not be performed parallel with the potable water service, due to hygienic reasons **(IATA 2009)**. But low cost airlines do not carry out cleaning and catering in all their flights. They make a security check process instead which usually is shorter but can also become the critical path when e.g. the LCA does not refuel at this airport.

The processes of unloading and loading are usually carried out by only one belt loader in LCA. Therefore until the unloading has not finished, the loading cannot begin. This procedure is a long and complex one because it involves many operators and equipment. Therefore, if un/loading process becomes a process on the critical path, the turnaround does not finish until the loading has also finished, which can entail a significant increase in the turnaround time. Besides, some bulks can appear in the last moment to be loaded, which can cause delays and rise the time. In short, improvements to the loading process can lead to an important reduction in the total turnaround time and reduce ground handling costs.

Other important process that takes a considerable amount of time is dis/embarking. This procedure is difficult to evaluate because of the human factor and it is hard to anticipate and simulate. But it is also a critical procedure which needs to be improved.

In Figure 2.5, a typical turnaround chart of a B737 is depicted. This figure shows the estimated times for each ground handling process and its interrelations. In this case, the cleaning and the dis/embarking processes are on the critical path.

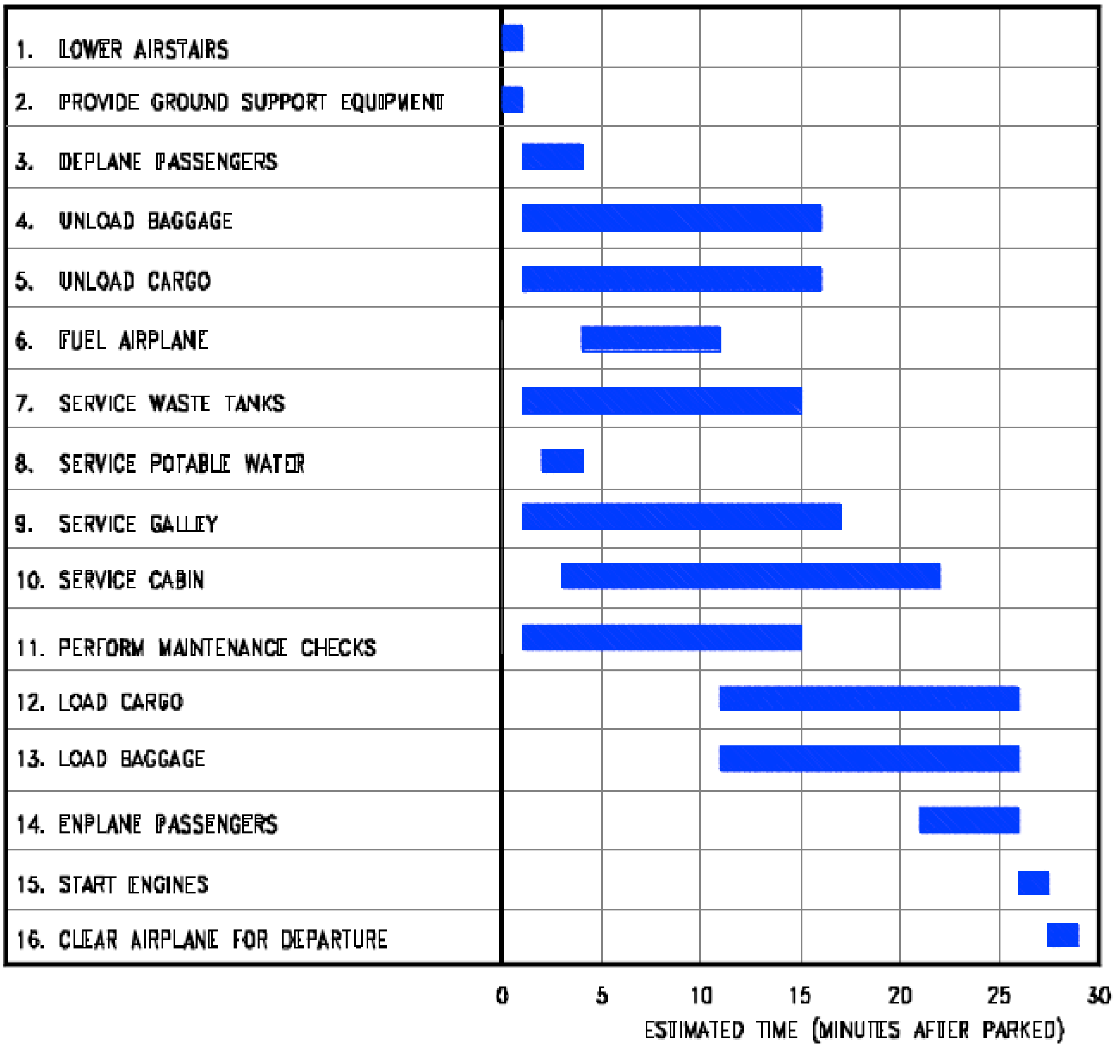



**Figure 2.5** Typical turnaround Gantt chart 737-900, -900ER **(Boeing 2005)**

# 3 Turnaround Gantt Charts

## 3.1 Introduction

In this chapter, turnaround Gantt charts have been created for each scenario by introducing the results of the statistical analysis. Since these results come from the videos recorded at real airport, the obtained turnarounds have a realistic character.

Each of the scenarios has different characteristics, but they all match up with using the same reference aircraft and capturing the same reference mission with a full ground handling service at the airport. As the reader could see in Chapter 2, the two main characteristics that primarily make a difference are the airline business model (conventional vs. low cost) and the parking position (terminal vs. remote apron). This all is reflected in the four defined scenarios as well as several ground handling service equipment.

This section discusses the resulting features of each scenario and compares the scenarios between them.

Finally, a half ground handling service is shown in order to make a comparison with the turnaround time of a full GH service. That is taken into consideration, due to the fact that companies do not usually clean the cabin, refill potable water and remove waste water at every flight, but a full service only occurs at every third or fourth turnaround on short-haul flights.

## 3.2 Results

In this section, the derived Gantt charts are depicted. They have been made by importing the statistical analysis of each turnaround process in an Excel table and creating the Gantt chart corresponding to each scenario.

The length of each bar is scaled according to each ground handling process time and the segments indicate the standard deviation of each process time. The arrows indicate the dependency of each activity but all derived Gantt charts do not take into consideration a refuelling parallel to dis/embarking. All scenarios and derived Gantt charts are thus based on realistic turnaround data.

### 3.2.1 Scenario 1

The modelled aircraft of the first scenario is an example of an aircraft operated by a conventional company. It reflects full service (catering, cleaning and water service) and disembarking and embarking are carried out through a bridge. Therefore pushback equipment is needed; which is in this case, a tow-bar-less truck. The ground power process will be done through the equipment integrated at the bridge. Loading and unloading is performed with a container loader and 4 ULD’s will be transported, 3 ULD’s in the after compartment (AFT) and 1 ULD in the forward compartment (FWD).

Table 3.1 shows the length of each process.

**Table 3.1** Data of scenario 1

| *Process* | **Equipment** | **Positioning** | **Connecting** | **Process** | **Disconnecting** | **Removing** |
|---|---|---|---|---|---|---|
| Disembarking | Bridge | 0:01:01 | | 0:07:00 | | |
| Refuelling | Truck | 0:00:15 | 0:01:51 | 0:02:44 | 0:01:15 | 0:00:16 |
| Catering | Truck | 0:00:14 | 0:00:29 | 0:05:11 | 0:00:32 | 0:00:22 |
| Cleaning | Personal | | | 0:07:33 | | |
| Potable Water Service | Truck (200l) | 0:00:12 | | 0:01:32 | | 0:00:11 |
| Waste Water Service | Truck (200l) | 0:00:12 | | 0:03:32 | | 0:00:11 |
| Embarking | Bridge | | | 0:08:16 | | 0:00:51 |
| Offloading | Cont. Loader | 0:00:36 | | 0:09:55 | | |
| Loading | Cont. Loader | | | 0:09:16 | | 0:00:31 |
| Ground Power | GP Bridge | 0:00:27 | | 0:21:39 | | 0:00:40 |
| Pushback | Tow bar less | 0:00:10 | 0:00:11 | 0:01:06 | | 0:01:05 |

The turnaround Gantt chart of this scenario is shown in Figure 3.1.

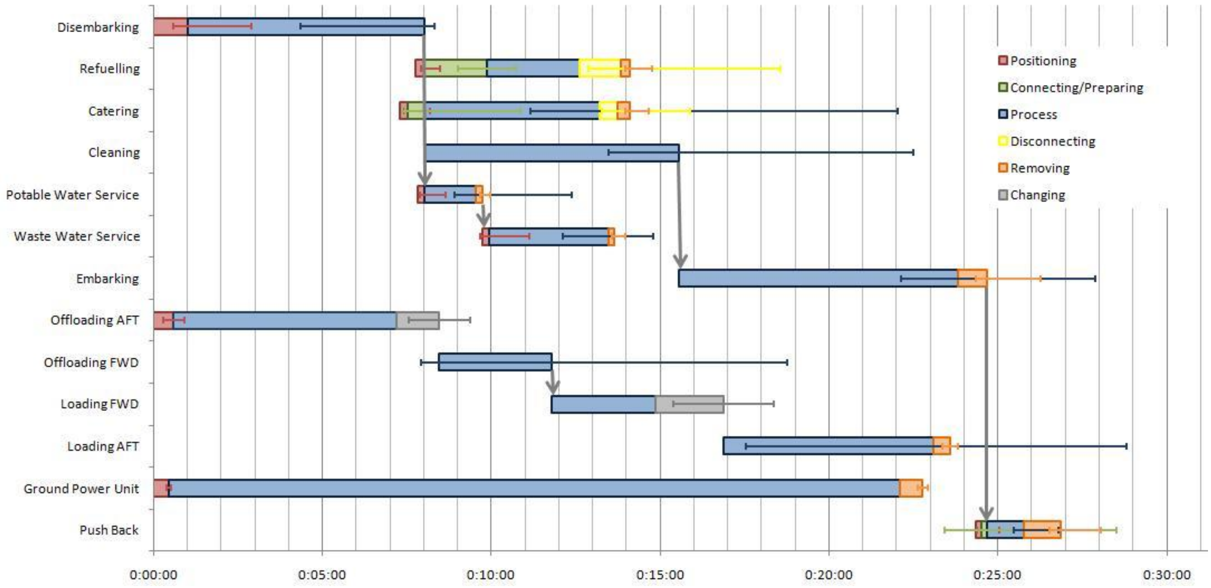



**Figure 3.1** Turnaround Gantt chart of scenario 1 (26.87 min)

In this first scenario, the turnaround time is directly depending on the embarking time, which cannot start until cleaning in this case. So if we achieve to reduce the embarking time or the cleaning, the turnaround time can be reduced. The unloading and loading process time is very similar to the actual time of the critical path, so it is possible that by altering the dis/embarking process or the cleaning the unloading and loading process becomes a process on the critical path. Therefore, improvements to loading equipment can also be useful to reduce the turnaround time.

### 3.2.2 Scenario 2

The second scenario shows an aircraft of a conventional airline. It also receives full service but in this case, the aircraft parks at the remote apron. Therefore, a Ground Power Unit (GPU) is necessary, but there is no need of pushback equipment. For the unloading and loading process a belt loader is necessary to carry 100 bags.

Table 3.2 and Figure 3.2 show the data and the Gantt chart corresponding with this scenario.

**Table 3.2** Data of scenario 2

| *Process* | **Equipment** | **Positioning** | **Connecting** | **Process** | **Disconnecting** | **Removing** |
|---|---|---|---|---|---|---|
| Disembarking | 2 Stairs | 0:00:53 | | 0:04:06 | | |
| Refuelling | Truck | 0:00:15 | 0:01:51 | 0:02:44 | 0:01:15 | 0:00:16 |
| Catering | Truck | 0:00:14 | 0:00:29 | 0:05:11 | 0:00:32 | 0:00:22 |
| Cleaning | Personal | | | 0:07:33 | | |

| *Process* | **Equipment** | **Positioning** | **Connecting** | **Process** | **Disconnecting** | **Removing** |
|---|---|---|---|---|---|---|
| Potable Water Service | Truck (200l) | 0:00:12 | | 0:01:32 | | 0:00:11 |
| Waste Water Service | Truck (200l) | 0:00:12 | | 0:03:32 | | 0:00:11 |
| Embarking | 2 Stairs | | | 0:05:51 | | 0:00:33 |
| Offloading | Cont. Loader | 0:00:51 | | 0:09:16 | | |
| Loading | Cont. Loader | | | 0:06:44 | | 0:00:22 |
| Ground Power | GPU | 0:00:16 | | 0:19:01 | | 0:00:37 |
| Pushback | N/A | | | | | |

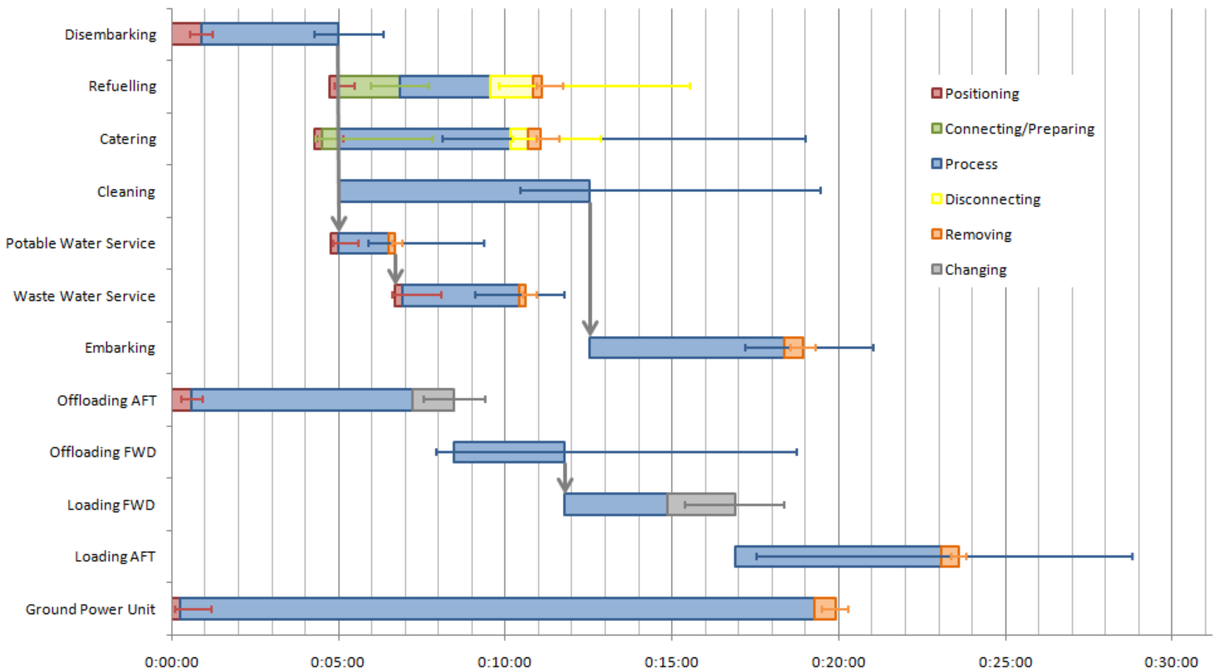



**Figure 3.2** Turnaround Gantt chart of scenario 2 (23.6 min)

This scenario is very similar to the first one, but in this case, passengers are deboarding and boarding with two stairs, which means two exits, and consequently faster disembarking and embarking processes. Owing to this fact, the off/loading process is on the critical path.

### 3.2.3 Scenario 3

This scenario is similar to the first scenario, but in this case, the aircraft is operated by a low cost airline, consequently the times of each process can vary due to the different way of management. But in this case also a passenger boarding bridge is used to carry passengers and a belt loader to load 100 bags. The ground power is supplied through the bridge and the pushback process is performed with a conventional truck.

**Table 3.3** Data of scenario 3

| *Process* | **Equipment** | **Positioning** | **Connecting** | **Process** | **Disconnecting** | **Removing** |
|---|---|---|---|---|---|---|
| Disembarking | Bridge | 0:01:01 | | 0:07:00 | | |
| Refuelling | Truck | 0:00:15 | 0:01:51 | 0:02:44 | 0:01:15 | 0:00:16 |
| Catering | Truck | 0:00:14 | 0:00:29 | 0:05:11 | 0:00:32 | 0:00:22 |
| Cleaning | Personal | | | 0:07:33 | | |
| Potable Water Service | Truck (200l) | 0:00:12 | | 0:01:32 | | 0:00:11 |
| Waste Water Service | Truck (200l) | 0:00:12 | | 0:03:32 | | 0:00:11 |
| Embarking | Bridge | | | 0:08:16 | | 0:00:51 |
| Offloading | Belt Loader | 0:00:51 | | 0:09:16 | | |
| Loading | Belt Loader | | | 0:06:44 | | 0:00:22 |
| Ground Power | GP Bridge | 0:00:27 | | 0:21:55 | | 0:00:40 |
| Pushback | Conventional | | 0:01:46 | 0:01:28 | | 0:01:02 |

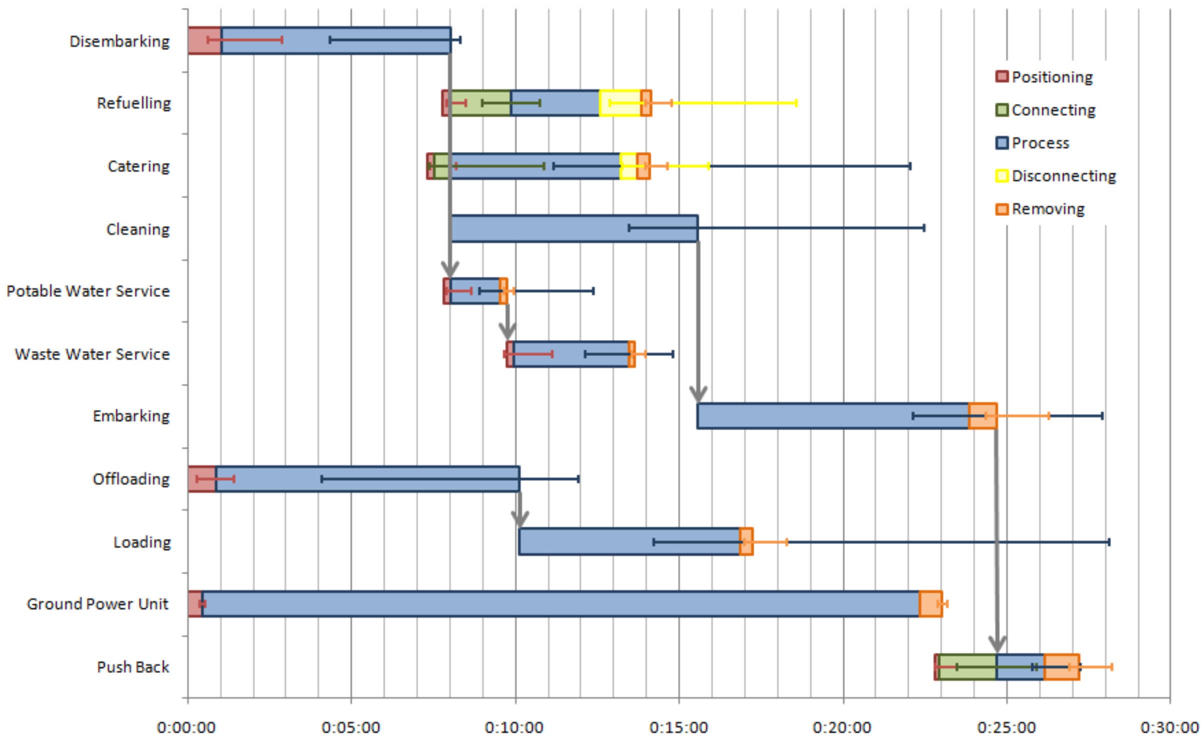



**Figure 3.3** Turnaround Gantt chart of scenario 3 (27.18 min)

The Gantt chart shows that the embarking process is on the critical path and that until the cleaning process has not finished the embarking cannot start. This scenario represents a LCA scenario and, as it has previously been mentioned, low cost airlines do not carry out a full service at every flight. Figure 3.4 shows the turnaround Gantt chart of this scenario without cleaning, catering and water services.

