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CAED D2: Modelling the Turnaround Process

CARE INO III: The Co-ordinated Airport through Extreme Decoupling

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Summary

This document provides the operational context for the Co-ordinated Airport through Extreme Decoupling (CAED). In the first chapter, the Collaborative Decision Making background of the project is sketched, as well as its relation to Total Airport Management. Next, the turnaround process is introduced in general terms.

In the second chapter, the turnaround process is further elaborated by describing the various ground handling processes to be performed during turnaround. Additionally, the relation between ground handling and stand planning is detailed. Finally, the importance of ground handling for punctuality and efficiency in airport operations is discussed.

In the third chapter, an outline is presented for a general model of the turnaround process. The planning problem addressed is described, as well as the actors, tasks and resources to be included in the model. Furthermore, the boundaries and limitations of the model are drawn by explicating the underlying assumptions.

In the fourth chapter, the model described in chapter 3 is given more contents. By means of an operational example, this chapter illustrates how the ground handling model can be applied in practice. The example is translated step by step into a Simple Temporal Network (STN) representation, which in turn is decoupled into local ground handlers' sub-networks. A set of solutions to these decoupled networks is proposed.

Contents

(51 pages in total)

1 Introduction

This document describes the operational context addressed by the Co-ordinated Airport through Extreme Decoupling (CAED) project. In this project, a general methodology is developed to support the integration of local planning functions into an encompassing, total airport planning. Central to this approach is the assumption that local parties are in the best position to plan their own resources and activities. Based on this assumption, a methodology called 'extreme decoupling' is investigated to ensure that – given an initial airport plan – local plans can be established and merged again into a conflict-free total airport plan.

In this chapter, first the context of the research project is outlined. Next, extreme decoupling is described as the airport planning methodology central to this project. Finally, a short overview is sketched of the operational process to which extreme decoupling will be applied.

1.1 CDM and Total Airport Management

Collaborative Decision Making (CDM) has been identified as an important enabler of capacity and efficiency [CDM Handbook]. CDM addresses the need for operational decisions to be made collaboratively to provide a common situational awareness for ATC, airlines, airports, handlers and other partners involved. It is about improving the way the different stakeholders in the ATM system work together at an operational level.

Of course, collaboration between different parties has to some extent always existed. However, until now the collaboration in ATM has been more of an ad-hoc and human-centred process. CDM can be seen as a philosophy in ATM that emphasises the importance of *collaboration* in planning and managing air traffic. In effect, CDM tries to replace the current *central* planning paradigm with a *collaborative* paradigm. To establish such a paradigm, information owned by individual actors is given free for all (in a useful system-wide representation). Access of all parties in ATM to sets of up-to-date information creates a common situational awareness. Thus, all actors involved will know better what goes on at a global level, improving their means to commonly reach a better overall planning.

A following step after CDM is Total Airport Management (TAM), which encapsulates CDM and brings a planning and decision support component to it [TAM]. Although airports, airlines, and ATC service providers try to optimise the efficiency of their local planning systems, there is little effort directed towards the real integration of these planning systems and procedures so as to maximise the performance of the entire airport system. This situation prevents optimal use of the available capacity, both at airports and in terminal area airspace. Total Airport Management

addresses this problem. The operational scope of TAM ranks from strategic decision making, on the one hand, to pre-tactical and tactical planning and decision making processes, on the other hand.

European CDM is mostly focussed on the airport processes around ATC. It has been recognised that for Total Airport Management, a broader scope, including airport and airline processes is necessary. In this document, we focus on the airport turnaround processes. Although turnaround management has played a part in research in the past (e.g., Gate-to-Gate [G2G], Airport Airside Management [AAM]), its detailed processes, responsible parties and complicated links to other airport processes have not yet been subjected to extensive research. By further explicating these processes and by integrating them with the overall planning and decision making processes at airports, this research aims to make a significant contribution to the further development of Total Airport Management.

1.2 Extreme Decoupling

The integration of ground services and turnaround management with the overall airport planning will be procured by means of a methodology called 'Extreme Decoupling'. This methodology, central to the CAED project, tries to overcome most of the above mentioned planning problems at airports (see section 3.1 for further details). To do so, a balance is sought between two extreme solutions to airport planning problems: fully centralised planning, and fully distributed planning.

When aiming at fully centralised planning, serious problems arise. For instance, central planning would require central planning tools to support the entire decision making process. Such central planning tools, however, will not be technically feasible since they would have to incorporate all planning constraints, regulations, schedules, and resources of all parties active at the airport. Reaching an acceptable planning solution in real time is then not an option.

Another problem in centralised planning stems from the organisation of operational processes at airports. Since many parties are active, having their own expertise, information, interests, and business model, they may not be willing to subordinate themselves to a central decision making process. In CDM terms: local parties are in the best position to take decisions. Most of the knowledge, know-how and expertise resides locally, and many parties may not be willing or able to explicate or share this local expertise with others in a central planning procedure.

To resolve these problems, a fully distributed planning process may be proposed. In this way, decision making is distributed amongst all parties, sharing relevant information with others to

reach a common planning solution. Unfortunately, this approach has its disadvantages as well. In projects such as the Fifth Framework project LEONARDO, for instance, it turned out that the co-ordination mechanism required to reach a common solution for any type of planning conflict was extremely complex [LEO]. For this reason, the project limited itself to a small number of pre-established conflicts.

Apart from complexity, another problem arose. In the distributed decision support system, a central planning 'agent' was still required to decide which parties should resolve a given conflict, and what solution was to be chosen. Thus, although fully distributed, the decision support tool still violated the autonomy of the parties involved.

For this reason, the approach taken in the CAED project tries to combine the best of two worlds. Central planning does not acknowledge the desire of local parties to plan their activities themselves (as much as possible). Moreover, the airport's human organisation in parties responsible for their own processes is not respected. A fully distributed system, on the other hand, may still require central co-ordination for each planning activity – thus violating the decision maker's autonomy. Furthermore, a fully coupled system may lead to insurmountable co-ordination problems resulting from its complexity in practice. In conclusion, the CAED project aims not to *couple* different planning functions to one another, but – on the contrary – to entirely *decouple* these planning functions. Hence the term 'Extreme Decoupling'.

The extreme decoupling approach can be described in three steps. First, overall planning constraints for a given airport domain are 'decoupled' from this domain and distributed amongst the underlying local planning domains. These constraints can be of any type: traffic regulations, slot constraints, resource limitations, etc. In this document, the stand allocation plan is chosen as the overall airport domain, whereas the local planning domains correspond to the ground handlers involved in the turnaround.

Second, given these additional constraints, the local planners can make their planning without further co-ordination with other planners, or with the Airport Authorities / Airline. In other words, no communication overhead (with corresponding complexity) arises: given the decoupled constraints, added to their local planning domain, the planners (e.g., the fuelling company, boarding operator, caterer) can do their planning independently according to their own insights, business model, and planning methods.

Third, the resulting local plans can be merged together into an overall plan for the given airport domain. For instance, for the turnaround domain, the stand allocation plan will then be completed by a detailed ground services plan yielding an overall stand & services plan. Given

certain properties of the decoupling algorithm (further detailed in [D1]), the merged solution is guaranteed to be conflict-free.

1.3 The Airport Turnaround Process

In the CAED project, this extreme decoupling methodology will be applied to the airport turnaround process. The airport turnaround process comprises all ground handling activities that need to be performed at an aircraft when parked at a stand[1]. These activities need to be performed between in-block, when the aircraft arrives at the stand, and off-block, when the aircraft leaves the stand. Example ground handling services are: baggage and cargo (un)loading, the (de-)boarding of passengers and crew, cleaning, catering, fuelling, and aircraft technical services. Figure 1 gives an overview of all services and corresponding equipment that are involved in the turnaround process of an aircraft at the stand.
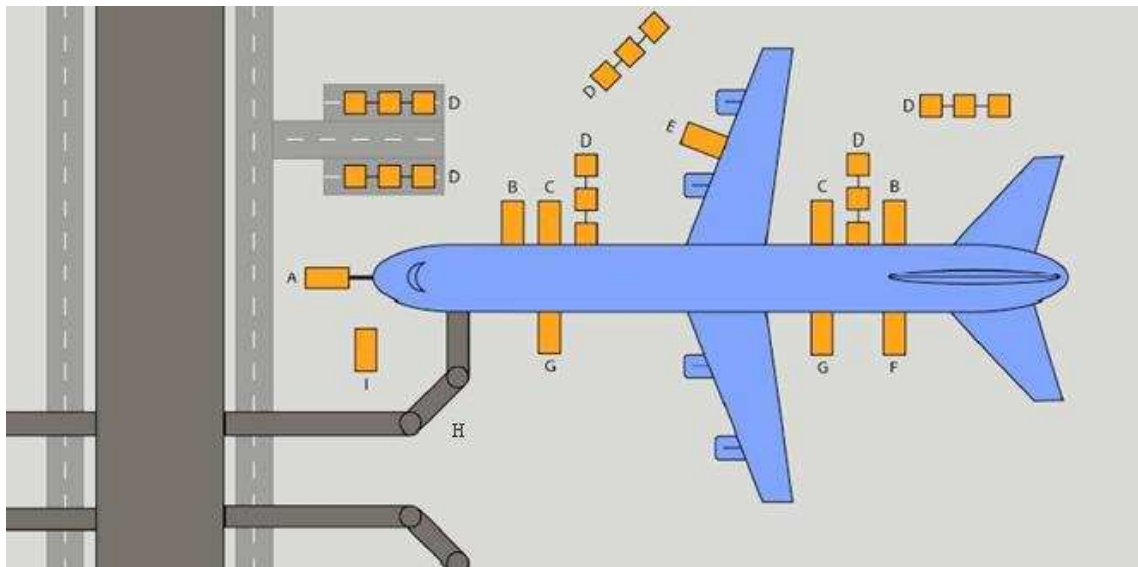
Figure 1: Aircraft at the stand

In this figure, the aircraft is docked at the pier. The following vehicles / equipment are shown:
   A. Push-back vehicle
   B. Vehicles for catering (galley services)
   C. Vehicle for unloading and loading of freight and mail
   D. Bulk cargo/baggage trailers

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[1] In this report, the terms turnaround processes and ground handling processes/services are used interchangeably. Note further that the term 'stand' is used for both stands and gates.

E. Fuel truck

F. Cleaning vehicle

G. Potable water and lavatory vehicle

H. Passenger bridge

I. Electrical cart

The exact number and position of these vehicles and equipment depend on the aircraft type, and the stand (remote stand, gate at the pier). Appendix A shows the exact airplane servicing arrangement for the two example aircraft types that will be used throughout this document: a Boeing 737-300 and a McDonnell Douglas 11.

Obviously, there is a lot of planning involved to make sure that these services are performed in time – without getting into each other's way. Figure 2 gives a high-level overview of the flow of ground handling services between on- and off-block. In this figure, the ground handling services have been divided into four different, parallel flows: the baggage and cargo processes, the passenger and cabin processes, the fuelling processes, and the aircraft technical services (typically only involving small maintenance and aircraft checks). Most of these activities can be undertaken simultaneously. Note that these processes need to be further subdivided into one or more sub-processes. The arrows in the figure indicate the required order of activities.
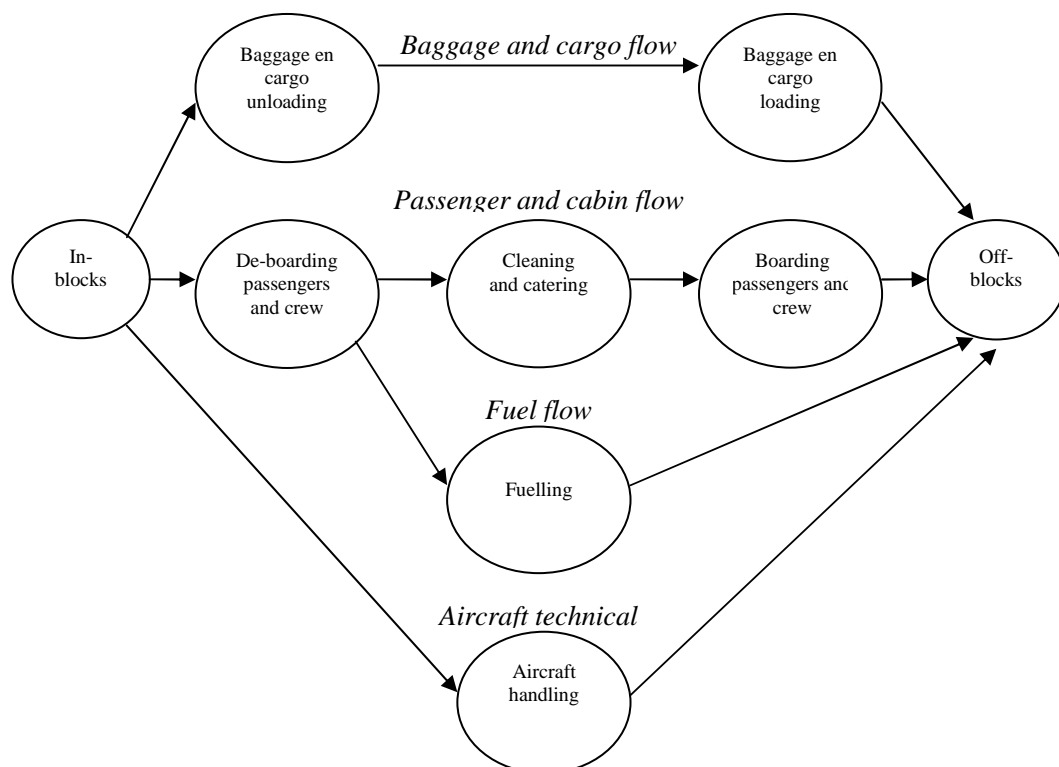
Figure 2: Workflow of the Turnaround Processes

The above processes can be further subdivided and related to the arrival part and the departure part of a flight during turnaround. In this manner, the following ground services can be distinguished:

- Arrival:
    - docking
    - de-boarding of passengers and crew
    - baggage and cargo unloading
    - security
- Departure:
    - cleaning
    - fuelling
    - catering
    - baggage and cargo loading
    - passenger boarding
    - security
    - aircraft check
    - push-back/tow away

Every aircraft type has a minimum turnaround time. The turnaround time depends on the number and complexity of processes that need to be performed. Turnaround time will be longer for larger aircraft or for airlines that provide more service (e.g. magazines, newspapers, meals) to their passengers.

