Airport Cargo Handling Operations after a Natural Disaster Event

Master of Science Thesis

Luka N. Van de Sype

TU Delft

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Luka N. Van de Sype

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	Dr. O. A. Sharpanskykh	TU Delft, Supervisor
	Ir. O. Stroosma	TU Delft, Examiner
	M. P. J. Vert	TU Delft, Examiner

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At the end of my studies in Aerospace Engineering, I was keen on finding a project that could add societal value. My supervisor, Alexei Sharpanskykh, introduced me to the topic of airport disaster management after a natural disaster.

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Luka Van de Sype
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List of Abbreviations

ATC Air Traffic Control

ATCO Air Traffic Controller

CHP Civilian Handling Personnel

EC Evacuation Coordinator

ESF Emergency Support Function(s)

FBO Fixed-Based Operator

GSE Ground Support Equipment

IATA International Air Transport Association

ICAO International Civil Aviation Organization

ICU Individual Cargo Unit

KPI Key Performance Indicator

LEMA Local Emergency Authorities

MAMD Menzies Aviation Managing Director

MAS Multiagent System

MHP Military Handling Personnel

MNCCC Multi-National Caribbean Coordination Cell

MOC Military Offloading Coordinator

MOVCON Movement Control

MST Mission Support Team

PAPI Precision Approach and Path Indicator

PI Performance Indicator

PJIA Princess Juliana International Airport

SA Situation Awareness

TAT Turn-Around Time

ToM Theory of Mind

UK United Kingdom

ULD Unit Load Device

UN United Nations

UNDAC United Nations Disaster Assessment and Coordination

UNOCHA United Nations Office for the Coordination of Humanitarian Affairs

USAR.NL Urban Search and Rescue

Introduction

Natural disasters happen every year and affect many lives. On average, each year these disaster claim the lives of 68,000 people and affect 218 million people [54]. During the response phase, after such a disaster event, people need to be evacuated and relief aid needs to go to these areas. Airports are important hubs for these operations, as there is a sudden increase in the capacity demand [22]. However, the cargo flow of the airport often forms a bottleneck in the humanitarian relief organisations [59]. Unfortunately, little research is done on airport operations under these circumstances [39]. The topic does become more popular, however there are hardly any formal models [25] [42].

An exception is another Master thesis, modelling the cargo handling and evacuation operations of Princess Juliana International Airport, on Saint Martin Island, after the hurricanes in 2017 [31]. Together with experts the bottlenecks in the case study and for similar cases were identified as lack of airport disaster plan, lack of resources for handling large aircraft and the arrival of unannounced flights [61].

The overall goal of this project was to research the identified bottlenecks by means of a formal model. The agent-based model of the Saint Martin case study of van Liere was used as the starting point.

In Part I, the research is presented in the form of a scientific paper. Part II contains the Literature Study performed, which includes a detailed description of the case study, research on coordination mechanisms and an investigation on modelling an airport. Part III provides additional information on the research. Section 1, presents an overview of van Liere's model. The calculations performed in the research and model are explained in Section 2. Additional results and graphs are given in Sections 3, 4, and 5.

I

Scientific Paper

Modelling and Analysis of Airport Cargo Handling Operations after a Natural Disaster Event with Incomplete Knowledge of Incoming Flights

Luka N. Van de Sype,*

Delft University of Technology, Delft, The Netherlands

Abstract

The severity of natural disasters is increasing every year, having an impact on many people's lives. During the response phase of disasters, airports are important hubs where relief aid arrives while people need to be evacuated out of there. However, the airport often forms a bottleneck in these relief operations, because of the sudden need for increased capacity. Limited research is done on the operational side of airport disaster management. Experts identify the main problems as lack of information on all incoming flights and the lack of resources. The goal of this research is to gain understanding of the effects of incomplete knowledge of incoming flights with different resource allocation strategies, on the performance of the cargo handling operations in an airport after a natural disaster event. To answer the research question, the following approach is taken: first, a better understanding of the existing model developed by van Liere for a relevant case study is provided. Secondly, a base model is created based on van Liere's model. In this model, realistic offloading strategies with different degrees of information uncertainty are implemented in the base model. The data required for the model and the generated outputs were validated by interviews with experts in the field. The model performance is measured by the average turn-around time, which can be split in offloading time, boarding time and the cumulative waiting times. The results show that the effects of one unannounced aircraft are negligible. However, all waiting times increase the more aircraft arrive unannounced.

1 Introduction

Many natural disasters happen every year. Between 1994 and 2013 it was recorded that a total of 6,873 natural disasters occurred worldwide [UNISDR and CRED, 2015]. At the same time, due to climate change, severity of these natural disasters is increasing every year [Berlemann and Steinhardt, 2017]. Many of those natural disasters already have a negative impact on many people's lives. Per year around 218 million people are affected by these disasters and on average 68,000 die [UNISDR and CRED, 2015]. Airports are important hubs during the response phase of a humanitarian crisis. However, during the response phase often a bottleneck arises in the ground handling operations of the airport as there is a sudden increase in incoming cargo while not all resources of the airport are available because of the disaster [Veatch and Goentzel, 2018, Feil, 2018]. At the same time, many people need to be evacuated out of the area, adding complexity to the operations. Lives can be saved if these ground handling operations are executed more efficiently.

Even though lives are at stake, according to [Polater, 2018], airport disaster management is still in its infancy in terms of academic research. The authors show that especially in the operational and business side of airport disaster management there is an academic gap. Disaster management is often a retrospective analysis of all the events. While research on airport disaster management is mainly focused on disasters that happen on the airport and not the airport as a hub for a larger disaster event. A related topic is disaster resilience, which is 'the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure' [UNISDR, 2005].

For the airport system, both disaster management and disaster resilience focus on strategies and interventions to build efficient emergency operations. However, there is a lack of studies that formally and systematically investigate the effects of resource allocation strategies on the aircraft handling operations performance, in particular in a context of limited information regarding incoming aircraft bringing support to the island's inhabitants. One of the few exceptions is van Liere's study [Liere, 2020], that simulates the cargo handling and passenger evacuation operations during the response phase on the Saint Martin Princess Juliana International Airport (PJIA) after the hurricanes in 2017 using the agent-based modelling paradigm.

*Msc Student, Air Transport and Operations, Faculty of Aerospace Engineering, Delft University of Technology

Agent-based modelling and simulation (ABMS) allows researchers to formally represent real-world complex systems using interacting agents, and investigate the systems' behaviours through scenarios that are computationally simulated. Agents are autonomous entities with complex believes (e.g.: goals, plans) that can make decisions based on their perceived information and act on their environment. ABMS also connect system local properties to system global properties, such that the actions of agents can be causally connected to the overall performance of the system. In particular, agents' coordination [Fines et al., 2020] and anticipation [Blok et al., 2018] of potential or effective disturbances can be modelled and investigated with ABMS. Airports are complex sociotechnical systems and the extensive use of ABMS in the literature to model airport operations have shown that is a suitable approach [Bouarfa et al., 2013, Blom and Sharpanskykh, 2015].

ABMS will be used in this study. Moreover, the model proposed in this work focuses on three problems: lack of information on incoming flights, lack of resources and lack of planning. As little research has been done on this topic, expert knowledge is essential for the model development. According to experts, in similar disaster relief there are generally three main reasons for delays: the arrival of unannounced flights, the airport not being equipped for handling large cargo aircraft and the preparation of airport management for such a disaster [Weeks, 2020]. These issues were also considered in van Liere's case study of Saint Martin island.

As the case study of Saint Martin addresses many general problems that occur during and after natural disasters, in particular related to lack of resources and information, this case will also be used in this research. van Liere's model simulates the cargo handling and passenger evacuation. This can be used to gain better understanding of the general bottlenecks that occur during airport cargo handling after a natural disaster event. This paper will focus on the offloading of civilian aircraft, as the airport focuses largely on civilian operations and the military, and civilian operations are often separated from each other. Furthermore, van Liere's study does not provide a detailed analysis of civilian operations.

The research objective is to gain understanding of the effects of incomplete knowledge of incoming flights, with different resource allocation strategies, on the performance of the cargo handling operations in an airport after a natural disaster event.

If we can formally analyse the scenario results then we can understand better what offloading coordinator decisions are the best. In order to fulfil the research objective, first the base model needs to be developed to realistically represent an airport after a natural disaster event. The main goal of the offloading coordinators need to be established, in order to know how the performance of cargo handling should be measured. Furthermore, it should be determined what resource allocation strategies are used for offloading civilian aircraft. Then, the influence of lack of information on incoming flights on the performance of the system can be analysed.

To answer these questions the steps of the methodologies are: first to gain the necessary background information for the research and understand the case study, in addition to understanding the existing model and its limits. This is done in Section 2. The second step is the development of the base model, based on the existing model. The changes to the existing model and the base model for this research are explained in Section 3. In Section 4 the base model is analysed and calibrated. The third step is to create and implement realistic scenarios with resource allocation strategies for offloading in order to reach the objective. These are more extensively explained in Section 5. In Section 6 the results of the experiments are given and in Section 7 those results are discussed. Lastly, Section 8 gives the conclusion of this research.

2 Background Information and Case Study

The context of airport disasters, and in particular the case of Saint Martin in 2017, are detailed in this section.

2.1 Airports and Disasters

A humanitarian disaster is *"an event or series of events that represents a critical threat to the health, safety, security, or well-being of a community or other large group of people, usually over a wider area."* [Jeong and Yeo, 2017]. This paper focuses on sudden onset natural disasters, there are *"triggered by a hazardous event that emerges quickly or unexpectedly."* [UN, 2020]. Examples of such a disaster is the Tsunami in Tonga in the beginning of 2022, or the hurricanes in Saint Martin in 2017.

Disaster management is mostly described in a cycle of four phases: mitigation, preparedness, response, and recovery [Lettieri et al., 2009] . This paper will focus on the response phase, which starts during or right after the disaster event. Reduction or elimination of the negative effects is the goal of this phase. It is in this phase when the airport forms a bottleneck as extensive relief aid needs to go to the impacted areas, but the means are not always present [Coppola, 2007, Berry, 2009]. Logistics is a large part of these humanitarian operations, and it has become a popular research field for the passed ten years. The *Humanitarian Supply Chain* however, is mostly looked at from an overall point of view and not only the airport is considered [Hanachi et al., 2014, Salvaldó et al., 2015].

To gain understanding of the general problems related to the airport during the response phase, an interview was held with an expert on airport disaster logistics. Delays were identified as one of the essential problems, and the main causes the expert identified for delays can be summarised as [Weeks, 2020]:

1. Scheduled flights are often not a problem, but the extra unscheduled flights cause a bottleneck, especially when the content of the cargo is unknown.

2. Island holiday destinations are mostly not equipped for handling large cargo aircraft, as normally most cargo comes in by ship or belly cargo.

3. Not all countries and airports have plans in case there is a disaster and part of the airport is destroyed. Moreover if there is one it is often not executed as it is specified.

2.2 Case Study: Saint Martin 2017

On September 6^{th} of 2017 a category 5, on the Saffir-Simpson scale, hurricane called Irma passed Saint Martin. This is the highest category on this scale. The hurricane reached wind speeds of almost 300 km/h [U.N.O.C.H.A, 2017]. There were 4 fatalities and 23 injuries and over 70$\%$ of the buildings on the islands were destroyed. This affected a lot of people and the total damage cost was estimated to be around 1.5 billion US Dollars [Cangialosi et al., 2018]. On September 8^{th} and September 18^{th}, two other hurricanes passed the Caribbeans called Jose and Maria respectively, they caused tropical storms at Saint Martin Island [Berg, 2018, Pasch et al., 2019].

On the first day after hurricane Irma, all efforts were put in making the airport operational again. There was a lot of destruction causing waiting times at the airport. The main issues were similar to the general problems identified by experts [Weeks, 2020]:

- There was no electricity, mobile connection, internet and civil air traffic control. Hence, there was no knowledge of incoming civilian aircraft and all communication was done face to face.

- Most buildings were destroyed, as well as equipment and aircraft. Meaning there was a lack of resources, equipment and personnel.

- As the airport management did not show up, there was a lack of overall coordination.

As the case study fits the general identified problems that occur during and after disasters, it makes it a suitable case study to investigate.

2.3 Case Study: van Liere's model

In this section a base model for Princess Juliana International Airport, abbreviated as PJIA model, is described based on a modified van Liere's model.

2.3.1 General Working of van Liere's Model

In van Liere's model, three different operations were considered: civilian offloading, military offloading, and evacuation operations.

The civilian offloading was organised by one central person who had the overview of all civilian resources, equipment and personnel. In this paper we call this person the offloading coordinator, abbreviated as OC. However, the OC often had no knowledge of incoming civilian flights due to the fact that the air traffic control tower was only working for military aircraft. So when an incoming aircraft arrived, the OC could see this out of the office window, which had a view of the whole tarmac, and would go to that aircraft to check its cargo content. Back at its office the OC would send the correct available equipment and personnel to the aircraft. In van Liere's model it was assumed that per type of cargo present in the aircraft only one set of minimal resources would be sent. A set of minimal resources consists of one civilian handling agent with correct ground support equipment (GSE) and one driver with tug and dollies or only the latter if it is a small aircraft. Which GSE the civilian handling agent used is dependent on the type of cargo.

Due to the absence of airport management, and as Saint Martin is part of the Kingdom of The Netherlands, the Dutch military took some functions upon them. For the military offloading operations there are two key players: the military offloading coordinator and the Movement Control (MOVCON). When ATC knew of an incoming military flight, they would tell the MOVCON and MOVCON would make an equipment reservation at the OC. The military offloading coordinator would steer its military handling personnel. It is assumed that the military offloading coordinator knew the content of incoming aircraft. For a large aircraft one military handling agent with tug and dollies is needed to assist the reserved civilian handling agent with high loader at the aircraft and one military handling agent with forklift truck at the terminal building. If it takes too long, combat offload is done. This is an cargo offloading method where the cargo is just pushed out of the aircraft onto the tarmac.

Lastly, for the evacuation operations the MOVCON would check when aircraft are ready for boarding and how many passengers (pax) it could take, it gives this information to the evacuation coordinator. The evacuation coordinator steers the marines who did passport control and escorting the pax to the aircraft.

A diagram of the workings of van Liere's model can be found in Supporting work Section 1.

2.3.2 Assumptions and Limitations

The main constraints of van Liere's model are the following:

First, there was no electricity and in the beginning of such operations gas is scarce [Weeks, 2020, Braam, 2020]. It is therefore assumed that all agents are walking, unless driving a ground support equipment (GSE). Also all communication was done face to face.

Second, at that time in Saint Martin, the military could use only one of the two highloaders as the safety barrier was in the way when going under the aircraft. For one of the highloaders the safety barrier was taken off [Liere, 2020].

In van Liere's model it is assumed that military highloader reservation needed to be done at least 30 minutes before arrival otherwise no reservation could be made. In that case combat offload would happen. This was implemented in the model as a combat offload actually happened in the case study. A combat offload can cause a lot of delay as it is more difficult to get the pallets from the ground onto a forklift truck than from the aircraft onto a highloader. From the interview with the PJIA MOVCON it appeared that the reservation system was more flexible in reality and the military could use the highloader when available, no matter the reservation time [Braam, 2020].

In van Liere's model, the OC knew, at all times, were all GSE and personnel where and which task they were performing. This is a strong assumption as in reality one agent cannot see and know everything, especially under such circumstances.

The offloading strategy of the offloading coordinator (OC) in van Liere's model is to send the minimum of resources to offload an aircraft. To serve a large aircraft with one type of cargo, and two cargo doors, the OC will only send one civilian handling agent with ground support equipment (GSE) and one driver with a tug with dollies. According to experts, this is not correct as in such a small airport the maximum available resources will be put to offload one aircraft [Weeks, 2020]. After interviewing all the experts it was identified that the main goal of the OC is to lower the turn-around time (TAT). Subsequently, in these meetings the resource allocation strategies, used in at PJIA and in general, were established as the following [Weeks, 2020, Braam, 2020, Bromet, 2020, Pilot, 2020]:

- Aircraft are offloaded in chronological order of arrival.
- Maximum set of resources are deployed to offload an aircraft.
- If it is known that another aircraft is coming in, this will be taken into account in order to allocate the resources.
- Even though the general rule is offloading in chronological order, priority also plays a role. This can be a humanitarian priority such as an aircraft with medical equipment. It can also be business priority such as a regular client, as contractors are still a business.

3 PJIA Model: The Base Model

In this paper a base model called Princess Juliana International Airport, or PJIA, model is described based on a modified van Liere's model. The changes in van Liere's model are mentioned in previous section. The specifications of the new model are explained in Section 3.2 and 3.3.

3.1 Base model

In the base model a new offloading strategy is implemented. As some of the constraints mentioned above are critical for the research, certain adaptations need to be made in van Liere's model in order to fit the model to the current research.

This research is focused on civilian offloading operations, therefore the other operations do not have to be modelled in detail.

The influence of military offloading on the civilian offloading operations is mainly through the use of equipment and the use of parking spots. Therefore, the military operations are simplified but still modelled as they influence the civilian operations. The main changes are that there is no reservation limit and no combat offload occurs in the model. As the latter can have a significant influence, it should be a conducted as a separate research. Furthermore the military handling agents are not modelled, but the military offloading coordinator will keep an military handling agent list, where each entry in the list represents the availability of one military handling agent. The same is done for the forklift trucks.

Evacuation operations always occurs after offloading is finished. The impact of the evacuation on the civilian offloading operations is the time when the tasks after evacuation can start, as well as the time when the parking spot is in use. For this reason the evacuation operations is only modelled as a time penalty. This means that there will be no evacuation coordinator agent, no marines and the MOVCON will not check the aircraft on the possibility of passenger evacuation.

Moreover, the OC knows of all the GSE, drivers and civilian handling agents if they are available or not, though the OC does not know exactly where they are or which subtask they are performing.

Lastly, van Liere's model was implemented in Netlogo. Netlogo has the advantage of having easy interface implementation. However, the downside is that it is hard to debug, everything is in one big file, running time is high and it is difficult to elaborate or use input from another programme. An alternative is Python MESA, with Python being a common and versatile language, which is a better choice when having to analyse difference scenarios and strategies.

As mentioned in Section 2.3.2, van Liere's model uses a minimal resource strategy. This is not a strategy that was used at the time, so this strategy will only be used to compare the new model with the existing one in Section 4.1. The base model will have a maximal available resource strategy, as this is a more correct representation of the case study. This means that for each available cargo door, one civilian handling agent with GSE can be sent and that each civilian handling agent can have up to two drivers with tug and dollies.

3.2 PJIA Model: Environment Specifications

With respect to van Liere's model, there are no changes to the model environment. The layout of the modelled airport environment can be found in Figure 1.