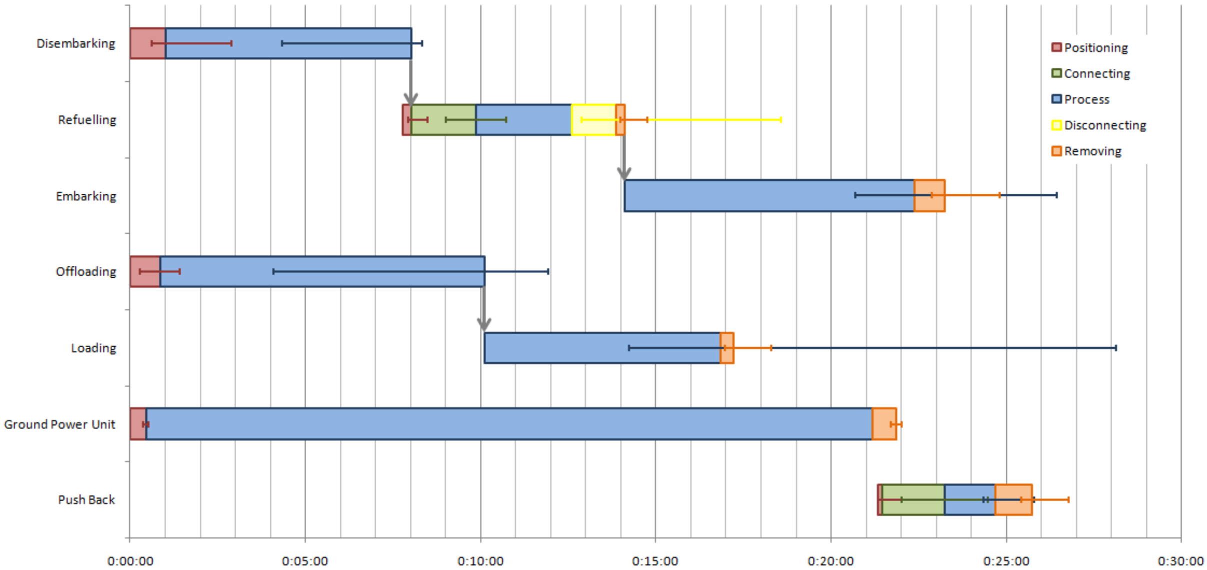



**Figure 3.4** Turnaround Gantt chart of half service at the terminal (25.73 min)

Having half service, the turnaround time is reduced from 27.18 minutes to 25.42 minutes, because now the embarking process only depends on the refuelling time which is shorter than the cleaning time.

### 3.2.4 Scenario 4

The last scenario shows a situation of an aircraft of a LCA, where the plane parks at the remote apron and needs to carry 100 bags. In consequence, the necessary equipment is a belt loader, a GPU and the other vehicles that are needed for the correct execution of the whole ground handling process.

**Table 3.4** Data of scenario 4

| *Process* | **Equipment** | **Positioning** | **Connect.** | **Process** | **Disconnect.** | **Removing** |
|---|---|---|---|---|---|---|
| Disembarking | 2 Stairs | 0:00:53 | | 0:04:06 | | |
| Refuelling | Truck | 0:00:15 | 0:01:51 | 0:02:44 | 0:01:15 | 0:00:16 |
| Catering | Truck | 0:00:14 | 0:00:29 | 0:05:11 | 0:00:32 | 0:00:22 |
| Cleaning | Personal | | | 0:07:33 | | |
| Potable Water Service | Truck (200l) | 0:00:12 | | 0:01:32 | | 0:00:11 |
| Waste Water Service | Truck (200l) | 0:00:12 | | 0:03:32 | | 0:00:11 |
| Embarking | 2 Stairs | | | 0:05:51 | | 0:00:33 |

| *Process* | **Equipment** | **Positioning** | **Connect.** | **Process** | **Disconnect.** | **Removing** |
|---|---|---|---|---|---|---|
| Offloading | Belt Loader | 0:00:51 | | 0:09:16 | | |
| Loading | Belt Loader | | | 0:06:44 | | 0:00:22 |
| Ground Power | GPU | 0:00:16 | | 0:15:16 | | 0:00:37 |
| Pushback | N/A | | | | | |

The bottom graphic (Figure 3.5) represents the turnaround process corresponding to scenario 4.

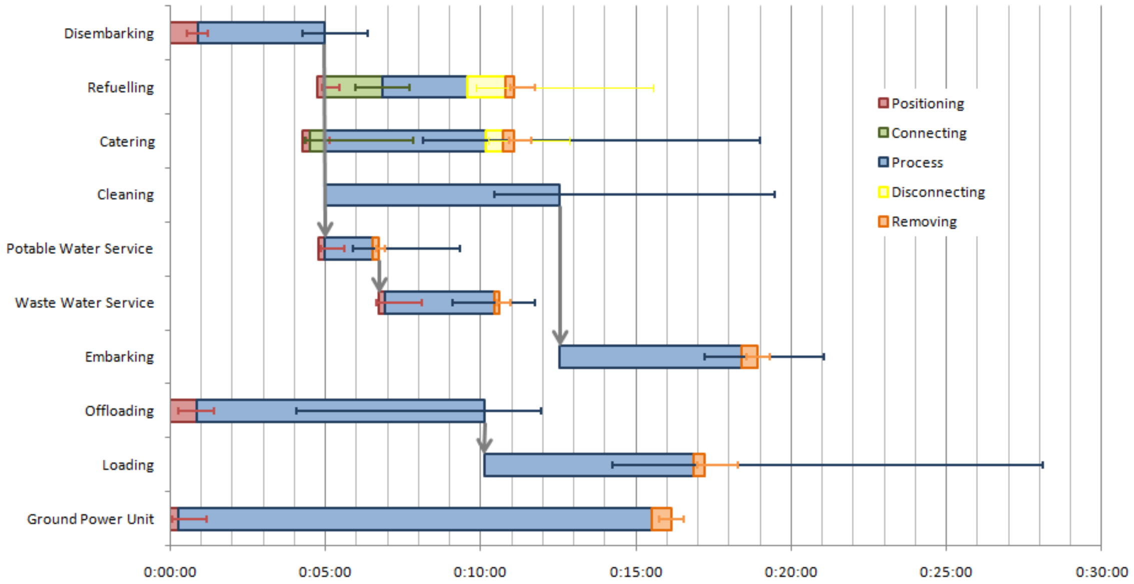



**Figure 3.5** Turnaround Gantt chart of scenario 4 (18.93 min)

It can be seen that the critical process which finally defines the total turnaround of the scenario is the embarking process. Nevertheless, if an improvement to embarking or in cleaning is achieved, the process time would be similar with the off/loading time, which would entail an improvement to loading equipment. If cleaning, catering and water service are omitted, the turnaround time changes. See Figure 3.6.

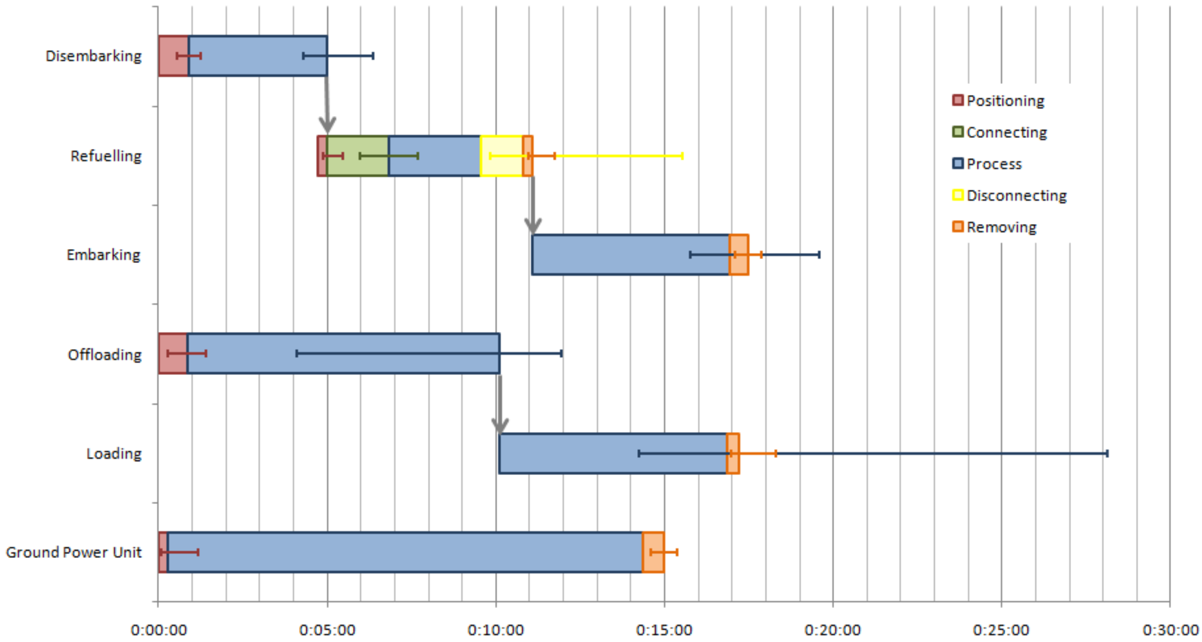



**Figure 3.6** Turnaround Gantt chart of half service at a remote apron (17.48 min)

In this case, a reduction of 1.45 min is achieved by having half GH service.
This case is the shortest one, since this scenario shows an aircraft parking at a remote apron, which uses two stairs and does not need pushback equipment.

## 3.3 Discussion

In short the main times of the turnaround process for each scenario are reflected in Table 3.5.

**Table 3.5** Process times of each scenario

| *Process* | **Scenario 1** | **Scenario II** | **Scenario III** | **Scenario IV** |
|---|---|---|---|---|
| Disembarking | 8:01 | 4:59 | 8:01 | 4:59 |
| Refuelling | 6:21 | 6:21 | 6:21 | 6:21 |
| Catering | 6:48 | 6:48 | 6:48 | 6:48 |
| Cleaning | 7:33 | 7:33 | 7:33 | 7:33 |
| PWS | 1:55 | 1:55 | 1:55 | 1:55 |
| WWS | 3:55 | 3:55 | 3:55 | 3:55 |
| Unloading | 10:31 | 10:31 | 10:07 | 10:07 |
| Loading | 9:47 | 9:47 | 7:06 | 7:06 |
| Embarking | 9:07 | 6:24 | 9:07 | 6:24 |
| Ground Power | 22:46 | 19:54 | 23:02 | 16:09 |
| Pushback | 2:32 | ----- | 4:23 | ----- |
| **Turnaround time** | **26:52** | **23:36** | **27:11** | **18:56** |

*times are expressed in format mm:ss

All the achieved times are similar between them, and all are in the range from 19 min to 28 min.

If the table is analysed, it can be seen that the time of dis/embarking is quite longer when a bridge is used (scenarios III and IV). The reason of that is that only one door is operative in the process of boarding and deboarding. In order to improve this situation, it would help to use one stair or another air bridge in the AFT door besides the finger, this way the two operative doors would be used and the time of disembarking and embarking would be thus reduced.

The time of unloading and loading is very similar for a belt loader and a container loader. But this is the longest process of the turnaround and any improvement to it like sliding carpet or ramp snake **(Gómez 2009)** could help reducing the overall turnaround time.

In Figure 3.7 two examples of turnaround Gantt chart **(Airbus 1995)** are depicted. In both cases refuelling process is parallel to deboarding and boarding and this situation was not considered in the defined scenarios. Nevertheless, these examples are useful to make comparison with the data of the manufacturer.

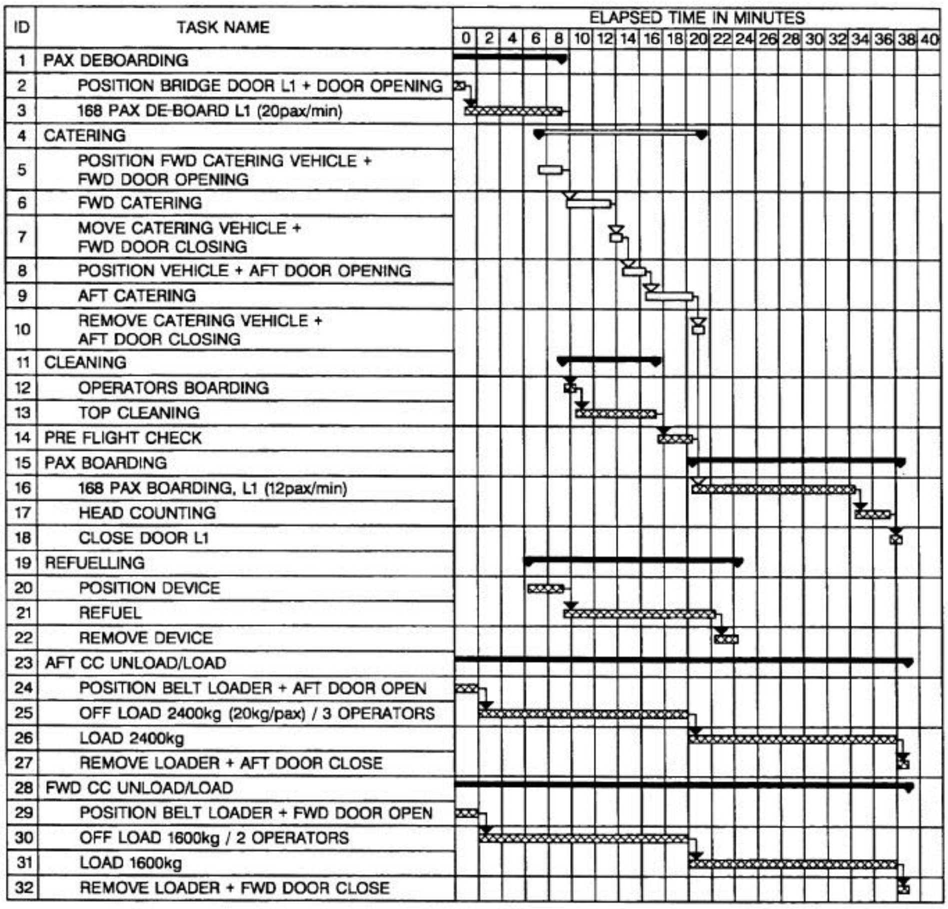



**Figure 3.7** Typical turnarounds Gantt chart A320, -900ER (38 min) **(Airbus 1995)**

Figure 3.7 is depicted in **Airbus 1995**. It reflects a situation of disembarking and embarking of 168 passengers with one operative door, unloading and loading 4000 kg with two belt loaders and with cleaning and catering services. The turnaround time of this scenario is 38 min which is approximately 10 min longer than the turnaround time of the scenario 3. This is due to the fact that, in this example, unloading and loading processes are on the critical path, since the cargo load is a lot bigger than in scenario 3.

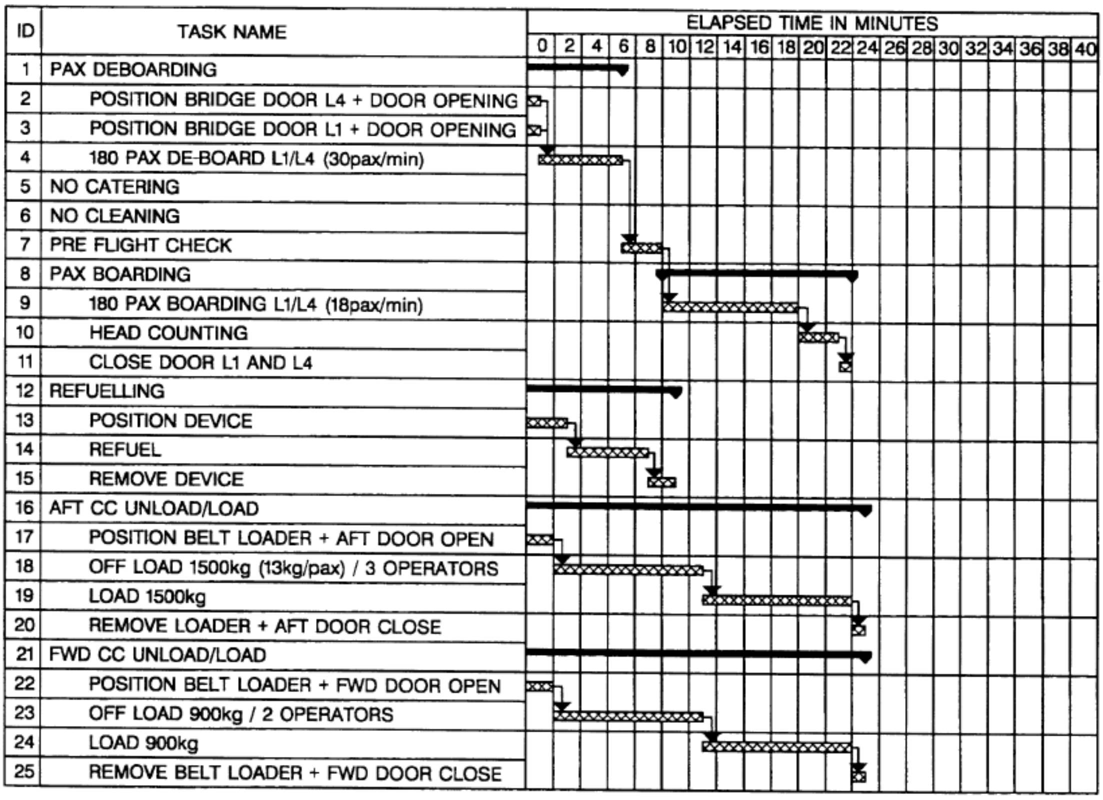



**Figure 3.8** Typical turnaround Gantt chart A320, -900ER (25 min) **(Airbus 1995)**

The second turnaround reflects a situation of disembarking and embarking of 180 passengers with two operative doors, unloading and loading of 2400 kg with two belt loaders and without cleaning and catering. Comparing with the scenario 4 without cleaning and catering (Figure 3.6) it can be seen that the last turnaround results in a shorter time, i.e. 7 minutes in total. This is due to the fact that the payload is smaller (less passenger and less cargo load) in scenario 4 which entail a shorter turnaround time.

In conclusion, the results obtained in each scenario are pretty similar to the manual turnaround times, although they are shorter. But if the standard deviation for each process is considered, the times specified in the manual will be in the range of the turnaround times of the scenarios.

The turnaround Gantt charts show that the processes that usually are on the critical path are disembarking, cleaning, loading and embarking. Nevertheless, catering and refuelling take also a long time and can also become a process on the critical path. Since they are on the critical path, any reduction in their times reduces directly the turnaround time, hence, a great effort must be done to achieve reducing the total turnaround time. Some improvements are studied in Chapter 6 and 7.

# 4 Ground Handling Cost Calculation

## 4.1 Introduction

When a company wants to buy a new aircraft the aspects which have an important influence on the acquisition of the aircraft are the following ones: **(Martínez-Val 2007)**

1. Aircraft economics:
   - Direct Operating Costs (DOC)
   - Aircraft price

2. Aircraft performances:
   - Payload-Range Diagram
   - Cruise speed
   - Performances in runway: take-off distance, landing distance...
   - Performance with critical engine inoperative

3. Manufacture:
   - Previous experience
   - Product support
   - Financing conditions
   - Delivery period

4. Other aspects:
   - Appeal to the passenger (cabin distribution, comfort,...)
   - Aircraft family
   - Noise, pollution,...

In order to make a cost analysis, there are a whole series of models for cost analysis, such as LCC (Life Cycle Costs), COO (Cost of Ownership) or DOC (Direct Operating Cost). Each method has a different concept about costs and its calculation and has an approach from different perspectives. **(Scholz 2010)**

But the most used method is the DOC method. Direct operating costs are the costs which are involved during the utilization of an aircraft by a company for one determined route during a defined time period. There are various cost calculation methods which are based on DOC concept like shown in Table 4.1. **(Scholz 2010)**

**Table 4.1** Overview of current available DOC-Methods **(Scholz 2010)**

| Organization | Comment | Year of Publication | Source |
|---|---|---|---|
| Air Transport Association of America (ATA) | Predecessors to this method are from the year: 1944, 1949, 1955 and 1960. | 1967 | ATA 1967 |
| American Airlines (AA) | The method is based on large studies sponsored by NASA. | 1980 | AA 1980 |
| Lufthansa | The method was continuously developed further. | 1982 | DLH 1982 |
| Association of European Airlines (AEA) | Method for short- and medium range aircraft | 1989 | AEA 1989a |
| Association of European Airlines (AEA) | Method for long range aircraft (a modification of the method AEA 1999a) | 1989 | AEA 1989b |
| Airbus Industries (AI) | The method was continuously developed further. | 1989 | AI 1989 |
| Fokker | the method was produced to evaluate aircraft design projects. | 1993 | Fokker 1993 |

As a rule, DOC methods calculate the direct operating costs of an aircraft from the cost C incurred to: **(Scholz 2010)**

- Depreciation
- Interest
- Insurance
- Fuel
- Maintenance, consisting of the sum of:
- Airframe maintenance
- Power plant maintenance
- Crew
- Cockpit crew
- Cabin crew
- Fees and charges
- Landing fees
- ATC or navigation charges
- Ground handling charges

Then, the DOC are the sum of these cost elements:

$$C_{DOC} = C_{DEP} + C_{INT} + C_{INS} + C_F + C_M + C_C + C_{FEE} \tag{4.1}$$

And the fees cost elements can be calculated by the sum of landing fees, navigation charges and ground handling charges:

$$C_{FEE} = C_{FEE,LD} + C_{FEE,NAV} + C_{FEE,GND} \quad (4.2)$$

Figure 5.1 reflects the different contribution of each aspect to the DOC.

But ground handling costs have an influence on the total DOC of the aircraft, which is not very big in comparison with aircraft price or depreciation, but it has its importance in overheads of the company. So, any improvement in the ground handling process or in the aircraft configuration which reduces any ground handling time will also entail a reduction in ground handling costs, since a cost reduction at one single ground handling process can be seen on the total ground handling costs. Nevertheless, as Chapter 6 explains, improvements to ground handling operation can increase the aircraft weight and delivery price or the Ground Support Equipment costs which can be detrimental to aircraft performances and other DOC cost items.