This chapter presented a brief overview of the CDM and TAM context of this research. Extreme decoupling has been outlined as the focal planning methodology, and the turnaround process was introduced. In the next chapter, this turnaround process will be described in further detail.

2 Ground Handling Processes

In this chapter, the ground handling processes constituting turnaround will be further elaborated. Also, the relation between these processes and other airport processes will be outlined. But first, an important question needs to be addressed. Why is ground handling such an interesting candidate for further research?

2.1 Why focus on Ground Handling?

Before getting into detail about the relationship between ground handling and other airport processes (see section 2.3 below), it should be stressed that ground handlers do not have much room to do their own resource planning. Ground handling should take place within the turnaround time, meaning that all ground services need to be planned within a pre-determined on- and off-block of aircraft. Ground handlers thus have to stick to these times, laying down the hard constraints within which their own planning should be fitted. One can easily see why this strict hierarchy could lead to a sub-optimal overall planning. For instance, when a fuelling company has to fuel five aircraft at pier A, one at pier D and another five at pier A, it could be very profitable for the fuelling company to suggest a gate change for the one aircraft at pier D (especially if this pier is at the other side of the airport). Under certain circumstances, it may indeed be possible to allow such a gate change. The problem with the current way of operating is that the fuelling company does not have a say in the process of allocating stands[2] to aircraft, or changing stand allocations – as we shall see in section 2.3 below.

From a CDM perspective, then, it seems profitable to allow ground handlers to join the decision making loop for allocating stands to aircraft. It would mean putting the power in the hands of the party best placed to take the decisions, enhancing each partner's commitment to the established allocation plan. Moreover, the overall efficiency of the stand allocation plan will increase when all parties involved in turnaround actually participate, which in turn has a positive effect on other airport processes. After all, turnaround is (literally) a pivoting process in airport planning.

But there are other reasons for focusing on ground handling. As stated in the introduction, although turnaround management has played a part in much research in the past, its detailed processes, responsible parties and complicated links to other airport processes have not yet been

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[2] The term 'stand' will be used for both gates and remote stands throughout this document.

the subject of extensive research[3]. Thus, the field is relatively new and may yield interesting improvements to total airport management.

Finally, ground handling is recognised as a common and important source of delays in the air transport system. According to research conducted at London Gatwick Airport, ground handling services are the second largest contributor to flight delays, right after air traffic control (ATC) related delays. In this research, ground handling services proved to be responsible for 25 percent of all delays at London Gatwick [Wu et al, 2004b, 2000]. Ground handling delays typically lead to delays in other airport processes – not only for the delayed aircraft itself (knock-on delays), but also for other aircraft, whether inbound, outbound or docked at other stands.

Thus, the performance of aircraft turnaround operations has a strong impact on the punctuality of the totality of airline operations. Punctuality, in turn, strongly influences the choice of passengers for selecting a certain airline company [Wu et al, 2004a] and thus plays an important role in the success of airlines. By improving ground handling operations, therefore, we hope to improve the punctuality of the entire air transport system. This will most certainly have a positive effect on the operations of all airport partners involved.

2.2 The Ground Handling Processes in Detail

Having underlined the importance of research into ground handling, this section will describe the different ground handling processes in detail. As much as possible, alternative options for carrying out a given task are described. For further details the reader is referred to [IATA, 2004]. In this airport handling manual, the network of airport business processes at the airport's ground surface is described in great detail.

2.2.1 Docking

Docking is the arrival at the exact location for arranging the handling processes. As pilots are not able to see the location of their wheels, a flagger is necessary to signal the crew how to move and where exactly to stop. At many airports, the flagger is replaced by an automated docking system, where on the wall in front of the aircraft, electronic signals indicate to the pilot what to do.

2.2.2 De-boarding

De-boarding starts with bringing an aviobridge or stairs to the aircraft.

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[3] Apart from the link to departure, arrival, stand and taxiway planning, modelling the turnaround process may also help to gain insight in the connection between airside and landside processes. After all, it is during turnaround that these distinct perspectives on airport processes meet.

In case passengers and crew de-board via stairs, additional airport personnel is necessary to guide them to the buildings. This can be a brief walk over the airport's surface or through a bus connection. The crew gets a special treatment as they will leave after the passengers and need more time for final checks.

2.2.3   Baggage and cargo unloading

Baggage unloading can typically start almost immediately after the aircraft has come to a stop. A dedicated company will take out the baggage and bring this to the terminal building.

Cargo, if not too voluminous, is unloaded at the aircraft's stand. More commonly, cargo from combi-aircraft is unloaded at the airport's cargo area, in which case the aircraft will be towed to that position with a tow vehicle.

2.2.4   Security

Aircraft with passengers from certain countries need a security check when they arrive at an airport.

2.2.5   Cleaning

Cleaning concerns the interior of the aircraft, which is prepared for the following flight.

2.2.6   Fuelling

Fuelling is performed with pump vehicles, which take the kerosene from hydrant wells, which are located at the gates. Alternatively, tank vehicles bring the fuel to the aircraft.

2.2.7   Catering

Catering delivers the necessary food to the aircraft. Depending on the destination of a flight, certain types of food are not allowed. Some airlines allow passengers to indicate special wishes (like vegetarian meals) beforehand.

Several airlines do not serve food to every passenger; instead they provide food and drinks at a cost. In this case, fewer catering items will be required.

2.2.8   Baggage and cargo loading

Like cargo unloading, if necessary, cargo loading is performed at the cargo area. Specific rules exist concerning live stock and cooling. These are not allowed to wait at the cargo area too long. Baggage loading is handled at the stand.

2.2.9   Passenger boarding

Passengers can board the way they de-board, either through an aviobridge, through a short walk on the surface or through a bus connection.

2.2.10 Security

All passengers and their luggage have to pass a security check. If this is performed at the gate, the process is included in the handling process.

At some airports, the security check is performed at a central area. In this case, the security check is not included in the handling process.

2.2.11 Aircraft check

The crew is responsible for the flight and will check the aircraft thoroughly before each flight. Aircraft checks concern inspections on the outside of the aircraft and proper functioning of the aircraft machinery and equipment (checks in the cockpit).

2.2.12 Push-back

When all boarding processes have been completed, the aircraft can depart. Aircraft at gates need to be pushed-back using dedicated push-back vehicles. Aircraft at stands mostly require a push-back as well, depending on the configuration of the stand. At some stands, aircraft can directly start up their engines and start taxiing.

Push-back is a link between the handler, the airline, and ATC.

2.2.12.1 ATC related

Push-back is part of the departure management process of ATC (at some airports the airport authority is responsible). Usually, a dedicated push-back (and start-up) controller is assigned for this task. Push-back must be organised so that departure slots are realised and/or that the sequence which is proposed by the departure manager (if available) is established.

A few airports already implement the pre-departure sequencing procedure as proposed by EUROCONTROL (currently Brussels and Munich are the farthest in this). This procedure requires from airlines that an *aircraft ready time* (ERDT or TOBT = Target Off Block Time) is provided to ATC, approximately 30 minutes before the aircraft will be ready for push-back. This enables ATC to plan the push-back events, using a pre-departure sequencing tool.

2.2.12.2 Handler-related

Push-back is performed by special companies that own the push-back vehicles. Different types of vehicles exist:

- Vehicles with tow-bar (conventional tugs). These vehicles attach a bar between the aircraft's nose wheel and the vehicle, after which the aircraft is pushed backwards.

- Vehicles that lift the aircraft (modern tugs). The aircraft is tilted onto the vehicle and then pushed backwards. This procedure is much quicker than the tow-bar because no manual actions to connect the aircraft to the vehicle have to be performed.

Two sizes of push-back vehicles exist: for smaller and larger aircraft. Some vehicles can only push aircraft, while other can push and pull/tow. For towing operations, to move an aircraft to another position, a pull tug is necessary. For pulling an aircraft, two people are needed: one to operate the vehicle and an additional technician in the cockpit. For push only, the vehicle can be operated by one person.

2.3 Ground Handling and Stand Planning

A next question that could be raised is how the processes detailed in section 2.2 are related to the overall airport planning processes. In this section, the most important related process chain will be described: stand planning[4]. Other airport processes, such as arrival management, taxi management, and departure management, are also related to and dependent on the turnaround of aircraft. Nevertheless, these processes are not as closely linked to ground handling and will therefore not be discussed in this document. Deliverable D3 of this project, however, will sketch a more detailed picture of the relation between ground handling and other airport processes.

2.3.1   Stand Planning per Planning Phase

Obviously, ground handling is not isolated from other processes taking place at an airport. The most important process chain, with which ground handling is thoroughly intertwined, is the process of stand planning. In this process, an initial stand plan is developed based on the airlines' preferences and the airport's stand availability. This is typically done half a year in advance, yielding a so-called seasonal stand allocation plan. Next, this seasonal stand allocation plan will be refined step by step towards the day of operations. Below, this process will be described in further detail and related to two planning phases: strategic and pre-tactical.

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[4] Stand planning is an airport process concerned with the establishment of a so-called stand allocation plan. This stand allocation plan describes how aircraft are assigned to their stands for a given time period for that airport. A stand allocation plan includes in-block and off-block time estimates and will be established for a particular day of operation.

2.3.1.1 The Strategic Phase

In the strategic phase, it is the airport's responsibility to establish a seasonal stand allocation plan, allocating the expected flights for a given day at the airport to its available stands. This seasonal stand allocation plan is established twice a year ample before the IATA Schedule Coordination Conference for that particular season is organised [AAM]. In the plan, developed by the stand planner, airline(s) and airport operator, a great many constraints and preferences are taken into account: infrastructural constraints, operational practices, the airport's declared capacity, flight expected schedules, airlines' stand planning preferences, ground handler capabilities, published IATA Schedules, etc. [AAM]. This seasonal stand allocation plan is considered as a master plan for a tactical stand allocation plan for that particular season (i.e., winter or summer).

2.3.1.2 The Pre-tactical Phase

In the pre-tactical phase, the stand planner of the airport refines and adapts the seasonal stand allocation plan via subsequent versions of a pre-tactical stand allocation plan towards a tactical stand allocation plan. The pre-tactical planning phase covers the timeframe starting 7 days in advance of the day of operations and reaches to about 2 hours before the event on the day of operations [AAM ConOps, p. 91]. At the day before operations, the stand planner includes the latest information on ATM scenarios, events, change proposals of airlines, and weather forecasts. The result of this process of refinement is a final pre-tactical stand allocation plan that describes, for the day of operations, exactly when each flight should go in- and off-block at which stand at the airport [AAM]. Two hours before operation, this pre-tactical plan will be published as the tactical stand allocation plan (to be modified only in case of unexpected events).

2.3.2 Involvement of Ground Handlers in Stand Planning

Assigning aircraft to a particular stand is the responsibility of the airport. In the establishment of a seasonal stand allocation plan, however, the airline will also be involved. In the scope of 2011-2020 addressed by the AAM project, large airlines are foreseen to provide their partial stand allocation plan for a preferred area [AAM]. This preferred area is assigned to the airline by the Airport Operator, based on the market, its market share and preferences. Within this area, airlines can develop their own stand allocation plan. The Airport Operator will then incorporate the airline specific seasonal stand allocation plans – using a Gate Management System – into one overall season planning for the airport [AAM].