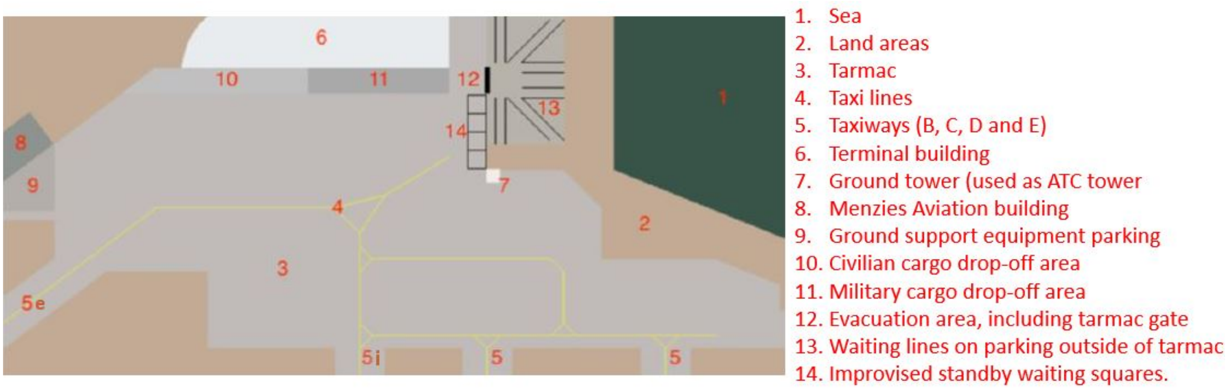

Figure 1: Airport environment in the existing and the PJIA Model.

Aircraft come in from taxiway 5i. They taxi over the taxi lines to a parking spot. The military parking spots are in the top part of the tarmac, the civilian parking spots are at the bottom part. The aircraft exit through the most left taxiway, taxiway 5e. The OC, civilian handling agents and drivers can be found in the Menzies Aviation building at 8. At 9 all the ground support equipment (GSE) can be found. The military offloading coordinator is standing on the tarmac in between 9 and 10. In front of the terminal building, 10 and 11 are cargo drop off areas for civilian and military cargo respectively. The MOVCON can most of the time be found in 11. The military air traffic control (ATC) agent can mostly be found at 7, the Ground Tower.
One step time in the model is equal to 5 seconds. The environment also includes objects, there are cargo objects and GSE objects.

3.2.1 Cargo Objects

There are three types of cargo objects, their starting point in the simulation is the same as the aircraft they come in with. After offloading, the cargo from civilian or military aircraft is put in the civilian or military drop off area respectively.

- One *LD3 Unit Load Device (ULD)* has an approximate weight of 1600 kg. They can be found in medium to large civilian aircraft.
- One *463L Master Pallet* has an approximate weight of 4500 kg. Only found in large military aircraft.
- One *Individual Cargo Unit (ICU)* has an approximate weight of 500 kg. This represents cargo in the form of boxes, packages and loose items. They can be found in all aircraft.

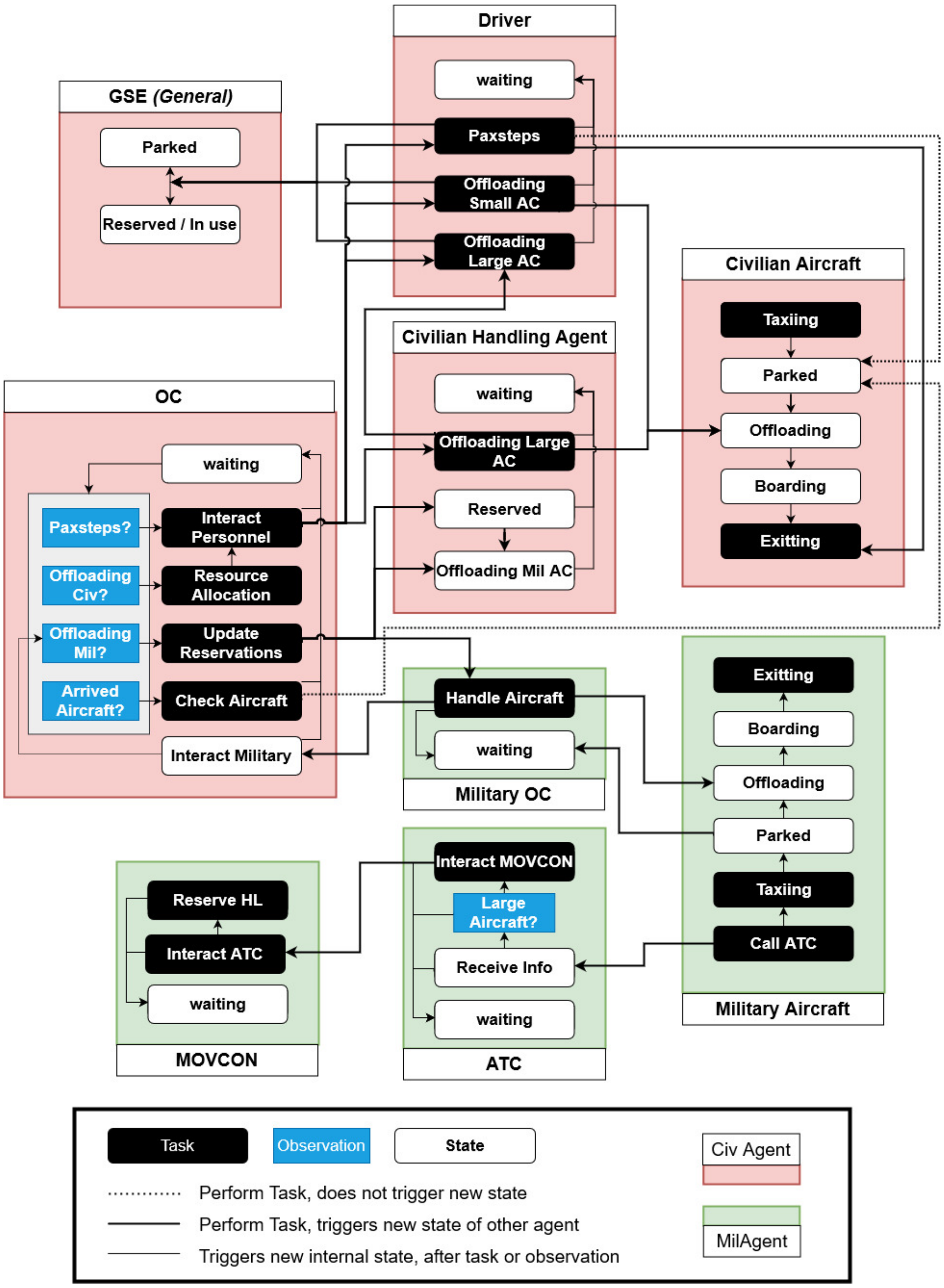

Figure 2: Overview of the workings and interactions of the agents in the PJIA Model.

3.2.2 Ground Support Equipment Objects

All GSE vehicles move with the maximum allowed speed on a tarmac: 30 km/h. The GSE can be found in the ground support equipment parking. There are four types in the model:

- *Pax steps* are used on large civilian aircraft to get passenger on the aircraft, as well as for the aircraft crew to come down or the OC to go up.
- *Tugs with dollies* are the carts that bring the cargo from the aircraft to the terminal building.
- *Belt loaders* are used to get ICU from large aircraft onto the dollies.
- *Highloaders* are used to get LD3 ULD and 463L Master Pallet onto the dollies. However, only one of the two highloaders can be used on military aircraft. In the model the highloader which was adapted for military use is the one with the highest model ID number.

In general, a GSE has two states: 'parked' or 'in use'. The change in state is caused by a driver or a civilian handling agent, using the GSE. In case the GSE is used for military purposes, the GSE also has a 'reserved' state. This state is induced by the OC.

3.3 PJIA Model: Agent Specifications

In this section the properties, states and interdependencies of all agents are explained. Figure 2 gives an overview of the model. As the equipment are objects, it was deemed not necessary to elaborate all of them in the figure. Therefore they are presented as general in the model overview.

3.3.1 Aircraft

Each aircraft crew and their aircraft was modelled as one agent. There are two types of aircraft agents: the Civilian Aircraft agent and the Military Aircraft agent. The arrival time of the agents is determined by the flight schedule, as explained in Section 5.1.

Call ATC Property This is only done by military aircraft. 15 minutes before arrival the aircraft calls the ATC and gives following information: its agent ID, arrival time, types of cargo, amount of cargo per type.

Taxiing Property The aircraft moves over the taxilines from its starting point to its destination point, using a predefined sequence of nodes.
ARRIVAL: Arrival starts at taxiway 5i and its destination point is a free parking spot closest to the OC building.
EXIT: Exit starts from the parking spot to the destination point at taxiway 5e.

As mentioned in Section 3.2, the military and civilian parking spots are different. As overflow measure in the model, it is possible for civilian aircraft to park on a military parking spot in case no civilian parking spots left. Vice versa for the military aircraft.

Parked Property The OC comes by and checks the aircraft content. The information the OC needs is: type of aircraft (large/small), types of cargo and amount of each cargo type. The OC leaves, the aircraft's status is changed to 'checked'. If the aircraft carry cargo, they wait for offloading.

Offloading Property If a large civilian aircraft carries cargo, then it will interact with the civilian handling agents. For a small civilian aircraft the interaction is directly with the driver. At each step, the civilian handling agent or driver is aware of the remaining cargo in the aircraft that they need to offload. They are only aware of another cargo type in the aircraft after they finish, as they can see if the aircraft is empty or not. If it is empty they communicate to the aircraft that offloading is finished.

For military aircraft a time penalty per kilograms of cargo is implemented. This timer starts at the moment when all the GSE and personnel are present at the aircraft.

Boarding Property When pax can be evacuated with the aircraft, a time penalty is implemented per pax. The calculations for all time penalties can be found in Supporting Work Section 2.

Table 1: Explanation of all times in the aircraft timeline.

Time	Explanation
T_{BP}	Before Parked Time
T_{BPS}	Before Paxsteps Ready Time
T_{BC}	Before Cargo Content is Checked Time
T_{BO}	Before Offloading Time
T_{Offl}	Offloading Time
T_{BB}	Before Boarding Time
T_{Board}	Boarding Time
T_{BPSR}	Before Paxsteps Removed Time
T_E	Exit Time

Decreasing the turn-around time (TAT) of civilian aircraft is the main goal of the OC, therefore an overview of the timeline of civilian aircraft is given in Figure 3. The TAT is defined from the moment the aircraft arrives until it exits the taxilane. In table 1, a brief explanation for all the time abbreviations is given. In this model the time between offloading and boarding is set to 12 minutes, which is equal to the average T_{BB} from van Liere's model. The T_E is negligible and will not be mentioned again. In this research these times are always mentioned in minutes.

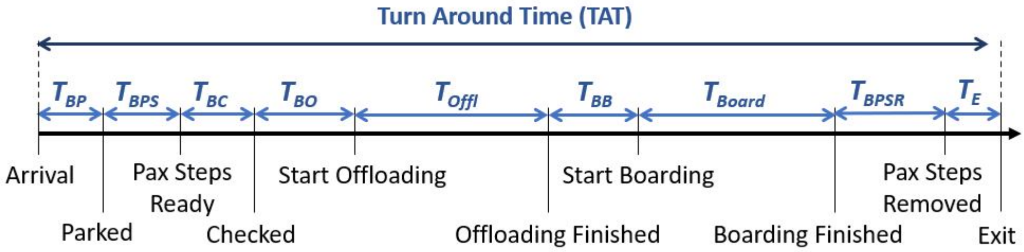

Figure 3: Timeline of the Turnaround process of a Civilian Aircraft.

3.3.2 Offloading Coordinator

At each step when the OC is waiting at its building, the OC does the first task that is necessary in the following order:

1. Send a driver to supply or retrieve pax steps;
2. Send personnel and GSE for civilian offloading;
3. Send/reserve personnel and GSE for military offloading;
4. Check a newly arrived aircraft.

In case no tasks need to be performed it stays in place and repeats the procedure in the next step.

Pax Steps Property
RETRIEVE: It is assumed that the OC has the knowledge when an aircraft is finished with boarding passengers or if no passengers are needed. It will send a free driver to retrieve the pax steps.
SUPPLY: It is assumed that the OC can see the whole tarmac from its office window, but is only aware of the civilian aircraft. When the OC sees a large civilian aircraft arriving, and one driver and one paxsteps are free, the OC will send the driver with paxsteps.

Arrange Offloading Property Resource allocation for offloading is performed chronologically with respect to arrival time. The OC tries to match the offloading needs for each aircraft with the available personnel and GSE. When a large aircraft has LD3 ULD it needs at least one civilian handling agent with a highloader and one driver with tug and dollies. When a large aircraft has ICU it needs at least one civilian handling agent with a belt loader and one driver with tug and dollies. When it concerns a small aircraft, then only one driver with tug and dollies is sent to offload the ICU. More explanation about the used function can be found in 5.2. The OC assigns the civilian handling agent and/or drivers with their corresponding tasks. After assigning the tasks to its personnel the OC resumes its *waiting* state.

Military Reservations Property After the MOVCON interacts with the OC and requests a highloader reservation, the OC checks the availability, as only one of the highloaders can be used on military aircraft. When available the OC changes the status of the highloader to 'reserved' and will not use it. When the military offloading coordinator interacts with the OC, the OC will do the same as with the highloader reservation. The OC got the time penalty time for the aircraft offloading and boarding from the military offloading coordinator. If all requested GSE are available it sets the timer.

Checking Aircraft Property When the OC sees a civilian aircraft arriving, it goes to the aircraft to check the cargo content. In case of a large aircraft it first sends a driver with pax steps ahead. After the OC interacts with the aircraft agent, the OC knows the cargo types and amount, if any. Afterwards, if another aircraft has arrived, the OC will check that aircraft, otherwise it will return to its office. It can check maximum three aircraft with cargo content in one go. This limit was set in van Liere's model to be realistic in what one person can remember.

3.3.3 Civilian Handling Agents

Civilian handling agents have two main properties, offloading large civilian aircraft and offloading large military aircraft. In between these two properties the civilian handling agent waits at the office building until instructions are given. The civilian handling agent can also be reserved, which is the same as waiting for the civilian handling agent, but instructions can only be given to offload a military aircraft. The walking speed of the civilian handling agent is 5 km/h and the driving speed, for driving belt loaders and highloaders, is 30 km/h.

Civilian Offloading Property First the civilian handling agent walks to its corresponding GSE, which is a highloader or a belt loader. Then it drives the GSE to its target aircraft together with its assigned driver, who drives the tug and dollies. The duration of the offloading, from one vehicle to another or to the drop off point, is determined by a time penalty. This time penalty takes the type of vehicle and the amount of cargo into account, the calculation can be found in Supporting Work Section 2. When the aircraft is empty, it will communicate this to the driver. Then the civilian handling agent will drive the GSE back to its parking spot. After parking the GSE the civilian handling agent will walk back to the office.

Military Offloading Property First the civilian handling agent walks to its corresponding GSE, which is the reserved highloader. Then it drives the highloader to the target aircraft. There it waits until the time penalty for the complete offloading of a military aircraft is finished. The time penalty is based on the amount of cargo (kg) and the offloading rate (kg/s), the calculation can be found in Supporting Work Section 2. Afterwards the civilian handling agent will drive the GSE back to its parking spot. After parking the GSE the civilian handling agent will walk back to the office.

3.3.4 Drivers

Drivers can have several tasks, namely: take pax steps to and from aircraft and offloading large and small aircraft. In between these tasks the driver waits at the office building until instructions are given. The walking speed of the driver is 5 km/h and the driving speed is 30 km/h.

Pax Steps Property First the driver walks to the pax steps, assuming the driver knows the location. Then the driver drives the pax steps to a destination point. This destination point is given by the OC during the task instruction. Next, the driver walks back to the office.

Offloading Large Aircraft Property The driver walks to the tug and dollies, it then drives the tug and dollies to the target aircraft. The driver waits while the civilian handling agent loads cargo on the dollies. When the dollies are filled the driver drives to the terminal building to drop the cargo. When it was the last batch of cargo, the civilian handling agent will have communicated this. As long as it is not communicated the driver drives back to the aircraft and the process is repeated. When the driver is finished it drives to the parking spot of the tug and dollies and walks back to the office.

Offloading Small Aircraft Property The driver walks to the tug and dollies and then drives the tug and dollies to the target aircraft. The driver is in contact with the aircraft and therefore always knows how much cargo is left in the aircraft. The driver loads the cargo on the dollies by itself. When the dollies are filled, the driver drives to the terminal building to drop the cargo. In case there is more cargo in the aircraft, the driver drives back to the aircraft and repeats the process. When finished, the driver drives to the parking spot of the tug and dollies and walks back to the office.

3.3.5 ATC

In this model the ATC agent has only one task: to give the information about incoming military flights to the MOVCON. As the ATC agent is a military agent, the agent walks with speed 6 km/h.

Find MOVCON Property After a military aircraft calls, see 'Call ATC Property' in Section 3.3.1, the ATC walks to the MOVCON and repeats the given information. The information includes: the aircraft agent ID, arrival time, types of cargo, amount of cargo of each type. Afterwards the ATC walks back to its tower.

It is assumed a second ATC agent stays in the tower to receive incoming calls, this agent is not modelled.

3.3.6 MOVCON

Movement Control is a military unit, in the case study the MOVCON oversees the airport. In this model the MOVCON is the connection between the ATC, the military offloading coordinator and the OC. The MOVCON is a military agent and therefore walks 6 km/h. The waiting spot of the MOVCON is the military cargo drop off area.

If the MOVCON gets information from the ATC about an incoming aircraft with 463L Master Pallets on board, the MOVCON agent needs to make a reservation, so it could use the civilian GSE and civilian handling agent on time of arrival of the aircraft.

Highloader Reservation Property The MOVCON walks to the OC office building. If the OC is not present or available the MOVCON waits. When the OC is present and available, the MOVCON interacts with the OC. The MOVCON gives the arrival time of the aircraft and asks for a highloader reservation. After the interaction the MOVCON walks back to its waiting spot.

3.3.7 Military Offloading Coordinator

The military offloading coordinator's waiting spot is near the military parking spots, in between the OC's office and the terminal building. The military offloading coordinator is a military agent and walks 6 km/h.

Handle Aircraft Property When a military aircraft is parked, the military offloading coordinator walks to the OC office building. If the OC is not present or available, the MOVCON waits. When the OC is present and available the military offloading coordinator interacts with the OC. The military offloading coordinator requests to borrow a tug with dollies. In case of a large military aircraft the military offloading coordinator also requests the civilian handling agent and highloader that have been reserved by the MOVCON. A military handling agent normally drives the requested tug and dollies as well as a forklift truck. However, the military handling agent and forklift trucks are not modelled. Instead, the military offloading coordinator also makes a reservation in its own military handling agent list and forklift truck list. These lists have the same length as the amount of military handling agents or forklift trucks, each entry is either a 0 (= available), an integer (= amount of steps that it is not available) or a string ('reserved'). It is assumed that the military offloading coordinator knows when the reserved GSE are available. At that step, the military offloading coordinator changes a 'reserved' entry in its military handling agents list and its forklift truck list to a timer entry. After the interaction the military offloading coordinator walks back to its waiting spot.

4 Analysis of the Base Model

In total six parameters needed to be calibrated in comparison to van Liere's model. The calibration was done in two steps, explained in Section 4.1 and Section 4.2. First, the PJIA model was calibrated before implementing the new resource allocation strategy, in order to compare and analyse the PJIA model with respect to van Liere's model. The second step is the calibration after the implementation, to guarantee a realistic output with respect to the expert' knowledge.

4.1 Analysis and Comparison to van Liere's Model

The PJIA model with the same resource allocation strategy as van Liere's model is analysed here to verify input parameters and the outputs of the model.