Normally a reduction in time leads to a reduction in costs, but reducing one single ground handling process time might not lead to an overall reduction in turnaround time. Only by reducing ground handling processes which are on the critical path a reduction in the overall turnaround time can be achieved. In addition, in order to achieve a reduction in DOC, the utilization of the aircraft must be increased. But an increase on the aircraft utilization is only obtained if the reduction in the turnaround time allows a further flight during the considered daily availability.

In conclusion, it is necessary to keep in mind that ground handling costs have only a small contribution in the DOC, and that by improving the aircraft so that it has a shorter turnaround time and a greater utilization and consequently less costs, can also increase the weight or other parameters which indirectly entails to increase the final DOC.

## 4.2 Process Cost Calculation in Ground Handling

Ground handling costs depends directly on the total turnaround which is defined by the services that the aircraft receives at the airport. That means that defining the costs of each process or service the total ground handling costs can be calculated separately.

In order to evaluate the costs involved during a turnaround, equipments and staff of each the ground handling process must be analysed and must be set depending on the variables of the process.

Crönertz developed a process oriented cost calculation method in his book *“Prozessorientierte Kalkulation von Flughafenleistungen. Schwerpunkt: Bodenabfertigungsdienste con Passagierflugzeugen”* which it is used here to estimate the turnaround costs of the scenarios.

This method calculates the cost of each ground handling process depending on variables of the process such as the operational parameter (no. seats, no baggage), average rate, number of necessary resources and fixed amount allocation.

These parameters have to be determined for each ground handling activity. With the statistical analysis in Chapter 2, the process time of each activity was calculated related to the parameter operational parameter determined in the scenarios definition. The cost drivers can be found in **Crönertz 2008**, in GSE manufacturers, ground handling companies and airports.

In addition, Crönertz developed an Excel tool which allows to calculate the costs of the process of a turnaround. This tool is based on a detailed spreadsheet which contains the costs involved in the turnaround such as costs of equipments, staff or materials. All data come from a research on the GH processes at German airports. With the costs and times of each GH process, Crönertz calculated the cost rates and by defining scenario features such as the aircraft model, the flight mission and the parking position at the airport, the tool obtains the costs of each process involved in the defined scenario.

Nevertheless, the costs of the processes of refuelling, catering and cleaning are not defined in the spreadsheet, but they are upraised according to the scenario features.

## 4.3 Application to the defined scenarios

In this chapter, the ground handling costs are calculated using Crönertz’s Excel tool for a preliminary evaluation of the turnaround cost.

This estimation is made by introducing manually the times and features (no. passenger, no. baggage, etc.) of each scenario obtained in the statistical analysis, and by using the cost rates and the necessary staff and equipments required by the tool.

Since the ground handling vehicles and staff are usually prepared earlier than the aircraft arrival, the introduced time of each process is not the time that the vehicle needs to carry out its task but the time since the aircraft arrives until the ground handling process has finished. In addition, in order to have a fast estimation the process times have been introduced without decimals.

Table 4.2 reflects the process costs of each scenario. Ground services include the equipment and staff which are necessary for the supply of the ground power and the air conditioning and the start-up support. Aircraft services are the cleaning of the cabin and toilets, PWS and WWS.

**Table 4.2** Involved costs in each scenario

| Resource | Scenario I | Scenario II | Scenario III | Scenario IV |
|---|---|---|---|---|
| Ground services | 45,05 € | 18,81 € | 45,05 € | 17,95 € |
| Dis/embarking | --- | 59,07 € | --- | 39,99 € |
| Off/loading | 74,63 € | 74,30 € | 51,77 € | 51,77 € |
| Aircraft services | 187,66 € | 164,23 € | 188,96 € | 173,11 € |
| GH Process cost | 307,33 € | 316,42 € | 285,79 € | 282,82 € |
| **Total cost** | **449,16 €** | **460,07 €** | **423,28 €** | **419,72 €** |

The dis/embarking through passenger boarding bridge does not appear in the spreadsheet of the tool, so the cost of the bridge and its equipments and staff are not directly considered. But in Table 5.2 it can be seen that scenario IV is the cheapest. This is due to the fact, that the aircraft parks at a remote apron and does not need pushback equipment. The loading is carried out with a belt loader which is cheaper than a container loader, and the times of the GH processes are shorter as seen in Chapter 3. In addition, it has been supposed that the boarding process does not need passenger buses, because this scenario is operated by LCA and LCA fly from and to secondary airports where it is possible to access to the terminal by feet.

If an example of a normal turnaround with the A320 for the same aircraft mission (150 pax, 100 bags) is calculated using the Crönertz tool, the GH process cost results in 403,76 € with an aircraft parking at the terminal. This cost is quite bigger than the calculated costs in Table 4.2, because the Crönertz tool calculates the costs with a turnaround time of 60 min and the turnaround times of the scenarios come from 17 to 28 min which are far below from the 60 min.

In consequence, it can be extracted from this preliminary cost analysis that parking at a remote apron of a secondary airport and loading with a belt loader turns out to be the cheapest turnaround cost and the shortest turnaround time. Nevertheless, the turnaround cost must be evaluated into depth in order to consider all the ground handling aspects

# 5 Simulation with CAST Ground Handling

## 5.1 CAST Ground Handling introduction (based on **CAST GH 2010)**

The Comprehensive Airport Simulation Tool Ground Handling (CAST GH) is a simulation tool for aircraft servicing developed by the Airport Research Center inside the software platform for simulation and planning of CAST.

CAST is a PC-tool that provides a virtual 3D environment for integrated simulation of all airport related processes with the high level of detail and accuracy. This simulation program is divided in several components which can be used stand alone or in combination, and it models different parts of an airport. CAST family is composed of CAST Terminal, CAST Pedestrian, CAST Aproncontrol, CAST Aircraft, and CAST Vehicle (Figure 5.1). ). CAST GH does not need expensive simulation equipment as it is optimised to run on personal computer. **(CAST 2010a)**

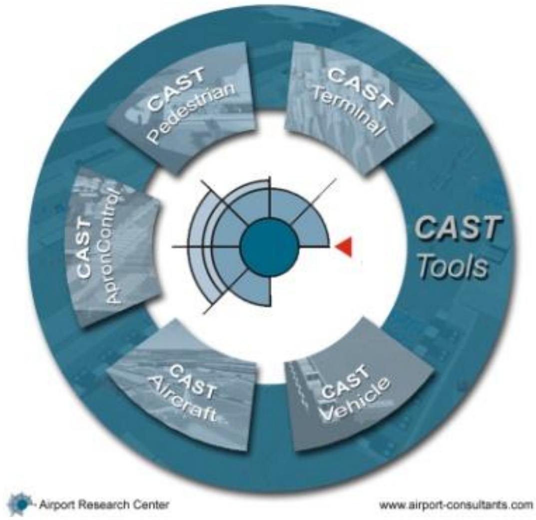



**Figure 5.1** CAST product family **(CAST 2010a)**

CAST Ground Handling simulates a variety of possible ground operations at the airport, looking for minimizing the turnaround time, as well as other GH aspects.

In addition, it is also possible to import detailed aircraft geometries from PrADO (Preliminary Aircraft Design and Optimization), which allows to simulate ground handling scenarios of different aircraft designs that have previously been designed and pre-evaluated with PrADO.

CAST Ground Handling is supposed to: **(CAST GH 2010)**

- Analyse turnaround time and critical path.
- Verify compatibility of aircraft and ground handling equipment.
- Use an extendable database of ground service equipment.
- Simulate tow curve of ground handling vehicles.
- Access to an extensive aircraft database.
- Detailed animation of apron movements.
- CAD-Interface (DXF).

The program is a powerful simulation engine, with a high-performance 3D fast time simulation system for all airport processes and has been developed to show the following features: **(CAST GH 2010)**

- Chronological process simulation.
- Process analysis as time bar chart.
- Visualization of service arrangement.
- Dynamic simulation of service vehicle movements.
- Aircraft-Ground service equipment compatibility analysis.
- Aircraft database with predefined services connections and service systems.
- GSE-database with measures and performance details of vehicles.
- Analysis of vehicle movements considering a possible collision.
- Front, side and top views
- Servicing cost analysis
- Layout of apron positions
- Performance parameters of servicing processes
- Import and export interface of DXF-files

Moreover, GH costs of the involved processes can be calculated with CAST GH, which allows to see the variation by changing some parameters such as the number of vehicles, the route of them or the services that the aircraft is receiving. It would also be desirable that the program would allow to extract the corresponding turnaround Gantt chart of the simulated scenario.

All this information and results could help to improve the aircraft configuration, the ground handling processes and the necessary equipments, and thus to reduce ground handling costs. Consequently, this program might be useful for all companies involved in GH, such as airlines, airports, aircraft manufacturers and ground handling companies.

## 5.2 CAST GH operational description

In this Chapter, the program is described and analysed based on the tutorial **(CAST 2010b)** provided by ARC to Aero group and the constant practice.

CAST GH is a simulation program which enables to model an airport with its ground handling equipments and to simulate different ground handling services which are performed on an aircraft during a turnaround.

The basic goal of CAST is to move "*goods*" from one point to another, where *good* is the used word in the program to designate anything which is carried, from baggage or fuel to passengers. *Goods* are placed on *goods containers,* which can be placed directly into the aircraft or on GH vehicles which transport *goods* from and to the aircraft.

The transfer of goods from one container to another is handled by the *container plug*, which is generated automatically when creating a container and must be defined according to the process. There are two types of plugs: active plugs and passive plugs. The passive ones are stationary and are connected to the active plugs, which are moved by GH vehicles to be connected to the corresponding passive plug. GH vehicles such as bulk loader or passenger stairs can also have both types of plugs to transfer goods from a source object to a target object. For example, in order to transport passengers from a passenger bus to the aircraft, it is used an active plug in the bus which is connected to the passive plug of the passenger stairs. At the same time, there is an active plug on the passenger stairs that connects the stairs to the aircraft door through a passive plug on the aircraft. This connection allows the flow of passengers to or from the aircraft.

When a new simulation is started, first of all, a new airport must be defined with all the needed areas such as depot, apron, holding, etc. Alternatively a sample airport can be loaded.

After creating the airport model, the user must load the chosen aircraft. There are some created models in the program such as an ATR 72, an Airbus A320 or a Boeing 747-400 (Figure 5.2). It is also possible to load different aircraft models or change their shape.

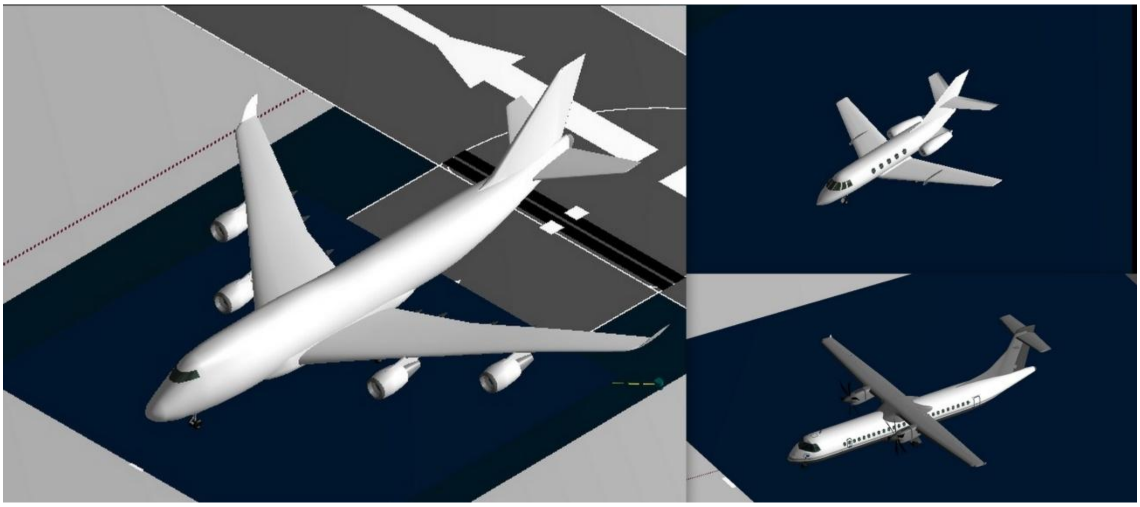


**Figure 5.2** CAST GH Aircraft model examples: B747, Falcon 20 and ATR 72

The aircraft has to be configured to hold all type of goods needed for each process of the simulation. Goods are held in containers which are placed into the aircraft and are transported from or to the aircraft by GH vehicles through plugs. The user can change the features of each object such as position, geometry and amount.

After designing the aircraft configuration with all the needed containers, goods and plugs, the corresponding ground handling vehicles, such as belt loader, passenger stairs and catering equipment have to be created.

Figure 5.3 shows the visualization of the aircraft with the containers and plugs and some GH vehicles placed at the aircraft stand.

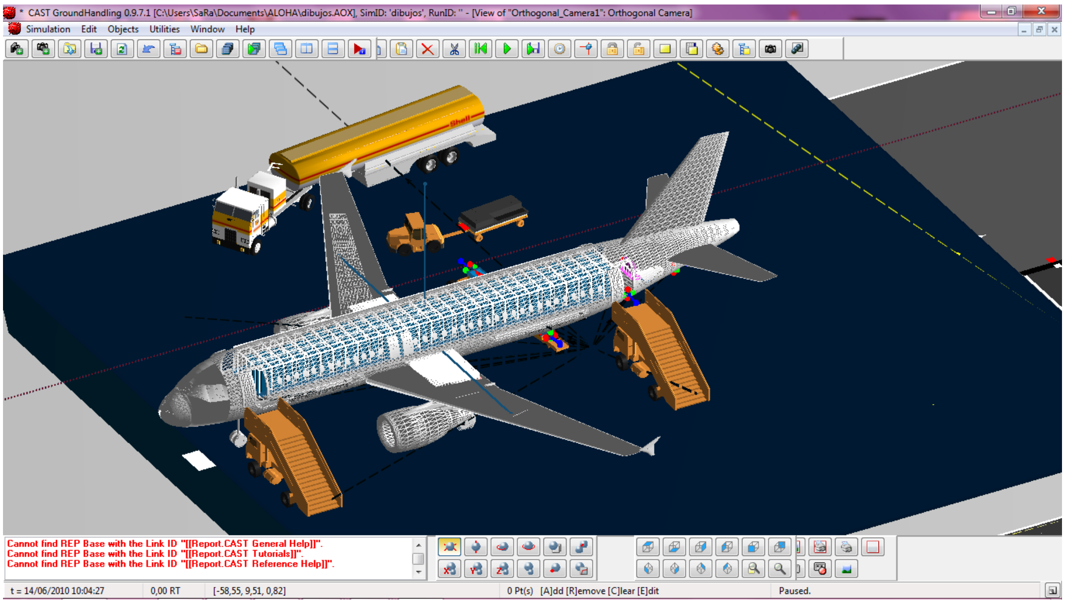



**Figure 5.3** CAST Ground Handling screenshot

Each vehicle has also a container, goods and plugs which have to be configured to match with the corresponding item of the aircraft. This task must be done carefully, defining correctly all the features and naming properly each item in order to make it easier and understandable. Containers placed on a GH vehicle must also include a *lifter*, enabling the vehicle to have a visually behaviour as in a real situation. These properties are only for visualization purposes, and transfer of goods will be possible even if the lifter is geometrically not able to reach the corresponding plug with the properties specified for the length, height and angle of the jib. There are a lot of GH vehicle examples of each GH sub process to be used, but it is also possible to create new ones or modify the samples to get real or hypothetical situations. All GH vehicles must be placed and assigned at the Home Depot where they will wait for instructions. (See Figure 5.4)

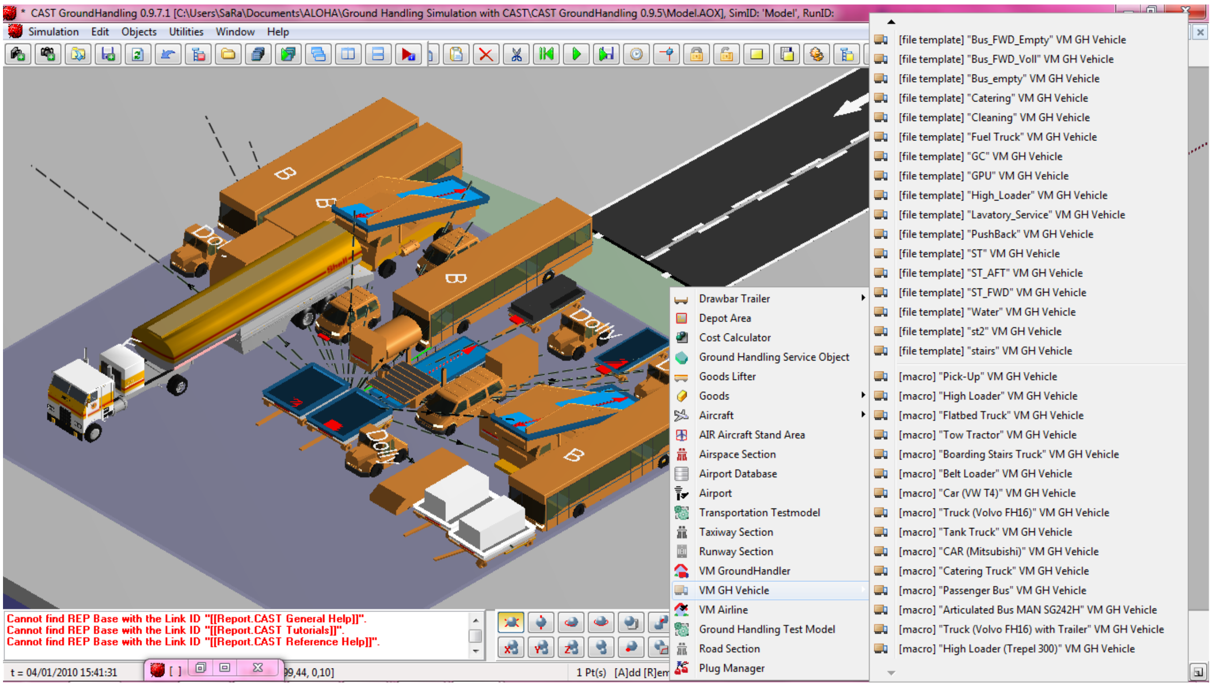



**Figure 5.4** CAST GH vehicles parked in Home Depot

For the cost calculation, it is necessary to attach a *Cost Definition Module* to the GH vehicle. This object must be configured assigning the cost for each sub process. See Figure 5.5.

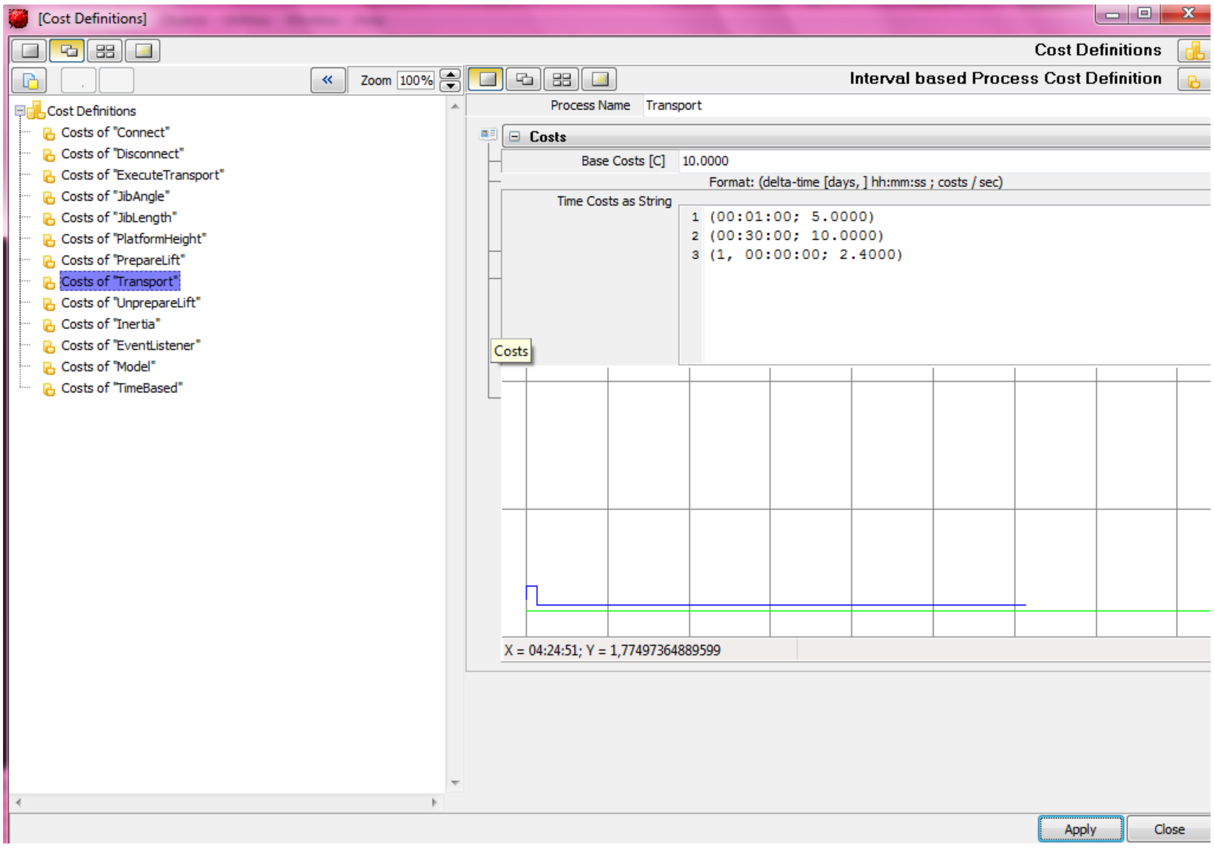



**Figure 5.5** Cost Definition

On the left of Figure 5.5, there is a list with each sub process of the GH vehicle procedure. On the right the costs must be defined according to the format (delta-time [days,] hh:mm:ss; costs/sec), i.e. in the specified time. This GH vehicle process cost will be calculated with this rate of cost. **(CAST 2010b)**

For example, in Figure 5.5, line *"(0:01:00; 5.0000)"* means that during the first time the GH vehicle is transporting goods the cost of the process is 5 units per second. Line *"(1;0:00:00; 2.4000)"* is defining that the GH vehicle costs 2,4 units per second once the first minute of this process has passed.