Given this (future) involvement of airlines, one might wonder why ground handlers are not also involved in the stand allocation process. Are not ground handlers crucial in the process of servicing aircraft at the stand? After all, if the ground services cannot be delivered on time at a

stand, the aircraft will never make its off-block time. Rather surprisingly, however, the ground handlers (alternatively called the local service providers) are not included in the decision making process. For them, the seasonal or pre-tactical stand allocation plan is a hard constraint: ground handlers simply have to make sure that they can deliver their services within the specified on- and off-block times for a given stand.

Fortunately, however, there is still some room for ground handlers to plan their own services. Namely, there is quite a bit of difference between the minimum service times, as specified by aircraft manufacturers (see appendix B for two examples), and the so-called norm times for services, as specified by the airport. Whereas the aircraft manufacturers specify the minimum service times required to perform a service, airports typically operate with norm times for services: the maximum amount of time the service is allowed to take. The difference between both, which can be considerable[5], allows the service providers the flexibility to plan their own services, since they can shift their tasks within this range.

Except for this latitude between the airport norm times and the minimum service times, however, there is not much room for ground handlers to do their own planning. They simply have to stick to the stand allocation plan[6], which lays down the hard constraints within which their own planning should be fitted. As outlined briefly in section 2.1, it is easy to see why this strict hierarchy could lead to a sub-optimal overall planning. From a CDM perspective, therefore, it seems profitable to allow ground handlers to join the decision making loop. Added to that the fact that ground handling is an important source of airport delays, it will be interesting to investigate the possibility of including ground handling in the airport planning process. In the next section, a first step will be taken in this direction.

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[5] In section 4, example norm times are given that are up to twice the minimum service times specified by the aircraft manufacturers.
[6] Depending on the moment local service providers are planning their resources, they will base this planning on the seasonal, or the pre-tactical stand allocation plan.

3   Towards a Model of Ground Handling

In this chapter, an outline is sketched to pave the way towards a general model of ground handling. The planning problem addressed is described, as well as the actors, tasks, and resources that will be included in the model. Furthermore, the boundaries and limitations of the model are outlined by explicating the underlying assumptions. In deliverable D3 of the CAED project, the preliminary model description offered in this chapter will be used as a baseline for the development of a mature, formalized ground handling model.

3.1 The planning problem addressed

In ground handling, many different airport processes can be distinguished. For the coordination of these processes, planning and scheduling play a crucial role. Sophisticated schedules have been developed to meet the high efficiency requirements and deal with the limited availability of resources for each airport process. Yet, even though the implementation of such specialised planning software has led to a considerable performance gain, inefficiencies are still encountered. This has to do with the dynamic and distributed nature of the domain, as well as the requirement to coordinate actions between actors.

The planning problem central to the CAED project, of which this document forms part, can be summarised as follows. How can multiple actors, operating in a highly dynamic and distributed environment, plan their activities independently whilst still assuring that the combined overall plan is consistent? In the new planning approach proposed here, it is recognised that every actor depends on the actions of other actors – but typically prefers to plan his own processes as much as possible. After all, each actor has his own goals, resources, performance issues, and business objectives. Applied to the ground handling domain, it is clear that many different companies are responsible for the safe and expedient handling of aircraft during turnaround. In the approach proposed here, these handlers are allowed to plan their processes locally as much as possible.

Such processes can be modelled as temporal problems. In [D1], examples have been given of simple and extended temporal models. Also, temporal decoupling has been described as a general technique to decouple a large planning domain into sub-domains suited for local planning. In this chapter, the temporal and decoupling theory will be applied to the domain of ground handling. A preliminary model of ground handling will be sketched based on the processes distinguished in section 2. As a first step, these processes will be further refined below in terms of the planning phases addressed and the actors, tasks and resources involved.

3.1.1 The Planning Phase

In airport planning, typically three different planning layers or horizons are distinguished: the strategic, pre-tactical, and tactical planning layer. By convention, task scheduling and resource utilisation is (re)planned at each layer – although, of course, there are many dependencies between the different layers. In our model, two planning layers are of particular interest – as we saw in section 2.2. First, the strategic planning layer determines the initial stand allocation that forms the baseline for all subsequent planning. At the slot conferences in March and September, about half a year before flight, the basis is laid for a seasonal stand allocation plan that establishes the slots in which all ground handling needs to take place. Therefore, all planning addressed by our model can only start after all strategic planning, resulting in a confirmed seasonal stand allocation plan, is finished.

On the other hand, the ground handling services should be planned before the actual flight. As explained in section 2, the tactical stand plan is published about 2 hours before operation by the Airport Operator by refining the seasonal stand allocation plan. This refinement takes place in the pre-tactical planning phase, about 7 days before operation, and is based on information about the current situation: weather forecast, cancelled flights, extra requests, etc. On the day of operation, the tactical stand allocation plan is used as the operational stand allocation plan and will only be modified in case of unexpected events. Thus, before the seasonal stand allocation plan is improved and 'frozen' into a tactical stand allocation plan, a planning of the ground handling services should have already taken place. In summary, the planning processes that are the focus of this document take place between the end of the strategic phase, roughly a few months before the actual flight, and the tactical phase, two hours before operations.

3.1.2 Actors, Tasks and Resources

At the ground handling level, a great many other actors[7] are involved – as we saw in section 2 above. From these actors, the following five actors (and corresponding tasks) could be chosen initially as the main actors to be included in the model:

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[7] In this chapter, the term 'actor' is reserved for any party, company or participant involved in ground handling.

- Cargo loading operator:
    - Unload compartment (FWD + AFT)
    - Load compartment
- Water, cleaning and lavatory servicing operator:
    - Service toilets
    - Service potable water
    - Clean cabin
- Fueling operator:
    - Fuel airplane
- Catering operator:
    - Cater aircraft via galley service
- Passenger boarding operator:
    - Position passenger bridges or stairs
    - Deplane passengers
    - Board passengers
    - Remove passenger bridges

Figure 3: Actors and Tasks

Actors such as the Technical Services Operator have not been included, since they may not be involved in every turnaround[8]. Moreover, other (sub)tasks, such as pre-boarding, boarding of the crew, cabin check, and the positioning and removal of the blocks/traffic cones, have not been included yet to further simplify the domain. The following resources are involved when completing the different tasks each actor is responsible for:

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[8] This depends on the Airport policies and the aircraft type. In the Airplane Servicing Arrangements, as specified by the Aircraft Manufacturers, these services are not included.

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-   Cargo loading operator:
        o   Bulk cargo loading vehicles,
        o   Container trailers
        o   Personnel
-   Water, cleaning and lavatory servicing operator:
        o   Water servicing vehicles
        o   Lavatory vehicles
        o   Cabin cleaning vehicles,
        o   Personnel
-   Fueling operator:
        o   Fuel trucks
        o   Personnel
-   Catering operator:
        o   Galley service trucks
        o   Personnel
-   Passenger boarding operator:
        o   Personnel to position/remove passenger bridges
            or stairs
        o   Boarding personnel
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Figure 4: Actors and Resources

Note that the actors, tasks and resources distinguished here are not final: if during further research in WP3 a more fine-grained description of the domain is required, this will be added to the above. We have merely outlined a baseline here for the development of an initial model.

3.2 Limitations of the Domain, Assumptions

Every good model is a simplification of reality, leaving out irrelevant detail and retaining only that which is considered to be essential. To judge whether a model correctly represents an operational domain, therefore, depends on the decisions made with respect to the scope and level of simplification. What is important enough to keep in the model, and what should be left out? This section addresses this question by describing the boundaries and limitations of the anticipated ground handling model. Note that these limitations follow in part from the planning phase addressed and the actors distinguished. Below, the assumptions made with respect to the domain are listed.

Assumption 1A
The following five activities are the main activities in the ground handling domain: cargo, cleaning, catering, fuelling, and boarding.

Assumption 1B

Related to the five main activities, five actors are distinguished: the cargo loading operator, the water, cleaning and lavatory servicing operator, the fuelling company, the caterer, and the boarding company. These actors are only responsible for the tasks and resources as listed in figures 3 and 4 above.

Assumption 1C

For the initial model, a set of about ten or fifteen aircraft types with corresponding service times will be sufficient to test whether the model is satisfactory.

Assumption 1D

The initial model will not take into account service times that are dependent on factors other than the aircraft type and certain airport specific requirements. For instance, airline-specific service times[9], or service times depending on specific stand allocation requirements, will be out of scope. The model, however, should be general enough to accommodate these requirements in a future version if necessary.

Assumption 2A

The model will address the strategic and pre-tactical planning layer: between the moment the initial stand allocation plan is conceived (strategic) and the moment the final stand allocation plan is fixed (tactical) 2 hours before the operation. In other words: the model will play a role in refining[10] the seasonal stand allocation plan towards the tactical stand allocation plan.

Assumption 3A

The domain covered by the model can be characterized as being dominated by largely autonomous, self-interested actors. Cleaning companies, fuelling companies, and catering services all have their own business interests and need to take into account business specific constraints when planning their activities and use of resources. Therefore, the ground handling processes are best served by putting the power in the hands of the local actors best placed to take the decisions (CDM).

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[9] At Schiphol, for instance, low cost carriers may use pier H which allows for a much shorter turnaround. Also, airlines may specify different turnaround times depending on the length of flight (KLM, for instance, distinguishes between continental and intercontinental flights). Finally, services for flights may be divided into real turnaround services, and services for flights that only arrive (loose arrivals) or depart (loose departures).

[10] Refining here means that an initial seasonal stand allocation plan, developed at the strategic planning layer, will be gradually complemented with a matching services planning (phase I). In phase II of the project, this refinement will include a feedback loop to allow service providers to actually make small changes to the initial seasonal stand allocation plan. See the description of these phases in section 3.3 below.

Assumption 3B

Related to the previous assumption, it is assumed that the ground handling tasks are best performed if every actor is responsible for carrying out his own tasks. Thus, every actor will benefit when the need for co-ordination with other actors during planning is minimised. Actors will prefer to do their planning in their own manner, satisfying their own business rules and insights as much as possible.

Assumption 4A

It is assumed that there is an important difference between the minimum service times, as specified by aircraft manufacturers, and norm times, as specified by the airport. This difference allows the service providers more flexibility to plan their own services, since they can shift their tasks within this difference range.

Assumption 4B

In case of deviation in the earliest start time between minimum service times and norm times, it is assumed that a service can never start earlier than the norm time specified by the airport. In other words, when determining the earliest possible start time for a service, the norm time specified by the *airport* takes precedence.

Assumption 4C

In case of deviation in the duration between minimum service times and norm times, it is assumed that the minimum time required to provide the service is the time specified by the aircraft manufacturer. In other words, when determining the minimum duration of a service, the minimum service time specified by the *aircraft manufacturer* takes precedence.

Assumption 5A

The model is intended to be used primarily by the service providers. It should assist them in making their own local planning, taking the constraints resulting from the seasonal stand allocation plan and other service providers into account.

Assumption 6A

It is assumed that, if the local service providers have more flexibility in planning their own resources and activities, this will lead to a better tactical stand allocation plan. After all, the interests of the service providers will be better covered, leading to a more *efficient* local planning.

<u>Assumption 6B</u>

Related to the previous assumption, it is further assumed that if local service providers are given more flexibility in planning, or are even rendered direct influence on the refinement of the seasonal stand allocation plan, this will also lead to a more *robust* local planning. In other words, a tactical stand allocation plan based on flexible ground handling planning is assumed to improve the ability to react to unforeseen disturbances in the tactical/operational phase.

3.3 Goals of the Model per Project Phase

In the previous two subsections, the outlines of a ground handling model have been sketched. The actors, tasks and resources involved have been detailed, and the assumptions made with respect to the model have been stated. In this section, the high-level goals that the model should meet will be listed.

These goals can be divided into two groups. The division corresponds to the two phases foreseen in the CAED project. Phase I, to be implemented in the first year of the project, addresses the development and possible automation of the extreme decoupling process from a mere stand allocation plan to a stand & services allocation plan. Phase II, to be performed in an additional two years of research, will build on the developed model, methodology and possible prototype in order to implement a loop, allowing ground handlers to actually change the stand allocation plan (via small-scale change proposals). This last phase is not addressed in this document, since the scope is restricted here to the first year of research. Section 3.4 below gives some more detail on both project phases.

Below, two sets of high-level goals are given. Goals 1 and 2 relate to phase I of the project. Goal 3 is only relevant to phase II. In WP3, the first two goals will be further elaborated and refined into a list of specific requirements for the ground handling model.

<u>Goal 1</u>

As can be concluded from assumptions 3A and 3B, the model's primary goal should be to minimize the required co-ordination in planning between actors as much as possible – whilst preventing that these plans are in conflict with one another.

<u>Goal 2</u>

Apart from preventing conflicts to occur between individual plans of service providers, the model should also prevent its user from making plans that are in conflict with the seasonal stand allocation plan. Thus, the model should be able to automatically constrain the search space of the local planner (the service provider) based on the stand allocation plan (the slots in which the

services should be performed), and aircraft and airport specific constraints (determining roughly the lower and upper bounds for each service to be performed).