The main performance indicator is TAT, in Section 3.3.1 the division of the aircraft TAT is shown. The TAT can be split in three main parts: the offloading time, the boarding time and the cumulative waiting time. The parameters to be calibrated are offloading and boarding rates. Therefore only the results for TAT, offloading time and boarding time are shown here. In order to compare the proposed base model with van Liere's model, only the results for large aircraft with cargo and pax are given, as those were discussed in depth in the paper of van Liere.

Table 2: Firs step calibration results (in minutes) for large aircraft with cargo and evacuation, compared with values of experts and van Liere's model [Liere, 2020].

	Civilian			**Military**		
	TAT	Offloading	Boarding	TAT	Offloading	Boarding
Experts	*120-150*	*60*	*30*	*60-90*	*30*	*30*
van Liere model	125.2	57.5	30.6	79.8	32.5	30.2
PJIA model C0	129.7	53.9	**37.3**	**97.0**	**37.0**	**40.0**
PJIA model C3	119.1	52.5	**29.2**	**79.0**	**29.0**	**30.0**

In Table 2 the calibration results for the van Liere model and the proposed PJIA model are shown. Here, the same resource allocation strategy is used as in van Liere's model. C0 stands for 0 calibrated input parameters, with respect to van Liere's model. The results of PJIA model C0 should be the equal to or less than van Liere's model, since some steps are omitted from the new model. In the first row the expectation of experts is shown [Weeks, 2020, Braam, 2020, Pilot, 2020].

As can be seen in Table 2 for PJIA model C0, the average offloading time of the civilian aircraft is a bit lower than the experts' value, which is as expected. The civilian boarding time, as well as the military boarding time, are 37.3 and 40.0 minutes respectively, which is more than 20% higher than they should be. The reason for this increase was found to be the assumption of van Liere's boarding rate per pax. This was determined so it matched the experts' boarding time, it was calculated with an average of 30 pax per civilian flight and 60 pax per military flight. However, when looking at the flights in the schedule, the average for civilian flights is 38 pax and for military flights is 80 pax. The reason why the values in van Liere's model matched with the experts is not found. Nevertheless for the PJIA model, the new boarding rates are recalculated with the new actual average pax. These times were close to the experts' times. Calculations can be found in the Supporting Work Section 2. Table 3 presents all the parameters from van Liere's model and the changed parameters. As the boarding times of both the civilian and the military aircraft were too high, this also increased their respective TATs.

The military offloading time of 37.0 minutes is also too high. The cause for this difference was the combat offload by one of the seven large military aircraft, in van Liere's model one aircraft did a combat offload. This combat offload is included in the average offloading time of van Liere's model. As a combat offload is an exception and therefore not part of the general offloading time, the calibration of the military offloading time in van Liere's model was not correct. Especially as there are only seven large military aircraft with cargo and pax, one combat offload has a large influence. As a result a new military cargo offload rate was implemented. This calculation can be found in Supporting Work Section 2.

To summarise, three parameters are calibrated, the 463L cargo offloading rate from aircraft to GSE, the military boarding rate and the civilian boarding rate, as seen in Table 3. These three changes give the results on the last row of Table 2, where PJIA model C3 is given. The calibrated parameters have the desired effect, although the civilian TAT and offloading time are low. No immediate reason was found for this, except that some steps were eliminated. As a new offloading strategy will be implemented in the next part, the civilian TAT and offloading time will be analysed there.

Results for small aircraft can be found in Supporting Work Section 4.

Table 3: All the changed parameters for calibration of both steps.

	van Liere model (C0)	PJIA Model (C6)	Parameter change
Offloading			
463L (AC to GSE) [kg/s]	7.5	10	C1
ICU (general) [kg/s]	5	4.5	C4
ULD (AC to GSE) [kg/s]	7.1	5.7	C5
ULD (GSE to TB) [kg/s]	45	40	C6
Boarding			
Boarding military [s/pax]	30	22.5	C2
Boarding civilian [s/pax]	60	47	C3

4.2 Calibration of the Base Model

The model of van Liere was calibrated in order to fit the expert knowledge, as the actual boarding and offloading rates are not known. However van Liere's strategy was not realistic, making the calibrated parameters unrealistic as well. The base model starts off with 3 changed parameters compared to van Liere's model. From this point on the PJIA model uses the *'maximum available'* resource allocation strategy.

Table 4: Second step calibration results (in minutes) for large aircraft with cargo and evacuation, compared with values of experts and van Liere's model [Liere, 2020].

	Civilian			**Military**		
	TAT	Offloading	Boarding	TAT	Offloading	Boarding
Experts	*120-150*	*60*	*30*	*60-90*	*30*	*30*
PJIA model C3	**115.7**	**48.1**	29.2	79.0	29.0	30.0
PJIA model C6	**126.6**	**58.8**	29.0	79.0	29.0	30.0

In Table 4, it is shown that because of the new offloading strategy, the average offloading time is more than 4 minutes faster than before. This also causes the average TAT to drop. As these numbers are unexpected according to experts, some parameters need to be recalibrated. In Table 3 the changed parameters are shown: the offloading rate of ULD from aircraft to GSE, and from GSE to terminal building are lowered, the ICU offloading rate is also lowered. This gives the outputs of PJIA model C6, which are all in between the expected values according to experts.

van Liere's model and PJIA model have exactly the same amount of military aircraft, with exactly the same arrival time. In both models there are 7 large civilian aircraft. Their arrival times were randomised in van Liere's model, meaning that in each of the 120 schedules it is randomised as well. In van Liere's model there were on average 30 small aircraft with cargo and 15 small aircraft without, the schedules of the base model have on average 30.3 and 15.8 respectively.

5 Experiments

This section presents the methodology to answer the main research question, namely what is the effect of unannounced incoming flights on the performance of the system using different resource allocation strategies. In Section 5.1 the test cases will be explained. Afterwards, in Section 5.2, the implementation of the test cases in the model is elaborated.

5.1 Strategies and scenarios

In a situation after a natural disaster event most scheduled flights fly if possible. However, extra flights come in and their arrival is not always announced. According to experts, this causes a disruption in the planning [Weeks, 2020]. An overview of all test cases in this research are summarised in Table 5.

Table 5: Simulation test cases.

		Scenarios		
		A: Unknown Flight Schedule	B: Known Flight Schedule	C: Incomplete Flight Schedule
Strategies	1: Max available	Case 1A	Case 1B	Case 1C u1 Case 1C u7
Strategies	2: Max available + anticipation	Case 2A	Case 2B	Case 2C u1 Case 2C u7

5.1.1 Incoming Flight scenarios

In the case study the airport was not operational so most flights were not scheduled. However, the military got the information on incoming flights in the morning of each day, the civilian flights all arrived unannounced. According to experts, in general the civilian schedule is known, but there are always unannounced aircraft causing delays [Weeks, 2020]. To achieve a better understanding of the influence of incomplete knowledge of incoming flights, three different incoming civilian flight scenarios are created:

A: **Unknown Flight Schedule**: The flight schedule is not known by the OC: this is what happened in the case study considered in van Liere's model.

B: **Known Flight Schedule**: The OC has full knowledge of the incoming civilian flight schedule. This scenario is used to compare the case with complete information with cases with incomplete information about the flight schedule.

C: **Incomplete Flight Schedule**: The OC has access to the incoming civilian flight schedule, but unannounced aircraft will come in. Implementation is done by making some large aircraft that are known in the second scenario unknown. This scenario is implemented to analyse how unannounced flights can disrupt the overall system.

In Table 5 it can be seen that for scenario C there are two test cases, *u1* and *u7*. This stands for one unannounced large civilian aircraft and seven unannounced large civilian aircraft respectively. There are only seven large civilian aircraft per schedule in the system, meaning the first is chosen to test the effects of one unannounced aircraft on the performance of the system and the other to test the effects when all large aircraft come in unannounced.

To be able to compare all the experiments, the same schedules should be compared. In van Liere's model the military flight schedule was fixed, this schedule is maintained. The civilian aircraft came in randomly, when there were less than 4 civilian aircraft on the tarmac, a new aircraft came in. Size and content of aircraft was randomised as well. As the exact schedule of the case study is not known, one schedule is not sufficient to perform the research. Therefore the base model was run in the same way as the van Liere model, for 120 times. With 120 schedules the coefficient of variation for the TAT, offloading time and boarding time were constant. The graphs can be found in Supporting Work Section 3. The incoming flight schedule of this run is kept as a base, all other test cases were executed with the same 120 schedules.

5.1.2 Resource Allocation Strategies

To test these scenarios, the model needs realistic offloading strategies. In Section 2.3.2, the realistic offloading, or resource allocation, strategies, as established by experts, are given. In the base model, chronological offloading and maximum available resources are already implemented. Having knowledge of the schedule is not used in this strategy, thus to make the model more realistic and able to react to unexpected circumstances a cognitive function needs to be implemented in the OC agent. This cognitive function needs to make the OC agent able to use the information at hand to make a prediction and based on that prediction a decision on resource distribution. As there was no electricity and thus no computers, all calculations in the model should be reasonable for a human to perform manually and quickly. The resource allocation strategies are summarised as:

1: **Maximal available**: One civilian handling agent with GSE and one or two driver(s) with a tug with dollies per aircraft, per cargo door. The amount that is sent depends on the amount that is available at that time step. Even if there are two cargo doors, only one civilian handling agent with GSE can be sent.

2: **Maximal set available + anticipation**: Is the same as the previous, only now the OC knows the average length of a task and can use that information to estimate when personnel and GSE will be free, as well as to take the needs for the next aircraft into account.

Table 6: Resource sets for each cargo type, for each aircraft type and strategy.

Cargo Type	*AC Type*	*Strategy*	Civilian handling agent	Highloader	Belt loader	Driver + Tug and dollies
ULD	*Civ Large*	*1*	1	1	-	1
	Civ Large	*2*	1	1	-	1 or 2
ICU	*Civ Large*	*1*	1	-	1	1
	Civ Large	*2*	1	-	1	1 or 2
	Civ Small	*1 & 2*	-	-	-	1
463L	*Mil Large*	*1 & 2*	1	1	-	-

In Table 6 the amount that can be sent per cargo type, aircraft type and strategy is shown.

5.2 Implementation of Strategy 2

In this section, the properties and functions that change for strategy 2 and scenario B and C, with respect to the base model, are explained.

Algorithm 1 Generate Best Option

```
/* RA_function returns Option Set containing the Amount Assigned, Estimated ULD and ICU Offloading Step, and the
   step where offloading can start:{AMA, est_ULD, est_ICU, start_step}, for args see Table 8              */
Function: RA_function(args):
  return Option Set

/*                         Start of algorithm                                                          */
Algorithm: Generate Best Option
   // list of estimated resources, ID of aircraft A, ID of aircraft B
Input: est_rss, A_ID, B_ID
Output: Best Option
/* Combination of arguments of the RA_function(), see Table 8                                          */
foreach Possible Argument Combination do
    Option Set A ← RA_function()
    // update the list of estimated resources to include Option Set A:
    est_rss ← rss_update(est_rss, Option Set A)
    // generate Option Set B with new est_rss:
    Option Set B ← RA_function()
    // maximum of the estimated ULD and ICU offloading finish steps of Option Set A and B:
    Latest End Time(Option Set A) ← maximum(est_ULD of A, est_ICU of A, est_ULD of B, est_ICU of B)
    // aircraft should not wait longer than max start time:
    if Start Time of Option Set A > Maximum Start Time of Option Set A then
        Latest End Time(Option Set A) += 100000
Best Option ← Option Set A with earliest Latest End Time
```

For small aircraft there is only one option for the resource allocation. Hence, nothing will change for strategy 2. For large aircraft, a function is implemented to find the best resource allocation plan, in terms of total TAT, for aircraft A being serviced, taking the next aircraft B into account.

It is important to note that the OC only goes into the *'resource_ allocation'* state, when there are enough resources to start offloading at least one of the cargo types of aircraft A.

In Algorithm 1, the algorithm finding the best resource allocation option is shown. The function `RA_function()` in the algorithm is given to indicate either the `RA_available()` function or the `RA_ahead()` function. The first is used to determine the maximum *Option Set* for the current time step, while the second is used to determine the minimum or maximum *Option Set* and establish when these *Option Sets* are possible. The output for both functions is the same, however the input slightly changes, as can be seen in Table 7.

This function uses the `RA_available()` of strategy 1, as well the `RA_ahead()` function, which is used to determine future availability. Both the `RA_available()` and `RA_ahead()` return the *Option Set* containing the following:

- *AMA*: Amount Assigned
- *est_ ULD*: Estimated ULD offloading finish step
- *est_ ICU*: Estimated ICU offloading finish step
- *start_ step*: (Estimated) step when offloading can/will start

Table 7: Elaboration on the RA_functions: RA_available() and RA_ahead(), with a brief explanation, return and input.

`RA_available()`	
What:	Maximum Option Set for available resources
Return:	*Options Set* = {*AMA, est_ ULD, est_ICU, start_ step*}
Input:	*free_ rss*: Free resources list *X_ ID*: ID of aircraft X

`RA_ahead()`	
What:	Minimum and/or maximum Option Set for one or both cargo types
Return:	*Options Set* = {*AMA, est_ ULD, est_ICU, start_ step*}
Input	*est_ rss*: resources estimation list *X_ ID*: ID of aircraft X *'ULD', 'ICU', 'All'*: choose which cargo type *'Max', 'Min', 'Best'*: choose which Option Set

The *Best Option* algorithm requires the list of estimated resources as input. This list contains each resource and the estimated timestep when the task is finished. In this list a distinction is made between available or free resources and unavailable resources. For the unavailable resources, the OC knows the estimated timestep when that resource is free. Here, the estimations for each task are the average times the resources are busy with a certain task, taken from case 1A. For the offloading times the OC has a different estimation for each cargo type, per amount of cargo and per amount of drivers. The use of two drivers can reduce the offloading time between 11-13% for ULD cargo and 32-35% for ICU cargo. The range is dependent on the amount of cargo. An overview of these times is given in Table 9. Furthermore, the aircraft IDs of the two first aircraft to be offloaded are given. The IDs are linked to the internal knowledge the OC has about that aircraft. Finally, the algorithm outputs the best option, which is then used to determine the next state and/or task of the OC. If the best option has a *start_ step* equal to the current timestep, the OC's new state is *'interacting_ personnel'*, else the OC sets its state to *'waiting'*.

There are two sets of possible `RA_function()` combinations for aircraft A and B. These combinations are given in Table 8. When the minimum set of resources for aircraft A cannot be reached at the current time step, it means that there are enough resources for only one cargo type to be offloaded. In that case, the option set for aircraft B is equal to the option set for aircraft A, but with the other cargo type. For example, the first option set that will be generated uses for *Option Set A*, aircraft A with only ULD cargo. For *Option Set B*, it is aircraft A with ICU cargo. In case the minimum set of resources for aircraft A can be reached at that time step, the minimum, the maximum, and the maximum available *Option Sets* are evaluated.

Table 8: All resource allocation function combinations between Option Set A and Option Set B.

	Set i	**Option Set A**	**Option Set B**
Time_min_A >current step	*1:*	RA_ahead(A_ID, est_rss, ULD, min)	RA_ahead(A_ID, est_rss, ICU, Best)
	2:	RA_ahead(A_ID, est_rss, ULD, max)	RA_ahead(A_ID, est_rss, ICU, Best)
	3:	RA_ahead(A_ID, est_rss, ICU, min)	RA_ahead(A_ID, est_rss, ULD, Best)
	4:	RA_ahead(A_ID, est_rss, ICU, min)	RA_ahead(A_ID, est_rss, ULD, Best)
Time_min_A <= current step	*1:*	RA_ahead(A_ID, est_rss, All, min)	RA_ahead(B_ID, est_rss, All, Best)
	2:	RA_ahead(A_ID, est_rss, All, max)	RA_ahead(B_ID, est_rss, All, Best)
	3:	RA_available(A_ID, free_rss)	RA_ahead(B_ID, est_rss, All, Best)

Table 9: Average offloading times in minutes per cargo type, per amount of cargo and per amount of drivers.

	Cargo Amount	15000 kg	18000 kg	20000 kg
ULD	1 driver	52	61	70
	2 drivers	46	54	61
	Cargo Amount	5000 kg	6000 kg	8000 kg
ICU	1 driver	35	37	54
	2 drivers	21	25	33

6 Results

In this section the results of the test cases are presented. The main results are considered in Section 6.1. In Section 6.2 the results of the test cases with different Arrival Time Interval Factors (ATIF) are specified.

Table 10: The average TAT and offloading time, including standard deviation, for large civilian aircraft per case.

			Scenarios			
			A	B	C u1	C u7
Strategies	1	TAT	130.4 ± 5.6	110.8 ± 4.8	111.8 ± 4.7	121.4 ± 5.2
		Offl	60.0 ± 3.9	59.4 ± 3.8	59 ± 3.7	59 ± 3.9
	2	TAT	128.7 ± 5.9	110.3 ± 4.8	111.2 ± 4.7	120.5 ± 5.4
		Offl	58.2 ± 3.7	58.2 ± 3.6	57.8 ± 3.7	57.9 ± 3.7

6.1 Comparison of Strategies and Scenarios

The average TAT and offloading time per test case are presented in Table 10. The average offloading times do not vary significantly per test case, but the average TAT changes per scenario. The average boarding time is the same for all cases, namely 29.1 minutes with a standard deviation of 1.1 minute.

The Cliff's-delta test is a non-parametric test to test the effect size of two datasets. If the effect size is large it is very likely that a datapoint of set 1 is smaller than a datapoint of set 2. The thresholds for each magnitude used in this research (negligible, small, medium, large) are defined by [Hess and Kromrey, 2004]. As the input of all test cases is the same, meaning the flight schedule and agents, but the strategy or scenario is different, this test can also be used to see if one test case performs differently than another.

Table 11: Compare results per scenario with cliff's-delta test (N= negligible)

Compare	**TAT**	$\mathbf{T}_{BPS}$	$\mathbf{T}_{BC}$	$\mathbf{T}_{BO}$	$\mathbf{T}_{Offl}$	$\mathbf{T}_{Board}$	$\mathbf{T}_{BPSR}$
1A vs. 1B	**Large**	Large	Large	Large	N	N	Medium
1B vs. 1C u1	**N**	N	N	N	N	N	N
1C u1 vs. 1C u7	**Medium**	Large	Large	Large	N	N	N
1C u7 vs. 1A	**Small**	Medium	Small	Small	N	N	Medium
2A vs. 2B	**Large**	Large	Large	Large	N	N	Medium
2B vs. 2C u1	**N**	N	N	N	N	N	N
2C u1 vs. 2C u7	**Small**	Large	Large	Large	N	N	N
2C u7 vs. 2A	**Small**	Medium	Small	Small	N	N	Medium

The two strategies were compared for each scenario using the Cliff's-delta test. According to that test, the differences are all negligible. When comparing the scenarios for each strategy, see Table 11, small to large differences can be detected. One unannounced aircraft does not influence the performance of the system in

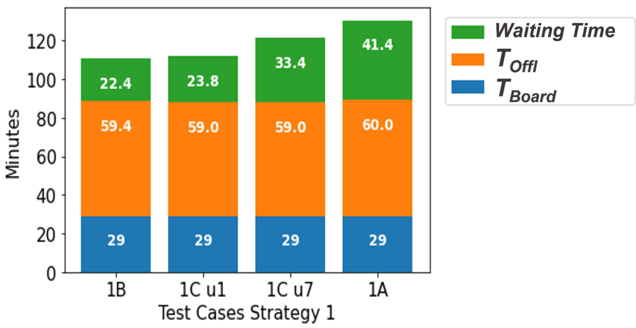

Figure 4: Distribution of the turn around time of large civilian aircraft for all test cases of strategy 1 in order of decreasing knowledge.