The next step, when every item has already been created and configured, is to build the road sections and taxi ways that will enable to access to the aircraft stand and give service to the aircraft. This program defines two types of roads: **(CAST 2010b)**

- Operational roads: These are roads that surround the aircraft stand and enable the vehicles to access the aircraft.

- Servicing roads: These are roads that exit the operational roads and lead to the aircraft; they usually have a specific direction and contain service points.

In order to commence their tasks, each GH vehicle needs a *service point*. A service point is a chosen point on a road section, where the GH will stop to perform its task. Since each process needs at least one service point, every service point must be named specifically and positioned in the right place.

Figure 5.6 shows the aircraft stand with the different types of roads. It can be seen that operational roads allow the approach of vehicles to the aircraft stand and that servicing roads lead vehicles to the service points where the task will be carried out.

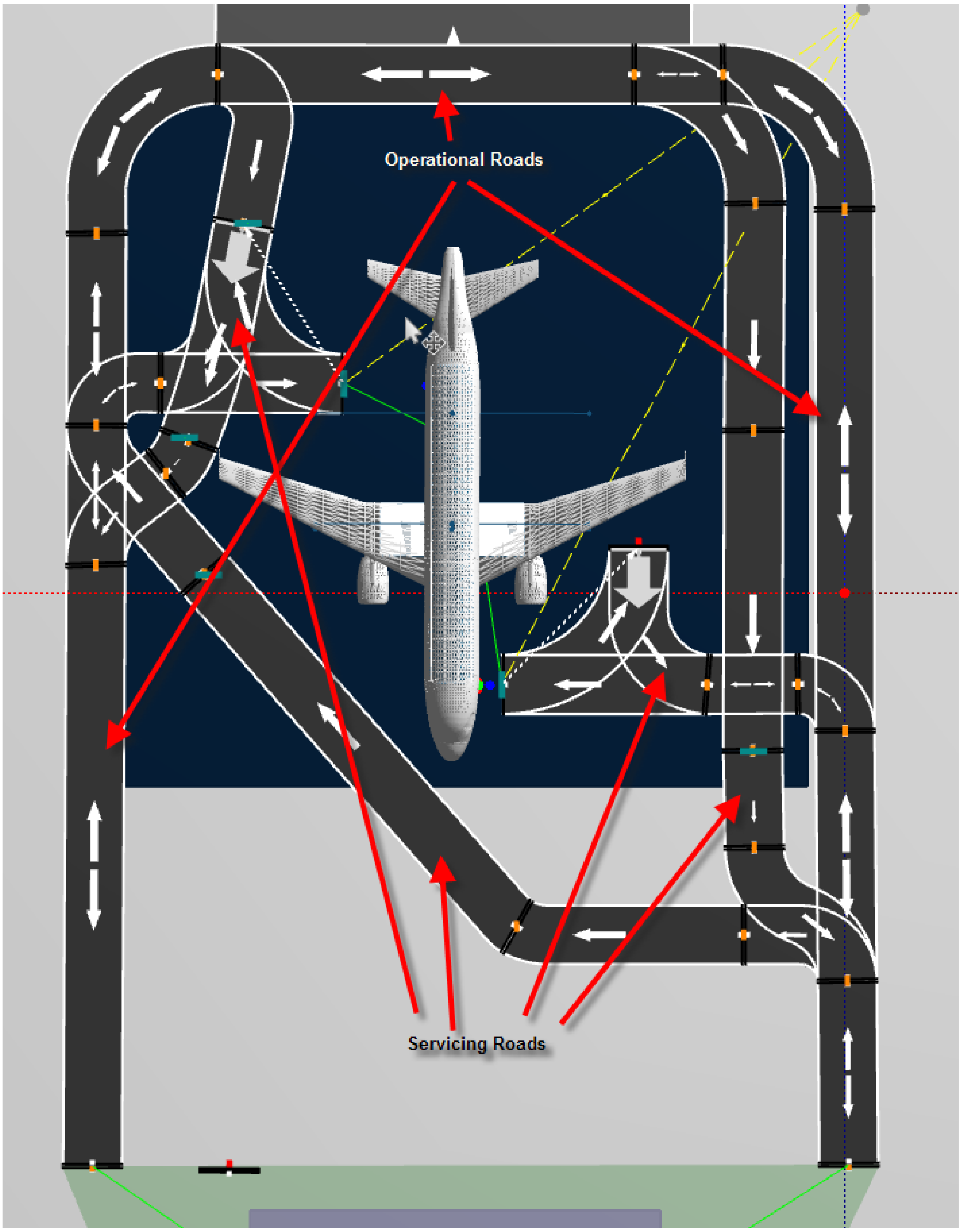



**Figure 5.6** Operational and servicing roads **(CAST 2010b)**

Road sections are connected by *road docks* to other operational or servicing roads. Each road section has two road docks, but it is also possible to add more docks to connect more road sections and build intersections. Servicing roads can be created manually by creating a road section and adding the needed service points or by creating a GH vehicle pushback linking the holding area with the corresponding GH object. This last action creates a pushback situation, including the service point and the road sections that the GH vehicle needs to go from the holding area to the desired position, and defines a vehicle manoeuvre. This kind of road section is composed of a service point and a set of arrows which define the movement of the GH vehicle. Each service point must be linked directly to a *TRA Service Access Point* and to the *Plug Manager* and it has to be given a unique name, in order to be able to select it later on the process definition.

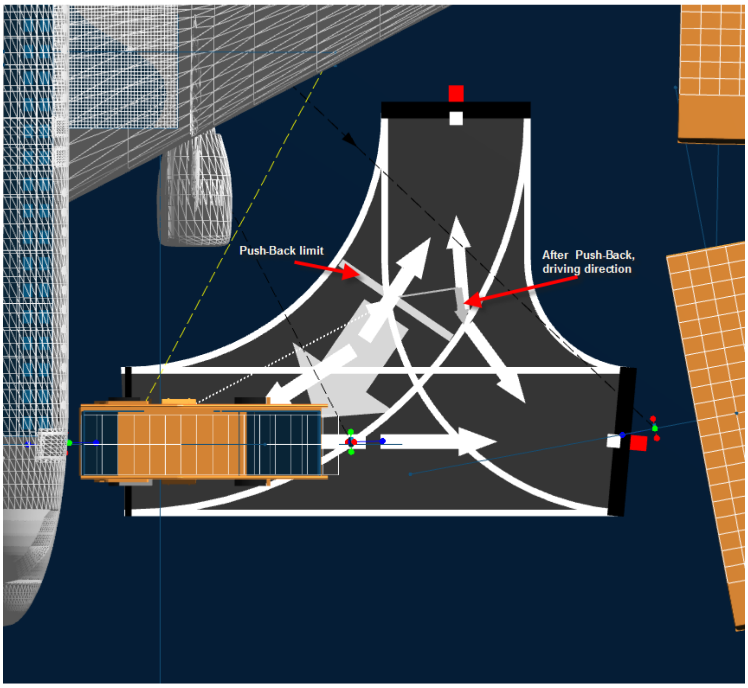



**Figure 5.7** Vehicle Manoeuvre **(CAST 2010b)**

Figure 5.7 shows a typical pushback road. The large arrow to the top of the lane is called Vehicle Manoeuvre Location arrow and indicates the direction of the pushback starting. The straight line which it is close to the Vehicle Manoeuvre Location arrow shows the pushback limit and can be placed where it is needed. The smaller gray arrow, which is on the right of the Vehicle Manoeuvre Location arrow, shows the driving direction of the GH vehicle after the pushback.

In the situation of Figure 5.7, the vehicle arrives from the right hand side and goes to its defined service point where it carries out its task. After the GH vehicle finishes its task, it leaves its service point, and following the arrows instructions, leaves the aircraft stand towards the right. **(CAST 2010b)**

Each process has its own service road, although the same service road can be used by different vehicles (e.g. belt loader and container loader). When every GH vehicle has its service road and its service point, each service road must be connected to the operational roads by creating and linking road docks. The user must define the direction of each road depending on the movements to be allowed. CAST GH also permits to make an analysis of vehicle movements considering a possible collision between them.

After the user has finished all relevant road adjustments, *Passage Restrictions* should be set. Passage Restrictions define road restrictions and specific GH vehicles driving behaviours in order to permit or deny the access of certain GH vehicles to some roads.

Once everything previously mentioned has been done, the next task is to define the process and set the vehicles dependencies. For this, the user needs to create a *HandleTurnaround* META Process and choose the *MAIN Process* menu item which shows the process layout. In this window, process chains are created by clicking *Create Vehicle Ground Handling Process Chain.* Each ground handling service needs its own chain which can be adapted for the necessary GH vehicle and the desired procedure.

As Figure 5.8 shows, a GH vehicle, a service point and a plug must be selected to define the process chain. All these names must match exactly with the names of the objects previously specified. The user must also introduce parameters and features of the process, such as the rate of pickup or the amount of items to be transported.

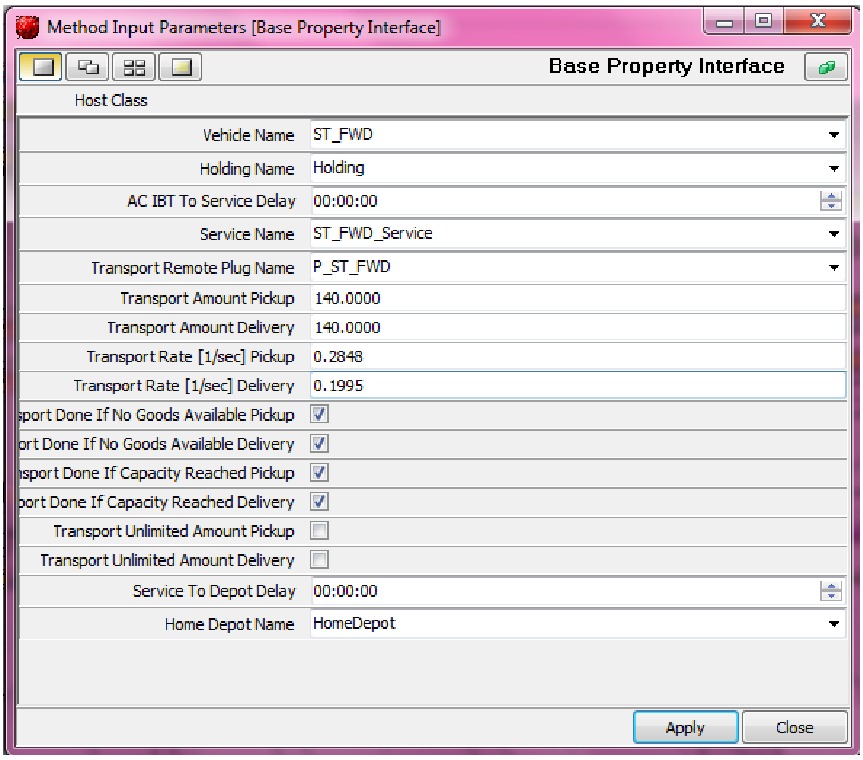



**Figure 5.8** Input Parameters of a process chain

After creating and configuring each process chain, the dependencies must be set. Every process chain has to be linked with the *Execute Model Mapper (EMM).* Most of the processes will also be linked with the TMO (Ten Miles Out) signal and with the AIBT (Aircraft In Blocks Time) signal, which the GH vehicle will receive from the aircraft mapper (Figure 5.9). Due to these connections, the GH vehicle would go to the Holding area as soon as the TMO signal would be sent from the aircraft. The GH vehicle would wait there until it receives the AIBT signal from the aircraft. After receiving the AIBT signal, the vehicle would go to its defined service point to perform its designated task. Then the GH vehicle would leave the service point and return to the holding area, before going back to the Home Depot **(CAST 2010b).** This behaviour matches with reality, as the GH vehicles are already prepared in their waiting positions (*Holding area* in the program) before the aircraft arrival.

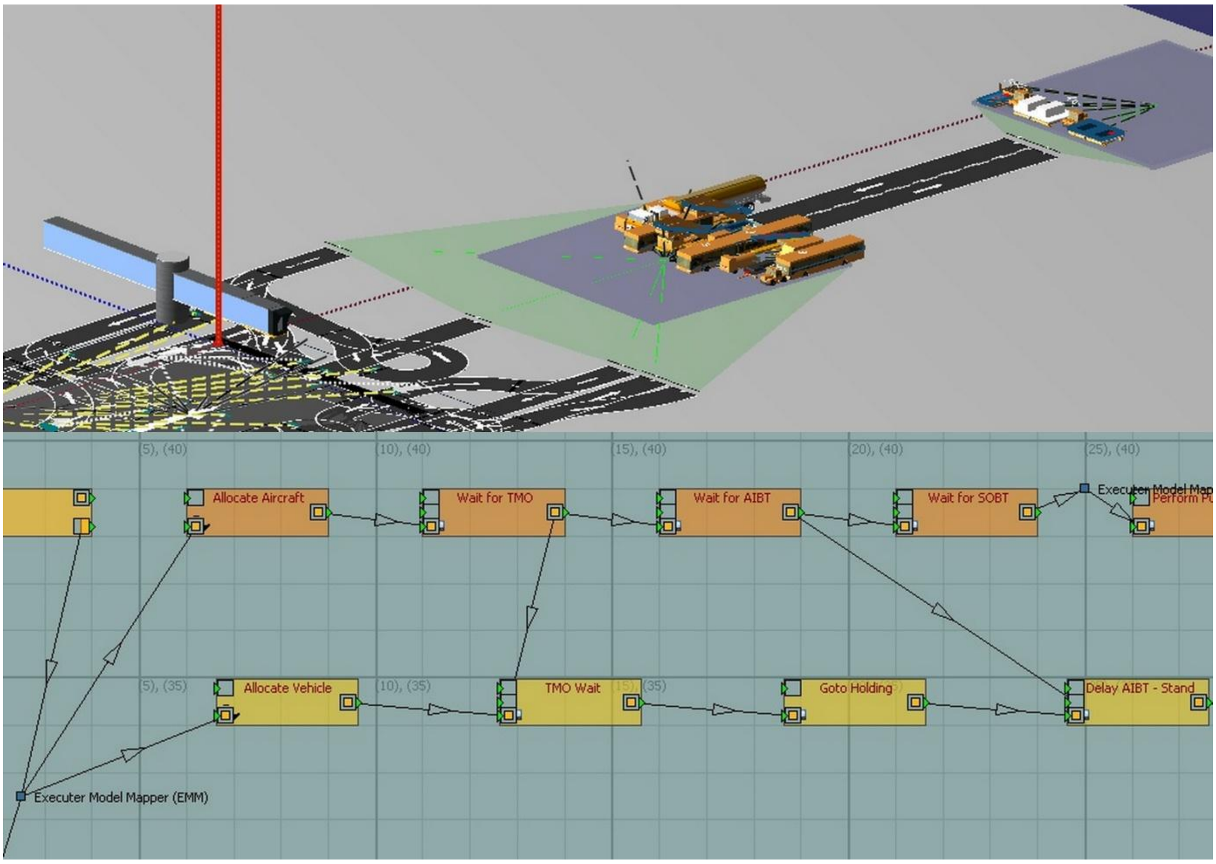



**Figure 5.9** Holding area settings

But some processes depend on the state of other processes and more dependencies must be defined. In this case, *Time Based Process Reference Sheets* and *EMM MultiSync Mapper* can be created and linked to the corresponding sheets with mappers. *Time Based Process Reference Sheets* can delay the start of a certain process or can establish relations with other processes making that one process does not start until the other has finished. But *Time Based Process Reference* can be only used for single vehicle dependencies, for multiple dependencies an *EMM MultiSync Mapper* should be used.

Figure 5.10 shows a case when refuelling cannot be started until deboarding from after and forward doors has finished.

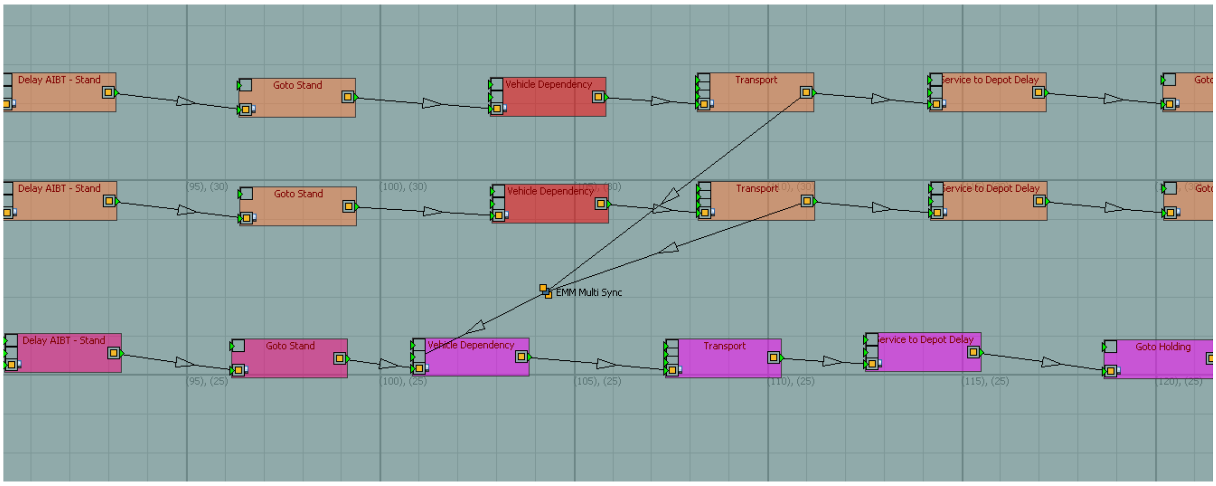



**Figure 5.10** EMM MultiSync Mapper

All processes can be interdependent and can have different transfer rates. Finally, after defining all the process chains, the user will obtain a similar image as shown in the following illustration (Figure 5.11).

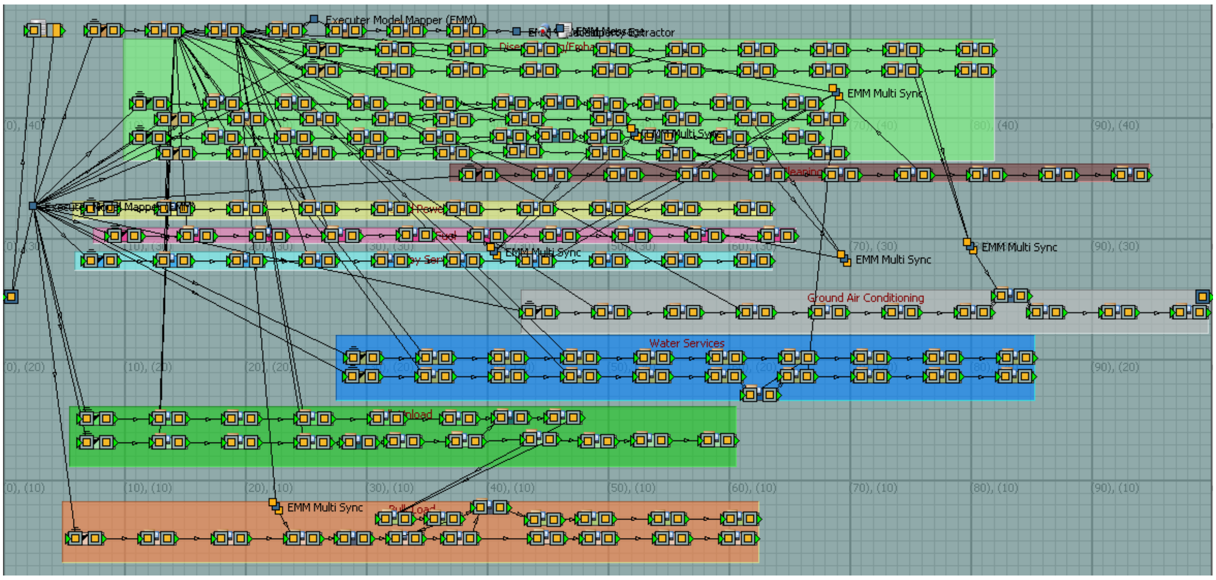



**Figure 5.11** Turnaround Definition

The Figure 5.11 reflects a scenario in which each coloured group corresponds to one ground handling service and the arrows are the dependencies between the processes.