<u>Goal 3</u>

The model should, in phase II, allow its users also to affect the seasonal stand allocation plan. Thus, service providers will be allowed to have an influence in the process of refining the seasonal stand allocation plan towards its mature state in the tactical stand allocation plan.

3.4 High-level Description of the Model

In this subsection, a first sketch will be given of a ground handling model that, within the limitations of section 3.1 and based on the assumptions of section 3.2, could meet the goals of section 3.3. The high-level description detailed here will be based on the two project phases distinguished in the previous section.

In phase I, the model could be used to automatically generate local search spaces, constrained by the seasonal stand allocation plan and the plans of other service providers. To achieve this, a Simple Temporal Network (STN) model should be constructed based on different sets of inputs: the seasonal stand allocation plan, aircraft type specific service times, airport specific constraints, etc. Section 4 below gives an example of such a STN representation of the domain. Next, the decoupling algorithm will be used to decouple the network into local networks - as discussed in [D1]. To this end, first the seasonal stand allocation plan constraints and corresponding airport-specific 'norm times for the gate services' are decoupled, taking advantage of the latitude that typically exists between these norm times and the minimal service times as specified by aircraft manufacturers. When properly decoupled, service providers (SPs) can do their own, local planning – without requiring any further co-ordination with other parties.

To establish their own local plan, service providers can either use their own planning methods and tools[11], or take advantage of the set of search algorithms for extended STNs as proposed in this research project (see chapters 4 and 5 of [D1]). Note that, given the latitude between norm times and minimal service times, the SPs will have quite a lot of flexibility in accommodating their local plans to their local constraints and local business models. Once established, the local plans are guaranteed to be conflict-free when merged again with other local plans due to the Mergeable Solutions Property of the decoupling algorithm. The result, then, is a tactical stand allocation plan that incorporates all local services planning. This result could be tested in the

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[11] These methods and tools should however be able to work with the STN representation that results from applying the decoupling algorithm.

tactical/operational phase, by demonstrating that the resulting tactical plan can deal better with unforeseen circumstances – for example during winter conditions.

In phase II, the implementation of a planning *loop* is foreseen, allowing for multiple iterations if necessary. This loop enables local planners to have an influence on the refinement of the seasonal stand allocation plan: a new operational feature. Thus, large inefficiencies in the local planning of service providers can be prevented by allowing slight modifications in the stand allocation plan. For instance, when a fuelling company has to service ten aircraft at the same time, requiring a large peak in personnel and fuelling vehicles, the company may propose to slightly change the stand allocation plan to better spread out the fuelling activity in time. Contrary to phase I, which only automates and aids the local planners in establishing their own local plans, phase II therefore actually allows local planners to influence and even modify the pre-tactical stand allocation plan.

4 A Ground Handling Example

This chapter describes how the preliminary ground handling model of the previous section can be applied in practice. To do so, first an operational example is given, which serves as a running example for the remainder of the chapter. Next, it is demonstrated how a STN model can be constructed based on this example – and other relevant domain knowledge (section 4.1). In the following, the decoupling of this model in local sub-models is shown (section 4.2). Finally, a set of solutions for these decoupled sub-models is presented (section 4.3).

4.1 Constructing a Model of the Domain

In this section, an simple example is used to demonstrate how a Simple Temporal Network (STN) could be constructed from the ground handling domain. In a step-by-step fashion, the example is elaborated and a set of variables, resources, and temporal constraints is distilled from the domain. Next, a network is built in which the nodes represent the variables and the edges between the nodes the temporal constraints of the domain. The resulting STN is a formal representation of the example domain.

Imagine the following, simplified partition of a seasonal stand allocation plan:

- Aircraft 1, KL310, type B737-300, Gate A17, in-block 12:00, off-block 13:15.
- Aircraft 2, LH200, type MD11, Gate A23, in-block 12:05, off-block 14:10.

Furthermore, imagine that we have technical information about the required turnaround time and corresponding service times for each aircraft type. This information can be split up into two groups, as explained above. In the first group, the airport-defined turnaround and ground handling services are stated. These are the so-called norm times, including – at most airports and for most airlines – a safety margin to absorb any small servicing delays that may occur in the operational phase. In the second group, the minimum service times are stated as specified by the aircraft manufacturers. For example, for the first aircraft, a Boeing 737, the following norm times could be defined[12] by the airport for three example services:

- Turnaround: 55 min. duration
- Fuelling: 25 min. duration (with and additional margin of 12 min), starting 8 min after in-block at the earliest

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[12] These norm times are example norm times, but can in fact be regarded as typical norm times for an airport.

- Cargo: 46 min. duration, starting 4 min after in-block at the earliest
- Boarding: 15 min. duration (with an additional margin of 4 min), starting 32 min after in-block at the earliest

Conversely, the Airplane Terminal Operations (Airplane Servicing Arrangement) for a B737-300 states [Boeing; see Appendix B for details]:

- Turnaround: 38 min. duration
- Fuelling: 10 min. duration
- Cargo: 30 min. duration
- Boarding: 5 min. duration

The same can be done for the McDonnell Douglas in our example. The norm times as defined by the airport:

- Turnaround: 120 min. duration
- Fuelling: 59 min. duration, starting 11 min after in-block at the earliest
- Cargo: 25 (unload) + 45 (load) = 70 min. duration, starting 3 min after in-block at the earliest
- Boarding: 36 min. duration, starting 80 min after in-block at the earliest

and the airplane servicing arrangement for a MD11 [Boeing; see Appendix B]:

- Turnaround: 51.4 min. duration
- Fuelling: 16.6 min. duration
- Cargo (2 subtasks): 18 + 18 = 36 min. duration
- Boarding: 16.2 min. duration

Based on the seasonal stand allocation plan and the information above, we can now construct a large STP by following a simple procedure:

```
For every flight (e.g., KL310) do the following:
    • Create for every subtask of every service for that
      flight a start and end variable (e.g., X₂ for the
      start of fuelling KL310¹³), and:
    • Create for every such start and end variable two
      temporal constraints:
        o The start or end time for the corresponding
          subtask based on the norm times of the airport
        o The start or end time for the corresponding
          subtask based on the minimum service times as
          specified by the aircraft manufacturer
```

Figure 5: Pseudo-code for constructing a STP-model given a seasonal stand allocation plan

The same procedure applies equally to all services. Together with adding the encompassing constraints (the in- and off-block times), our example will yield the following set of variables, resources and temporal constraints for flight KL310:

Variable	**ACtype**	**Re-source**	**In/Off block**	**T_{start} Norm[14]**	**T_{end} Norm**	**T_{start} Min[15]**	**T_{end} Min**
X_1 (in-block)	B737-300	Gate A17	12:00				
X_2 (start fuel)	Idem	Idem		12:08		12:08	
X_3 (end fuel)	Idem	Idem			12:45		12:18
X_4 (start cargo)	Idem	Idem		12:04		12:04	
X_5 (end cargo)	Idem	Idem			12:50		12:34
X_6 (start board)	Idem	Idem		12:32		12:32	
X_7 (end board)	Idem	Idem			12:51		12:37
X_8 (off-block)	Idem	Idem	13:15				

Table 1: Variables, resources and temporal constraints for flight KL310

In the same manner, the variables, resources and temporal constraints for flight LH200 can be generated:

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[13] Note that, in the example detailed in this chapter, the services (e.g., cargo) are not further divided into corresponding subtasks (e.g., unload compartment, load compartment).

[14] The norm time for a specific aircraft type as defined by the airport.

[15] The minimum service time as specified by the aircraft manufacturer. Note that, although the aircraft manufacturer typically specifies an earlier possible start time than the airport, we will assume that a service cannot start before the earliest possible start time specified by the airport (see assumption 4B, section 3.2).

Variable	ACtype	Re-source	In/Off block	T_{start} Norm	T_{end} Norm	T_{start} Min	T_{end} Min
Y_1 (in-block)	MD11	Gate A23	12:05				
Y_2 (start fuel)	Idem	Idem		12:16		12:16	
Y_3 (end fuel)	Idem	Idem			13:15		12:33
Y_4 (start cargo)	Idem	Idem		12:08		12:08	
Y_5 (end cargo)	Idem	Idem			13:18		12:44
Y_6 (start board)	Idem	Idem		13:25		13:25	
Y_7 (end board)	Idem	Idem			14:01		13:41
Y_8 (off-block)	Idem	Idem	14:10				

Table 2: Variables, resources and temporal constraints for flight LH200

These tables can be constructed as follows. The first flight (KL310), for instance, is a Boeing 737-300. In the corresponding airplane servicing arrangement, it is stated that fuelling can begin 8 minutes after in-block at the earliest [Boeing, B737]. Moreover, since fuelling will take a minimum of 10 minutes, the earliest completion time of the task is, according to this document, 18 minutes after in-block. Given the in-block time of 12:00 noon, this yields a T_{start} Min of 12:08 and T_{end} Min of 12:18. The same can be done for the norm times of that aircraft, and for all other flights. For example, the T_{end} Norm of the boarding of flight LH200 can be calculated by adding the duration (36 minutes) to the earliest starting time from in-block (80 minutes) to the in-block time (5 minutes after 12:00 noon). Note the margin between the minimum end time and the end time as specified by the airport (e.g., 12:18 and 12:45 for fuelling of flight KL310).

At this point, a remark should be made. When defining minimum end times of services, one might think that it is always good to deliver services as quickly as possible. This is not always the case, however. When servicing has been completed and all passengers are on board half an hour before the planned off-block time, passengers tend to get agitated. More concretely: extra constraints should hold for at least two services, de-boarding and boarding. After all, de-boarding should take place as soon as possible after in-block, and boarding not too long before off-block. In our example, only boarding plays a role. We will assume here that passengers should not wait longer than 15 minutes after boarding before going off-block.

Based on our example, Tables 1 and 2 above now defines eighteen tasks, and a variety of temporal constraints. These temporal constraints specify when the tasks should be executed. The norm times could now be regarded as hard constraints, marking the earliest start and latest end time of a task. The minimum service times, in turn, could indicate the minimum duration of

a task – and thus, indirectly, the margin which the service provider has for planning his service in the hard-constrained slot. Some other temporal constraints should be taken into account, however.

Apart from so-called time bound constraints, which specify *at what time*, or *before* or *after what time* a task should be executed, another type of temporal constraints applies to the domain: precedence constraints. Whereas time bound constraints determine the *time* at which tasks should be executed, precedence constraints determine the *order*. In the tables above, only time bound constraints are defined, constraining the time at which tasks should start or end. However, many precedence constraints between the tasks exist as well, constraining the way they should be ordered in time. Such precedence constraints are, for example:

- 'In-block' occurs before all other services
- 'De-boarding' must take place before catering, cleaning, boarding
- 'Position passenger bridge' must take place before all other services
- 'Cabin cleaning' must take place after 'De-boarding' and before 'Boarding'
- For many aircraft types, airport, airlines, it holds that 'Fuelling' should not take place during 'De-boarding' or 'Boarding', unless the fire brigade is present
- 'Off-block' occurs after all other services

In our example, the start and end time of the fuelling task may depend on whether de-boarding is completed, or boarding has commenced. This in turn depends on airport regulations, airline policies, or even aircraft-specific rules[16]. The dependencies relevant to our example are:

- 'In-block' occurs before 'Fuelling', 'Cargo', 'Boarding'
- 'Fuelling', 'Cargo', 'Boarding' occur before 'Off-block'
- 'Fuelling' occurs before 'Boarding'

At this stage, we are ready to construct a Simple Temporal Network (STN) based on the domain. For the "fuelling" and "boarding" tasks of Flight 1, for instance, we could build the following STN consisting of 7 nodes and 9 edges:

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[16] Note that most airplane servicing arrangements, specified by the aircraft manufacturer, do in fact rarely prohibit the simultaneous execution of fuelling and (de)boarding.
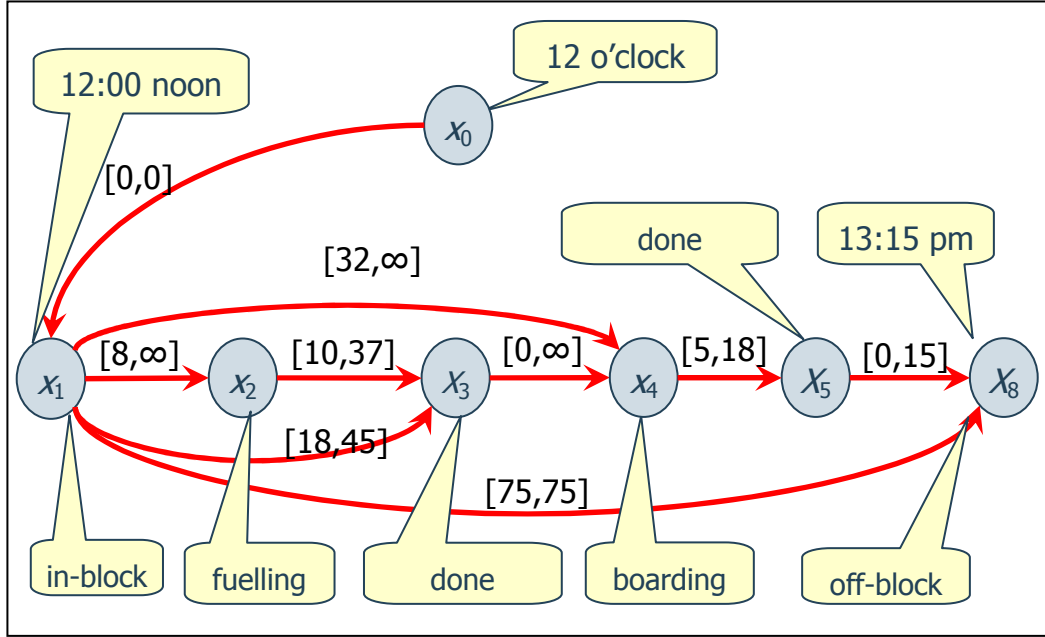
Figure 6: STN for services "fuelling" and "boarding" of Flight 1

In this Figure, six variables have been selected from Table 1 above: X_1, X_2, X_3, X_4, X_5, and X_8. Note that the precedence constraints determine the order in which the variables are placed in the STN. Additionally, the temporal reference point X_0 is added. The reader is referred to [D1], chapter 2, for further information on STNs. For the reference point X_0, the time 12:00 noon is chosen. Since flight 1 goes in-block at exactly 12:00 noon, the minimum and maximum time allowed between variable X_0 and X_1 is simply *[0,0]*[17] – as indicated next to the edge. The following task, X_2, is the fuelling activity itself. The temporal constraint *[8,∞]* between X_1 and X_2 denotes that fuelling can start 8 minutes after in-block at the earliest, and that there is no direct upper bound known given our information[18].