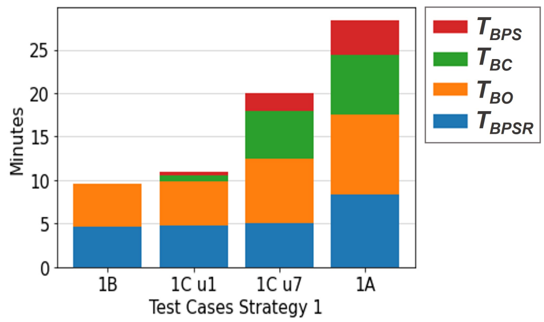

Figure 5: Distribution of the waiting times of large civilian aircraft for all test cases of strategy 1 in order of decreasing knowledge.

either of the strategies, whereas seven unannounced aircraft do make a difference. This difference in TAT is mainly due to the change in waiting times as the differences in offloading and boarding times are all negligible. This is also shown in Figure 4, which shows the distribution of the TAT for strategy 1 per scenario in order of decreasing available knowledge. From this figure it is clear that as expected, the boarding times, that are computed as a time penalty, do not change. Furthermore, the offloading times barely vary per test case. Only the total waiting times increase with decreasing available information.

Figure 5 presents the different waiting times. T_{BPSR} does not vary significantly, unless the flight schedule is fully unknown. The T_{BO} increases slightly with less available information. When the schedule is known, the cargo content does not need to be checked, hence the T_{BC} increases with increasing unannounced flights. Interestingly, scenario A still has higher T_{BC} even though there are only seven large civilian aircraft for each run. Next to that, the T_{BPS} also increases with decreasing knowledge. The graphs for strategy 2 can be found in Supporting Work Section 5.

From these results one can see that the offloading times do not change, regardless of the strategy or scenario. Additionally, the overall difference between strategies is negligible. This might be because the resources are always sufficient to serve the demand. The arrival time interval, representing the demand for resources, will be changed to investigate this phenomenon further.

6.2 Effects of Change in Arrival Time Interval

To be able to compare the experiments with a change in arrival time interval, all schedules were run with an Arrival Time Interval Factor (ATIF), which modifies the arrival times.

In Table 13 an overview is given of all the average TAT and Offloading times for all cases with four different ATIFs: 1.2, 1.0, 0.8, 0.6. An increment and decrement of 0.2 is chosen in order to systematically observe an effect on the system's performance. Note that factor 1.0 is the original arrival time interval.

Comparing the strategies, the TAT and T_{Offl} stay the same. There is a larger difference between no knowledge of incoming aircraft and seven unannounced aircraft, in comparison to ATIF 1.

Moreover, it can be seen in Table 13 that, as expected, both the TAT and offloading time increase with decreasing ATIF. The difference between strategy 1 and strategy 2 is still negligible, which is confirmed by the Cliff's-delta test. Even though the offloading times increase with smaller ATIF, this increase is not as substantial as the increase of the TATs. This suggests that it is again mainly the waiting times that influence the increase in TATs. Table 13 also shows that the standard deviation increases with decreasing interval.

Table 12: Cliff's deltas for the TAT and offloading time for ATIF 0.6 and ATIF 1.2, when comparing strategies.

	delta TATs		delta T_{Offl}	
	ATIF 0.6	ATIF 1.2	ATIF 0.6	ATIF 1.2
1A vs. 2A	0.004	0.056	0.12	0.018
1B vs. 2B	-0.026	0.042	0.09	0.007
1C u1 vs. 2C u1	-0.016	0.045	0.08	0.027
1C u7 vs. 2C u7	0.01	0.047	0.093	0.04

In Table 12, the deltas for the TAT and T_{Offl}, produced by the Cliff's-delta test for ATIF 0.6 and ATIF 1.2 which compare the strategies are shown. Even though the values in the figure are all considered negligible, as they are below 0.147, there is a clear increase seen in the deltas of the offloading time.

Table 13: Overview of average TAT and Offloading times per ATIF for all cases.

ATIF	TAT		Offloading		TAT		Offloading	
	Case 1A				Case 2A			
1.2	125.3	± 5.2	59.2	± 3.8	123.6	± 5.6	57.1	± 3.7
1	130.4	± 5.6	60.0	± 3.9	128.7	± 5.9	58.2	± 3.7
0.8	140.4	± 8.2	62.4	± 5.6	139.7	± 7.3	61.1	± 4.6
0.6	162.1	± 11.2	65.0	± 5.1	161.6	± 13.3	64.8	± 6.3
	Case 1B				Case 2B			
1.2	109.4	± 4.7	58.3	± 3.7	108.7	± 4.7	57.0	± 3.6
1	110.8	± 4.8	59.4	± 3.8	110.3	± 4.8	58.2	± 3.6
0.8	113.2	± 5.4	60.6	± 4.0	113.5	± 5.4	59.5	± 4.0
0.6	120.1	± 6.8	62.9	± 4.6	121.0	± 6.5	62.8	± 4.6
	Case 1C u1				Case 2C u1			
1.2	110.3	± 4.6	58.1	± 3.8	109.6	± 4.9	57.0	± 3.8
1	111.8	± 4.7	59.0	± 3.7	111.2	± 4.7	57.8	± 3.7
0.8	114.2	± 5.1	60.1	± 4.1	114.0	± 5.3	59.1	± 4.0
0.6	121.3	± 6.9	62.9	± 4.6	121.8	± 6.4	62.4	± 4.3
	Case 1C u7				Case 2C u7			
1.2	119.2	± 4.7	58.5	± 3.6	118.1	± 4.8	57.1	± 3.8
1	121.4	± 5.2	59.0	± 3.9	120.5	± 5.4	57.9	± 3.7
0.8	125.5	± 6.0	60.6	± 3.9	124.8	± 6.3	59.3	± 4.1
0.6	134.4	± 8.2	62.6	± 4.7	134.5	± 8.6	62.0	± 4.9

7 Discussion

7.1 Strategy 1

For each strategy, in all test cases the offloading time stays more or less the same. In strategy 1, a factor that could influence a change in offloading time is that the OC does not need to check cargo content. Hence, offloading can start earlier. Comparing the two most extreme cases, scenario A and B, the average time difference for the start of offloading is 18 minutes. This does not mean that at that point in time more resources are available. This can also be seen in Figure 6, which represents a timeline with three incoming flights. Each aircraft's TAT for scenario A and scenario B are shown, as well as their offloading time. When the offloading of aircraft A is finished, the resources are available for aircraft B. On one hand, in scenario B, the first aircraft has just departed when the second aircraft arrives. The resources are most likely available immediately. On the other hand, in scenario A, the first aircraft has not departed while the second aircraft arrives. The offloading of aircraft A has been finished, meaning that the resources are probably available to offload the second aircraft. However, first the second aircraft still needs pax steps and its content needs to be checked. For the first task, a driver is needed. This takes a longer time as the first aircraft also needs a driver to remove its pax steps. This also contributes to the increase in T_{BPS}. For the second and third aircraft, it can be seen that even though the TAT is shorter, the time offloading starts only slightly differs. For the second and third aircraft it can be seen that for scenario B the TAT is shorter. As the offloading can start earlier it is also finished earlier. Even though the second aircraft is finished earlier with offloading, this will not make a difference for the third aircraft, as it can start sooner with offloading as well.

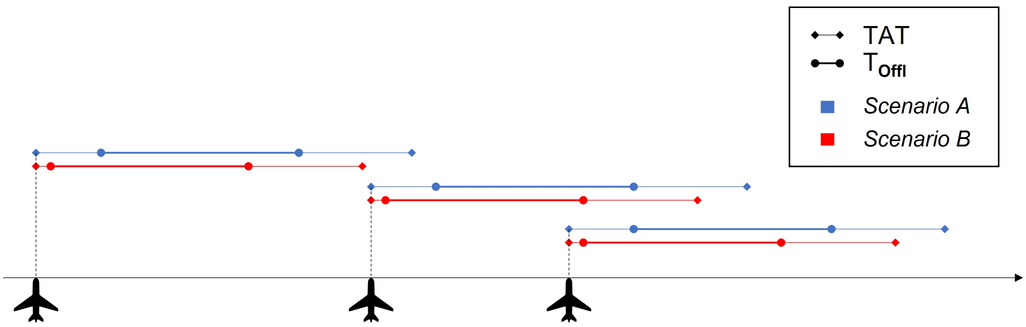

Figure 6: Aircraft TAT and offloading time influence.

7.2 Strategy 2

In strategy 2, the OC can make a resource allocation decision for aircraft A while taking the needs for resources for aircraft B into account. This means that even though there are enough resources to start offloading aircraft A, the OC can decide to wait. The OC can also decide to give aircraft A the minimum amount of resources, despite of more resources being available. Yet, these decision are not often made because they are assess by the OC as suboptimal. Furthermore, the OC bases its decision on the earliest finish time for both aircraft A and B, and not the lowest offloading time.

The decrease in waiting times for increasing certainty in information can be explained by the availability of the OC. When the OC has knowledge of an incoming flight, it has also knowledge of that flight's cargo content. This means that the OC does not need go to the aircraft to check the cargo content. This, on one hand, decreases the waiting time T_{BC}. On the other hand, the OC is not leaving its office and is available to react to new tasks thus decreasing the waiting times of other tasks. As other tasks are finished earlier, the resources are free at an earlier point in time. This in its turn, also makes it possible to start a new task sooner.

Only three scenarios with unannounced flights are evaluated: one large aircraft, all large aircraft, all aircraft. In the results one unannounced aircraft did not have a visible effect on the TAT. The reason is that the OC only needed to leave its office once, so the effects on other waiting times because of an absent OC is not as strong. Seven unannounced aircraft do have a clear effect on the average TATs and the average waiting times. As the scenarios in between one and seven unannounced aircraft were not investigated, the amount when the effects become significant is not known.

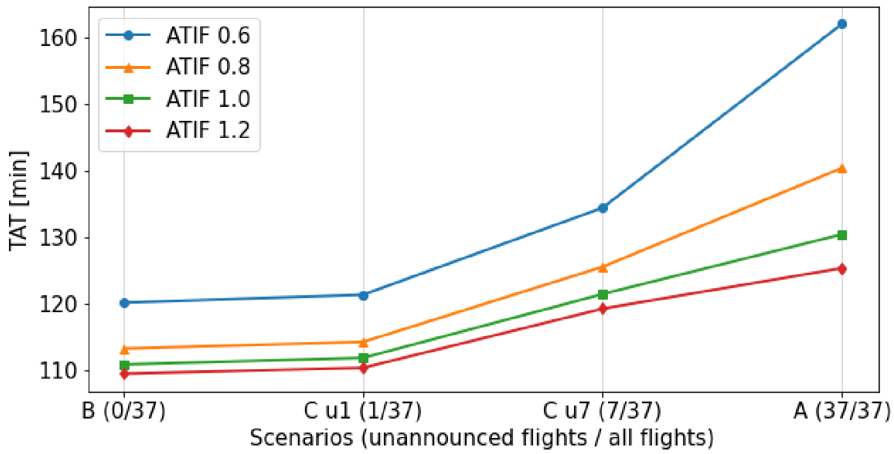

Figure 7: TAT trend for decreasing knowledge of incoming flights, for strategy 1 with all ATIFs.

7.3 Arrival Time Interval Factors

The results of the tests with different ATIFs suggest that the waiting times have the largest influence as the offloading time only slightly increases in comparison to the TAT. Analysing the results of the different ATIFs, the TAT increases with decreasing interval time. This is shown in Figure 7, where the TAT for all test cases of strategy 1 are shown for all different ATIFs. For all scenarios, the TAT increases considerably the smaller the ATIF becomes. However, the increase in offloading time is substantially less than the increase in TAT. The results of the test cases with different ATIFs indicates that it is mainly the waiting times that increase the TAT. The reason is likely the same as for the main results: as the OC is more at its office, the OC is able to take quicker action. Since the arrival time interval has been decreased, quicker action is needed more often.

The difference in results between the strategies is negligible for all ATIFs. However, the increase in deltas in Table 12 indicate that further increasing the ATIF result in a noticeable difference in offloading time between the two strategies. This can be explained by the airport being too crowded. Waiting for more resources to become available in order to have faster offloading will always take longer than for the available, and probably, minimum amount of resources. This is also the reason why the offloading times increase when the airport is more crowded.

It can be concluded that in the case study, the effects of anticipation on the performance of the cargo handling are negligible. However, this might have an effect when the airport becomes less crowded. Furthermore, the results suggest that one unannounced aircraft does not have a clear effect. However, the less information is known about incoming aircraft, the higher all the waiting times. Moreover, in this case study under these particular scenarios and circumstances the variation in offloading times can be neglected.

7.4 Resilience

This study is intrinsically connected to resilience at two levels. The first level is the resilience of Saint Martin Island after the hurricane disaster. Many buildings and infrastructures were damaged, and the recovery process has been effective due, among other, to ports and airports. Goods, food, and other resources have be carried by ships and planes and delivered to the island. Consequently, efficient airport operations contributed to the island community resilience. The second level is the airport level. Ongoing cargo and passengers handling operations can be significantly disturbed by unannounced incoming flights. These flights need to receive instructions regarding the use of runway, taxiways, parking spots, etc. The airport performance, which corresponds to the turnaround time in this study, can be impacted by unannounced incoming aircraft. The officer coordinator needs to manage these aircraft, and adapt plans to the new information.

Resilience can be seen as a graceful extensibility of a system [Woods, 2018]. It is the capability to anticipate bottlenecks ahead and to be ready to respond to unknown events. These unknown events can create disturbances in the system's organisation. This corresponds to the airports cargo handling operations as analysed in the study: the OC can make a prediction regarding the resources needed by an incoming flight to unload its cargo and handle the passengers that need to be evacuated. The OC needs to adapt the resources allocation schedule in real time to any new unplanned flights. In Figure 7, the average turnaround times are presented with respect to the number of unknown incoming flights. The offloading operations are only a little impacted by one unannounced aircraft: the average offloading times remain constant. However, when more disruptions occur (7 or 37 unplanned flights), the turnaround time increases, corresponding to a decreasing the system's performance. The system extends its handling capacity until the decompensation occurs. At that stage, the system has exhausted its adaptive capacity and the performance gracefully degrades. There is no collapse of the system in the investigated scenarios (i.e. the situation where aircraft cannot be unloaded), however an ATIF significantly lower could make the airport performance collapse. This would be the case in the following conflicting situation: when incoming aircraft need to use the runway to land but there is no parking spots available, and at the same time aircraft on the ground need to use the runway to takeoff.

7.5 Future Work

In the future, the amount of unannounced flights could be varied to examine which amount of unannounced flights give a significant results. In addition, different case studies could be tested, as well as the effects of miscommunication on TAT of the aircraft. To study the influence estimation and anticipation have on the performance of the system, the ATIF could be increased even more. Additionally, other anticipation strategies, e.g., optimising for offloading time, could be examined as well. Although this research aimed to be as close to reality as possible, assumptions needed to be made. For one, the evacuation operations are modelled as a time penalty. The evacuation operations are likely to cause more delays. Secondly, it is assumed that when the OC has knowledge of the incoming flight, that knowledge is always correct. Unfortunately, in a real situation that is not always the case. The same applies to the communication between all agents. In reality miscommunications happen, especially in such a complex system.

8 Conclusions

In this research a base model was developed based on van Liere's model. After analysing the case study it was found that the offloading strategy used in van Liere's model was unrealistic. According to experts a realistic strategy is to use as many available personnel and GSE to offload an aircraft. In case the next aircraft to offload is known, this aircraft should be taken into account, as the main goal of the cargo handling coordinators is to minimise the TAT. In order to evaluate a change in TAT, the TAT can be split in three main parts: the offloading time, the boarding time and the cumulative waiting time. In this paper, the evaluation of the performance of the TAT was done by testing different scenarios while implementing the identified strategies.

The effects of incomplete knowledge of incoming flights are first of all, one unannounced aircraft has a negligible effect on the total average TAT. If all seven arrive unannounced the TATs are visibly increased. As the scenarios in between one and all seven are not tested, the exact amount that causes a significant change in the TAT is not known. Secondly, in all test cases the difference in offloading time and boarding time is also negligible, meaning that the waiting times are influenced the most. With decreasing knowledge of incoming flights, the waiting times increase. As the OC needs to walk to the aircraft to check the content, the waiting time of that aircraft increases. At the same time, the OC is not at its office and cannot react to new tasks.

Additionally, the difference between the two resource allocation strategies are negligible for this case study. When changing the arrival interval time between the aircraft, these effects were still insignificant. However, the deltas of the Cliff's-delta test do increase when increasing the arrival interval time. This suggests that when this interval time is widened more, an effect might be noticeable between the two strategies. Nevertheless, the results suggest that, for this case study, the maximum available resources strategy would have been sufficient.

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II

Literature Study

previously graded under AE4020

1 Introduction

Every year a lot of natural disasters happen that have an impact on many people's lives. It was recorded that between 1994 and 2013 in total 6,873 natural disasters occurred worldwide. On average these disasters claimed the lives of 68,000 people and affected around 218 million people per year. [54] At the same time, the amount and the severity of the natural disasters are increasing because of climate change [3] [43]. During such a humanitarian crisis, airports are important hubs for delivering relief aid and evacuating people out of that area, while often these airports are affected as well by the disaster. In order to save a lot of lives, it is of great importance that these ground handling operations still go as efficiently as possible. However the cargo flow of the airport often forms a bottleneck in the humanitarian relief organisations [59].

The main question for this literature study is: What research can be done to further analyse and understand the ground handling operations at an airport as humanitarian hub? The answer to this question should lead to a research proposal for a MSc Thesis in Aerospace Engineering at the Technical University of Delft.

There already exists an agent based model created by G. van Liere for his MSc Thesis. The model simulates in detail the ground handling operations at Princess Juliana International Airport (PJIA) on Sint Maarten after hurricane Irma in 2017. In this literature study the application of this model with respect to the research should also be investigated.

In this report, in Chapter 2, the gaps in academic research and the bottlenecks in an airport's disaster management are identified. Here the scope of the research is narrowed down and a preliminary research question is formed. The case study of the PJIA model is used as an example. In Chapter 3, it is investigated what coordination mechanisms can be used to analyse the ground handling operations of an airport as a humanitarian hub. Chapter 4 investigates what research method should be applied and if the PJIA model can be used. Furthermore this chapter explains how the identified coordination mechanisms can be modelled. Finally a research proposal is given in Chapter 5. This section also contains a summary of the literature study.

2

Humanitarian Disaster at PJIA

When there is a conflict or a natural disaster, relief aid needs to go to these areas and people need to be evacuated out of these areas. A humanitarian hub is where at least one of these activities are done. An airport can be the place where both things happen. In this chapter the role and problems of airports in a disaster stricken area is explained in Section 2.1. Afterwards the case study of Sint Maarten is explained in Section 2.2. Section 2.3 explains the ground handling operations in more detail. Conclusions on this chapter are given in Section 2.4.

2.1. Airports in a disaster stricken area

As disasters and the coordination and management thereof are very broad themes, this section will give definitions to narrow down the scope. First a general classification of disasters is given in Section 2.1.1. Afterwards, in Section 2.1.2, the general Disaster Management Cycle is explained. In Section 2.1.3, the response phase of the Disaster Management Cycle with respect to airports is explained. In Section 2.1.4 a summary of literature on airport operations during a humanitarian crisis is given.