As the reader can realize, the definition and configuration of each process and its dependencies are a complex task which must thus be done precisely.

When all that is made the simulation can be started by installing the process and clicking *play* button and the ground handling process can be seen in movement.

## 5.3 Application of CAST Ground Handling to the scenarios

The results from the spreadsheet analysis do not reflect the reality of the process because they do not cover the component of the interaction between vehicles and other factors such as delays and others possible incidents in the ground handling process **(Krammer 2010b)**. Simulations allow to estimate the performance of systems too complex for analytical solutions and to take the interaction component into consideration. A simulation program can also be used to explore and gain new insights into new technology. The defined scenarios are simulated with these purposes.

In order to simulate the four defined scenarios, the above mentioned steps were followed. The simulated reference aircraft is an Airbus A320, but its shape and geometry were loaded by importing a PrADO geometry which had been previously designed and pre-evaluated by Aero group (Figure 5.12). The containers and plugs of the aircraft were created and placed according to the position of the cabin, baggage compartments, doors, service points, etc. which could be found in the Aircraft Manual of the A320. See Appendix A.

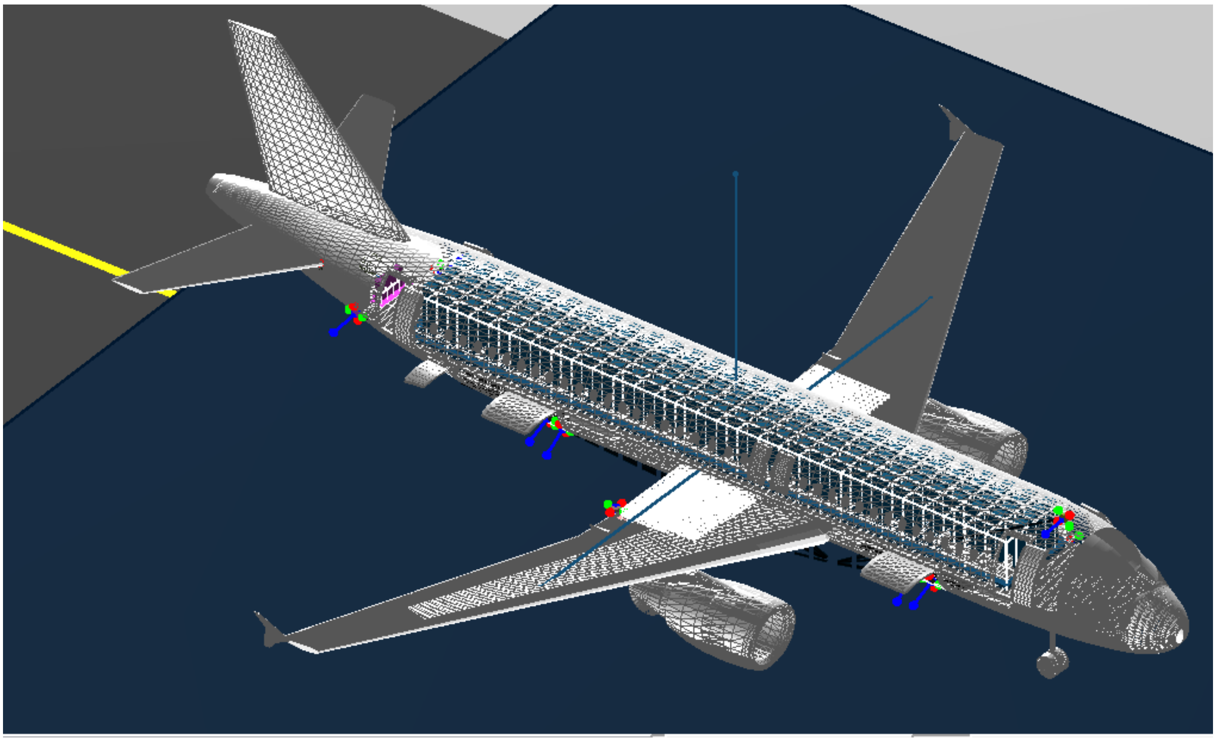


**Figure 5.12** Screenshot of the aircraft A320

Each GH vehicle was created and configured depending on its task. Afterwards, operative and servicing roads were created and positioned according to the service connections (Figure D.3) and GH vehicles were linked and placed in the Home Depot.

The process of the construction and design of the airport was done taking into account possible interactions between vehicles and looking for the shortest and fastest way to carry out each task avoiding collisions. If there is any conflict in the roads that affects the vehicle movement, the program will show a mistake window and the simulation will be stopped.

Figure 5.13 shows the final airport, aircraft and vehicles.

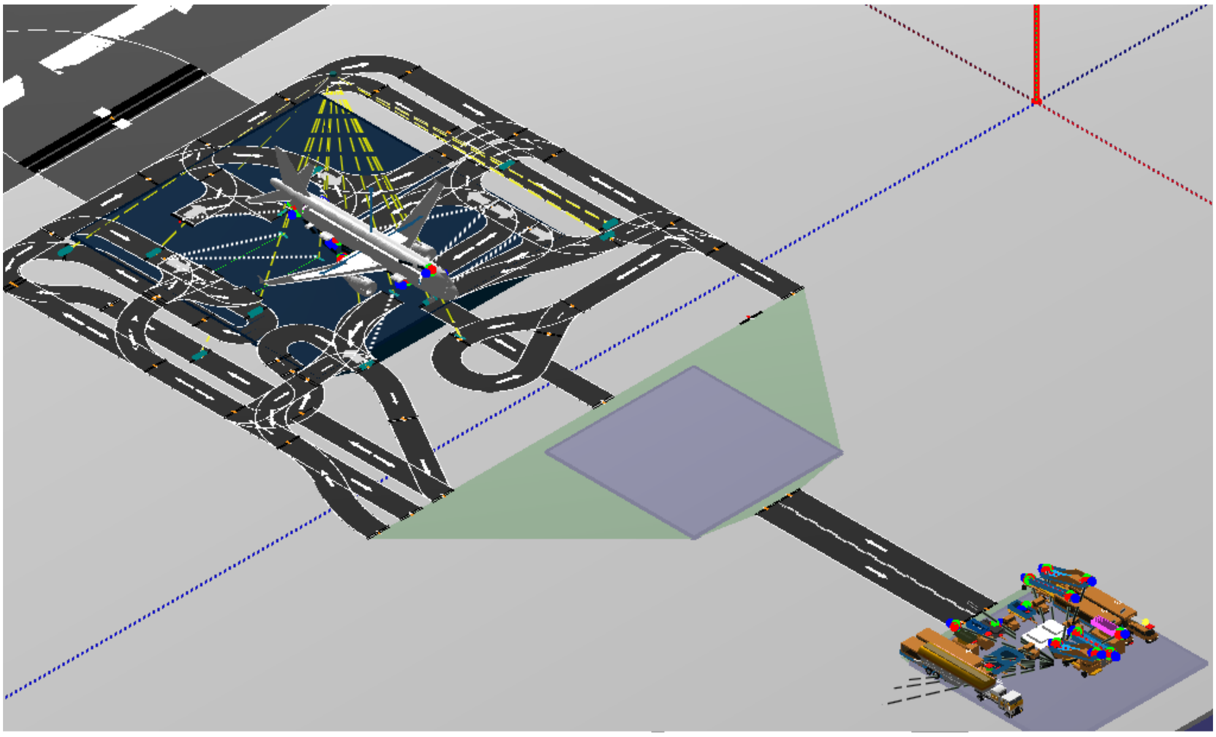


**Figure 5.13** Screenshot of the whole airport

After creating, designing and configuring all the required items (airport, aircraft, vehicles), the next step was to define each scenario. This is the most important task, since it is where the ground handling processes are defined and all the dependencies between vehicles must be set.

For the definition of each process chain, as it was explained above, the user must introduce some parameters of the process such as amounts and rates. The amount of each process was already defined at the beginning of this thesis (Table 3.1). But there are not defined rates of each process. After doing the statistical analysis it could be seen that, according to the actual data, most of the processes are exhibiting a log-normal distribution characteristic. Only a few of them can be approximated by a mathematical regression.

As this thesis is looking for a real simulation, the introduced rates have been calculated to start from the total process time chosen for each main process. For example, unloading with a belt loader was approximated by a quadratic polynomial, and carrying 100 bags resulted in a time of 9.27 min. By making a simple operation, a rate of 0.1798 bag/sec is obtained and introduced in the program as the rate of unloading with a belt loader. On the other hand, there was not a good fit in the case of loading with a belt loader; therefore, the chosen value was the mode of the log-normal, resulting in a time of 6.73 min. By calculating the rate with this time, the rate results in 0.2477 bag/min.

The same procedure was followed for each process and the calculated rates were introduced in the definition of each process in the program. Finally, all the processes were defined and interconnected taking into account the considerations mentioned in the previous chapters about how the turnaround process must be performed according to specific regulations, safety restrictions or special procedures.

In Figure 5.14, different screenshots of the turnaround simulation can be seen.

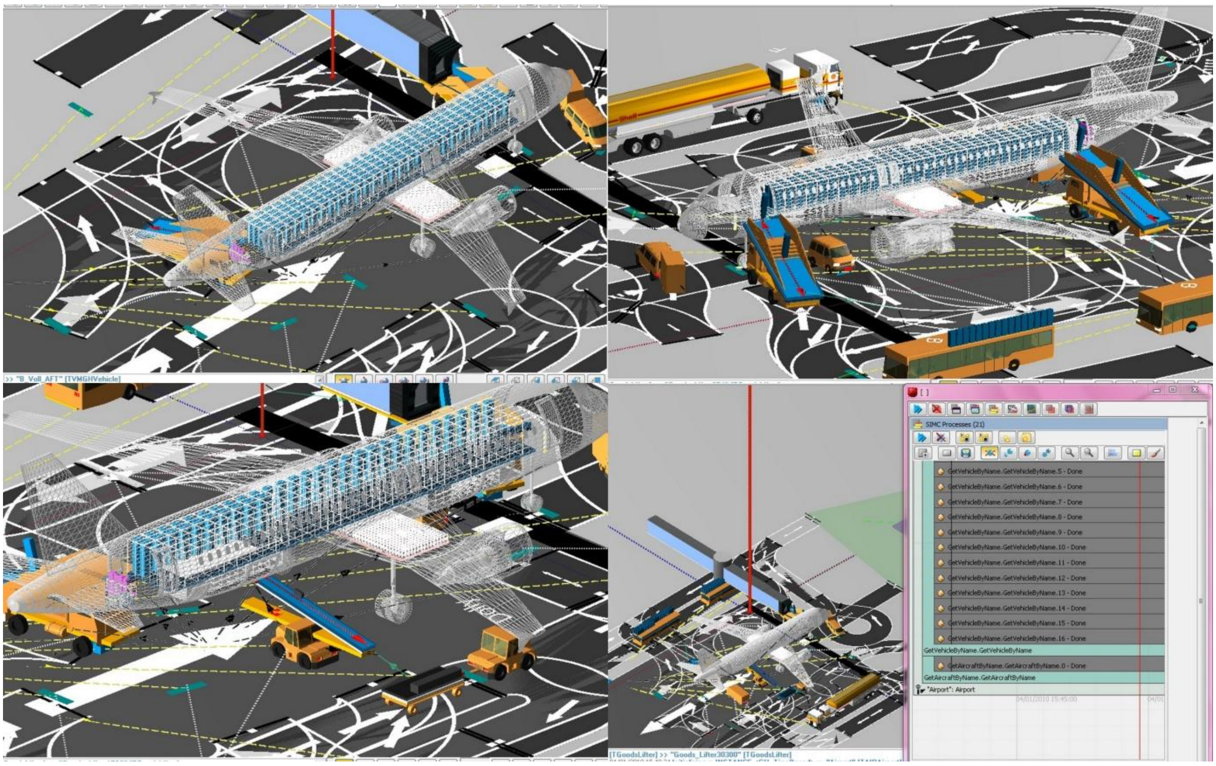
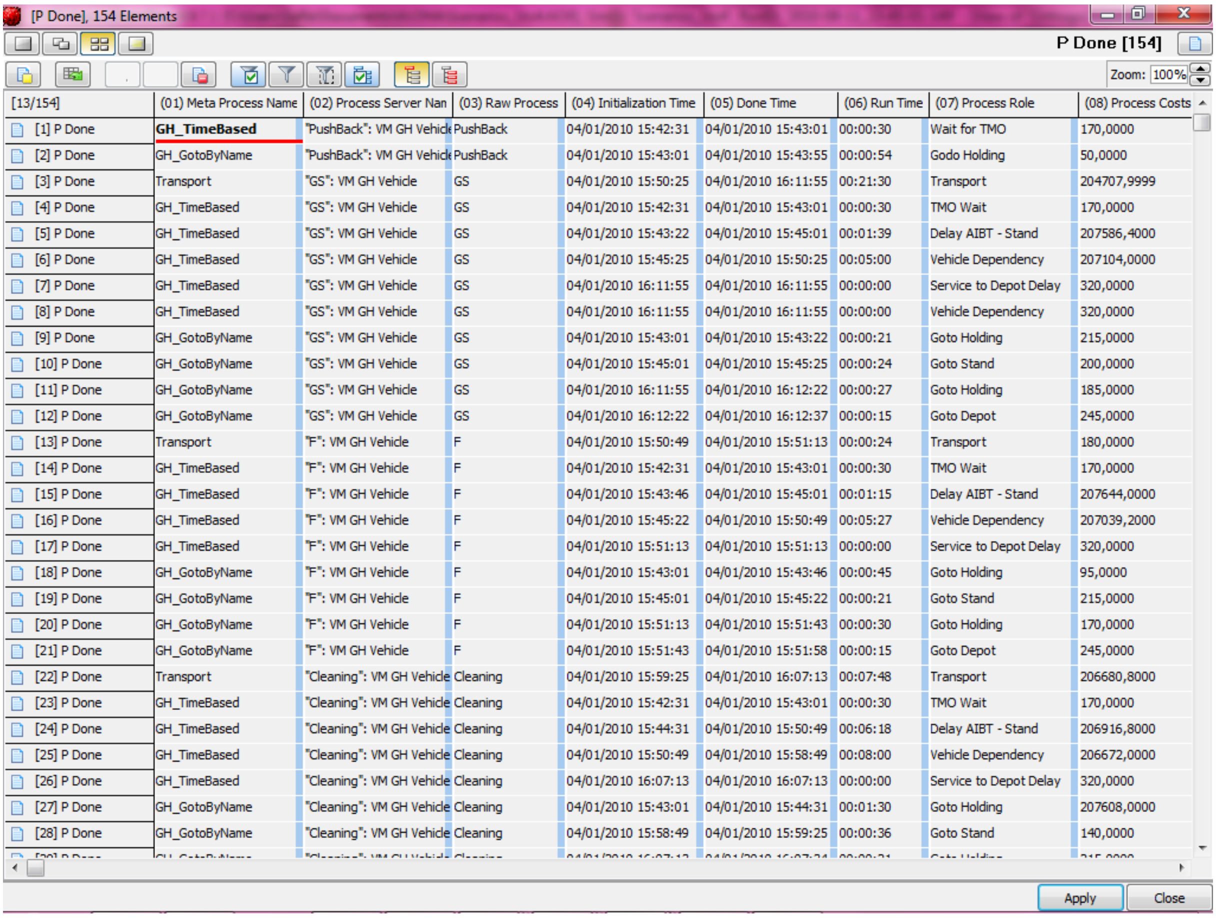


**Figure 5.14** Screenshots of the simulation

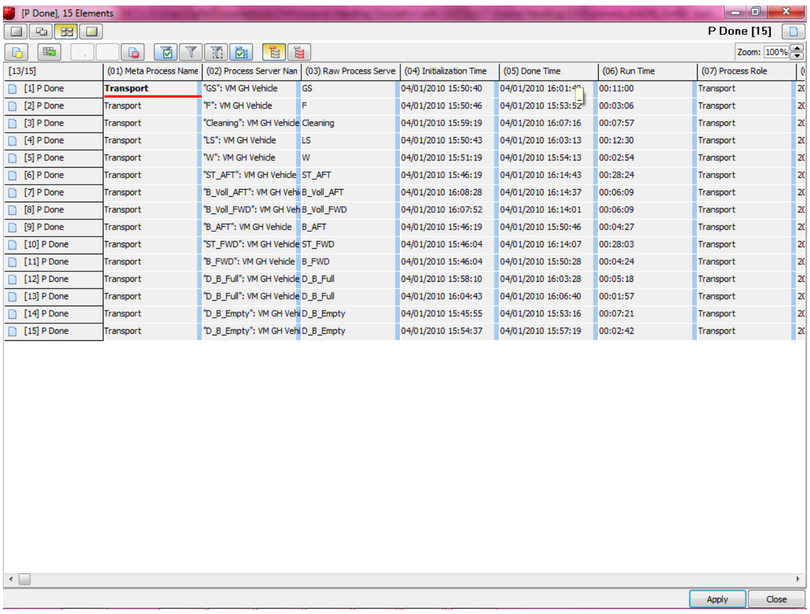
Once the different scenarios have been simulated and the turnaround processes have been completed, CAST GH also allows to extract a spreadsheet showing the simulation results such as times and costs of each GH process. See Figure 5.15.




| [13/154] | (01) Meta Process Name | (02) Process Server Nan | (03) Raw Process | (04) Initialization Time | (05) Done Time | (06) Run Time | (07) Process Role | (08) Process Costs |
|---|---|---|---|---|---|---|---|---|
| [1] P Done | GH_TimeBased | "PushBack": VM GH Vehicl | PushBack | 04/01/2010 15:42:31 | 04/01/2010 15:43:01 | 00:00:30 | Wait for TMO | 170,0000 |
| [2] P Done | GH_GotoByName | "PushBack": VM GH Vehicl | PushBack | 04/01/2010 15:43:01 | 04/01/2010 15:43:55 | 00:00:54 | Godo Holding | 50,0000 |
| [3] P Done | Transport | "GS": VM GH Vehicle | GS | 04/01/2010 15:50:25 | 04/01/2010 16:11:55 | 00:21:30 | Transport | 204707,9999 |
| [4] P Done | GH_TimeBased | "GS": VM GH Vehicle | GS | 04/01/2010 15:42:31 | 04/01/2010 15:43:01 | 00:00:30 | TMO Wait | 170,0000 |
| [5] P Done | GH_TimeBased | "GS": VM GH Vehicle | GS | 04/01/2010 15:43:22 | 04/01/2010 15:45:01 | 00:01:39 | Delay AIBT - Stand | 207586,4000 |
| [6] P Done | GH_TimeBased | "GS": VM GH Vehicle | GS | 04/01/2010 15:45:25 | 04/01/2010 15:50:25 | 00:05:00 | Vehicle Dependency | 207104,0000 |
| [7] P Done | GH_TimeBased | "GS": VM GH Vehicle | GS | 04/01/2010 16:11:55 | 04/01/2010 16:11:55 | 00:00:00 | Service to Depot Delay | 320,0000 |
| [8] P Done | GH_TimeBased | "GS": VM GH Vehicle | GS | 04/01/2010 16:11:55 | 04/01/2010 16:11:55 | 00:00:00 | Vehicle Dependency | 320,0000 |
| [9] P Done | GH_GotoByName | "GS": VM GH Vehicle | GS | 04/01/2010 15:43:01 | 04/01/2010 15:43:22 | 00:00:21 | Goto Holding | 215,0000 |
| [10] P Done | GH_GotoByName | "GS": VM GH Vehicle | GS | 04/01/2010 15:45:01 | 04/01/2010 15:45:25 | 00:00:24 | Goto Stand | 200,0000 |
| [11] P Done | GH_GotoByName | "GS": VM GH Vehicle | GS | 04/01/2010 16:11:55 | 04/01/2010 16:12:22 | 00:00:27 | Goto Holding | 185,0000 |
| [12] P Done | GH_GotoByName | "GS": VM GH Vehicle | GS | 04/01/2010 16:12:22 | 04/01/2010 16:12:37 | 00:00:15 | Goto Depot | 245,0000 |
| [13] P Done | Transport | "F": VM GH Vehicle | F | 04/01/2010 15:50:49 | 04/01/2010 15:51:13 | 00:00:24 | Transport | 180,0000 |
| [14] P Done | GH_TimeBased | "F": VM GH Vehicle | F | 04/01/2010 15:42:31 | 04/01/2010 15:43:01 | 00:00:30 | TMO Wait | 170,0000 |
| [15] P Done | GH_TimeBased | "F": VM GH Vehicle | F | 04/01/2010 15:43:46 | 04/01/2010 15:45:01 | 00:01:15 | Delay AIBT - Stand | 207644,0000 |
| [16] P Done | GH_TimeBased | "F": VM GH Vehicle | F | 04/01/2010 15:45:22 | 04/01/2010 15:50:49 | 00:05:27 | Vehicle Dependency | 207039,2000 |
| [17] P Done | GH_TimeBased | "F": VM GH Vehicle | F | 04/01/2010 15:51:13 | 04/01/2010 15:51:13 | 00:00:00 | Service to Depot Delay | 320,0000 |
| [18] P Done | GH_GotoByName | "F": VM GH Vehicle | F | 04/01/2010 15:43:01 | 04/01/2010 15:43:46 | 00:00:45 | Goto Holding | 95,0000 |
| [19] P Done | GH_GotoByName | "F": VM GH Vehicle | F | 04/01/2010 15:45:01 | 04/01/2010 15:45:22 | 00:00:21 | Goto Stand | 215,0000 |
| [20] P Done | GH_GotoByName | "F": VM GH Vehicle | F | 04/01/2010 15:51:13 | 04/01/2010 15:51:43 | 00:00:30 | Goto Holding | 170,0000 |
| [21] P Done | GH_GotoByName | "F": VM GH Vehicle | F | 04/01/2010 15:51:43 | 04/01/2010 15:51:58 | 00:00:15 | Goto Depot | 245,0000 |
| [22] P Done | Transport | "Cleaning": VM GH Vehicle | Cleaning | 04/01/2010 15:59:25 | 04/01/2010 16:07:13 | 00:07:48 | Transport | 206680,8000 |
| [23] P Done | GH_TimeBased | "Cleaning": VM GH Vehicle | Cleaning | 04/01/2010 15:42:31 | 04/01/2010 15:43:01 | 00:00:30 | TMO Wait | 170,0000 |
| [24] P Done | GH_TimeBased | "Cleaning": VM GH Vehicle | Cleaning | 04/01/2010 15:44:31 | 04/01/2010 15:50:49 | 00:06:18 | Delay AIBT - Stand | 206916,8000 |
| [25] P Done | GH_TimeBased | "Cleaning": VM GH Vehicle | Cleaning | 04/01/2010 15:50:49 | 04/01/2010 15:58:49 | 00:08:00 | Vehicle Dependency | 206672,0000 |
| [26] P Done | GH_TimeBased | "Cleaning": VM GH Vehicle | Cleaning | 04/01/2010 16:07:13 | 04/01/2010 16:07:13 | 00:00:00 | Service to Depot Delay | 320,0000 |
| [27] P Done | GH_GotoByName | "Cleaning": VM GH Vehicle | Cleaning | 04/01/2010 15:43:01 | 04/01/2010 15:44:31 | 00:01:30 | Goto Holding | 207608,0000 |
| [28] P Done | GH_GotoByName | "Cleaning": VM GH Vehicle | Cleaning | 04/01/2010 15:58:49 | 04/01/2010 15:59:25 | 00:00:36 | Goto Stand | 140,0000 |