The same can be done for the other constraints. For instance, fuelling itself can last anywhere between 10 minutes (airplane servicing arrangement) and 25 minutes + 12 minutes margin = 37 minutes (norm time). Thus, the transition between 'fuelling' X_2 and 'done fuelling' X_3 is constrained by *[10,37]*. Furthermore, the transition between 'in-block' X_1 and 'done fuelling' X_3 should be anywhere between the earliest end time T_{end} Min and the latest end time T_{end} Norm: *[18,45]*. The next constraint is *[32,∞]*, indicating that 'boarding' X_4 cannot start earlier than 32

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[17] This indicates that the flight must be in-block at exactly 12:00 a.m.

[18] Note that, if required, one could infer an upperbound. Since fuelling will last until 12:18 at the earliest (T_{end} Min), and 12:45 at the latest (T_{end} Norm), as stated in table 1, and since the minimum time for fuelling is 10 minutes, as identified in the B737-300 airplane servicing arrangement, fuelling can start no later than 12:35 if the activity should be completed at 12:45. Therefore, the upper bound for the start of X_2 could be 35. It is much easier, however, to use precisely the information we have (not stating an upperbound) and instead add the temporal constraint *[18,45]* between X_0 and X_2. The upperbound 45 between X_0 and X_2 will then also constrain the transition X_0 and X_1.

minutes after in-block X_1. Boarding itself may last minimally 5 minutes (T_{end} Min) and maximally 18 minutes (T_{end} Norm), yielding *[5,18]*. After 'boarding', moreover, there should be time for other services not included in our example. This is why node X_5 is added: to indicate that 'boarding' is done. Since we have said that passengers should not have to wait longer than 15 minutes before off-block, the time between X_5 and X_8 is constrained by *[0,15]*. Also, since the off-block should take place at exactly 13:15 p.m., there is a time constraint of *[75,75]* between in-block (X_5) and off-block (X_8). Node X_8, finally, indicates the end of the turnaround process.

In a next step, we could add the cargo service to the STN above. This would yield the following model of Flight 1:
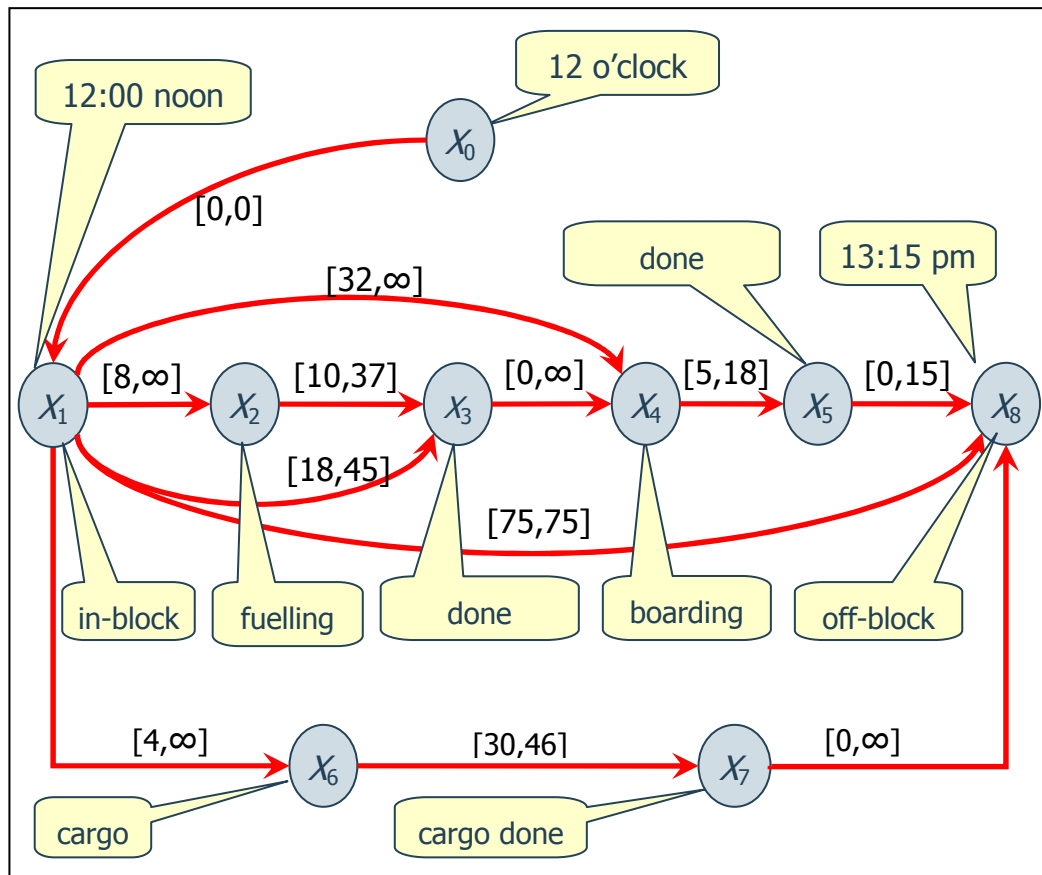
Figure 7: STN for services "fuelling", "boarding" and "cargo" of Flight 1

Note that, in Figure 7, variables X_6 and X_7 have been added for the 'cargo' and 'cargo done' activities, respectively. From the figure, one can conclude that unloading and loading the cargo can start 4 minutes after in-block at the earliest, whereas the activity itself requires at least 30 and at most 46 minutes.

Having put all three example services of flight 1 in a Simple Temporal Network, the next challenge is to include other flights in the network. Figure 8 below demonstrates how flight 2 of our example can be added. Note that, in order to keep the figure manageable, only the fuelling and boarding services of both flights are included. In this manner, the network can – in principle – be expanded to any number of flights and services.
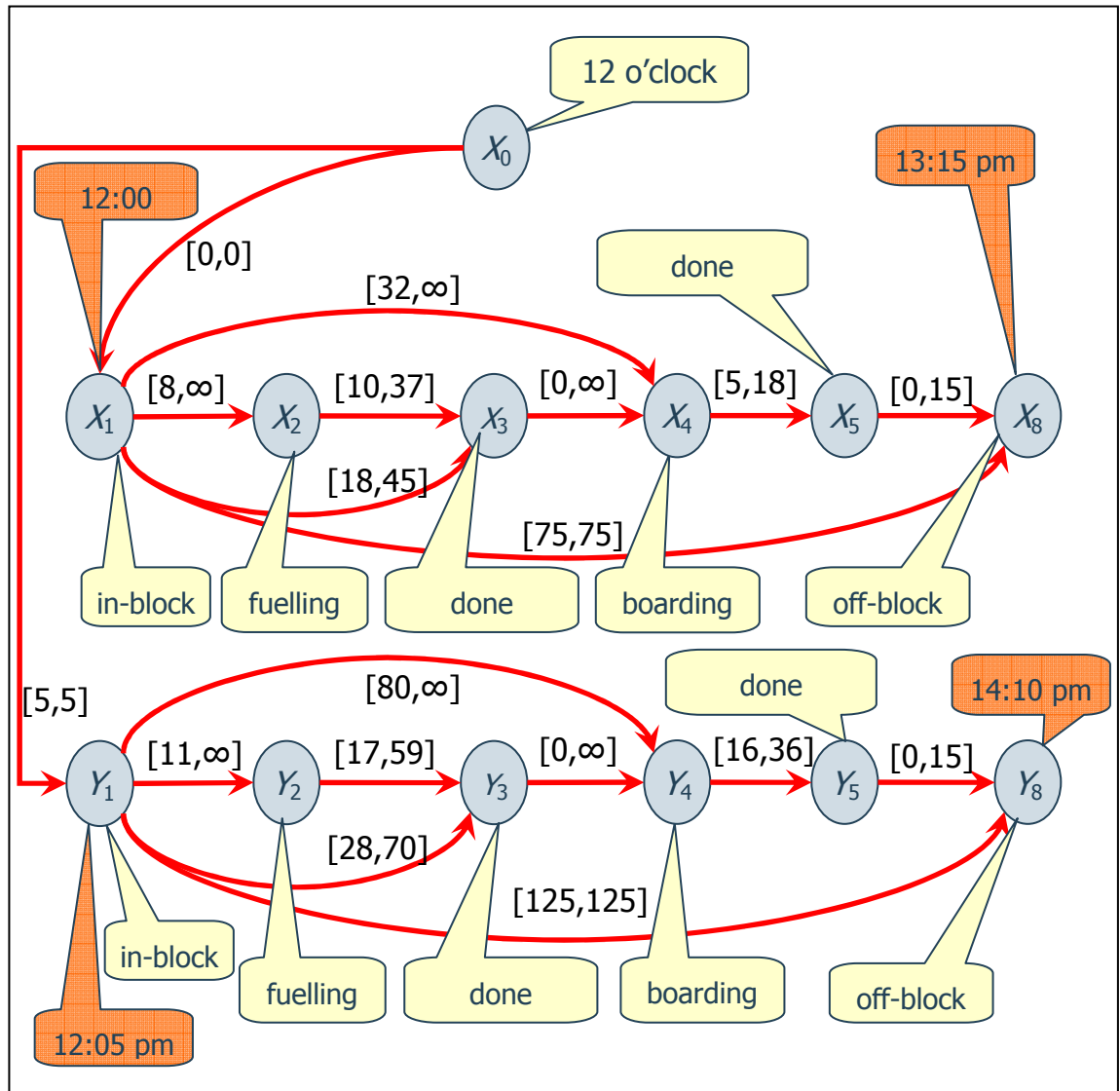

Figure 8: STP for services "fuelling" and "boarding" of Flights 1 and 2

In this section, an example stand allocation plan has been used to demonstrate how, step by step, a Simple Temporal Network (STN) can be constructed. Further, a procedure in pseudo code has been given to show how this construction process can be automated. The resulting STN is a representation of the entire ground handling domain. It matches the example stand allocation

plan and all constraints that can be deduced from it. In a next step, this high-level ground handling STN should be decoupled and divided amongst the various service providers. The next section addresses this issue.

4.2 Decoupling the Domain Model

In this section, the example STN built up in the previous section will be used to demonstrate Hunsberger's decoupling algorithm. It is assumed here that this algorithm is implemented and can be applied to STNs representing our domain. For the theory behind decoupling the reader is referred to chapter 5 of [D1]. This section merely shows how Hunsberger's algorithm can be applied to the domain – and what the resulting partition of local planning domains could look like.