2.1.1. Disaster Classification

Disasters have their own classification scheme. However, there are a lot of different definitions for a humanitarian disaster. As the United Nations (UN) is an intergovernmental organisation, involved in most humanitarian disasters, their definition will be used. The UN defines a humanitarian disaster as:

‘An event or series of events that represents a critical threat to the health, safety, security, or well-being of a community or other large group of people, usually over a wider area.’ [26]

A humanitarian disaster can have a lot of causes, but is most of the time caused by other disasters. In Table 2.1 the general classification of disasters is shown according to The International Disaster Database [19].

Disaster Group	Disaster Subgroup	Hazard Examples
Natural	Geophysical	Earthquake, Volcanic Activity
	Meteorological	Extreme Temperature, Fog, Storm
	Hydrological	Flood, Landslide, Wave Action
	Climatological	Drought, Glacial Lake Outburst, Wildfire
	Biological	Epidemic, Insect Infestation
	Extraterrestrial	Impact, Space Weather
Man-made / Technical	Transport Accident	Air, Road, Rail, Water
	Industrial Accident	Chemical Spill, Gas Leak, Radiation
	Miscellaneous Accidents	Collapse, Explosion, Fire

Table 2.1: General classification of disasters.

As can be seen in Table 2.1, there are two disaster groups, the natural disasters and the man-made disasters. Additionally, there is also a third category called the complex disasters, which is a combination of the previous two. All of these disaster subgroups can cause or influence a humanitarian disaster.

How the emergency operations look like is dependent on many factors. The local government structure, the type of disaster, the state of facilities and so on. Nevertheless, in general, emergency types can be divided in two groups by the on-set of the disaster.

To narrow down the focus, only natural disasters with a sudden on-set will be considered in this research. The definitions are given by the UN:

- A sudden-onset disaster: "is triggered by a hazardous event that emerges quickly or unexpectedly." [52]
- A slow-onset disaster: "is defined as one that emerges gradually over time." [52]

As the time frame that defines 'quick' or 'gradual' can vary relatively, in Table 2.2, the on-set for every natural hazard is given as considered in this research.

Category	**Hazard**	**Onset of Disaster**
Geophysical	Earthquakes	Sudden
	Tsunamis	Sudden
	Volcano eruptions	Sudden
	Landslides	Sudden
	Avalanches	Sudden
Hydrological	Floods	Sudden
	Stormsurges	Sudden
Meteorological	Hurricanes	Sudden
	Typhoons	Sudden
	Cyclones	Sudden
	Storms	Sudden
	Blizzards	Sudden
Climatological	Droughts	Slow
	Wildfires	Sudden
	Extreme temperatures	Slow
Biological	Epidemics	Slow
	Infestations	Slow

Table 2.2: Natural disasters and emergency on-set

2.1.2. Disaster Management Cycle

The disaster management cycle has four phases, which can be put in two groups. As explained, among others, by [10] and [4], there is a 'before' a disaster event and an 'after' a disaster event. As can be seen in Figure 2.1 the four phases form a circle, meaning that the 'before' part can learn and use facts from the 'after' part of an already occurred disaster.

Mitigation - In this phase the risk and/or consequence of a disaster and its impact are to be mitigated or reduced. The goal of this phase is long-term and can include smaller activities, like making houses earthquake proof, but it can also be a larger project such as building dikes in flood-sensitive areas.

Preparedness - In this phase everyone is getting prepared for a possible disaster. Here, people that are possibly affected and those that might be able to help are equipped with the needed tools.

Response - This phase is performed during or right after the impact, or disaster event. In this phase one also tries to eliminate or reduce certain negative effects of the disaster. It is in this phase that the military and relief organisations come in.

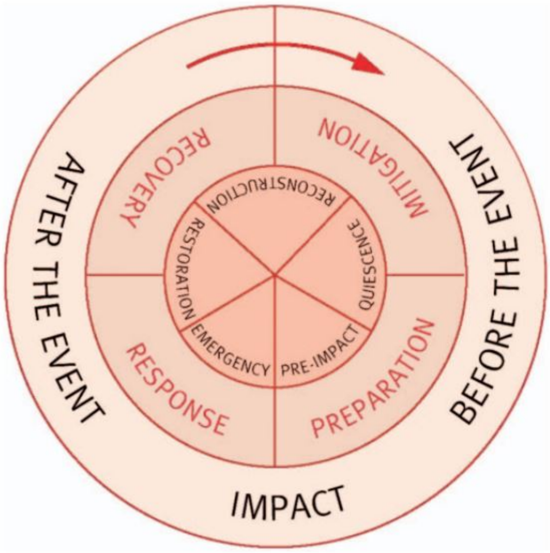


Figure 2.1: Disaster Management Cycle [10]

Recovery - In this phase one will try to restore and reconstruct everything, in order to get back to normal life. The best way is to reconstruct in a way that also mitigates (the effects of) future disasters.

This cycle can also be applied to airports. However the research will mainly focus on the response phase of the Disaster Management Cycle. In this phase the airport is used for receiving relief aid and evacuating people with the help of the military and relief organisations.

2.1.3. Response Strategies at Airports

As mentioned by [39], in the initial response phase it is vital to coordinate well between all the airport stakeholders and their operational decision making processes. At the moment the overall coordination of all stakeholders is done in a cluster system. However, in an airport the airport management stays in charge. Clusters are autonomous entities using flexible design rules. These separate entities can be the military forces, the different relief organisation or other stakeholders. The system where all the entities are put together is quite complex. The environment is always changing, because of, or resulting in, interventions and external influences. In other words, plans cannot always be followed, making the outcome always uncertain. In the response phase there are many stakeholders coordinating with each other, but each keeping their own organisational structure. This makes coordination sometimes difficult.

The main groups of stakeholders regarding humanitarian hubs are: the local Government, the Military, the Airport, Civil Aviation and International Humanitarian Organisations.

Government The government of the affected area plays a role in every phase of the disaster management cycle. The government is responsible for training people and acquiring the right equipment in the preparation phase. In the response phase its main responsibility is making sure aid is coming. Besides the national instances, it can also appeal to external organisations to get help. Such organisations are for example, the UN, DHL, Red Cross and many more. But it can also ask help from other governments, these governments also have the right to decline the help. Help can also be asked before the disaster, when one knows one is coming and it is very probable the effects will be grave. [31] [53]

Military The military, national or international, can provide extra relief services, equipment, supplies and personnel. These services can vary depending on the situation, examples of such services are: distribution of relief goods, transportation of relief goods and personnel or repairing necessary infrastructure. It is important that the military organisation is self-supporting during their mission, as not to put any extra strain to the local authorities or the other humanitarian organisations. [53]

Airports As mentioned before, an airport can become an important humanitarian hub by providing means to evacuate people out of the area and get relief aid in that area. therefore there is never only one airport involved as it needs a connection elsewhere. However this research focuses on the ground handling operation where the airport is used as a hub for incoming aid and evacuating people out. An airport owner and manager are most of the time two different people, or groups of people. A disaster does not change anything about this. The airport keeps doing its business 'as usual' as far as it is possible. However it is very likely that, as the research is about sudden on-set natural disasters, that not all people and facilities are present and that adaptions are needed. However this is very different from case to case and making a general approach is therefore quite difficult. [31]

Civil Aviation Even though most of the time it is not possible to have civil aviation during or right after a disaster, sometimes an exception is made when the airline is helping. There are some airlines that are often helping humanitarian organisations, for example DHL, Samaritan's Purse and UNHAS. Some commercial airlines and some aircraft lease companies can also be put in use. International Air Transport Association (IATA) and International Civil Aviation Organization (ICAO) decide on the air transport policies and the way they can support humanitarian operations. [31]

Humanitarian Organisation These organisations can be national or international. One of the most commonly known is the UN. The UN is an intergovernmental organisation with the goal to maintain international peace and security. The division that has the objective to help when a humanitarian crisis occurs is United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA). It can also serve as a contact point for all the other organisations. Furthermore it can also send specialised teams, such as United Nations Disaster Assessment and Coordination (UNDAC). [35]

There are many other international humanitarian organisations. These organisations can provide help in the response phase by sending specialised teams e.g. Emergency Medical Teams. The goal is to be there as soon as possible in order to save as many lives as possible. In the first 72 hours they need to be self-sufficient, therefore they usually bring their own specialised equipment. [31]

2.1.4. Literature on airports as humanitarian hub

Research in humanitarian logistics is becoming more popular [59]. However when looking at the academic literature, regarding the scope of this research, there is still not an overload of research. Indicating that there is room left for research. This is also confirmed by [39], where it is concluded that airport disaster management is, in terms of academic research, still in its infancy. Another conclusion was that there is an academic gap in airport disaster management considering the operational and business side.

Academic research gaps

Airport disaster management can be looked at from different point of views. On the one hand there is the logistic side and on the other hand there is the organisational side. The logistic part of disaster management has been a relative popular research field for the passed ten years. The Humanitarian Supply Chain however is mostly looked at from an overall point of view and not often only at the airport. [25] [42]

The organisational part of disaster management can be divided in different fields as well. There is the organisational structure and team coordination. Both fields have been thoroughly research, but not in the specific case of airport disaster management. More detail on this can be found in Section 3. Another field of study is information management. The informational part of disaster management has mainly been researched by exploratory analysis of multiple case studies. The information processes have most of the time been evaluated for the whole humanitarian operations and not specifically for airport operations. For the whole operations, one of the main problems identified was the distrust between the different entities. [58]

Information management happens in a standardised way and comes from 'tried and tested' processes, however is that the most efficient method? In an uncertain environment there will always be something that does not fit the standardised procedures. And it happens that some work is duplicated only in order to fit the standardised processes. It can be said that standardisation reduces the flexibility of a system and people do not know how to cope with unfitting information. Furthermore, another common identified problem is information overload of people in such a stressful situation. [14] [15]

Identified problems
According to [16], [21] and [59] a large problem in the humanitarian response phase is that an airport, as humanitarian hub, forms a bottleneck. An airport has a certain capacity and suddenly there is lot of relief cargo coming in, while people, facilities and other resources are not fully available. At the same time there are also relief organisations arriving at the airport, causing coordination difficulties. The main difficulty is that each organisation has its own structure, 'language' and equipment that needs to be coordinated as one whole. Furthermore every airport and country has their own culture, so it is not easy to compare different cases or to make one general plan of attack. In other words, the two main identified problems in airport disaster management are the cargo flow and the coordination between different entities.

For solving the cargo flow issue, one looked at improving it by better scheduling, investigating prioritisation and making more efficient parking spaces [22] [59]. However there is no research trying to solve the problem by changing the way of coordination or by looking at the information processes of the operations. And thus forming the next question:

Can the cargo flow become more efficient by changing the information processes?

Furthermore there are also some coordination difficulties, which also might affect the cargo flow, therefore the following research question can be asked:

Can the cargo flow become more efficient by changing the organisational structure?

Possible methods
Two research gaps are identified, but a more elaborate literature research needs to be done to define the change that might be implemented and how this should be done. In academic literature it was found that for airport disaster management there is need for an elaborate detailed model and not only model with sample data [59]. However at the same time, there is also need for more general research so that more global conclusions can be made [25] [42].

Therefore it should be ideal if the research is applied to a detailed model, which incorporates global problems. And where the model can be expanded if more detail or more generality is needed in later research. There already exists a detailed agent-based model which simulates the ground handling operations of PJIA on Sint Maarten after Hurricane Irma in 2017 [31]. The case study of this model will be looked at more closely in the next section. In the course of this report it will be checked if this model can be used or adjusted to suit the academic needs of the research question.

2.2. Humanitarian Disaster at Sint Maarten

The case study used in the PJIA Model will be elaborated on in this section. First some background information on Sint Maarten is given in Section 2.2.1. Section 2.2.2 describes the lay out of PJIA. Afterwards a summary of the events at PJIA in September 2017 is given in Section 2.2.3.

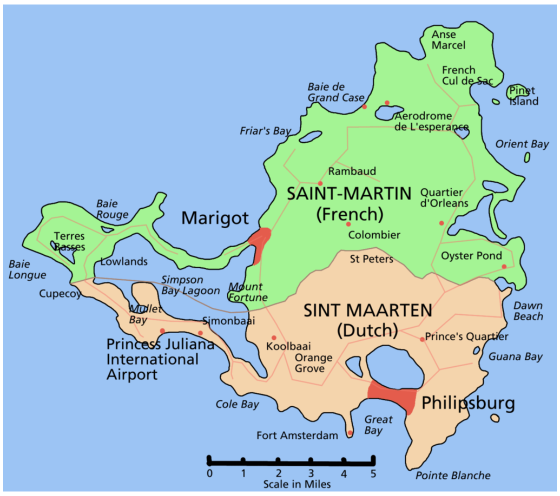


Figure 2.2: Map of Saint Martin. [63]

2.2.1. General information of Saint Martin

Saint Martin is a Caribbean island with 75,000 residents on 88km^2. As can be seen in Figure 2.2, the island is divided in two. It has a French part, called Saint Martin and a Dutch part, called Sint Maarten. On the Dutch part lies the PJIA. Sint Maarten has around 42,000 citizens divided over 34km^2. [56]

On September 6th of 2017 a category 5, on the Saffir-Simpson scale, hurricane called Irma passed Saint Martin. This is the highest category on this scale. The hurricane reached wind speeds of 290 km/h [55]. There were 4 fatalities and 23 injuries and over 70% of the buildings on the islands were destroyed [9]. This affected a lot of people and the total damage cost was estimated to be around 1.5 billion US Dollars [9]. On September 8th and September 18th, two other hurricanes passed the Caribbeans called Jose and Maria respectively, they did not go over Saint Martin but caused tropical storms. [2] [37]

When there is a sudden humanitarian disaster the Emergency Support Function(s) (ESF) is there for coordination. It is a group of ten supporting bodies, who aid the prime minister during these times. The organisational structure of this management can be found in Figure 2.3. As can be seen in the figure the prime minister is the head of this group, helped by the public prosecutor and the Royal Dutch Marines. The Fire Chief is the head of all coordination during a disaster, with the ten ESF underneath him. [48]

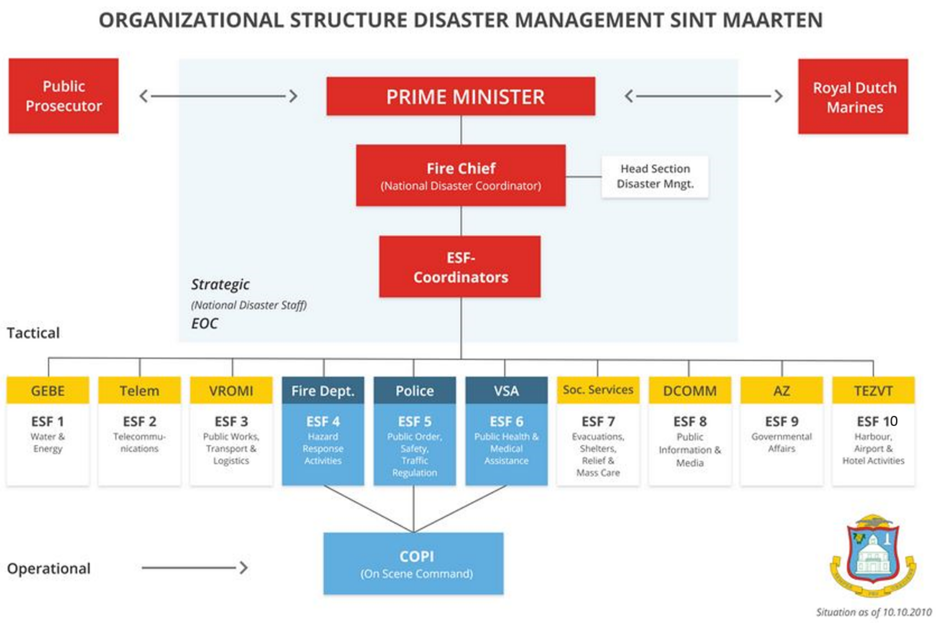


Figure 2.3: Organisational structure of Sint Maarten during a disaster. [48]

2.2.2. Lay Out of PJIA

When desiring to understand the ground handling operations, one needs to have an understanding of the lay out of the airport. PJIA is situated in the South-West of Saint Martin. The airport area is more than 640,000m^2, including 30,500m^2 of terminal building. The capacity of the airport is between 36 to 40 movements per hour [47]. The airport has one runway, which is 2300m long and 45m wide [20]. In Figure 2.4 one can see the lay out of the airport before the hurricanes. On the West side of the airport there was the cargo building and the control tower and in the North there was the terminal building. In the North-East the ground handling tower is next to the technical buildings, fire department and Fixed-Based Operator (FBO). In the West the runway has magnetic heading 10 degrees and 280 degrees in the other direction.

Figure 2.4: Princess Juliana International Airport General Lay Out before Irma [23].

After hurricane Irma the following facilities and equipment were destroyed:

- There was no running water, electricity, mobile connection and internet.
- All four jet bridges were destroyed.
- Terminal building had collapsed roofs and (water)damage.
- Runway and tarmac unusable (sand, water and debris), the Precision Approach and Path Indicator (PAPI) lights were destroyed.
- Perimeter fence was gone.
- All ground vehicles and aircraft suffered impact and water damage.
- The Air Traffic Control (ATC) (tower, radar and beacon) had severe water damage, same for the meteorology station. They were not operational.
- Out of scope:
  - Cargo handling building, destroyed and not in use.
  - FBO building, destroyed and not in use.
  - Fire station building, damaged but in use.

Only Menzies Aviation was able to handle aircraft.

Figure 2.5: Princess Juliana International Airport General Lay Out after Irma [23].

In Figure 2.5 it is shown what is left after hurricane Irma passed the island. As can be seen the cargo building, the ATC tower and the terminal building were destroyed. The cargo that arrived was put in front of the terminal building on the tarmac. On the East side of the former terminal building the evacuation waiting lines were put. A bit to the South there was the Ground Handling Tower which, after the arrival of Pathfinders Platoon, was also used for air traffic control. [31]

2.2.3. Main Events at PJIA

Liere [31] was able to gather information of the events at PJIA on a day to day basis. In this chapter a summary of it is given.

On Saturday the 2nd of September 2017 it was clear that hurricane Irma would pass Sint Maarten, so assistance of the Dutch Ministry of Defence was asked. It was agreed that Dutch marines that were at Aruba or Curaçao would be deployed. Two days later, on the 4th of September, the Dutch military arrived with 90 marines. Also the French military arrived with 30 servicemen, as the airport on the French part is too small for most aircraft. Furthermore Air France arrived with 57 civilian reinforcement. In addition also 14 firemen, 2 mobile hospitals, 7 medical staff and additional equipment arrived that day. That same day WINAIR moved all its aircraft to more southern areas in the Caribbean in order to save them from the coming hurricane.

The next day, on the 5th of September, the airport closes at 2 PM in preparation of hurricane Irma that would strike the next day. For that reason it was also asked to move or secure all the light weight private aircraft. At that point in time, Irma was a category 4 on the Saffir-Simpson scale.