**Figure 5.15** Screenshot of the results of a scenario

CAST GH also allows to extract a spreadsheet with a specific number of processes, as Figure 5.16 shows. This can be useful to focus on the main results of the turnaround.




| [13/15] | (01) Meta Process Name | (02) Process Server Nan | (03) Raw Process Serve | (04) Initialization Time | (05) Done Time | (06) Run Time | (07) Process Role |
|---|---|---|---|---|---|---|---|
| [1] P Done | Transport | "GS": VM GH Vehicle | GS | 04/01/2010 15:50:40 | 04/01/2010 16:01:4 | 00:11:00 | Transport |
| [2] P Done | Transport | "F": VM GH Vehicle | F | 04/01/2010 15:50:46 | 04/01/2010 15:53:52 | 00:03:06 | Transport |
| [3] P Done | Transport | "Cleaning": VM GH Vehicle | Cleaning | 04/01/2010 15:59:19 | 04/01/2010 16:07:16 | 00:07:57 | Transport |
| [4] P Done | Transport | "LS": VM GH Vehicle | LS | 04/01/2010 15:50:43 | 04/01/2010 16:03:13 | 00:12:30 | Transport |
| [5] P Done | Transport | "W": VM GH Vehicle | W | 04/01/2010 15:51:19 | 04/01/2010 15:54:13 | 00:02:54 | Transport |
| [6] P Done | Transport | "ST_AFT": VM GH Vehicle | ST_AFT | 04/01/2010 15:46:19 | 04/01/2010 16:14:43 | 00:28:24 | Transport |
| [7] P Done | Transport | "B_Voll_AFT": VM GH Vehi | B_Voll_AFT | 04/01/2010 16:08:28 | 04/01/2010 16:14:37 | 00:06:09 | Transport |
| [8] P Done | Transport | "B_Voll_FWD": VM GH Veh | B_Voll_FWD | 04/01/2010 16:07:52 | 04/01/2010 16:14:01 | 00:06:09 | Transport |
| [9] P Done | Transport | "B_AFT": VM GH Vehicle | B_AFT | 04/01/2010 15:46:19 | 04/01/2010 15:50:46 | 00:04:27 | Transport |
| [10] P Done | Transport | "ST_FWD": VM GH Vehicle | ST_FWD | 04/01/2010 15:46:04 | 04/01/2010 16:14:07 | 00:28:03 | Transport |
| [11] P Done | Transport | "B_FWD": VM GH Vehicle | B_FWD | 04/01/2010 15:46:04 | 04/01/2010 15:50:28 | 00:04:24 | Transport |
| [12] P Done | Transport | "D_B_Full": VM GH Vehicle | D_B_Full | 04/01/2010 15:58:10 | 04/01/2010 16:03:28 | 00:05:18 | Transport |
| [13] P Done | Transport | "D_B_Full": VM GH Vehicle | D_B_Full | 04/01/2010 16:04:43 | 04/01/2010 16:06:40 | 00:01:57 | Transport |
| [14] P Done | Transport | "D_B_Empty": VM GH Vehi | D_B_Empty | 04/01/2010 15:45:55 | 04/01/2010 15:53:16 | 00:07:21 | Transport |
| [15] P Done | Transport | "D_B_Empty": VM GH Vehi | D_B_Empty | 04/01/2010 15:54:37 | 04/01/2010 15:57:19 | 00:02:42 | Transport |

**Figure 5.16** Screenshot of the simulation of scenario 4

As shown in the last picture, there is a difference between the process times in the simulation and the calculated times with the statistical analysis. This happens because, in some cases, there are mistakes in the process definition but in other cases, where the times are similar, the difference is due to the waiting time, this is, since the vehicle arrives to its service point until the first good is transported. This difference in times is because the program needs to connect the plugs of the containers. As several processes use several plugs, this time is crucial for the total process time and must be taken into account.

## 5.4 Analysis of CAST Ground Handling Program

CAST Ground Handling simulates ground handling scenarios which must be correctly defined to achieve realistic vehicles movements, realistic iterations between them and a whole real situation with realistic final results.

Table 5.1 summarises the inputs which are necessary to define a ground handling scenario and run a simulation, and the resulting outputs the program allows to extract.

**Table 5.1** Relation of inputs and outputs

| Inputs | Outputs |
|---|---|
| Aircraft configuration | Model of an airport |
| Layout in the aircraft of cabin, compartments, doors, service points, etc. | Visualization of service arrangement<br>Chronological process simulation |
| Airplane position arrangements | Dynamic simulation of the GSE movements |
| GH vehicles geometry and movement features | Process analysis as time bar chart |
| Turnaround process defining desired services and considering special restrictions | Spreadsheet with results about the turnaround<br>Parameters of servicing processes |
| Rates of each GH process | Servicing cost analysis |
| Costs of each operation | |

CAST Ground Handling is a simulation program which has been recently developed. Therefore, there are some aspects that can be analysed.

CAST GH is a powerful engine which needs a lot of memory to run fast and although it can be run on personal computers, it is advisable to work with a more powerful computer in order to fulfill the tasks faster and to visualize the simulation more fluently.

When creating the background of the simulation, CAST GH allows to carry out different aspects of the simulation by using quite detailed modelling abilities and powerful objects. Nevertheless this task is not an easy one, since the design of every single object must be configured individually and taking into account its own aim, its interaction with the other objects and even the whole process. In consequence, the creation and configuration of a scenario must be done accurately in order to avoid mistakes during the simulation which takes a long time.

In short, although CAST GH enables a detailed model and simulation, it is very important to develop meticulously the scenarios and test them step-by-step.

From the point of view of realistic simulation, CAST GH achieves reflecting realistic GH vehicles, airport and turnaround scenarios. But the following aspects could be improved:

1. CAST GH analyses the compatibility between the aircraft and the ground handling equipment but keeping in mind that the simulation can be run despite the features and geometry are incorrectly designed.

2. In the turnaround time analysis, CAST GH does not consider any important times such as the time which takes the loader to reach the height of the compartment. Moreover, this parameter is very important, since it also depends on the clearance of the aircraft which has a direct effect on the aircraft design, and can modify the turnaround time. Other time which is not taken into account in CAST GH is the time the ground handling personal needs to carry each bag or container to or from the belt loader, but this time is not important because it can be considered in the whole process of off/loading.

3. In addition, it would be an advantage if CAST GH included stochastic staff. This would make possible to introduce statistical parameters with the input values such as the mean of the process or the standard deviation. The current program carries out a deterministic modelling assigning a good estimate to each variable, and simulates the situation the user defines, but by adding stochastic staff, simulation methods, as Monte Carlo Method can be used. This method considers random sampling of probability distribution functions as model inputs and produces hundreds or thousands of possible outcomes instead of a few discrete scenarios. Monte Carlo algorithmic makes possible a quantitative probabilistic analysis resulting in a more realistic simulation where the variables are not strictly defined, but they are limited by a range of variation.

4. Furthermore, it would also be a worthwhile improvement to be able to introduce equations instead of rates since, as previous chapters reflect, some processes can be modelled by equations in which the time of the process depends on a certain parameter.

5. CAST GH allows to extract a big and complex spreadsheet which shows the values of times, costs and other specifications of each sub process of the turnaround time. This document is very detailed but it would be very useful to extract a short report which permits a clear visualization of the final and most important results, such as the turnaround time, the turnaround cost or the times and costs of each main process.

6. Another useful improvement could be that CAST GH showed at the end of the simulation a turnaround Gantt chart similar to the ones shown in Chapter 2, which would allow to have a clear image of the ground handling process, dependencies and it would define the critical path.

In conclusion, CAST GH is a potential powerful tool that allows to model realistic airports and aircraft and to instantiate GH vehicles reflecting the ground handling processes for the desired scenario. This program achieves a real visualization of the simulation of the ground handling processes of each previously defined scenario, including the analysis of times and costs involved in each process. Nevertheless, it can be improved by adding tools that permit the statistical analysis and the extraction of the most important information resulting of the turnaround process simulation, completing the CAST Ground Handling engine.

# 6 Possible improvements to Ground Handling Process

In this Chapter some improvements to the GH activities which are on the critical path are studied in order to decrease the total turnaround time. Since these tasks change directly the turnaround time, great efforts should be taken in these areas.

## 6.1 Improvements to Ground Support Equipment

With the arrival of the Airbus A380, it has been shown that some adjustments of airports are necessary to get ready for this new aircraft. The turnaround time of the A380 is supposed to be around 80-140 minutes with conventional ground handling equipment, attuned the aircraft mission and services. That is an important amount of time during which the aircraft is stopped at the airport without any profit. But some measures can reduce the turnaround time such as belly catering, additional air bridges or adjustments to airports **(Horstmeier 2001)**.

In order to reduce turnaround time and ground handling costs, ground support equipments must be improved, although, as it was pointed out in the previous Chapter, this task must be carefully done in order not to increase indirectly the DOC.

One way to reduce ground handling costs consists in improving the ground handling vehicles making them more efficiency and faster. In particular, **Raes 2008** goes into pushback and taxi procedures in depth, showing that they are currently very fuel inefficient because of the high fuel consumption of the engines compared to the work required since they are used for different airports and different types of airplanes. In addition, **Raes 2008** shows that pushback process is also a critical process since it can lead to delays and the missing of slots. But special equipment for each aircraft would be more expensive and bigger improvements to the ground handling vehicles can involve higher costs.

Therefore, if the required GSE and ground handling staff are reduced, ground handling costs might consequently be reduced. That can be accomplished by reducing the interfaces between the aircraft and the airport terminal, i.e. making the aircraft more autonomous. This self-sufficiency can be achieved by means of specialized systems that are incorporated onboard but taking into account that these equipments can also increase the aircraft weight and deteriorate the aircraft performances. Furthermore the ground characteristics of the aircraft must be compatible with the operation on main airports. **(Gómez 2009)**

The main specialized systems which nowadays are being researched are:

- Ramp snake
- Power stow
- Sliding carpet
- Normalized container
- Autonomous pushback
- Onboard equipment
- Foldable passenger seats
- Bellycatering

A possible measure is the use of *bellycatering* which consists on moving the trolleys from the passenger deck to the lower belly. In this manner, the catering process becomes completely independent from the passenger process and more space for seats will be available on the passenger deck, and therefore revenues will increase. **(Horstmeier 2001)**

As shown in the turnaround Gantt charts, cleaning is also a typical process on the critical path. One possible way to reduce its time is to decrease the quality of the process. Actually, LCA normally do it making an inspection of the cabin by the crew, called *security check.* Another possibility would be to increase the number of the cleaning staff. But with this measure not only the saved time must be considered, but also the increase of the personal cost.

In conclusion, there are some improvements to the ground handling process which may have a positive influence on aircraft DOC. For example, in the report **Gómez 2009** it is shown that an A320 mounting two air stairs, an automatic pushback system, and a sliding carpet will have a cost per flight and seat 3.45% lower compared to a standard A320 or as shown in **Horstmeier 2001,** catering might become independent by using bellycatering. Therefore, it can be concluded that these systems should be incorporated into the next generation of LCA aircraft.

## 6.2 Improvements to Aircraft Configuration

Recently the KLM airline has updated its fleet. This company was using Fokker 100 and decided to acquire the 100-pax Embraer 190 reducing its fleet but increasing its utilization. But this change also meant an unexpected change. The Fokker 100 has the engines placed at the fuselage tail. The Embraer 190 has the engines placed under the wing which leads to a higher landing gear so the engines do not come into contact with the ground. Due to this fact the loading process of the Embraer 190 needs three people instead of the two necessary people in the Fokker 70. Therefore, this change involves higher ground handling costs, but because of the new performances of the Embraer 190 this change do not increase the total DOC. **(Flug Revue, June 2010)**

As it has been observed any change in the external configuration of the aircraft can lead to a change in the ground handling process. This interdependence is not a strong one, and must be checked carefully. Currently, aircraft are optimised with methods which maximize the efficiency, e.g. minimizing drag or reducing fuel consumption, but aircraft can also be designed treating with ground handling costs as a variable to be optimized. Some changes in configuration that might lead to a better ground handling aircraft are: **(Gómez 2009b)**

- Placing fuselage closer to the ground for faster and easier boarding and cargo loading.
- Easy accessible cargo holds and doors.
- Larger fuel and water capacity.
- Service points area clearance. No collision of vehicles with lifting surfaces or engines.
- Enough space in longitudinal direction for a third exit in the fuselage for de/boarding.
- FWD and AFT cargo holds connected in order to have simultaneously unloading and loading.

Each of these measures is analysed above according with the literature research.

As the example of KLM shows, placing the fuselage closer to the ground might lead to a faster and easier boarding and cargo loading and also to a reduction in the necessary personal staff, making even possible not to use any loading ground support equipment. But then the engines must be placed above the wing, at the fuselage tail or with the wing at the top of the fuselage. Each one of these possibilities entails advantages and disadvantages which must be looked into in detail. For example, placing the engines at the tail leads to a short, light and easily integrated landing gear but also to a bigger centre of gravity movement in different states of loading. On the other hand, placing wing and engines at the top of the fuselage in a high wing configuration provides the engines with a bigger ground clearance, but leads to a more complex landing gear.

In order to make easier the cargo holds and distribute the service points with bigger clearance, besides the height of the fuselage and the position of the wing, empennage configurations can be modified. But that can also lead to drawbacks in the aerodynamic or in the weight of the aircraft.

Loading and unloading are usually long processes. Having connected FWD and AFT cargo holds can allow to have simultaneous loading and unloading by using a freight door to unload and the other to load, making thus the process shorter and achieving a reduction in the turnaround time. This action can be achieved by eliminating the main landing gear e.g. making use of a tandem landing gear or a ground based landing gear, which are measures that are currently under investigation.

Increasing the fuel and the water capacity can allow the company to carry out more flights without refuelling or water services, which might lead to lower ground handling costs and, since refuelling is usually on the critical path, to a reduction in the turnaround time. But this measure does not seem really profitable, because then the aircraft weight might undergo an important increase and this fact is detrimental to cruise, landing and take-off performances.

Since disembarking and embarking processes are usually on the critical path any measure which reduces de/boarding time will also reduce the total turnaround time. A change in the configuration that might improve the ground handling process is to add a third door to achieve a shorter de/boarding process. But this action would change completely the aircraft configuration, it would be necessary to evaluate the position and height of the wing, tail and engines, the emergency doors, service points, etc. In addition, this measure would need enough longitudinal direction which leads the investigation to larger or unconventional aircraft configurations. Moreover, as it has been seen for the A380, the airport must be prepared for servicing these configurations and enabling the boarding process with several air bridges. (Figure 6.1)

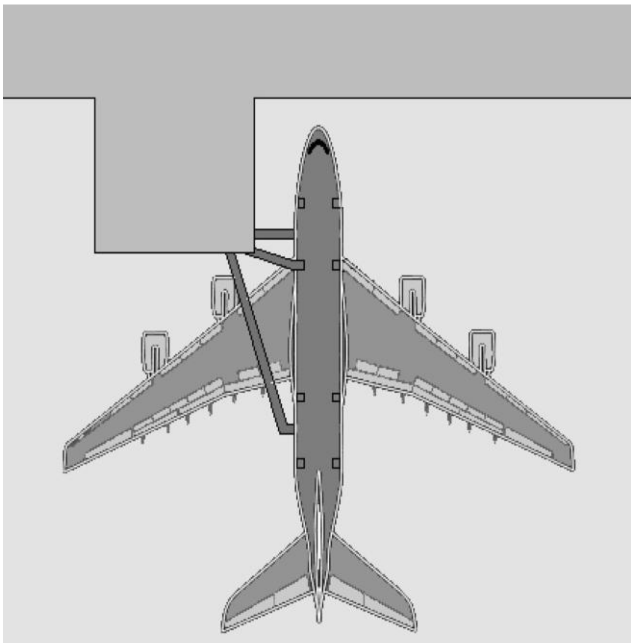


**Figure 6.1** Additional service for the A380 **(Horstmeier 2001)**

In general, the classical configuration can be modified in order to reduce ground handling costs and it would be very useful if CAST GH would allow to simulate these aircraft configurations in order to see how possible changes in the design, such as the ground clearance of the aircraft or a continuous cargo deck, influence the ground handling processes and the overall turnaround time.

# 7 Ground Handling Process of Unconventional Aircraft

Civil aircraft of the future are requested to improve significantly their performances due to the grown of the number of flights and the new requirements. Typical requirements of the future are **(Frediani 2006)**:

- More available space and comfort.
- Time reduction for boarding and disembarkation of passengers and luggage.
- Improvement of cargo capacity.
- Possibility of operating from present runways and airports.
- Reduction of DOC
- Better flight performances: 0.85 Mach cruise speed, reduced approach and landing separations, noise and emission reductions.
- Reduction of initial investment and costs for maintenance.

When a new aircraft is designed, it is optimized according to flight performances and costs, but paying less attention to ground handling operations. The aim of this master thesis is to research improvements to the ground handling process which lead to a significant reduction in DOC and which might be done in new aircraft. Nevertheless, as shown above in Chapter 6, since that can be hardly accomplished by optimisation of conventional aircraft configuration, so unconventional aircraft might be a good solution to also include these new requirements in the ground handling operations. Therefore, some new non-conventional aircraft configurations are being studied and are considered here from the point of view of the ground handling process.

## 7.1 The box wing configuration

According to Prandtl, the lifting system with minimum induced drag is a box-like wing (named “Best Wing System”) in which the following conditions are satisfied: same lift distribution (superposition of a constant and an elliptical part) and same total lift on each of the horizontal wings and butterfly shaped lift distribution on the vertical tip wings. **(Frediani 2006)**

In this configuration the wing is joined to the horizontal stabilizer that becomes bigger like a wing but has a forward sweep. The fuselage remains similar to the conventional configuration, so it is supposed to be compatible with current airports and use the same ground handling equipment. The fuselage is just an enlarged fuselage where the wings are assembled. Both wings are joined by a vertical fin between their tips and high lift devices must be positioned along the whole span of both wings. The front wing crosses the fuselage under the cargo floor allowing a wider cargo compartment than that of a conventional aircraft. In addition, the landing gear can consist of multiple legs with small wheels positioned along the lateral fairings in a way similar to a cargo aircraft. This solution allows to obtain a cargo bay along the whole aircraft without any interruption due to the landing gear. Moreover, the PrandtlPlane configuration of **Frediani 2006** allows to have four cargo doors, two on the rear fuselage and two doors in the front fuselage ahead the boarding door**.** This measure allows to have a continuous cargo deck where any device such as sliding carpet or power stow can be placed in, achieving simpler and faster loading and unloading. Moreover, due to the several cargo doors, the process takes less time and unloading and loading can be carried out simultaneously. For example, loading through the two doors on the rear fuselage and unloading through the two doors in the front fuselage nearer the terminal.