As a first step, Figure 9 below shows how the above STN, representing (part of) the example domain, can be decoupled in two parts. The first part (shaded) matches the temporal network for the fuelling company, the second (spotted) the network for the boarding company.
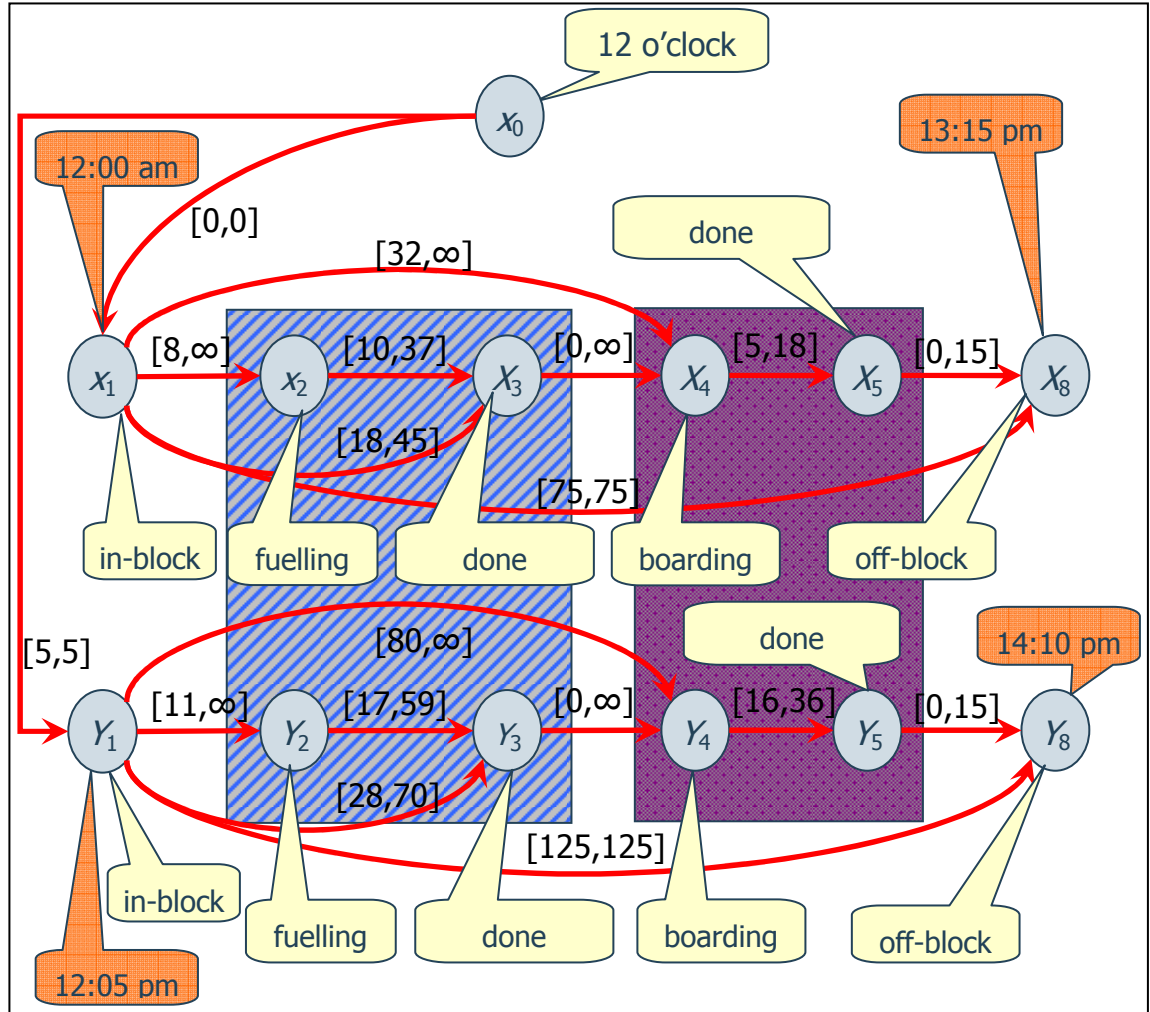
Figure 9: Decoupling "fuelling" and "boarding" from the STP

When applying the decoupling algorithm, the overall, high-level ground handling domain will be split up into sub-domains relevant for the various service providers. These sub-domains will inherit the constraints that apply to the specific service. Moreover, extra constraints may be added to ensure that no dependencies exist between different service providers. For example, for the boarding company, an extra constraint is required to ensure that its domain is independent of the domain of the preceding fuelling service.

Additionally, extra constraints may be added that apply to the local situation. For instance, a local constraint may be added stating that there should be at least a 10-minute gap[19] (see Figure 11) between fuelling aircraft KL310 (X) and LH200 (Y) to allow the fuelling vehicle and its personnel to get from gate A17 to A23. Figures 10 and 11 below show two local domain

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[19] Note that, since we do not know in advance the order in which fuelling takes place, defining this constraint would involve disjunctions (e.g., [-∞,-10] □[10, ∞]). See D1, chapter 3 and 4 for further details.

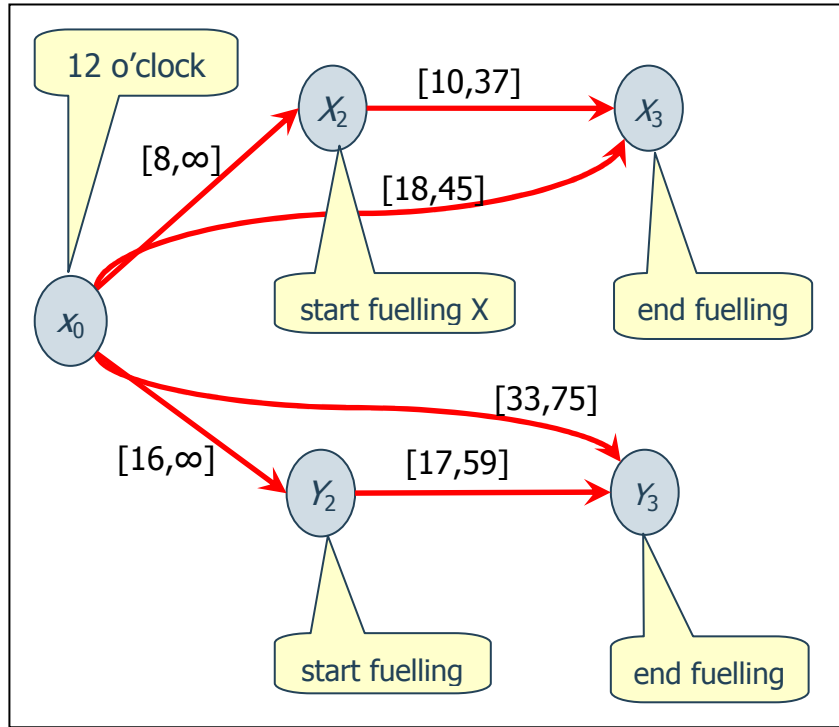representations that may result from applying the decoupling algorithm to the example domain above.

Figure 10: The decoupled "fuelling" service

Note that X_0, the reference point, is part of both figures 10 and 11, whereas the in-block variables X_1 and Y_1 are not. As a result, constraints are added between X_0 and X_2 / Y_2 in figure 10 and between X_0 and X_4 / Y_4 in figure 11 to reflect the previous constraints between in-block and the start and end of the core activity. For example, in figure 10 the set of constraints *[5,5] and [11, ∞]* between variables X_0, Y_1 and Y_2 is translated into the constraint *[16, ∞]* between X_0 and Y_2 to reflect that fuelling of aircraft Y should start at least 5 + 11 = 16 minutes after 12:00 noon. Similarly, the set of constraints *[5,5] and [28,70]* is translated into the constraint *[33,75]*.
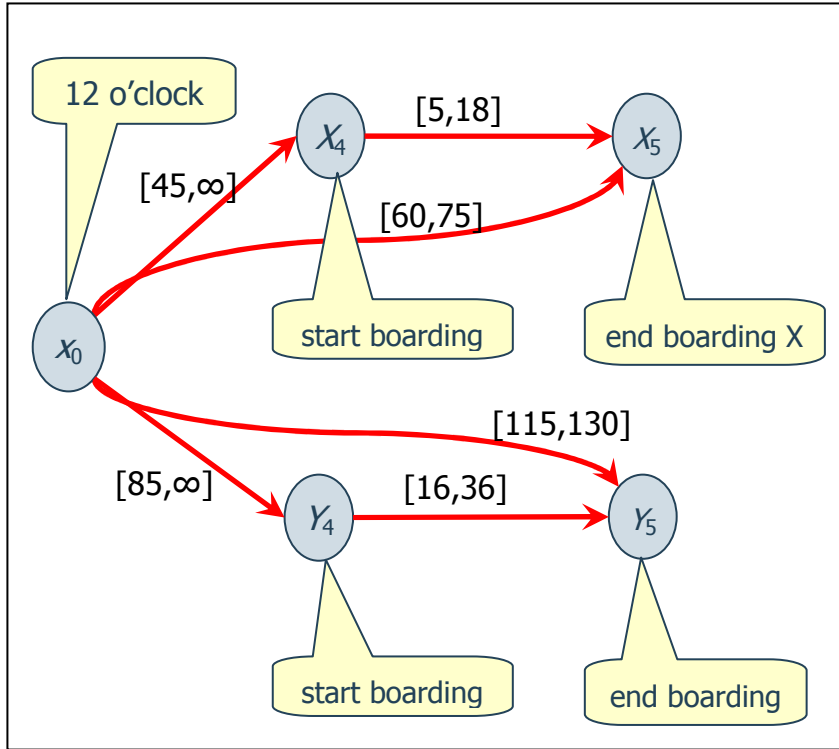
Figure 11: The decoupled "boarding" service

In figure 11, boarding of aircraft Y can start $5 + 80 = 85$ minutes after 12:00 noon at the earliest, denoted by constraint *[85,∞]* between X_0 and Y_4. Further, the duration of boarding doesn't change (*[5,18]*, *[16,36]*), but the end time of boarding does. For aircraft X, for instance, boarding should end between 60 and 75 minutes after 12:00 noon This constraint is the result of decoupling boarding from the constraint *[0,15]* between 'end boarding' and 'off-block': since the aircraft should go off-block at 13:15 p.m. and the boarded passengers shouldn't wait longer than 15 minutes, boarding should end at least 60 minutes and at most 75 minutes after in-block. The constraint *[115, 130]* between X_0 and Y_5 is calculated in a similar fashion.

At the other end, an extra constraint is created when decoupling boarding from the previous activity: fuelling. This constraint is the temporal constraint *[45,∞]* between X_0 and X_4. It is obtained through the following process. First, constraint *[32,∞]* between X_0 and X_4 is copied from the original domain to the boarding domain (we can replace X_1 with X_0 because of the constraint *[0,0]* between them). Next, however, we observe that the precedence constraint between fuelling, which should take place first, and boarding, which should follow, results in a more restrictive constraint. Since fuelling may take up to 45 minutes, boarding cannot start

before 12:45 p.m. if we are to ensure that there is no interference between both activities. Thus, the more restrictive *[45,∞]* replaces *[32,∞]* as the temporal constraint between X_0 and X_4.[20]

This section gave an idea of how the decoupling algorithm could be applied to our example, and what the resulting sub-networks might look like. All we have done so far, however, is related to constructing a model of reality. We built a representation of the overall problem domain (section 4.1) and decoupled this representation into small sub-models (section 4.2). We have not solved anything yet, though.

4.3 Solving the Decoupled Planning Problems

In this section, we will look at example solutions to the local planning problems depicted in figures 10 and 11. The process of arriving at this solution, whether through Floyd-Warshall's algorithm, the ΔSTP algorithm, or through Local Search, is beyond the scope of this document. The reader is referred to chapters 2 to 5 of [D1] for a description of algorithms that could do the job. In deliverable D3, an extensive description will be given of how the algorithms of [D1] can be utilised to solve the operational problem sketched in this document. In this section, we merely offer example solutions that satisfy the temporal constraints laid down in figures 10 and 11.

For figure 10, it is not difficult to find a solution. Since for aircraft X fuelling can start at t=8, whilst aircraft Y should wait until t=16, it seems natural to first fuel X, then Y. If we further assume that the fuelling company wants to minimize the time required for fuelling (10 minutes for X, 17 for Y), we could get the following solution:

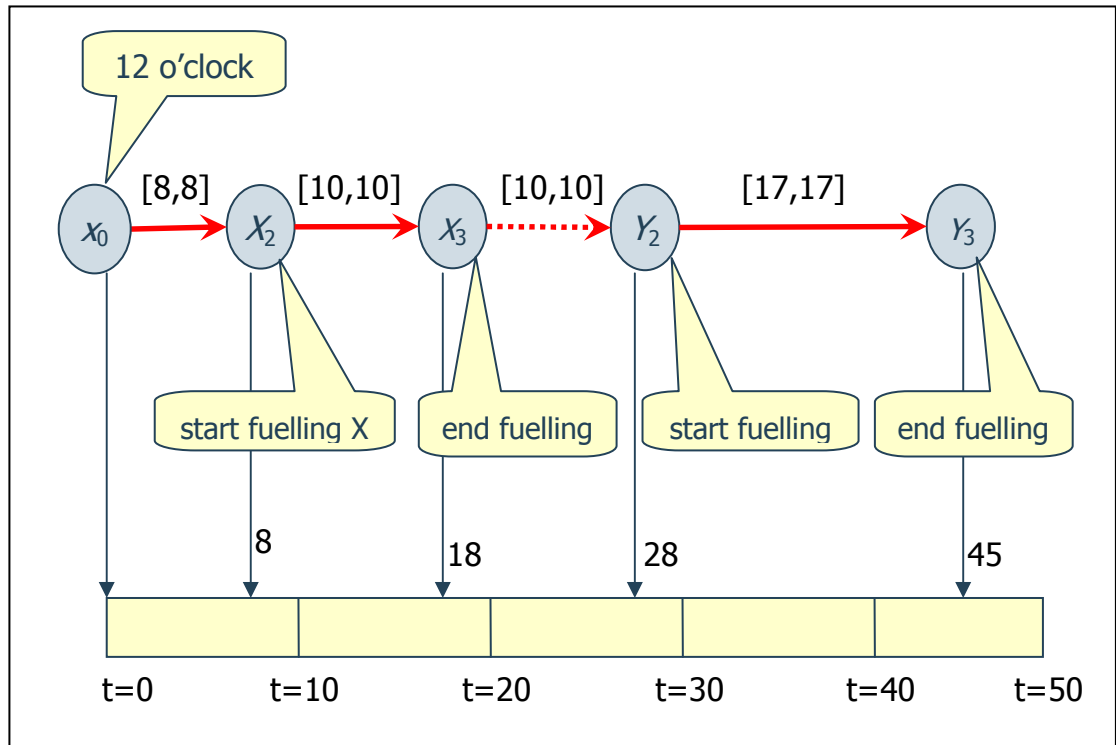[20] Note that other, less restrictive decouplings are possible here.