On that Wednesday, September 6, Irma passed the island with local wind speeds up to 370km/h, making it a category 5 hurricane on the Saffir-Simpson scale. The wind was strong enough to make the aircraft flying around and smash everything in its way. Also the rain and storm surges helped destroy a significant part of PJIA. This costed the life of one of the airport contractors. A complete list of all the damage to the airport can be found below, where the lay out of PJIA is analysed.

The day after hurricane Irma, the Local Emergency Authorities (LEMA) and the Dutch military started to make the airport operational again. Once the runway could be used again, relief personnel and cargo came in and people were evacuated out. Part of the airport terminal was now used as a cargo warehouse. There was little coordination there, so cargo that did not fit was stored outside. Furthermore it took a while before the apron was fully free from debris.

On September 8th the Movement Control (MOVCON) arrived, as well as the Air Traffic Controller (ATCO)'s of the Dutch Air Force. Furthermore the first civilian relief flight took place by Samaritan's purse, they were also able to evacuate some people.

That night hurricane Jose passed by the island as a tropical storm, causing only heavy rainfall. Air traffic operations could recommence again on the 9th. On that day people form Urban Search and Rescue (USAR.NL) and UNOCHA arrived. A person from UNOCHA picked up the coordination of cargo storing. Furthermore on the 9th and the 10th more military personnel and equipment arrived, not only Dutch and French but also of other countries. Two Dutch C-130's were used to fly the daily bridge between Sint Maarten and Curaçao twice. However this was not always possible as the Ground Support Equipment (GSE) was not always available in time. The French Air Force also made an airbridge with a A400M and two CASA CN-235 aircraft. PJIA was only used for relief flights at that time. General coordination of all relief movements in the Caribbean was done by the Multi-National Caribbean Coordination Cell (MNCCC). Which existed of United Kingdom (UK), French and Dutch military, based in Curaçao. Monday 11th of September a second civilian relief flight was performed by Samaritan's Purse, having relief cargo, like shelters and hygiene kits, for 12,000 people.

On the 13th of September it became clear that a lot of the water, food and medical supplies were still stored at the airport. On this day the Pathfinders Platoon of the Dutch Army 11th Airmobile Brigade also installed temporary air traffic services. This caused more civilian relief flights to be able to come in. WINAIR, for example, flew of 60 times. On the 16th of September KLM also send a Boeing 747 that brought relief cargo and could evacuate 268 people. The Red Cross provided 11 tonnes of relief cargo to Curaçoa which was partly flown to Sint Maarten on the 17th of September.

Hurricane Maria's largest effect on the island was on the 18th of September, there were no flight movements during this day. Luckily it only caused a tropical storm with heavy rainfall.

In the following days a lot more relief cargo came in and airport operations became more stable. On the 23rd the French airport reopened for commercial flight. A couple of days later there was satellite connection again at PJIA. In the end PJIA reopened again on the 10th of October 2017.

An overview of the main events can be found in Figure 2.6.

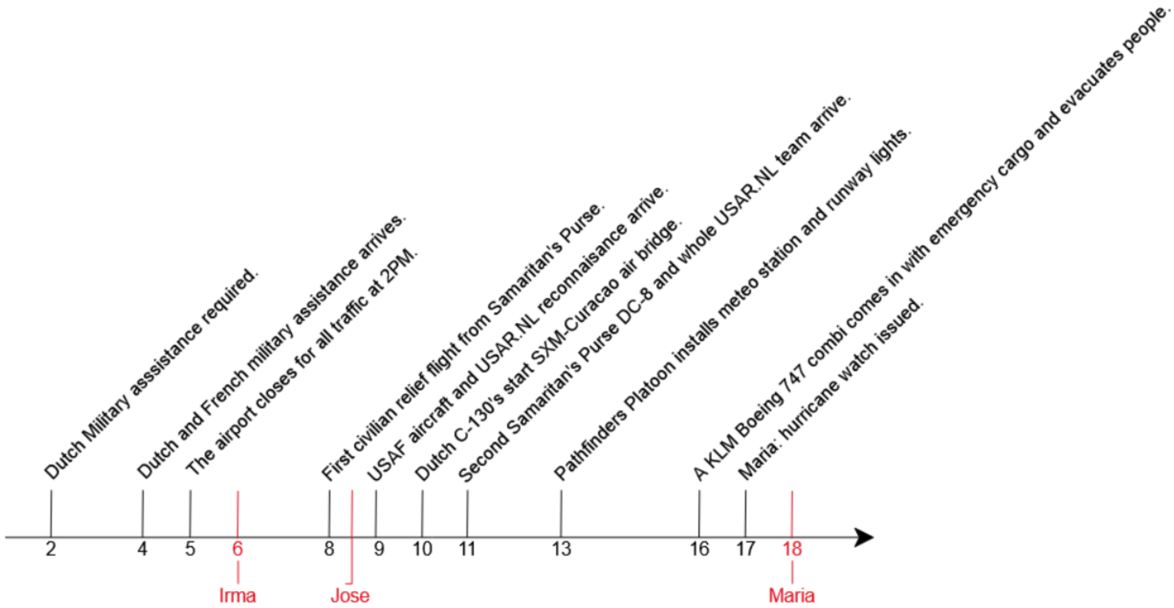


Figure 2.6: A timeline of the main event at PJIA in September 2017. [31]

2.3. Ground handling operations at PJIA

This section will explain the difference between the actual performed ground handling operations and the ones that are modelled in the PJIA model. Most of the information and figures in this section are based on the thesis of Gael van Liere [31]. Section 2.3.1 will go into more detail in the ground handling operations that were actually performed at PJIA after the hurricanes in 2017. Afterwards, in Section 2.3.2, it is explained which and how those ground handling operations are modelled in the PJIA model.

2.3.1. Actual ground handling operations

In this section the ground handling operations as they were in the first phase after hurricane Irma and José are discussed. In order to understand the ground handling operations better, first the different stakeholders need to be explained.

Key actors

Figure 2.7 gives an overview of the different stakeholders and key actors and how they are related. The figure is not a correct representation of the hierarchy.

A quick description of all the stakeholders that were present and their tasks is given below.

The Military forces can be split in two groups, Dutch military and foreign military. The Dutch military is the national army of Sint Maarten as it is part of the Kingdom of the Netherlands. So they were largely responsible for the coordination at the airport. The French, German, U.S.A. and U.K were also present at the airport.

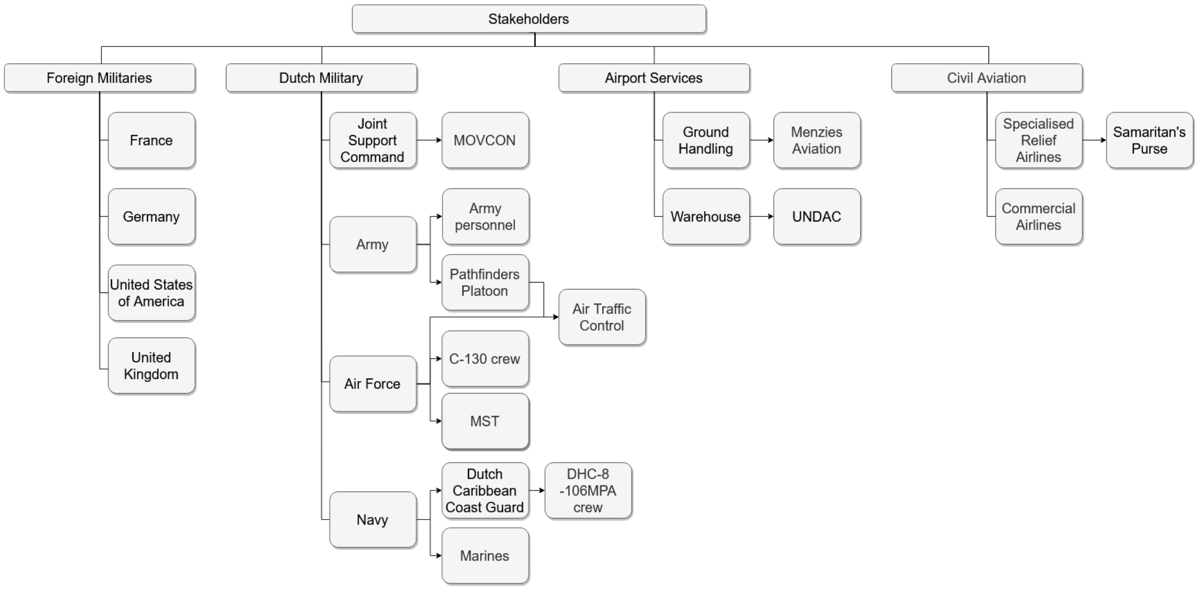


Figure 2.7: Stakeholders of PJIA which were present in the response phase.

- ***Movement Control*** is a unit under the Joint Support Command. They did the coordination of ramp handling (cargo and transportation). They were also the link between ground control and flight crew. The MOVCON consists of a MOVCON Chief leading a MOVCON official.

- ***The Pathfinders Platoon***, part of the Army, provided temporary meteorological stations and runway lights. They were, in cooperation with the Air Force, in control of the ATC Tower.

- ***Army Personnel*** helped with cleaning and clearing of runway. Also helped in repairing and guarding perimeter (fence).

- ***MST***: The Mission Support Team (MST) specialises in aircraft handling, refuelling and spare part maintenance for (Dutch) military aircraft. The teams consisted of a team leader, load controllers and qualified ground handlers.

- ***C-130 crew***, of the Air Force, consisted of a captain and a loadmaster. In real life, but not in the model, there were also co-pilots and flight engineers. The two C-130's made an air bridge to Curacao.

- ***The Dutch Caribbean Coast Guard*** had two DHC-8-106MPA available to add to the air bridge. Each aircraft has a captain (and a co-pilot, but the co-pilot is not considered in the model).

- ***The Marines*** helped out with the evacuation operations. They also helped guarding the perimeter and the passengers.

The Airport was, as mentioned before, largely taken over by the military. However, there were other organisations present.

- ***Menzies Aviation*** for ground handling operations and GSE.

- UNDAC for warehouse (out of the scope).

Civil Aviation sector is not allowed for commercial purposes, but they were present to help with bringing relief aid and evacuating people.

- ***Commercial airlines:*** KLM, Sunwing, Spirit Airlines, Royal Jordanian, PAWA Dominica, JetBlue, Delta, WINAIR, Westjet and Airbus and IFRC

- ***Specialised relief airline:*** Samaritan's Purse

Even though disaster management happens in clusters, airports are still managed locally [59]. Not only the airport management is important, as explained in section 2.2, in Sint Maarten also the ESF had a crucial role. After the hurricanes in 2017, there were three key actors missing for coordinating the airport:

Chief Airport Operations: chief of passenger operations, ramp handling operations and ATC. Civilian cargo manifests were send to this person, however as this actor was missing, the manifests never reached the coordinating people.

ESF 10 coordinator: together with the chief responsible for airport operations. This was partly taken over by MOVCON and Menzies, but there was no upward feedback.

ESF 7 coordinator: responsible for people evacuation in cooperation with chief airport operations. This was taken over by Dutch military and Menzies.

Performed Ground Handling Operations

Ground handling operations comprises every step needed from the terminal building to the taxiing aircraft and back. It is basically everything that happens on the tarmac. There are a lot of different services provided during ground handling. There are four main categories: ramp services, field operation services, passenger services and on-board services. However after a disaster not all of these services are possible or necessary. Below a list of the provided services at PJIA after the hurricanes is given. The ones marked in blue are part of the PJIA model. [31]

- Ramp Services:
  - ***Aircraft Marshalling:*** This is the one-on-one communication with a pilot by use of (arm)gestures and illumination of beacons. Done by MOVCON and qualified military and civilian handling personnel.
  - ***Air Start Units:*** This unit is used to start engines of aircraft without an auxiliary power unit (e.g. DHC-8-106MPA).
  - ***Ground Power Unit:*** This unit provides electricity when engines are shut down.
  - ***Air Conditioning Unit:*** Even though engines are shut off, air conditioning is still necessary when the cabin is over 10°C and it needs to transport passengers.
  - ***Air Cargo Handling:*** Getting the cargo to and from the aircraft and terminal building. All of the ground support equipment was owned by Menzies Aviation, but manual lifting was also needed. This service was performed by Menzies Aviation and the military.
  - ***Passenger Stairs:*** The passenger stairs were available due to contractor Menzies aviation.
- Field Operation Services:
  - ***Air Traffic Control:*** Pathfinders Platoon and Dutch Air Force installed their own ATC systems. There was no ground control and not all aircraft called in at ATC as they were possibly unaware of the services.
- Passenger Services:
  - ***Passenger Departure:*** The people that needed to be evacuated were put in waiting lines according to their nationality. The priority for evacuation from high to low: medical reasons, family with young children, nationality, age, gender, place in waiting line.

As mentioned before not all services could be provided due to destroyed equipment/facilities or non-priority or the mission. A list of those services is given below:

Ramp services: Pushback services, Lavatory drainage, Water cartage, Luggage services, Refueling

Field Operation Services: Aircraft dispatch

Passenger Services: Passenger arrival, Passenger security, Baggage handling

On-board Services: Cabin services, Catering services

2.3.2. Modelled ground handling operations

The PJIA model [31] is simplified to simulate the coordination done in the aftermath of hurricane Irma and hurricane José in a realistic way. In Section 2.3.1 an overview is given of all the key actors actually present, however here an overview is given of those actors and services that are modelled in the PJIA model. Section 4.2 For more detailed information on the PJIA model can be found.

Ground handling operations

In Section 2.3.1 a list of all ground handling operations is given that were performed in PJIA. The PJIA model focuses on the following services:

- Main services:
  - ***Air Cargo Handling***
    The incoming civilian aircraft are offloaded by Menzies aviation and the incoming military aircraft are offloaded by the Dutch military. The equipment used in the case study are: 2 high loaders, several cargo belts, 6 tugs with dollies, fork lift trucks. All of this was owned by Menzies Aviation, but the Dutch military is allowed to use the equipment. However only one of the high loaders is adapted for military aircraft. The equipment needs to be reserved 30 minutes before use.
    There are 3 types of cargo, each need different loading equipment, also dependent on type of aircraft.
  - ***Passenger departure***
    This is the evacuation operation. In the model there are waiting lines according to nationality, however no priority is included in the model. The evacuation operations are done by the Marines.
- Supporting services:
  - ***Passenger stairs***
    These passenger stairs are owned by Menzies Aviation. This is a small service but is added to make the model more realistic.
  - ***Air Traffic Control***
    ATC service itself is not modelled in detail. It is done in such a way that some arrivals are not known by the ATC, but if it knows it will communicate it with the MOVCON. This is included to simulate the effect of delay because of face to face communication.

The model evolves around the air cargo handling and the passenger departure, so they are crucial to the model. The supporting services are added to make the model closer to reality. Nevertheless, the Air Traffic Control is following a predefined schedule so it could be omitted for simplifying the model. The passenger stairs influence the Turn-Around Time (TAT) so it is not recommended to omit this service.

Coordinating agents

There are four coordinating agents in the system, this means that they are the only ones that can make decisions. Everything else in the model are either executing agents or equipment.

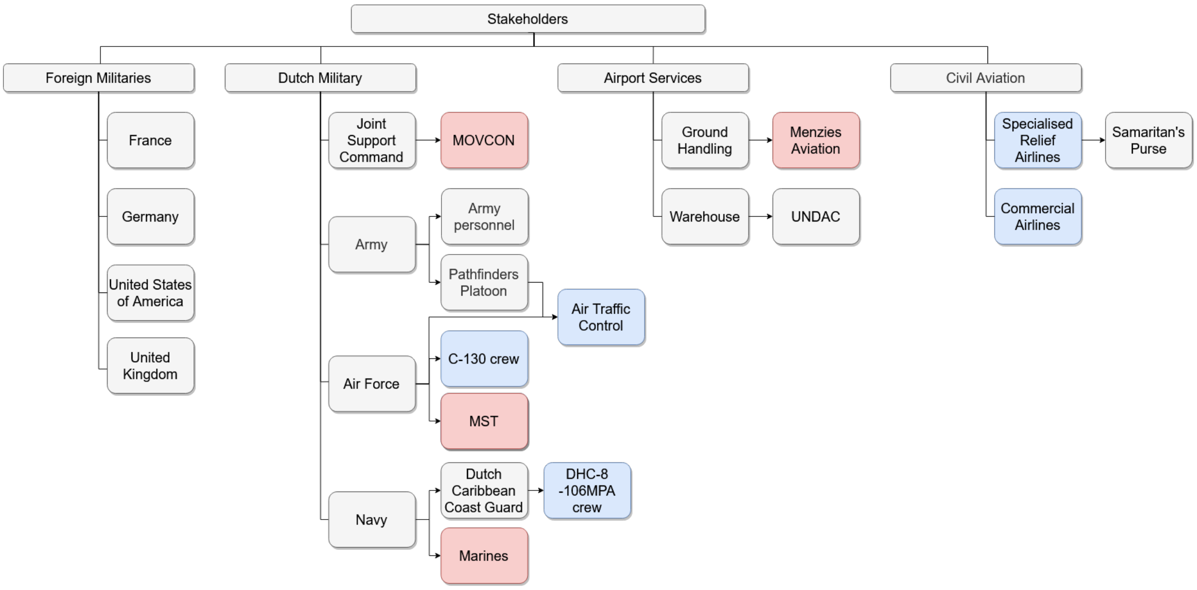


Figure 2.8: Stakeholders of PJIA, where the coloured ones are represented in the model.

The four coordinating agents in the system are part of the red blocks in Figure 2.8. MOVCON normally had one leader and one official, however in the model there is only the leader. MST is also a big group but is represented by a leader, the Military Offloading Coordinator (MOC), and four executing agents. The marines have the Evacuation Coordinator (EC) as a leader with six executing agents. Menzies Aviation is represented by the Menzies Aviation Managing Director (MAMD) as leader with nine executing agents.

The four coordinating agents, even though in reality some of them were multiple people, are:

MOVCON:
The MOVCON is responsible for reserving ground support equipment for military offloading with the MAMD. It also provides the EC with evacuation information (nationality, amount and when).

MAMD (Menzies Aviation):
Can be found in the Menzies Aviation building. Its main tasks exist in coordinating civilian aircraft offloading and coordinating the ground support equipment and non-military personnel.

MOC (MST):
The MOC is part of the MST. The MOC is responsible for the offloading of all military aircraft. It is assumed that the MOC knows the cargo content of the incoming military aircraft.

EC (Marines):
The EC gets information from the MOVCON and with that information the EC coordinates the marine personnel that do the evacuation operations, e.g. checking passports.

In Figure 2.8 the blocks that are marked in blue represent the executing agents that follow a predefined schedule.

Executing agents

Here a list of all the executing agents and their coordinators is given below. The equipment that the agents can use is also given.

- Coordinated by MAMD:
  - Driver personnel
    using tugs with dollies and passenger stairs.
  - Civilian handling personnel
    using high-loaders, belt loaders and tugs with dollies.
- Coordinated by EC:
  - Marine personnel
  - Passengers
- Coordinated by MOC:
  - Military handling personnel
    using forklift trucks and tugs with dollies.
- Following a predefined schedule:
  - ATCO
  - Aircraft and crew

Additional assumptions and simplifications

As can be seen in Figure 2.8, a number of stakeholders have been left out of the PJIA model.

The goal of the PJIA model was to simulate the events of the ground handling operation, more specifically the coordination in the cargo handling and passenger evacuation. The Performance Indicator (PI)'s of the model focus on the turn around times of the aircraft. In other words the model simulates the ground handling operations from landing to the terminal building and vice versa. Therefore the warehouse is not part of the scope.