This configuration can be used to design a complete family of aircraft and depending on the height of the wing and the length of the fuselage, disembarking and embarking might be carried out using several doors, more than two, reducing the process time. Nevertheless, safety regulations related to refuelling and engine position must be taken into account.

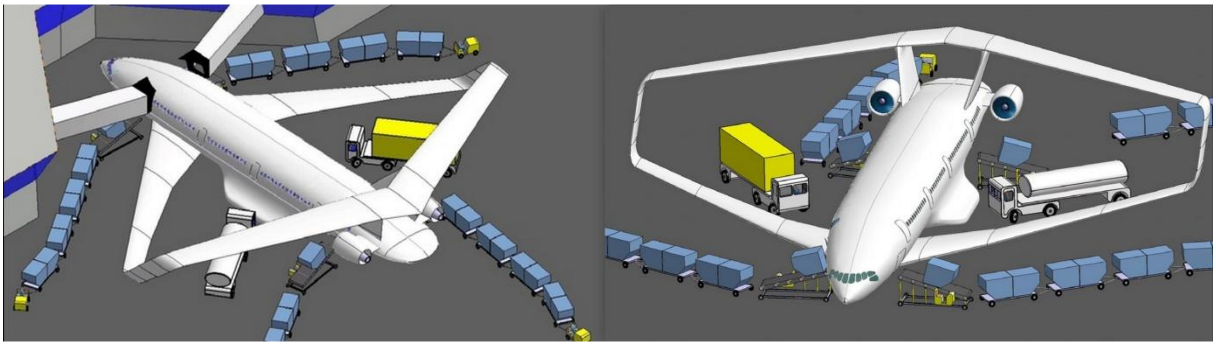


**Figure 7.1** Ground handling operations in PrandtPlane 250 pax **(Frediani 2006)**

Figure 7.1 represents a ground handling situation in which the disembarking is carried out through two bridges in the front of the fuselage and the unloading is carried out through the four cargo doors with four belt loaders.

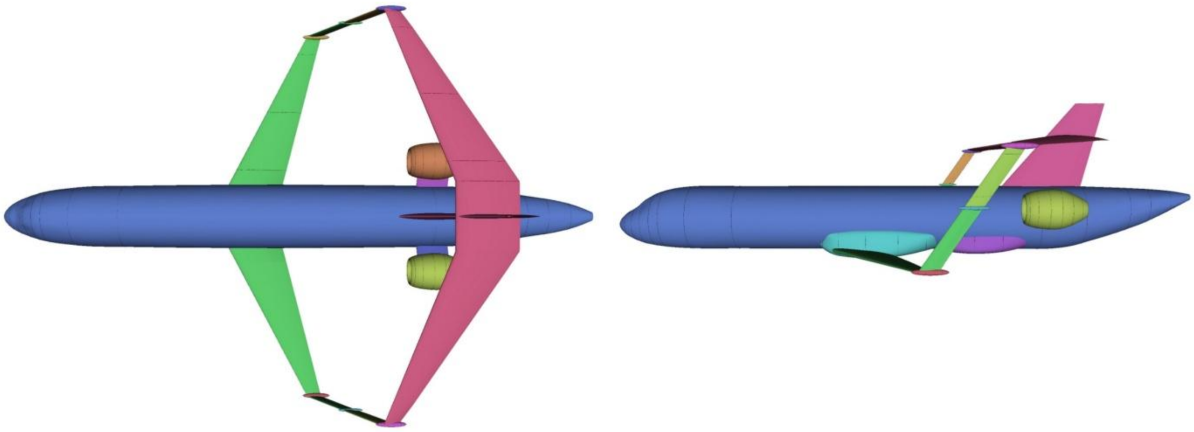


**Figure 7.2** Box wing configuration made with SUMO **(Fahad 2010)**

The sketch depicted in Figure 7.2 of a box wing configuration was made with SUMO **(Fahad 2010)**, an aircraft geometry modeller. This configuration has been designed as an A320 configuration with the engines aft. The wing has been moved backwards comparing with the aircraft of Figure 7.1 and the aircraft size is smaller.

Figure 7.3 shows another possibility of the layout of the ground handling equipments during a turnaround. Because of the new features and in order to look for other possibilities, the embarking is carried out through a bridge on the left side. The loading of the baggage is performed with two loaders on the right side as well as the refuelling process. Catering is carried out through two points, one in front of the fuselage and the other at the rear. Water services are performed in the middle of the fuselage, since the height of the wing is enough to allow the way of the GH vehicles.

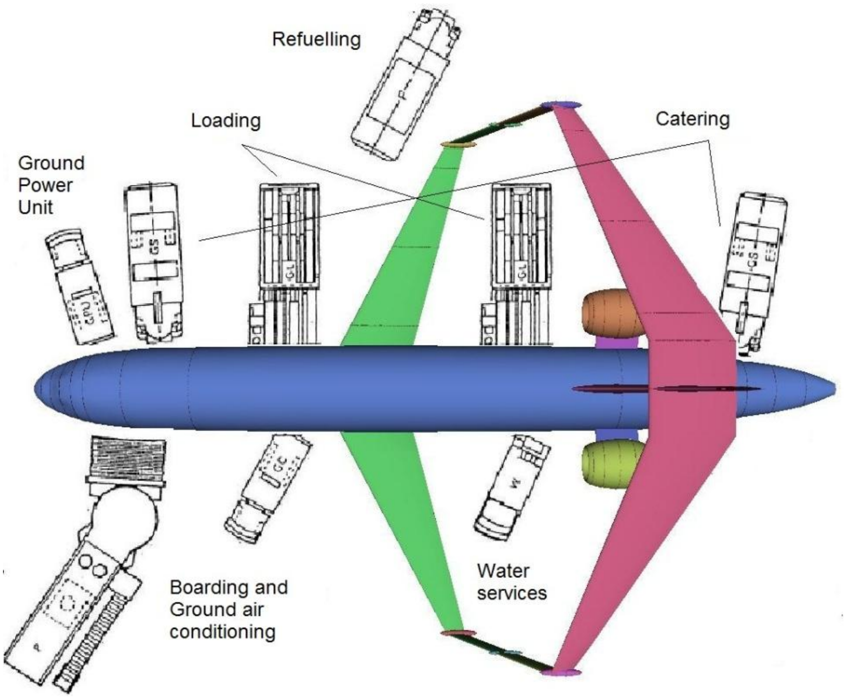



**Figure 7.3** Ground handling operations in a Box wing configuration

As the geometry of the cabin and the GSE of this box wing configuration can be the same to the A320 and the disembarking process is carried out through a passenger boarding bridge, the data of the statistical analysis can be used and ground power, water services and catering can also remind similar to the GH processes of the A320.

This example of a turnaround is very similar to the scenario I (Figure 3.1). In consequence, the overall turnaround time and cost are supposed to be similar to scenario 1 and disembarking, cleaning and embarking would be on the critical path. The time of the offloading and loading processes might be shortened by using two container loaders or having simultaneously loading and offloading because of the continuous cargo deck. But, since these processes are not on the critical path, the turnaround time would not be reduced and besides the cost of the loading process would increase because of the use of two container loaders and the need of more personal.

In conclusion, the ground handling operations of this configuration would be similar to the GH of the A320 so the second wing has not an influence on the turnaround. In consequence, using the same ground handling equipments and without having any improvement to the GSE of the aircraft, this unconventional configuration would be compatible with actual airports. Nevertheless, the position and height of the engines can have an influence on the disembarking and embarking processes through a second operative door at the rear.

If any improvement to the cleaning or boarding processes is accomplished, the turnaround time would be shorter than in scenario 1 and offloading and loading processes might become processes on the critical path. Then, the loading time reduction because of the use of two containers loaders would be useful to reduce the overall turnaround time, although the costs of the loading might increase. In addition, in order to achieve a reduction in DOC, the aircraft price of this new configuration and other costs such as the cost of the new equipments and the new required maintenance should be considered.

## 7.2 Blended Wing Body (BWB)

This airplane concept blends the fuselage, wing, and the engines into a single lifting surface, allowing the aerodynamic efficiency to be maximized. This configuration is supposed to be the configuration with less drag, less wetted area, better distribution of useful load along the span (reduction of bending moments) and, hence, improvement to wing span due to light structures.

Passengers, baggage and cargo are held in the internal volume, fuel along the wing structures and all the lift devices are positioned along the wing edges. Engines are located aft on the centre body. See Figure 7.4.

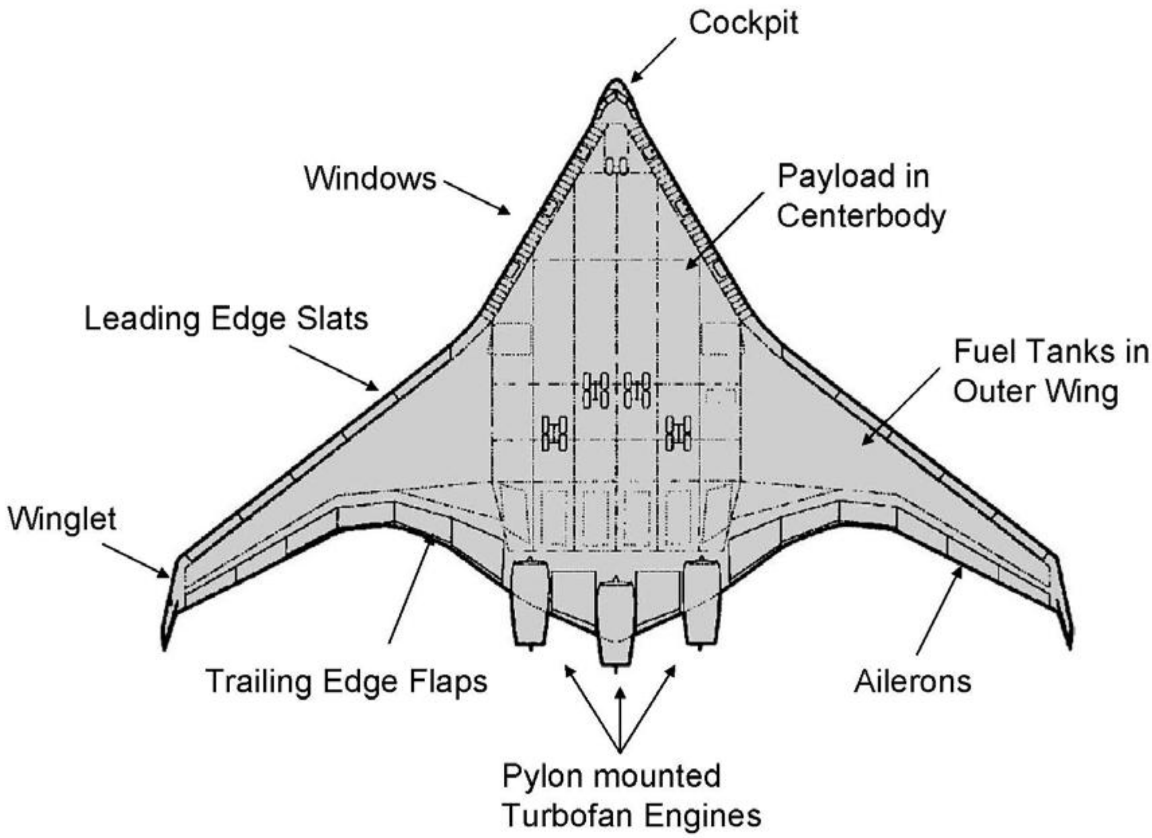



**Figure 7.4** The Boeing BWB-450 baseline **(Liebeck 2004)**

The cargo load is placed under the passenger deck. As shown in Figure 7.5, the cabin is divided into bays. These partitions are wing ribs which are primary structural members that might make embarking and loading processes difficult. Galleys and lavatories are located aft, which provides passengers with an unobstructed forward view. **(Leiffson 2009)**

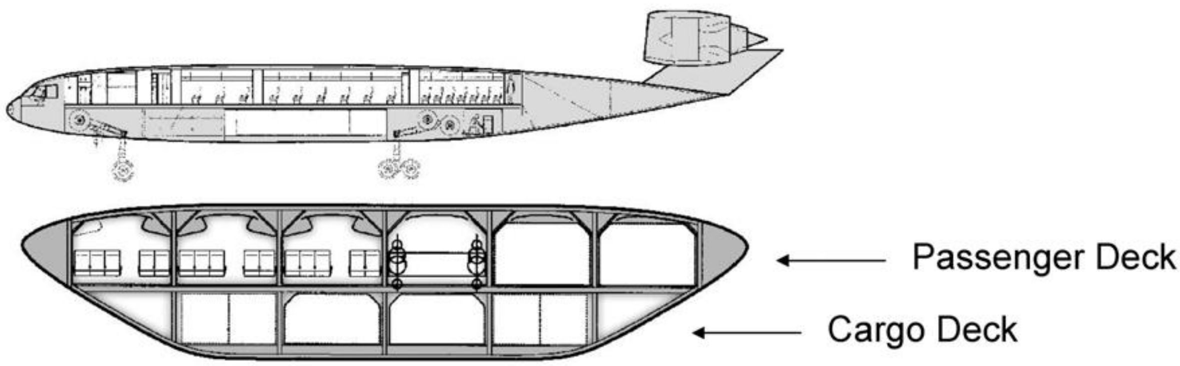



**Figure 7.5** Centerbody interior cross section **(Liebeck 2004)**

The ground handling process is critical since it is a total new configuration where service points might be positioned in different places comparing with conventional aircrafts. Figure 7.6 shows a possible layout of ground handling services.

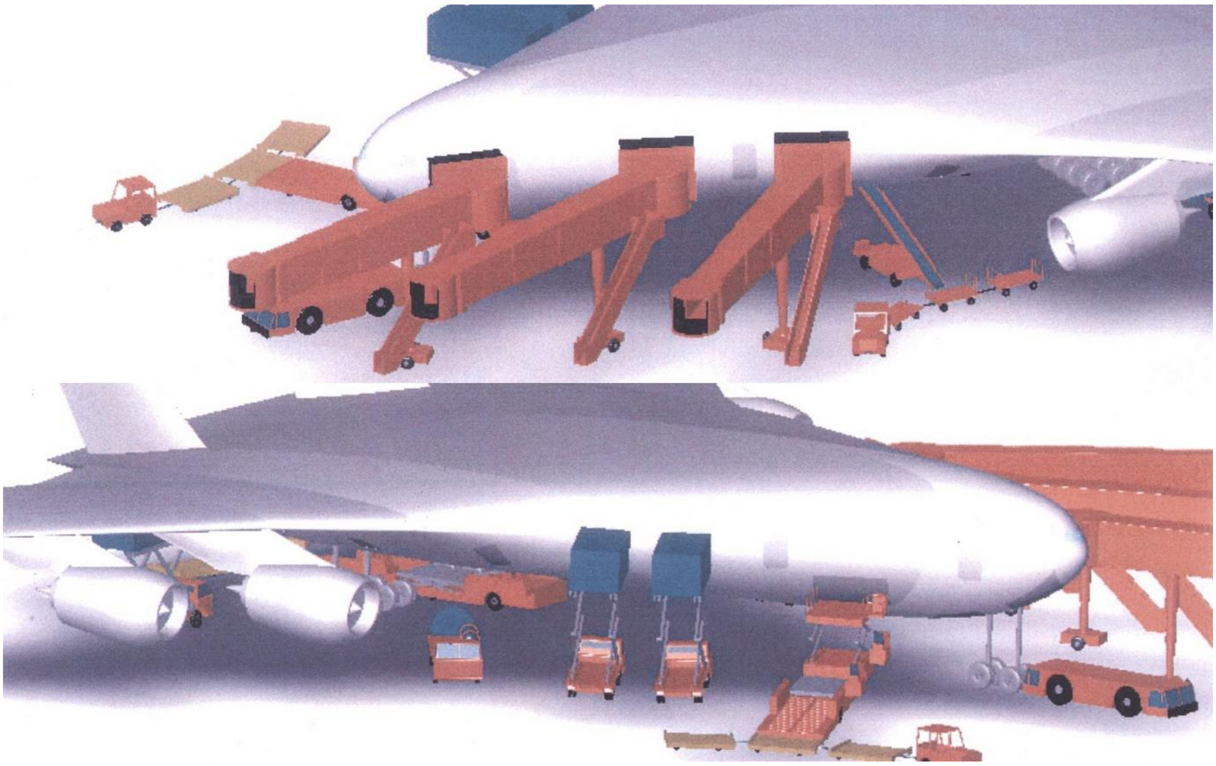


**Figure 7.6** Ground handling services for BWB **(Scholz 2007)**

In Figure 7.6 boarding process is carried out through three bridges on the left side and loading with lifting systems on the right side as well as the process of catering. The refuelling is performed under the right wing and water services are carried out on left side of the trailing edge. **(Scholz 2007)**

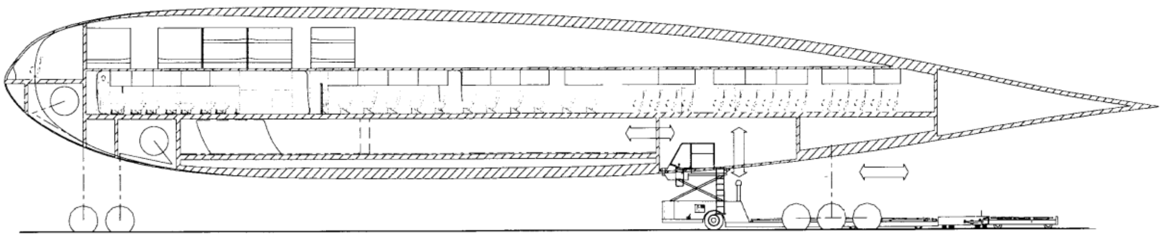


**Figure 7.7** Cargo loading **(Scholz 2007)**

Due to the structure of this configuration and the position of the ribs of the cross section, the more efficient way to load baggage is by using cargo loaders with lifting systems (Figure 7.7) and including any system inside the freight compartment such as a sliding carpet. The use of normalized containers can be worthy to save time and take advantage of the whole space of the bay. In addition, several doors can be placed and well positioned in order to make the loading process simpler and faster.

The boarding is a critical process, since the cabin is divided with the wing ribs. This fact can be used to separate the different travel classes, divide the cabin in different zones and assign each bridge to each zone. An example of the layout of some services is shown on the right part of Figure 7.8.

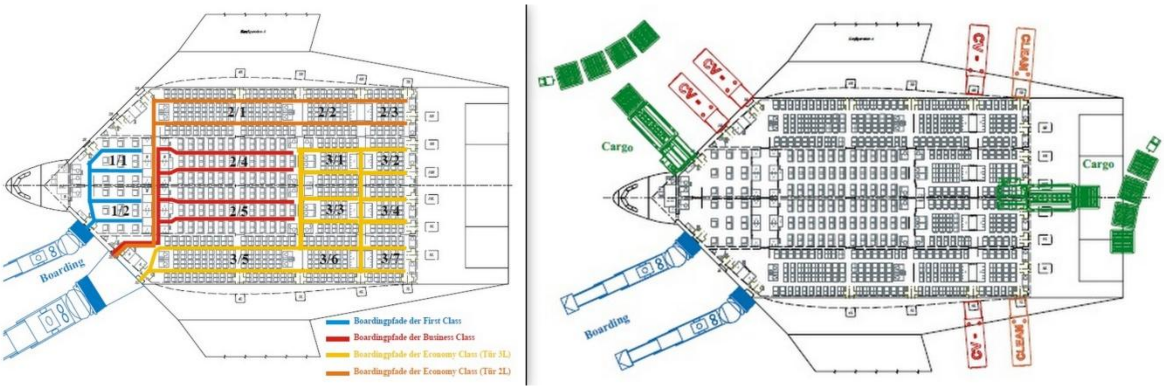



**Figure 7.8** Boarding process (left) and equipments layout (right) **(Lee 2003)**

The estimation of the turnaround time and the ground handling process is a more difficult task for this configuration. Due to the aircraft size and the seats layout the boarding time is going to be longer. In addition, the necessary amount of fuel, water and catering is going to be bigger, in consequence the overall turnaround time and costs would be experiment an important increase.

Boarding through several passenger bridges would require bigger parking position at the terminal and special infrastructure. Loading requires special container loaders with lifting system and due to the size of the cargo deck, any special equipment such as sliding carpet would be necessary so as not to have a very long loading process. Depending on the height and the geometry the rest of the GH equipments might be the same ones used by conventional aircraft.

In conclusion, the ground handling costs of BWB configuration would increase and the turnaround time would take longer. Furthermore, airports must be adapted in order to give service efficiently to such large aircraft.