Figure 12: An example local planning for the "fuelling" service

Note that the dashed arrow between X_3 and Y_2 indicates a local constraint: the minimum time between the end of fuelling aircraft X and the start of fuelling aircraft Y. This constraint may depend on a variety of factors: the distance between both aircraft, the personnel and fuelling vehicles disposable for both services[21], etc. Figure 12 just offers one example solution – many different solutions in fact exist. Note further that this planning can be regarded as very strict: although it offers a minimal solution (45 minutes between in-block of X and end fuelling of Y), any disruption in the tactical/operational phase may lead to a delay that cannot be absorbed by subsequent services.

For figure 11, representing the STN for boarding, a planning solution can be depicted in a similar fashion. Figure 13 below shows an example solution for the boarding company, allowing aircraft X to be boarded between t=45 and t=60, and aircraft Y to be boarded between t=99 and t=115.

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[21] In this example, it is assumed that the same vehicle and personnel will service aircraft X and Y in consecutive order. Moreover, X is located near Y, since gate A23 is at the same pier as gate A17 (see the original example description).
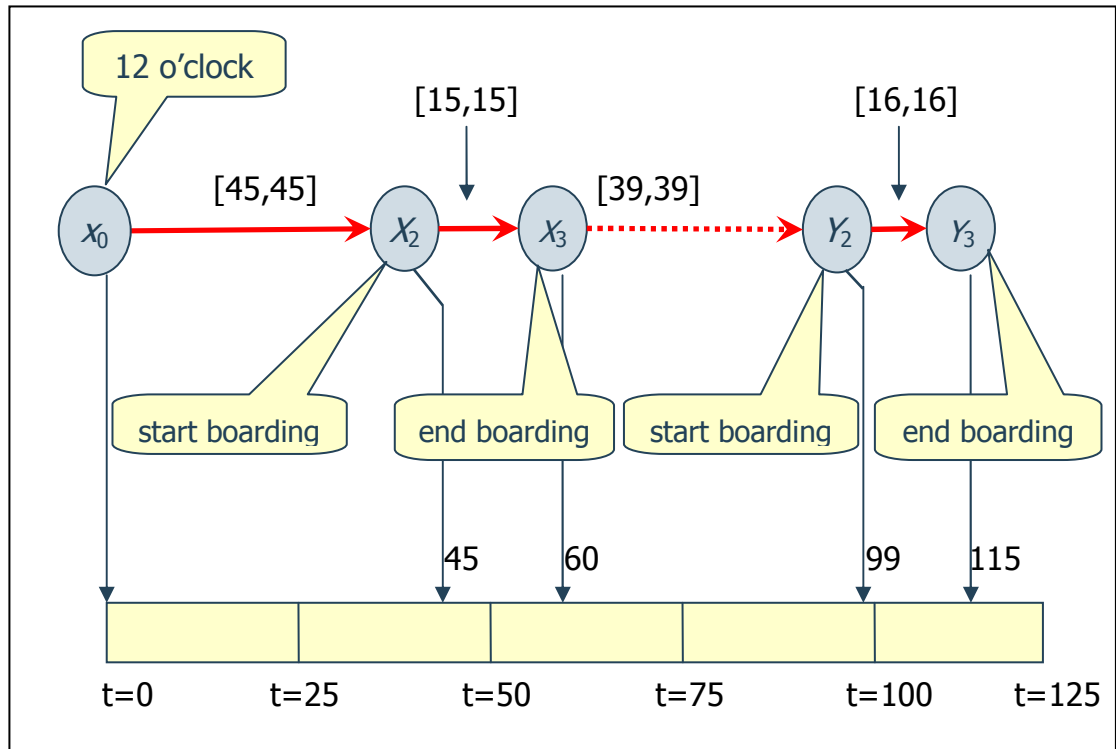
Figure 13: An example local planning for the "boarding" service

In figure 13, the dashed arrow indicates a minimum gap of 39 minutes separating the boarding of X and Y. This gap, which might be used by the boarding company to board another aircraft in between (depending on local constraints), is the result of two constraints: first, Y cannot start boarding before t=85 (see Figure 11), since this is in-block time (12:05 p.m.) plus the norm time (80 min.) for boarding for a MD11. Second, however, since the aircraft should take off at 14:10 p.m. (t=130) but the boarded passengers shouldn't have to wait longer than 15 minutes before take-off, boarding should finish not earlier than t=115. In figure 13, a solution is chosen which maximizes the time between the end of boarding and take-off of Y (e.g., to maximally absorb any possible delay). Additionally, the gap between the end of boarding of X and Y is maximized – for instance to allow another aircraft to be boarded in between. Finally, boarding of X is started as early as possible to be able to absorb any possible delays that might occur before or during boarding[22].

This concludes the discussion of our ground handling example. In the previous sections, a high-level STN has been constructed to represent the example domain, and a decoupling of this STN

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[22] Note that, for this reason, the boarding is planned to take place between t=45 and t=60: 15 minutes instead of the minimum of 5 minutes for a B737-300.

into two local STNs has been detailed. In this section, two example solutions have been presented to demonstrate the result of local planning given the decoupled STNs.

5   Conclusions and Future Work

In this document, the operational context for the Co-ordinated Airport through Extreme Decoupling (CAED) has been described. The first chapter sketched the CDM and TAM context of the project, as well as the overall turnaround process – the CAED application domain. In the second chapter, this turnaround process was further elaborated by describing the various ground handling processes to be performed during turnaround. Moreover, the relation between ground handling and stand planning has been addressed. Additionally, the importance of ground handling for punctuality and efficiency in airport operations has been emphasised as our starting point for further research.

In the third chapter, an outline has been presented for a general model of ground handling. This outline will be developed further in deliverable D3 of the project, describing a mature ground handling model. In chapter 3, the planning problem addressed has been described, as well as the actors, tasks, and resources that will be included in the model. Furthermore, the boundaries and limitations of the model have been drawn by explicating the underlying assumptions.

In the fourth chapter, finally, the model described in chapter 3 is given more contents. By means of an operational example, this chapter illustrated how the ground handling model can be applied in practice. The example was translated step by step into a Simple Temporal Network (STN) representation. This STN, in turn, was decoupled into local sub-networks – matching the perspective of the local ground handlers. Finally, a set of solutions to these decoupled networks has been presented.

This concludes the description of the operational domain of the CAED project. The turnaround process has been described in detail, as well as its relation to other airport processes. Furthermore, a direction has been sketched for further modelling of the turnaround process. A general methodology has been outlined to support the integration of local planning functions into an encompassing, total airport planning by means of extreme decoupling. Together with [D1], describing the theory behind decoupling and temporal networks, this document aims to pave the way for deliverable D3 of the project.

In this deliverable, the extreme decoupling methodology sketched here will be further elaborated. Deliverable D3 will provide a more mature turnaround model (representation), a detailed description of the decoupling process in steps (a methodology), and set of local solving strategies (algorithmic implementation). By means of this model, methodology and solving strategies, local service providers will be able to decouple their overall planning constraints

from the stand allocation plan, solve their planning problems locally, and merge their local plans to a guaranteed conflict-free stand and services plan. Moreover, if time permits, a simple prototype will be developed and described in D3. This prototype will be used to test the new planning concept against a small-scale, yet realistic scenario, demonstrating its benefits and possible drawbacks.

6 References

References are divided into document references and online references.

6.1 Document References

AAM ConOps   Eurocontrol, *Eurocontrol ATM Operation Concept - Concept of Operations for 2011*, volume 2, Ed. 1.0, May 2005

D1   Eurocontrol, CAED Deliverable D1, *Literature Survey on Temporal Decoupling,* March 2007

IATA   IATA, *Airport Handling Manual*, International Air Transport Association, 24th edition, 2004.

LEO   Pim van Leeuwen, *Requirements and Design Document for LEONARDO's collaborative decision making multi-agent system CDMMA*, Technical Report NLR-TR-2003-653, National Aerospace Laboratory NLR, January 2004.

Wu et al.   Cheng-Lung Wu, Robert E. Caves, 2000, Aircraft operational cost and turnaround efficiency at airports, *Journal of Air Transport Management*, vol 6, issue 4, pp 201-208.

Wu et al.   Cheng-Lung Wu, Robert E. Caves, 2004a, Modelling and Simulation of Aircraft Turnaround operations at Airports, *Transportation Planning and Technology*, vol 27, issue 1, pp 25-46.

Wu et al.   Cheng-Lung Wu, Robert E. Caves, 2004b, Modelling and Optimization of Aircraft Turnaround Time at Airports, *Transportation Planning and Technology*, vol 27, issue 1, pp 47-66.

6.2   Online references

AAM   Eurocontrol, Airport Airside Management project, Airport Operations Architecture Description Document. In the course of this project a number of Use Cases and Operational Scenarios have been developed to describe operations around stand allocation. Also, actors lists including e.g. the Stand Planner have been developed. Downloadable at:

http://www.eurocontrol.int/oca/gallery/content/public/docs/
OATA-P2-D4.2.7-04-52%20Airport%20Operations%20ADD.pdf

See page 13 for the 'Stand Planner' actor; page 18 for the 'Establish Stand Allocation Plan', page 20 for the 'Update Stand Allocation Plan'.

Boeing   Boeing website, Airplane Servicing Arrangements, downloadable at:

http://www.boeing.com/commercial/airports/acaps/737.pdf (Boeing 737)

http://www.boeing.com/commercial/airports/acaps/md11.pdf (MD11)

CDM Handbook   Eurocontrol, Airport CDM Guide, February 2003, downloadable at:

http://www.eurocontrol.int/airports/gallery/content/public/pdf/cdm_guide.pdf

G2G   Eurocontrol, Gate to Gate Programme (5th Framework, started in 2002). For more project information:

http://www.eurocontrol.int/eec/public/standard_page/SSP_gate_to_gate.html

TAM   Eurocontrol, Total Airport Management preliminary study, final report, November 2001, downloadable at:

http://www.eurocontrol.int/care-innov/gallery/content/public/docs/
studies2001/tam_finalreportr1.1.pdf