Other simplifications in the model are:

- The Dutch military took over most of the coordination of the airport. As the other foreign military forces did not play a crucial role in the coordination they have been left out for simplification.
- The Army was important for making the airport ready for use again. However they did not play an active role in the ground handling operations. Therefore they have been left out as well.
- Aircraft and crew are considered one agent as the crew did not take part in the coordination. The aircraft agents are incoming with a predefined schedule based on what is known of the real schedules at the time.
- The ATCO agents 'know' the aircraft schedule, only some aircraft are left out to simulate the fact that not all incoming aircraft are known.
- It is assumed that the MOC knows the cargo content of the incoming military aircraft.
- There is no prioritisation in the evacuation operations, other then nationality. This could still be added if needed.

2.4. Conclusions

This chapter gives a definition to disasters and the management thereof. Furthermore it gives an overview to all the involved organisations. All this information was mainly used to narrow down the scope of the research to the following:

An airport as a humanitarian hub in the response phase after
a sudden onset emergency because of a natural disaster.

Moreover this part looked at other relevant literature. A couple of points can be concluded. First of all it is very difficult to make a general plan of attack, as each airport and country is very different. Secondly, in the research field of airport disaster management there is still a lot to be discovered. And third, it can be concluded that the cargo flow in the airport often forms a bottleneck in humanitarian relief operations. It has been researched how this can be improved by optimising the supply chain itself, e.g. optimise schedules, parking spaces, prioritisation etc. However the effect of a change in coordination has not yet been investigated in such an environment. This gives the preliminary research questions:

1. Can the cargo flow become more efficient by changing the informational processes?
2. Can the cargo flow become more efficient by changing the organisational structure?

It should be investigated what change should be implemented and how. In literature it was found that there is a need for a detailed model, as well as a generalised model. However there already exist a detailed, retrospective model of the ground handling operation of PJIA after the hurricanes in 2017. In the next chapters it should be examined if this model is suitable to use for the research.

This chapter already looked in more detail to the events at PJIA on Sint Maarten. When analysing the main events, the present and missing stakeholders and the ground handling operations at PJIA some bottlenecks can be identified:

- Destroyed ATC and therefore no knowledge of incoming civilian aircraft.
  - Unannounced inbound civilian aircraft.
  - No civilian cargo manifests.
- Lack of personnel.
- Only face to face communication.
- Not enough apron surface area.
- Long offloading waiting times.

The lack of available resources and overall coordination between the different entities, is not only a problem in this case, but can also be found in literature. This makes the case study useful and relevant. The suitability of the PJIA model will be considered in Chapter 4.

The scope of the model is to simulate the coordination in the ground handling operations from landing to the terminal building and vice versa.

At the moment there are four coordinating actors in the model, they are called the MOVCON, the EC, the MOC and the MAMD. Together they coordinate all the executing agents and the ground support equipment, except the ATCO and the aircraft as they follow a predefined schedule. How the coordination between them can change regarding organisational structure and information processes will be investigated in Chapter 3.

3

Coordination Mechanisms in Organisations and Teams

This section is about what coordination structures and mechanisms are applicable as strategies to improve the cargo flow in a humanitarian hub. As coordination is a very broad concept first the definitions of coordination theory will be given in Section 3.1. Afterwards, in Section 3.2 coordination in organisation structures will be researched. Section 3.3 will then examine the coordination mechanisms used in a team. Lastly, in Section 3.4, a conclusion of this section will be given.

3.1. Coordination and Application

In this section the coordination search term will be defined. First, in Section 3.1.1 definitions are discussed and chosen for this research. Section 3.1.2 further describes which aspects of coordination need to be researched.

3.1.1. Coordination Theory

When googling the term 'coordination' Wikipedia already suggests five different fields where the term 'coordination' is popularly used. Each field has its own specific definition, however this research is about the coordination of a group of people and their equipment. But even when specifying this, there are still a lot of definitions used for the term 'coordination', some examples are given here:

"The act of making all the people involved in a plan or activity work together in an organized way." - Cambridge dictionary [8]

"Coordination is the attempt by multiple entities to act in concert in order to achieve a common goal by carrying out a script they all understand." - Klein 2001 [27]

Coordination is "the additional information processing performed when multiple, connected actors pursue goals that a single actor pursuing the same goals would not perform". - Malone 1988 [32]

In other words in order to have coordination one needs multiple agents/actors with their own tasks and goals. It is important to note that their tasks and goals do not have to be the same, but at least one or more tasks and/or the goals need to be interdependent.

An example of this might be an aircraft manufacturing company. The company has a set of goals, e.g. to produce (different types) of aircraft. These goals can be achieved by actors performing certain tasks. The set of actors in this case might be people but can also include machines. In order to have coordination there should be interdependencies, examples for this case can be the use of the same resources in the assembly line or the order of certain tasks. The goals and motivation of the actors will probably not be the same, some might work just for the money and others like to have a promotion. But they do need to coordinate together and work towards the same common goal, in order to achieve their own personal goal. [12]

In later research of T. Malone, it was found that coordination also exists when only one actor is involved, as long as there are 'multiple interdependent activities' performed to achieve goals. Therefore another definition for coordination was formulated:

> 'the act of managing interdependencies between activities performed to achieve a goal'. [12]

Both definitions of Malone can be used for this research, but as the second one does not exclude the first one. This second definition will be considered.

3.1.2. Application of theory

In 1988 Thomas Malone defined three applications of coordination theory. The applications, as can be seen in Figure 3.1, all use the coordination theory as the base of the design. The first is about designing human organisations and organisational structures. The second, coordination technology, is to design technology that helps humans to coordinate. And the third is to design computer systems that can process in parallel or do distributed processing. [32]

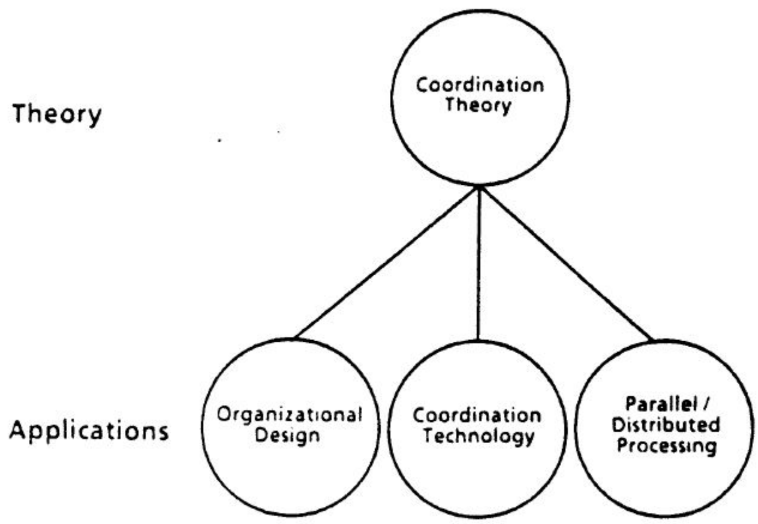


Figure 3.1: Application of Coordination Theory according to Thomas Malone [32].

The planned research is of the complex socio-technical kind, as there are interactions between humans and technical equipment. Additionally there are also different facilities, procedures and different organisations that play a role [7]. As coordination is done by and between the organisations and instances that are there to help manage the airport during a crisis, the coordination theories will be applied to organisational design and the interaction between the human agents. The focus will be more on the human side and organisational side, but is potentially assisted/enhanced by implementing technology (e.g. walkie talkies) and thus using coordination technology.

The research will investigate the effect a change in coordination mechanisms has on the cargo handling and passenger evacuation in an airport. The coordination mechanisms in this research are in terms of organisational structure and the way information is shared.

3.2. Coordination in an Organisation

According to [45] there are three sides on which one can evaluate an organisation. The first is their complexity, the second is their centralisation and the third is their formalisation or standardisation. An elaboration can be found in Section 3.2.1, Section 3.2.2 and Section 3.2.3 respectively. Afterwards these definitions are used to evaluate the organisational structure of the PJIA case study in Section 3.2.4.

3.2.1. Complexity

Complexity is the degree of differentiation, the amount of different jobs, roles, hierarchical levels, work centres etc. The organisation can be complex in three ways: vertically, horizontally and spatially. [45]

In an airport after a disaster, the organisation is managed by the airport management. However this was not the case in the case study, as there was no airport management. Even though there were not many vertical layers in the management of the airport, there was complexity in the horizontal direction. The airport was not managed by one organisation, but by different entities that needed to work together. Each entity had their own specialisation and their own organisational structure. Furthermore there was also a lack of equipment and facilities that needed to be shared and improvised. The third point that is mentioned is spatial complexity. Even though all the coordinating and working people were in the same airport, there was no telecommunication possible on the island. So when there was a need for communication it had to be done face-to-face. Another point that might have been an issue was the cultural differences, as there were the local ground handlers, as well as several international armies present. The uncertainty of the whole situation can also add in the complexity.

3.2.2. Centralisation

The coordination and the structure of the management can be measured in the hierarchy of authority, but also in the degree that different entities in the organisation participate in the general decision making and coordination. This is called the degree of centralisation, for now three main categorisations will be used. [60]

- **Centralised coordination** - The coordination authority is concentrated and thereby also the autonomy. In an organisation this means most of the time that a higher or top level management is making all the decisions. [13][49]
- **Decentralised coordination** - Coordination authority is not concentrated. In an organisation this means that the decision making and control is more spread over the entities within an organisation. In a lot of cases the top management shares the decision authority with the middle management. Decentralised coordination thus implies more autonomy in the different layers of an organisation. However the different entities do not coordinate with each other, they can work independently towards the same goal. [49] [51]
- **Distributed coordination** - Coordination authority is not concentrated. In an organisation this means that the decision making and control is spread over the entities within an organisation. The different entities then coordinate directly with each other instead of one concentrated point of coordination authority. [62]

Multiple sources say that it is not possible to have either one as counting for the whole organisation, there is always a mix. However, the terms can be applied to where the balance within the organisation shifts, hence the term 'degree of centralisation'. Each structure has there own advantages and disadvantages, depending on the situation one can be more desirable than another. [45] [49] [46]

In a centralised organisation, the information is centralised as well. This means that the autonomous people have a good overview to make the correct decisions. This overview also means that they can avoid the fact that work has been done twice and that the overall process of the organisation can be optimised. The whole organisation is then coordinated in a uniform way. However, this causes to give the top management a lot of work and if they are making a mistake there is no back up. Furthermore as they probably have little contact with the lower layers of the organisation, they do not know what is going on there and what the needs are.

In a decentralised organisation on the other hand, the autonomous decision-makers are closer to the people and can respond to the local needs. The feeling of the people, that they have more influence, can increase the morale and commitment. However, as the multiple entities in the organisation are not centrally leaded or coordinating with each other, this can cause conflicts of goals and interests. Moreover as the information is scattered, this can also lead to duplication of efforts, also called the silo effect. [33]

A distributed organisation enables more direct and efficient communication and thus local problems and needs can be solved more effectively. Nevertheless, it can also solve certain problems in the wrong way if there is no appropriate way of information sharing between the individuals or entities. If it goes wrong, this also increases the overall uncertainty within an organisation. Furthermore there needs to be a way to harmonise the goals and interest of individual entities versus those of the organisation. [46]

In Table 3.1 summarises the advantages and disadvantages of the three degrees of centralisation. Most advantages and disadvantages all result from the completeness of information that the decision-makers have.

Advantages	*Disadvantages*
Centralisation	
• Uniformity. • Enables global optimisation. • Eliminates duplications • Reduces risk-factor in decision-making by less informed or less skilled subordinates.	• High decision load on top management. • Causes alienation and lack of initiative. • Inappropriate response to local requirements. • Slower communication • Single point of failure.
Decentralisation	
• Facilitates intra-unit communication. • More appropriateness in responding to local situations. • Increases morale and commitment.	• Causes conflicts of goals and interests. • Duplication of efforts.
Distribution	
• More direct and efficient communication. • More appropriateness in responding to local situations.	• Difficult to harmonise goals and interests. • Increase in uncertainty as knowledge is spread over the organisation

Table 3.1: Summary of advantages and disadvantages of centralised, decentralised and distributed coordination.

For the research it would be possible to discuss three different scenarios. In Saint Maarten airport at the time after the hurricanes in 2017 there was no higher management. All the coordination was done by the different organisations, with four main coordinating actors. The Menzies Aviation Managing Director (MAMD) for ground handling, Military Offloading Coordinator (MOC) for offloading the military aircraft, Evacuation Coordinator (EC) and the Movement Control (Movcon). This is called distributed coordination. To go from this case to centralised coordination, there should be a higher level of management available that is coordinating the different groups. Decentralised coordination would in this case mean that the different coordinating actors would not directly coordinate with each other. This would be possible if the MOC and EC would have their own equipment instead of borrowing and using people from Menzies Aviation.

3.2.3. Standardisation

Before discussing the standardisation in an organisation, the difference with centralisation needs to be emphasised. The degree of centralisation is about the autonomy, which means determining the goals and how to achieve those goals yourself. While the degree of standardisation is about control, how much influence does one have on a given situation. In other words if the goals and rules set by the autonomous people are very strict, the other people have little control. So centralisation is about, who are the autonomous people. And standardisation is about, how strict are the goals and rules set by the autonomous people. [65]

Regarding the degree of standardisation, there are two main streams of classical coordination philosophies an organisation can have, which are well described by [30]. The streams differ in how they manage uncertainties. According to [65] there are two general sources for uncertainty. There are the transformation processes that can take place and there is the environment in which these processes occur.

In the first option an organisation can go for a lot of standardisation. This is done by using fixed rules, jobs and routines. [45] By minimising the freedom (to make mistakes), coordination can be used to minimise the uncertainties in a company. Most of the time the procedures come from higher up the management ladder, with a feed-forward control.

The other approach strives for more flexibility, with the underlying idea to cope with the uncertainties instead of minimising them. Most of the time there is more autonomy within the organisation and there is feedback control.

However this theory can also be applied the other way around. When there is a lower degree of uncertainty, standardisation and routines are easily applicable. Moreover when there is a higher degree of uncertainty, there is more need to the ability to cope with it in a competent way. When looking at it from this point of view, being able to switch between the coordination philosophies seems ideal.

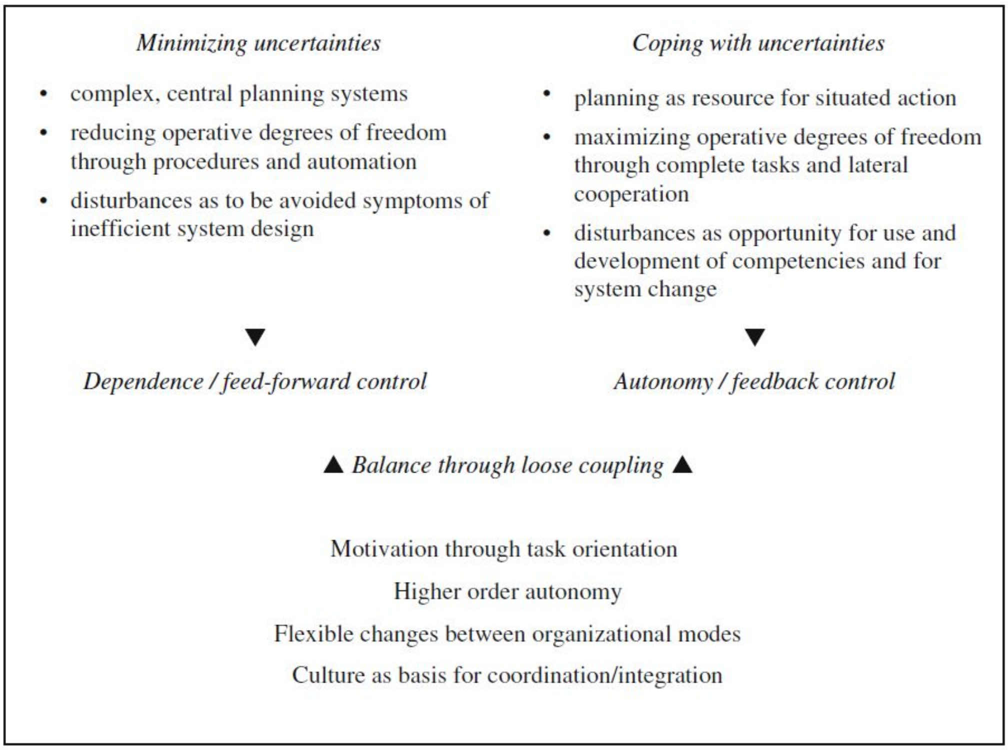


Figure 3.2: Two approaches to handling uncertainties in an organisation. [30]

This 'switching' philosophy can be seen in Figure 3.2 as a third option. Besides the 'minimising uncertainties' and the 'coping with uncertainties', the third option is called 'loose-coupling'. Here the point of view is to find a balance between the previous two options. One way is to be able to switch between organisational modes, but another option is to formulate the rules in a different way. [30] and [24] suggest to achieve this loose-coupling by flexible routines, which is then achieved by flexible rules. They identified three kinds of rules:

- Goal rules: define the to be achieved goal.
- Process rules: define how decisions and course of actions should be decided upon.
- Action rules: define the actual actions.

It was found that especially process rules would be suitable for a flexible, but stable, system. These rules could then be used to give boundaries and define when to use which rule, when being close to such a boundary. [40] When having more flexible rules stating the reasoning behind the rule also helps the actors to reason themselves when to apply such a rule. This can be in the form of a goal rule. [30]

Applying all this to an airport one can say that airports are normally very standardised. These rules are not only set by the airport itself, but by external instances e.g. ICAO or UN. Be that as it may, during a humanitarian crisis, this is not always still possible. The uncertainties the airport then faces are on the one the hand the issue of who will be there to lead the airport and what airport rules are still valid (transformation processes). On the other hand there is the question of what will be left of the airport in terms of equipment and facilities (the environment). So under normal circumstances an airport manages well with standardisation, but during a crisis it might need another strategy.
In order to get a loosely coupled system in airport, the rules of the such instances like ICAO and UN should be more flexible. Complete flexibility in control is for airports under normal circumstances and at the moment not possible. The first reason is as that aviation is an international business, it is hard to keep track for pilots if every airport has its own system. Furthermore there is the safety issue that demands certain standards.

The research will not go into depths of how to switch modes, but will only look at the point in time after a switch can have occurred. Therefore a distinction will be made in this report between the two ways to achieve loose-coupling. When an airport can switch modes, from standardised to flexible and vice versa. Applied to the research this means that the airport is standardised under normal circumstances, but after (or during) a disaster it goes over to the flexible mode. This will not be called loose-coupling, but will be just called 'flexible control'. The second option is that the rules always were flexible, before and after a disaster. This is what in the research will be called 'loose coupling' or 'loosely-coupled control'.

3.2.4. Organisational coordination in case study

This section will elaborate on what kind of organisation in the case study is used and which ones can be researched. As mentioned before, the complexity of the organisation will not be looked into detail, so one should look at the combinations with autonomy and control in an organisation. For autonomy there are three options: centralised, decentralised or distributed organisation. For the control in the organisation there are also three options namely: standardisation, loose-coupling and flexible control.

In the [30] they actually only talk about three combinations of autonomy with control, see Figure 3.2.