# 8 Conclusions

This master thesis is focused on ground handling operations.

The statistical analysis reflects that most of the ground handling processes present a log-normal or a normal distribution and only few have a linear behaviour. Sometimes this is because the amount of data is not enough, or because the data is very dispersed. Therefore the statistical results might be improved by implementing more real data of the turnarounds.

The turnaround analysis of the scenarios shows that when de/boarding through two doors and parking at a remote apron the turnaround time and cost can be reduced significantly.

The turnaround charts are very useful to see the overall ground handling process and study the critical path. The dis/embarking process and the off/loading process are most likely to be on the critical path and therefore, their time must be reduced by improvements to their process or equipment. Nevertheless, reductions in other processes such as catering or cleaning can also reduce the turnaround time since they are also sometimes on the critical path and only improvements to processes on the critical path can lead to a reduction in the total turnaround time.

Since the turnaround process is a complex process where several equipments and staff are in constant interaction, a simulation can be very useful to estimate the performance of the process taking into account interactions and allowing to explore new configurations and technology. CAST Ground Handling allows to visualize a realistic simulation of a determined scenario and to model the airport and ground handling equipment in detail. The definition of the turnaround process is a task where cost, rates and dependencies of each ground handling process must be precisely defined. A spreadsheet with results of the costs and times of each process can be extracted as a result of the simulation. Although CAST GH is a powerful simulation program, it can be improved by adding stochastic staff and other tools which allow a simple extraction of the most relevant turnaround results.

In order to achieve a reduction in DOC, an increase in the aircraft utilization or a reduction in the ground handling costs must be accomplished. These aims can be carried out by improvements to the ground support equipments such as bellycatering, foldable passenger seats or sliding carpet, or by adaptations of the aircraft configurations such as reduction in the sill height or a continuous cargo deck which allows simultaneous offloading and loading. All these measures can be taken into account in the design of new aircraft but keeping in mind that they might increase the aircraft mass or be detrimental to the aircraft performances.

Finally, two unconventional configurations have been investigated and the possible ground handling processes have been analysed showing sketches of the possible layout of the ground handling equipments. The result is that ground handling processes of a box wing configuration based on the A320 might be similar to the ones of conventional aircraft but airports should be adapted to BWB configuration due to its geometry.

In conclusion, all mentioned aspects must be considered in order to create an optimized aircraft whose design reduces the overall DOC.

# 9 Summary

Four different scenarios have been defined for the same determined aircraft mission in order to create different turnaround charts which reflect the ground handling operations of a reference aircraft based on the Airbus A320 at the airport.

Ground handling operations have been statistically analysed with a Matlab program based on data collected by the company ARC Aachen. According to requirements and safety regulations and the turnaround Gantt charts have been created based on the statistical analysis. The critical path has been studied and the turnarounds have been analysed according with the Gantt charts for each case. The evaluation of the scenarios shows that the scenario with the shortest turnaround time is number 4, which corresponds to an aircraft parking at a remote apron. This time is about 19 min and it is the shortest because the boarding process is carried out thorough two doors and there is no need of pushback equipment. The processes which are on the critical path on the defined scenarios are dis/embarking, cleaning and off/loading.

Continuing with the ground handling analysis, a cost evaluation of the scenarios has been carried out with a cost calculation method. This evaluation shows the influence, on the total cost, of features of the aircraft and its mission such as the parking position, the payload and the ground handling equipments. The cost analysis of each scenario shows that when dis/embarking through two doors at a remote apron the turnaround cost is reduced due to the shorter ground handling process times.

CAST GH is a simulation program which allows to model an airport with its ground handling equipments and to simulate the different ground handling services that are performed on an aircraft during a turnaround. This program has been described in detail and a simulation based on the statistical analysis has been conducted showing how the program works and which results can be obtained. Some aspects of the program have been analysed and have been suggested as stochastic staff in order to make the program more useful some improvements.

As a result of the literature research on improvements to the ground handling process it can be concluded that the turnaround time can be reduced by incorporating new technology onboard or modifying the aircraft geometry.

The investigation of unconventional configurations shows that, although airports are compatible with the box wing configuration based on the A320, the turnaround process of these configurations will be quite different from conventional ground handling processes and some adjustments should be carried out at current airports.

# Acknowledgements

First of all, I want to thank my parents, my sisters, my grandparents, my uncles and my whole family for their constant support, patience and love. Thank you for being always there and helping me to make my dreams come truth.

Especially, I would like to thank my uncle Javier for “adopting” me in Madrid and my aunt Fuencis for helping me with my English and offering me her care, advices and encouragement during my whole life and particularly during these years in Madrid.

I want to thank Prof. Dr.-Ing. Dieter Scholz for allowing me to make my thesis as part of ALOHA project at the HAW Hamburg and let me participate in the Short Course Aircraft Design. Thanks to my tutor Dipl.-Ing. Philip Krammer for all his help, patience, advices and corrections of my thesis. And thanks to all of the Aero group for allowing me to be a part of this research group. I wish you a lot of luck and success.

I particularly want to thank my lovely Buddy Diana for being not only an excellent buddy but being a great friend.  Due to all your advices, help and support my stay in Hamburg has been wonderful.

Bundle of thanks to all my Spanish and Erasmus friends; I really appreciate all the constant support, help and encouragement I have received from you.

Finally, I would like to thank to all the people who have made my Erasmus in Hamburg possible. It has been a rewarding experience which has helped me to improve my English and German language skills and has taught me a lot about work and life.

# List of References


**Adkins 1997** G. ADKINS; U.W. POOCH: *Computer Simulation: a Tutorial. Computer*, vol. 10, no. 4, April, 1997

**Aguanno 2002** AGUANNO, Kevin: *Critical Path: An Extended Definition* URL: http://www.agilepm.com/downloads/CPMdefinition.pdf (2010-08-28)

**Airbus 1995** AIRBUS INDUSTRY: *A320 Airplane Characteristics For Airport Planning*. France: Airbus, 1995

**Airbus GH 1995** AIRBUS INDUSTRY: *Ramp Compatibility, Ground Handling/Servicing. Airbus Directives (ABD) and Procedures*, ABD0065. Blagnac, France: Airbus, 1995

**ARC 2010** AIRPORT RESEARCH CENTER: Main web page. URL: http://www.airport-consultants.com/ (2010-7-25)

**Boeing 2005** BOEING COMMERCIAL AIRPLANES: *B737 Airplane Characteristics for Airport Planning. Section 2: Airplane Description; Section 5: Terminal Servicing*. Seattle, Washington: Boeing, 2005

**Beyer 2004** BEYER H.T.: *Online-Lehrbuch – Allgemeine Betriebswirtschaftslehre. Erlangen*, University of Erlangen, Institut for Economics, Lecture notes, 2004, URL http://www.economics.phil.uni-erlangen.de/bwl/ (2010-8.30)

**CAST 2010a** AIRPORT RESEARCH CENTER: *CAST Overview*, Airport Research Center GmbH, Aachen, Germany, URL: http://www.airport-consultants.com/index.php?option=com_content&view=article&id=46&Itemid=68 (2010-7-25)

**CAST 2010b** AIRPORT RESEARCH CENTER: *CAST Ground Handling Tutorial*. Airport Research Center GmbH, Aachen, Germany, 2010

**CAST GH 2010** AIRPORT RESEARCH CENTER: *CAST GroundHandling - Simulation of Ground Handling Processes*, Airport Research Center GmbH, Aachen, Germany, URL: http://www.airport-consultants.com/index.php?option=com_content&task=view&id=23&Itemid=50/ (2010-7-25)

**Crönertz 2008** CRÖNERTZ, Oliver: *Prozessorientierte Kalkulation von Flughafenleistungen. Schwerpunkt: Bodenabfertigungsdienste von Passagierflugzeugen*. Saarbrücken : VDM Verlag Dr. Müller, 2008 – ISBN: 978-3-8364-8460-2

**Frediani 2006** FREDIANI, E. RIZZO; C. BOTTONI; J. SCANU; G. IEZZI: *The Prandtlplane Aircraft Configuration.* Aeronautics Days, (Wien), June 2006

**Flug Revue 2010** HOEVELER PATRICK: *Abschied von der Fokker-Flotte.* Article of Flug Revue, June 2010

**Gómez 2009** GÓMEZ, Francisco: *Improvements to ground handling operations and their benefits to direct operating costs.* Hamburg University of Applied Science, Aircraft Design and Systems Group (Aero), 2009

**Gross 2007** GROSS**,** Sven: *Handbook of Low Cost Airlines*. Berlin: Erich Schmidt Verlag, 2007

**Hortsmeier 2001** HORTSMEIER, Theo; DE HAAN, Floris: *Influence of ground handling on turn round time of new large aircraft*. Volume 73, Number 3: *Aircraft Engineering and Aerospace Technology*. MCB University Press, 2001

**IATA 2009** INTERNATION AIR TRANSPORT ASSOCIATION**:** *Airport Handling Manual.* Effective 1 January – 31 December 2009. Montreal - Geneva: IATA, 2009

**JAR-OPS 2007** JOINT AVIATION AUTHORITIES: *JAR-OPS 1. Commercial Air Transportation (Aeroplanes)*. The Netherlands: JAA, 2007

**Krammer 2010a** KRAMMER, Philip; RICO, Diana; SCHOLZ, Dieter: *Cost Estimation and Statistical Analysis of Ground Handling Process.* Hamburg University of Applied Science, Aircraft Design and Systems Group (Aero), 2010

**Krammer 2010b** KRAMMER, Philip; JUNKER, Olaf, DENGLER, Axel; SCHOLZ, Dieter: *Aircraft Design for Low Cost Ground Handling – The Final Results of the ALOHA Project*. Paper accepted for the *ICAS 2010 - 27th Congress of the International Council of the Aeronautical Sciences Conference* (Nice, France, 19-24 September 2010), publication pending

| | |
|---|---|
| **Lee 2003** | LEE, Stefan. *Konzeptionelle Untersuchung einer Flying Wing Zweideckkonfiguration.* Hamburg University of Applied Science, Aircraft Design and Systems Group (Aero), 2003 |
| **Leifsson 2009** | LEIFSSON L.T.; MASON W.H.: *The Blended Wing Body Aircraft.* Virginia Polytechnic Institute and State University Blacksburg, VA, USA, 2009 |
| **Liebeck 2004** | LIEBECK, R. H.: *Design of the Blended Wing Body Subsonic Transport*, Journal of Aircraft, Vol. 41, No. 1, pp. 10-25, Jan-Feb, 2004 |
| **Limpert 2001** | LIMPERT, E.; STAHEL, W.S.; ABBT, M.: *Log-normal Distributions across the Sciences: Keys and Clue.* BioScience Vol. 51 No. 5, May 2001, (URL: http://stat.ethz.ch/~stahel/lognormal/bioscience.pdf) (2010-8-27) |
| **Martínez-Val 2007** | MARTÍNEZ-VAL, R. PEREZ, E.; CUERNO, C.: *Cálculo de Aviones. GUIONES Y FIGURAS.* Lecture notes. Escuela Técnica Superior de Ingenieros Aeronáuticos, 2007 |
| **Müller 2009** | MÜLLER: *Optimal Boarding Methods for Airline Passengers.* Hamburg University of Applied Science, Aircraft Design and Systems Group (Aero), 2009 |
| **Raes 2008** | RAES, Dwayne: *Efficient autonomous pushback and taxiing – a step forward to reduce costs and pollution.* Hamburg University of Applied Science, Aircraft Design and Systems Group (Aero), 2008 |
| **Rico 2009** | RICO, Diana: *Analysis of Ground Handling Characteristics of Innovative Aircraft Configurations*. Hamburg University of Applied Science, Aircraft Design and Systems Group (Aero), 209 |
| **Rico 2010** | RICO, Diana; KRAMMER, Philip: *Program Development for Analyzing Ground Handling Data.* Hamburg University of Applied Science, Aircraft Design and Systems Group (Aero), 2010 |
| **Shannon 1975** | R. F. SHANNON: *Simulation: A Survey with Research Suggestions*. AIIE Transactions, Vol. 7, No. 3 September, 1975 |

**Scholz 2007** SCHOLZ, Dieter: EWADE - *A Student Project of a Blended Wing Body*. Hamburg University of Applied Science, Aircraft Design and Systems Group (Aero), 2007

**Scholz 2010** SCHOLZ, Dieter; BÖTTGER, Ole; TRAHMER Bernd: *Short Course on Aircraft Design*. Hamburg University of Applied Science, 2010

**Stavenhagen 2002** STAVENHAGEN**,** Tom: *Analysis of the aircraft turn-round for modelling and improving the cabin cleaning process*. Espoo, 2002

**Tesch 2007** TESCH, Werner: *A Turnaround and Ground Handling Aspects. Presentation for Universität Stuttgart*. Praxis-seminar, Stuttgart, 2007

# Appendix A

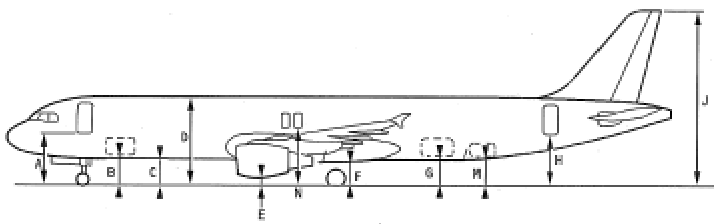
# Aircraft features

This appendix collects the data and figures of the Aircraft Manual of Airbus A320.

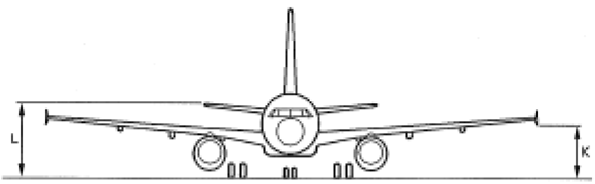
The following Figures A.1 to A.3 show the main characteristics that were taken into account for the ground handling simulation.

**A320**

**AIRPLANE CHARACTERISTICS**




NOTE: POINT 'K' IS THE BOTTOM OF THE WING TIP FENCE.
POINT 'M' IS AN OPTION.



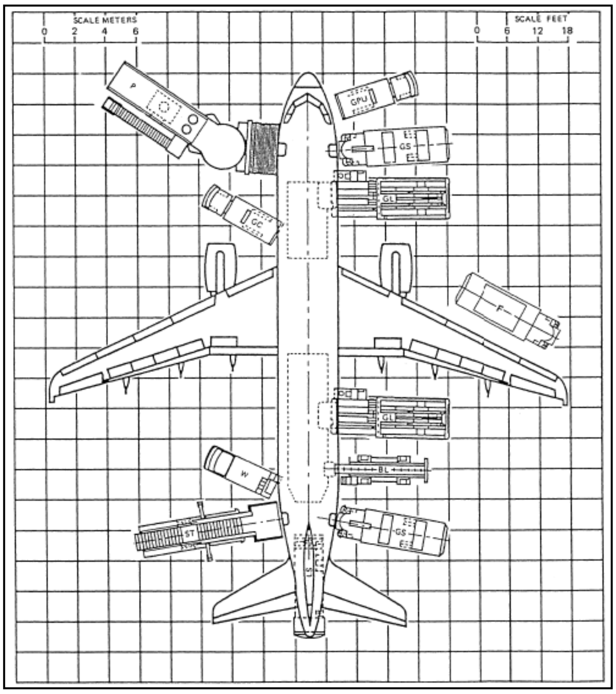

| | | OPERATING WEIGHT EMPTY | | MAXIMUM RAMP WEIGHT FORWARD CG | | MAXIMUM RAMP WEIGHT AFT CG | | AIRCRAFT ON JACKS * | |
|---|---|---|---|---|---|---|---|---|---|
| | | m | ft | m | ft | m | ft | m | ft |
| A | | 3.47 | 11.39 | 3.39 | 11.12 | 3.48 | 11.42 | 4.11 | 13.48 |
| B | | 2.09 | 6.86 | 2.01 | 6.59 | 2.07 | 6.79 | 2.70 | 8.86 |
| C | | 1.86 | 6.20 | 1.77 | 5.81 | 1.81 | 5.94 | 2.43 | 7.97 |
| D | | 6.00 | 19.69 | 5.91 | 19.39 | 5.96 | 19.52 | 6.58 | 21.59 |
| E | CFM56 | 0.68 | 2.23 | 0.59 | 1.94 | 0.61 | 2.00 | 1.24 | 4.07 |
| | V2500 | 0.78 | 2.56 | 0.68 | 2.23 | 0.71 | 2.33 | 1.83 | 6.00 |
| F | | 1.72 | 5.64 | 1.62 | 5.32 | 1.63 | 5.35 | 2.26 | 7.42 |
| G | | 2.25 | 7.38 | 2.13 | 6.99 | 2.08 | 6.82 | 2.70 | 8.86 |
| H | | 3.73 | 12.24 | 3.60 | 11.81 | 3.48 | 11.42 | 4.11 | 13.48 |
| J | | 12.14 | 39.83 | 12.00 | 39.37 | 11.83 | 38.81 | 12.45 | 40.85 |
| K | | 4.04 | 13.26 | 3.92 | 12.86 | 3.87 | 12.70 | 4.49 | 14.73 |
| L | | 5.57 | 18.28 | 5.42 | 17.78 | 5.25 | 17.23 | 5.87 | 19.26 |
| M | | 2.51 | 8.24 | 2.38 | 7.81 | 2.30 | 7.55 | 2.92 | 9.58 |
| N | | 3.96 | 12.99 | 3.87 | 12.70 | 3.87 | 12.70 | 4.50 | 14.76 |

*NOTE: THESE FIGURES WILL GIVE AN AIRCRAFT CENTERLINE (C/L) OF 4600 MM.

NAC8 02 03 00 0 ABN0 01

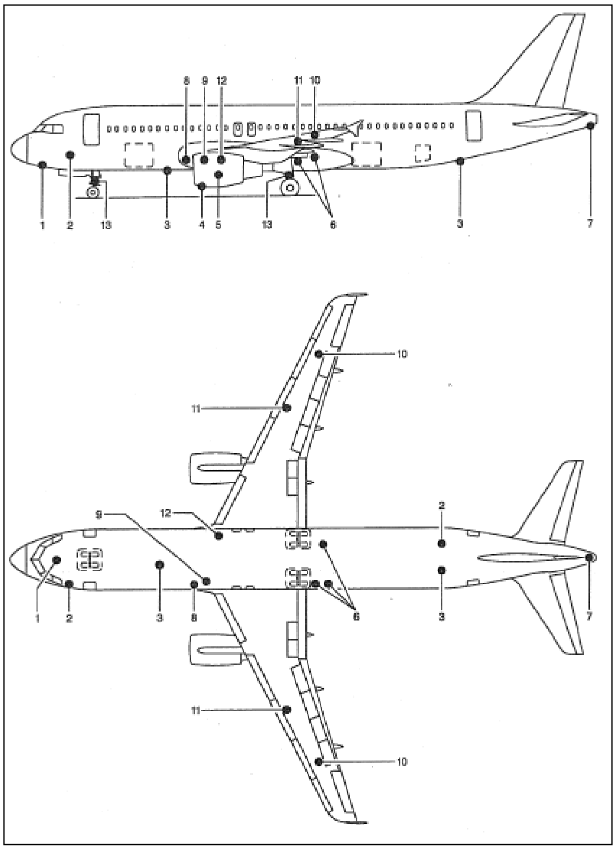
Ground Clearances
Model 200

**Figure A.1** Ground Clearances (**Airbus 1995**)




| | | |
|---|---|---|
| AS | – | AIR STARTING UNIT |
| BL | – | BULK LOADER |
| D | – | DOLLY |
| F | – | FUEL TANKER |
| GL | – | GROUND LOADER |
| GPU | – | ELECTRICAL GROUND POWER UNIT |
| GS | – | GALLEY SERVICE TRUCK |
| P | – | PASSENGER LOADING BRIDGE |
| ST | – | STAIRWAY |
| T | – | TRANSPORTER |
| LS | – | LAVATORY SERVICE TRUCK |
| W | – | WATER SERVICE TRUCK |
| GC | – | GROUND AIR PRECONDITIONING UNIT |

**Figure A.2** Typical arrangements of ground support equipment during a turnaround A320 (**Airbus 1995**)



| | | |
|---|---|---|
| 1 | – | GROUND ELECTRICAL POWER RECEPTACLE |
| 2 | – | TOILET SERVICING |
| 3 | – | WATER FILLING AND DRAINAGE |
| 4 | – | IDG OIL FILLING CONNECTOR |
| 5 | – | ENGINE OIL FILLING CONNECTOR |
| 6 | – | HYDRAULIC |
| 7 | – | APU OIL FILLING CONNECTOR |
| 8 | – | GROUND SERVICE CONDITIONED AIR CONNECTOR |
| 9 | – | GROUND AIR CONDITIONING AND AIR START CONNECTOR |
| 10 | – | GRAVITY FILLING PANELS |
| 11 | – | REFUEL/DEFUEL CONNECTOR |
| 12 | – | REFUEL/DEFUEL PANEL |
| 13 | – | AIRCRAFT GROUNDING |

**Figure A.3** Ground service connections A320 (**Airbus 1995**)