Appendix A Airplane Servicing Arrangements for the B737-300 and MD11

Source: [Boeing]. On the Boeing website, the airplane characteristics for a range of aircraft can be found. Section 5 of these documents yields the so-called 'Airplane Servicing Arrangements'.
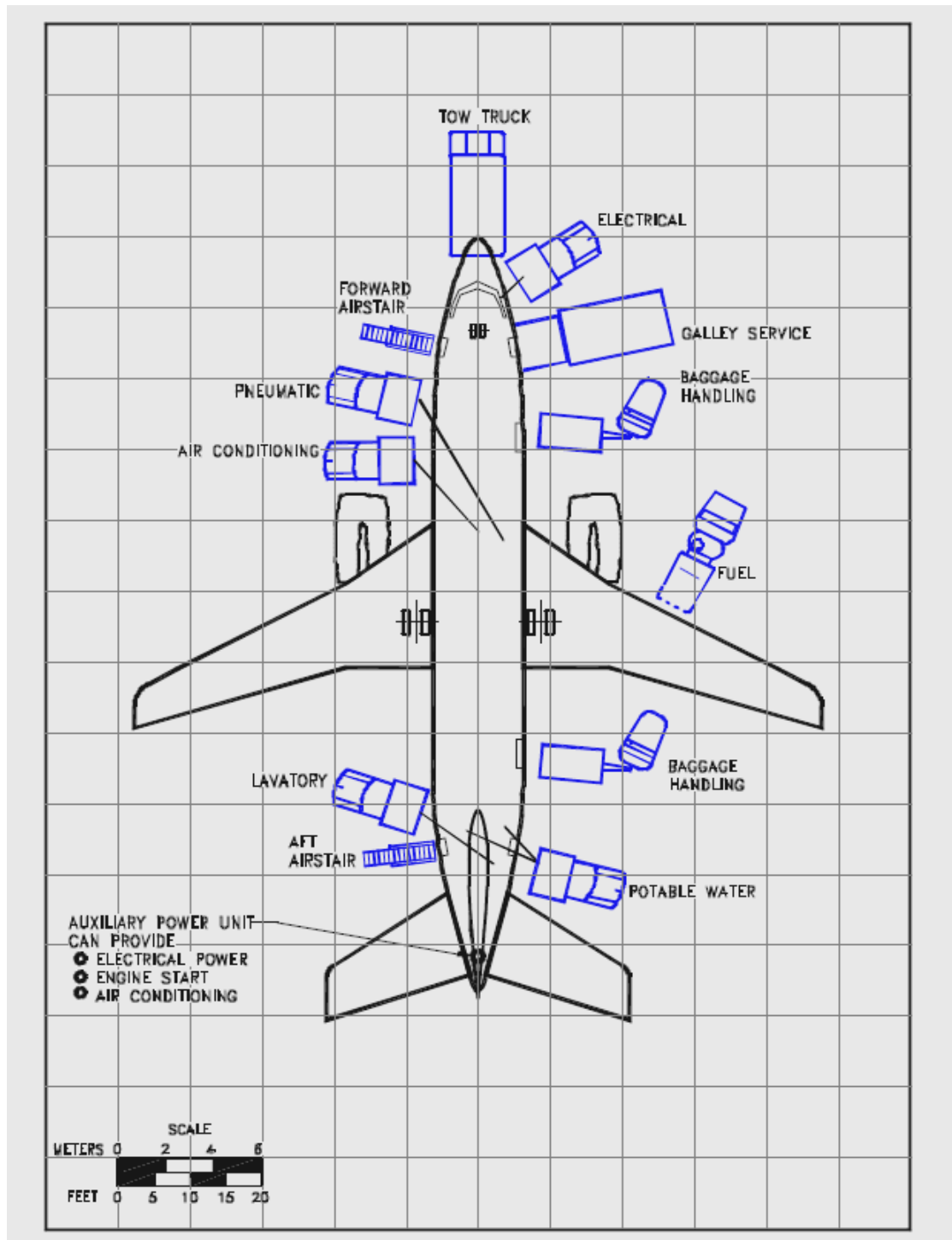

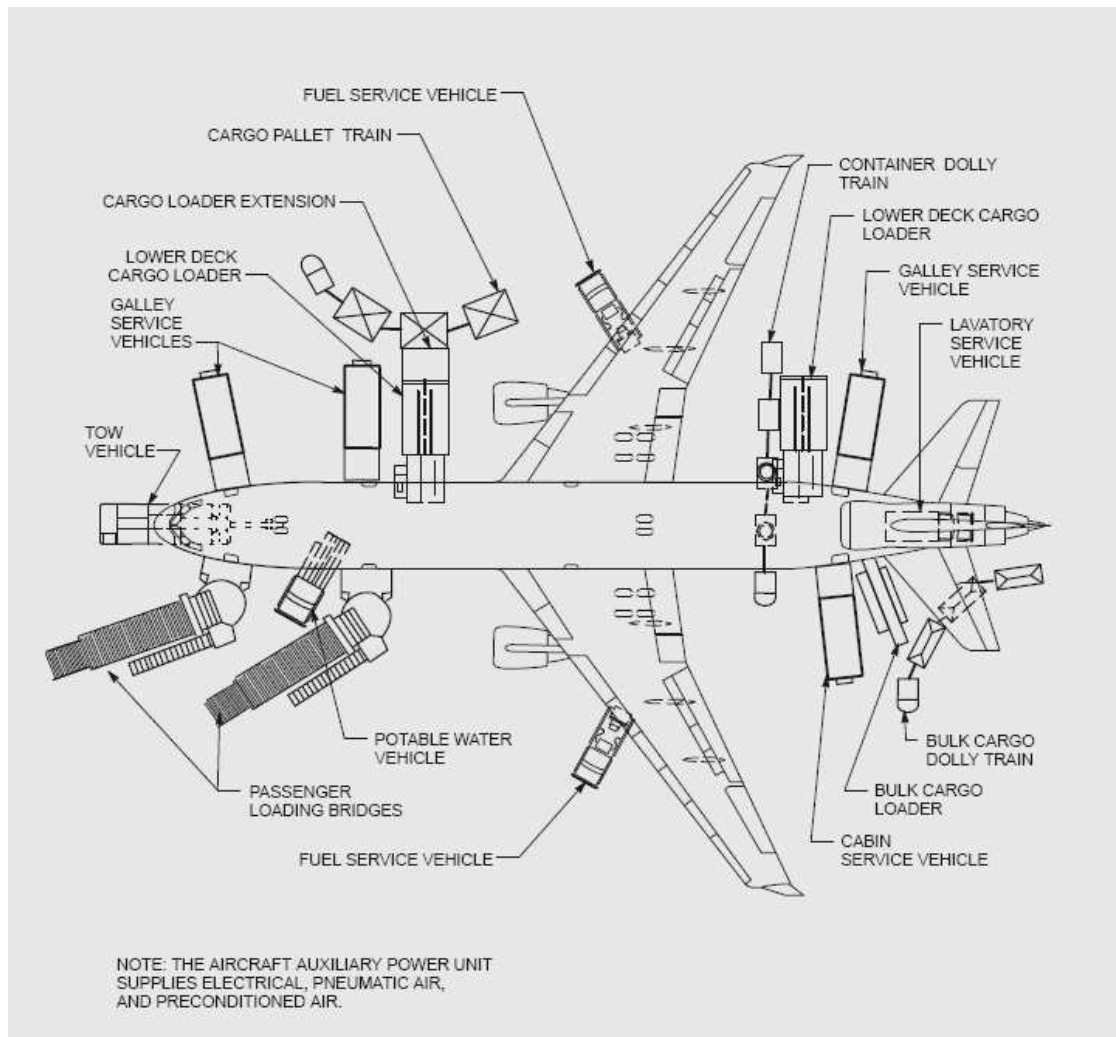*Figure 14: Airplane Servicing Arrangement for the B737-300.*

Figure 15: Airplane Servicing Arrangement for the MD11.

Appendix B   Airplane Terminal Operations for B737-300 and MD11

Source: [Boeing]. On the Boeing website, the airplane characteristics for a range of different aircraft can be found. Section 5 of these documents yields the so-called 'Airplane Servicing Arrangements'. Within this section, subsection 5.2 details the so-called Terminal Operations for the turnaround. There, the minimum service times and overall service schedule of the specified aircraft are given.
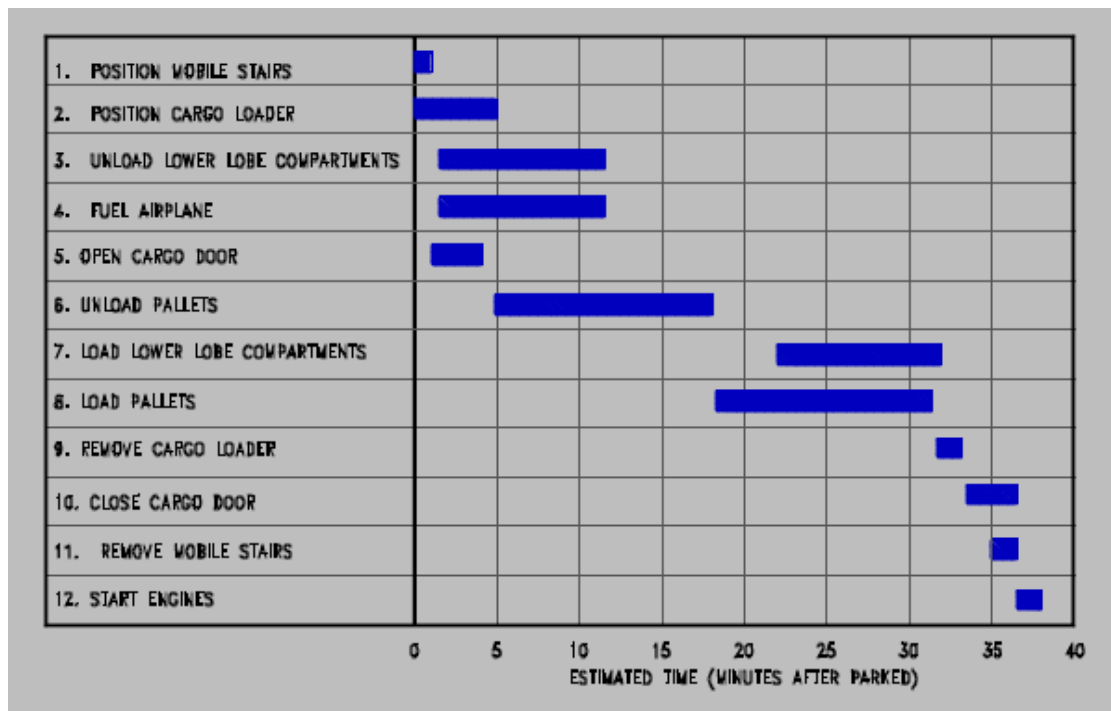

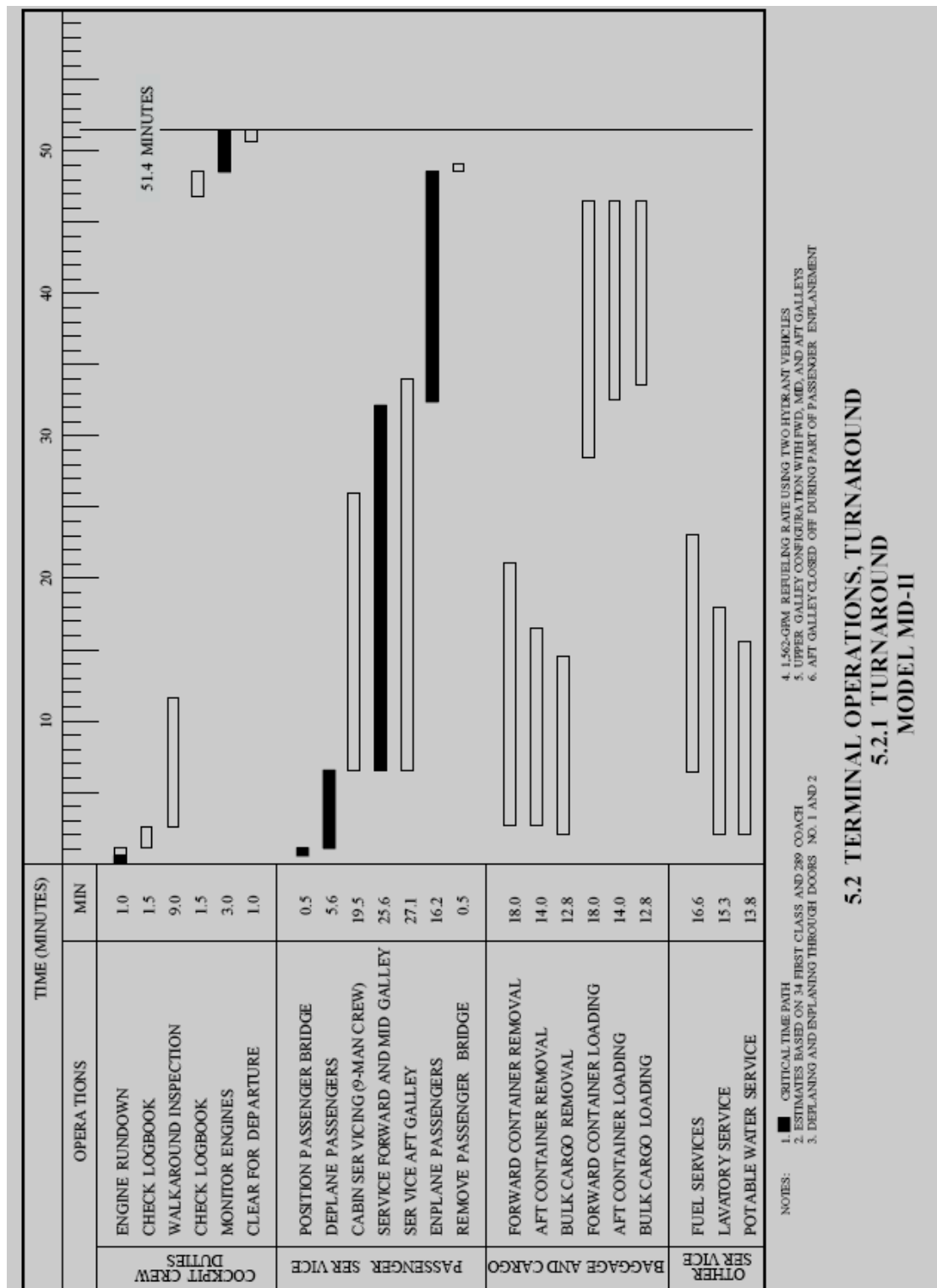*Figure 16: Terminal Operations for turnaround for the B737-300.*

Figure 17: Terminal Operations for turnaround for the MD11.