- Centralised organisation with a lot of standardisation: autonomy and control in highest layer of management.
- Distributed organisation with little standardisation: autonomy and control at the head of each entity in an organisation. Not standard hierarchical coordination, but more lateral.
- Centralised coordination with flexible rules: autonomy and control in highest layer of management, but also control in the lower layers.

It should be noted that at the moment in the existing model there is a more distributed organisation, with all the entities coordinating with each other. Everybody has their own task and there is little flexibility in how to perform the task, so it has standardised control.

Some cases can already be excluded from the research. The choice made for the research proposal is that the organisational structure and information processes would have been applicable to the case study. As in a decentralised organisation the entities should be completely independent, while still working on the same goal, this is not applicable to the case study. In order to be independent, the military should have their own equipment to unload the aircraft and to get the passengers on board. A decentralised organisation is therefore excluded from the research.

An important assumptions that will be made is that the environment will be fully cooperative and there is no competition between the entities. Flexible control implies a certain degree of competition, so flexible control will be out of the scope of the research. This leaves the following options:

Centralised + standardisation This case has been explained before, see Figure 3.2. There is a higher management deciding upon strict rules.

Centralised + loose-coupling This case has been explained before, see Figure 3.2. There is a higher management, that gives boundaries for certain rules.

Distributed + standardisation The heads of the different entities need to coordinate together, using the preset rules of an external organisation.

Distributed + loose-coupling The heads of the different entities need to coordinate together, using the preset rules of an external organisation. The rules are guidelines, giving boundaries and goals.

When one wants to use the case study, and the PJIA model, it would mean th at the research, in terms of organisational coordination, can go in two directions:

One can compare the distributed organisation with a centralised organisation, while keeping the standardisation. Or one can compare a distributed organisation with standardised control with one that has less standardisation.

As the existing PJIA model simulates a distributed organisation with standardised control, it has been chosen that the focus of the research will be more on elaborating on the coordination in a distributed organisation. When implementing centralisation the model should need to change too much to be able to verify its validity.

3.3. Coordination in teams

In the previous section the coordination modes and balances in an organisation are discussed, but in this section the coordination mechanisms, or the managing of interdependencies, within a team is explored. Section 3.3.1 will discuss the basis for coordination, namely having common ground. Then this information will be used to look at the concept of a joint activity in Section 3.3.2. Section 3.3.3 gives the difference between explicit and implicit coordination. Lastly, in Section 3.3.4, the co-ladder model is explained.

3.3.1. Common Ground

When wanting to start coordinating with a team there is need for some common ground. One can say 'we have common ground', but actually common ground is not a state but a process. It needs communication, testing, regular updating and repairing of the mutual understanding. According to [64], common ground is having suitable and mutual beliefs, knowledge and assumptions. Together they can support interdependent actions when there is a joint activity, a list of examples of support are:

- the roles and functions of each participant;
- the routines that the team is capable of executing;
- the skills and competences of each participant;
- the goals of each participant;
- the stance of each participant (time pressure, level of fatigue, competing priorities)

There is always a risk of losing common ground, however the risks of its loss can be reduced by proactively working on it. According to the research of [64] the following are the main reasons for the loss:

- the team members may lack experience in working together;
- they may have access to different data;
- they may not have a clear rationale for the directives presented by the leader;
- they may be ignorant of differences in stance (e.g., some may have higher workload and competing priorities);

- they may experience an unexpected loss of communications or lack the skill at repairing this disruption;
- they may fail to monitor confirmation of messages and get confused over who knows what.

The loss of common ground is an important reason for the failing of a joint activity.

3.3.2. Joint Activity

The concept of Joint Activity is explained by [64], the definition of a joint activity covers some of the key concepts of team coordination. A joint activity is explained by the criteria, the requirements and the choreography of a Joint Activity, as can be seen in Figure 3.3.

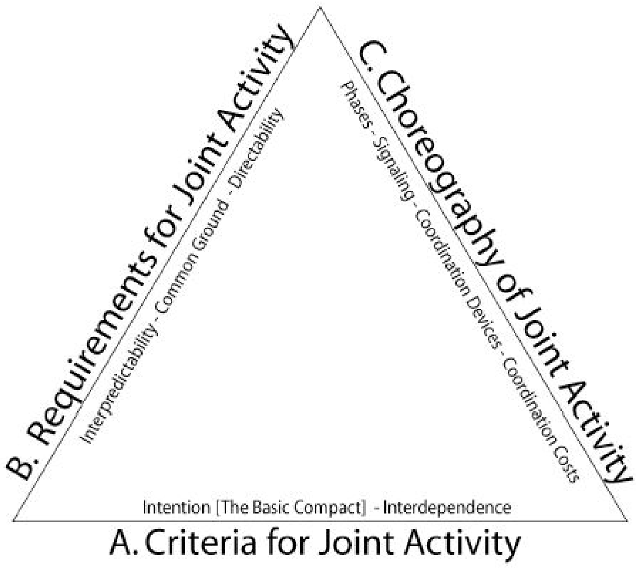


Figure 3.3: Description of a Joint Activity. [64]

A. **Criteria**
   There are two criteria in order for something to be a Joint activity. First, a Joint Activity is an activity that is aimed at producing something that one person working alone could not do. The other criteria is called the basic compact, it is the agreement that each participant intents to carry out the required coordination responsibilities.

B. **Requirements**
   To make joint activity work, there are three main requirements. The first is having common ground. This concept has already been explained in Section 3.3.1. The second requirement is interpredictability, the degree of this depends on the ability and accuracy that one can predict the actions of the other participants. Lastly, there is directability. These are 'deliberate attempts to modify the actions of the other partners as conditions and priorities change' [64]. Deliberate in a positive way, if one participant notices something wrong, that person can notify its partner.

C. **Choreography**
   The choreography of a joint activity exist of three phases: entering a Joint Activity, a joint action and exiting the Joint activity. The joint action can contain more Joint Activities. Furthermore the Joint Activity can be influenced by the amount of moments different participants have to communicate or signal to each other as well as the opportunities and usage of coordination technology. Lastly, coordination also comes with a cost. This cost can be the time lost or effort in order to be able to coordinate with the other participants.

3.3.3. Explicit and Implicit coordination

The two ways of coordination are well explained by [29]. Explicit coordination mechanisms are processes that are purposely used by the team to coordinate. While implicit coordination mechanisms is about using shared knowledge to understand or anticipate a certain task or certain decisions of other team members.

Explicit coordination processes are the most studied, however almost every team uses both coordination mechanisms. In certain situation explicit coordination is better than implicit. According to [29] when a team is new (and they have little shared knowledge) explicit coordination, like a lot of communication, is the most efficient. However if the project progresses, and the shared knowledge increases, implicit coordination is more efficient.

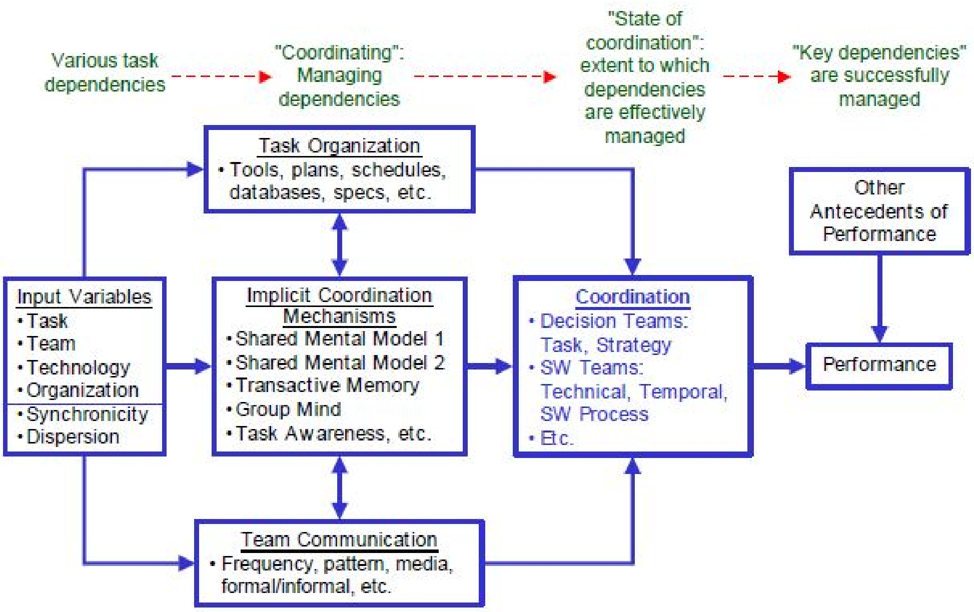


Figure 3.4: Dependencies, Team Coordination and Performance. [29]

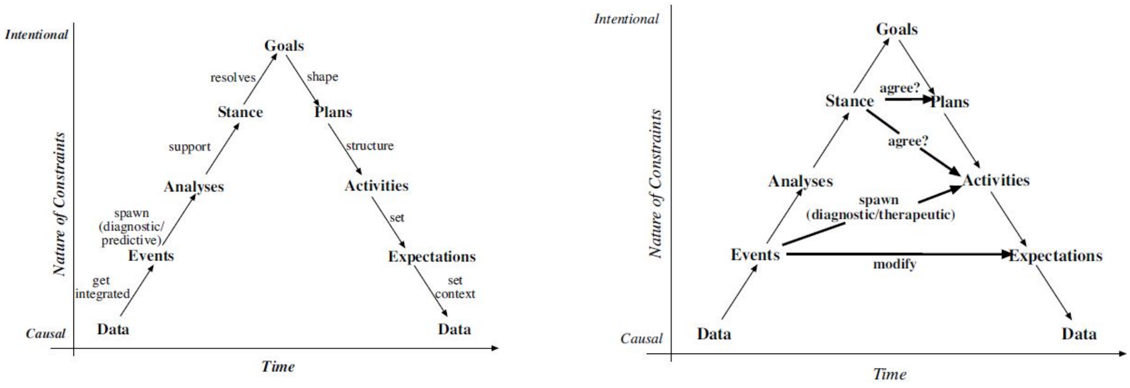
Figure 3.4 gives a full scheme of what coordination is and comprises, where Task organisation and Team Communication are forms of explicit coordination. It starts with the 'input' which is the team, tasks, the dependencies etc. In order to perform the tasks coordination is done via implicit and explicit coordination mechanisms. Then a check should happen where the 'state of coordination' is examined. This is actually checking the common ground and is more elaborated on in the next section. The only thing missing in this figure is a feedback loop if there a loss of common ground is found. This feedback loop can also be applied to the next section if the performance or outcome is not what is expected.

3.3.4. Co-ladder model

The co-ladder model represents all the communication types and coordination processes of human-human coordination. This model was defined by [38], and shows that there are eight types of information one agent can communicate to another agent. This communication can also be between groups of agents. The information types are: Data, Events, Analyses, Stance, Goals, Plans, Activities and Expectations. In the model these information types are represented by nodes, linked together by arrows which represent the coordination processes. The basic form of this co-ladder model is shown in Figure 3.5(a). As can be seen the uplink is in support of anomaly response, while the downlink is in support of replanning. This is, as mentioned, the most basic form as actually more links in between the different nodes are connected as can be seen in Figure 3.5(b).

In a real project a lot of these pyramids are connected to each other, an example is shown in Figure 3.6.

If the agents do not agree on the goal in the stance face, analysis needs to happen again. This happens until everybody agrees on the goal.



(a) The Basic Form. (b) More relations between nodes.

Figure 3.5: Co-Ladder Model of Coordinative Functions in Distributed Replanning. [38]

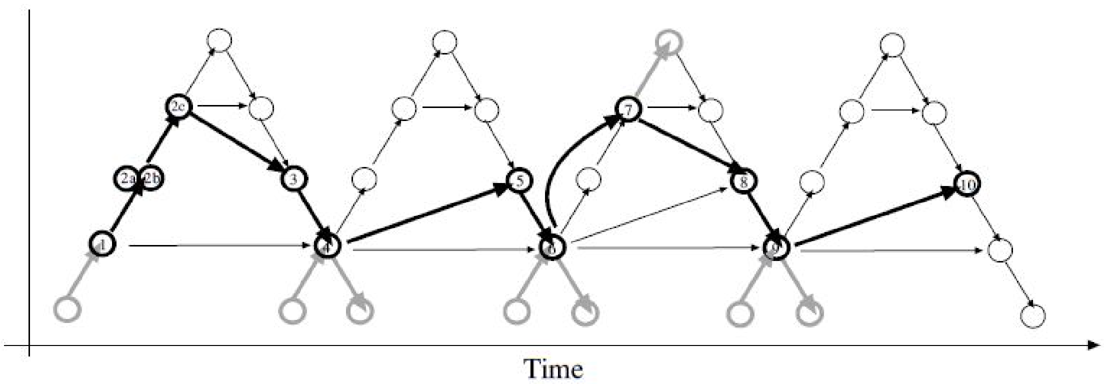


Figure 3.6: Co-ladder Model, example of complete project. [38]

3.4. Conclusions

Coordination is a very broad term, the definition used in this research is:

> "the act of managing interdependencies between activities performed to achieve a goal" [12]

Coordination in the research will be more on the human and organisational side, with a possibility to implement coordination technology. Coordination mechanisms can be applied to the whole organisation and to a smaller team.

First of all the organisational structure of the existing PJIA Model is analysed. It can be concluded that in the model, it is a distributed organisation using standardised control. The best way to elaborate the model is to look at a distributed organisation with loosely coupled control. Loosely coupled control means having rules that leave some freedom for interpretation/reasoning, depending on the situation. The complexity of the organisation will stay the same, as well as the degree of centralisation. The degree of standardisation creates different scenarios that can be investigated.

Before implementing this room for reasoning in a model, first the actors, tasks, goals and interdependencies need to be analysed. These interdepedencies can be the use of the same resources, or the need for information from another agent. Afterwards the key question is, how to change and evaluate these interdependencies?

Common Ground can be used to analyse and compare the standardised control with the loosely coupled control. It would be interesting to see in each investigated scenario what the resistance is against loosing common ground. There are some situations that can be possibly implemented:
- Agents/Entities get different data, but not complete.
- Agents/Entities get different data, but one is wrong.
- Agents/Entities are not able to communicate with each other (can't find the other?)

The analysis of the model can also be used to investigate what the necessary information is for each agent/entity. Because not everyone can find value in every piece of information.

The concept of Joint Activity is useful for defining the coordination and the agents in the model. Common ground and interpredictability are part of the Situation Awareness (SA) of agents. A joint activity can also be influenced by the amount of moments different participants have (or can) communicate with each other and to which extend they are aware of each other. The implementation of the use of telecommunication devices or bikes can also be an interesting feature to analyse. Furthermore also meetings can be planned to synchronise the common ground. However these extra moments of communication also come with a (time) cost. This can be added as an extra Key Performance Indicator (KPI).

In research it was found that having explicit coordination in the beginning is important and then slowly moving to more implicit coordination is what works the best for teams. In the case study this could be for example, when certain agents are able to anticipate an event. For example, if the EC can recognise an incoming aircraft then it would know how many people of what nationality should go on board of that aircraft. Therefor the EC might decide to already check passports, before the MOVCON comes by.

The co-ladder model can potentially be used to construct each agent and to map the interactions with different agents.

All in all comparing the effect of loosely-coupled rules with respect to standardised rules, by using different information processes in the PJIA model is definitely possible. These different information processes can be a change in how the information goes from A to B, in the amount of information an agent gets or in the correctness the information is given. This means that the change in organisational structure and the change in information processes are actually dependent of each other.

4

Modelling an Airport as a Humanitarian Hub

This chapter aims to look into how the research should be done. Section 4.1 discusses why the Multiagent System (MAS) paradigm is suitable for a complex sociotechnical system. Afterwards the existing PJIA Model is explained in more detail in Section 4.2. Section 4.3 describes how an agent-based model can be expanded and how this should be done in the research. Conclusions on this chapter are given in Section 4.4.

4.1. Modelling airports as complex sociotechnical systems

The reason why an airport is a complex sociotechnical system and how such a system can be modelled is discussed in 4.1.1. Afterwards the MAS modelling paradigm is explained in Section 4.1.2.

4.1.1. Complex sociotechnical systems

Before choosing the method for simulating model, the characteristics of the system should be discussed and the research objective should be defined.

First of all an airport is a complex sociotechnical system. A sociotechnical system is a system where there are interactions between humans and technical equipment, which is the case in an airport, as stated in [7]. According to [57] a system is complex when there are different types of components, which are not all stationary. Meaning that the components have non-linear dynamics and that the output of one component can have an influence on the input of another. Furthermore the system should have a certain hierarchy, with subsystems that can also be complex systems. Moreover when looking at a small group of components the behaviour of the whole system cannot be predicted. This is all true for an airport, as there are different facilities, procedures and different organisations that play a role.

Secondly the broad objective of the research is to investigate the effect of information processes and less standardised rules in an airport as a humanitarian hub.

A suitable and commonly used paradigm when modelling a complex socio-technical system, is agent-based modelling [5]. This MAS modelling paradigm is also used in the PJIA model. According to [57] it is applicable when:

- the system has a distributed character;
- the subsystems operate in a highly dynamic environment;
- the subsystems have to interact in a flexible way;
- the subsystems are characterised by reactivity, pro-activeness, cooperativeness and social ability.

As the problem at hand has all the above characteristics, agent-based modelling is a suitable method. One of the main differences of agent-based modelling with other models is that it is made from the bottom up. It is based on the individuals that together make a whole, which is exactly the purpose when looking in more detail to coordination mechanisms. [1] The fact that this way of modelling is applicable means that the PJIA model is definitely suitable to use for the research.

There are two main reason that it is chosen not to go for Operation Research, which means finding an optimal solution [41]. The first reason is that it is very difficult to optimise something if there is not much known about the general effect. Secondly, PJIA model should then be changed too much in order to be able to do that and not much time will be left for actual research.

4.1.2. MAS modelling paradigm

An agent-based model consists out of a MAS that reflects or represents a reference system [1].
"A multi-agent system is a set of agents interacting in the environment to solve problems, achieve goals, or execute tasks that are difficult or impossible for a single agent" [44]. In other words there are three pillars of the system: the agents, the environment and the interactions. These can also be found in Figure 4.1. One of the main differences of agent-based modelling with other models is that it is made from the bottom up. It is based on the individuals that together make a whole. [1] [50]

Figure 4.1: A visual representation of a Multi-agent System. [50]

An agent is an autonomous, and computed, entity that is able to asses a situation and can make decisions using a set of rules [44] [6]. All the agents in the system can be the same, so they have the same set of rules and goals, in that case the system has homogeneous agents. When there are different types of agents, it is called heterogeneous. A distinction can be made between two types of agents, reactive and proactive agents. Reactive agents observe the situation and react on it. Proactive agents have an internal state and are able, in a simulated way, to reason. All the agents have behavioural properties. Which means that they can act upon an observation of their environment and other agents. Agents can also act upon an internal state or change an internal state, this is called a cognitive property.

The interaction between an agent and other agents or the environment can be evaluated in different ways. There is the communication, which can be done directly or indirectly. However there is also the coordination, specifically, are the agents able to cooperate or are they competitive?

The environment where the agents are put in can contain objects which are not agents. However agents can observe these objects and may react to them. Furthermore an environment can be static or dynamic. In a static environment only the agent itself can change the environment, otherwise everything remains the same. The environment can also be deterministic, which means that an action has a priory known effect. If there is uncertainty in the resulting effect it is called non-deterministic. Lastly an environment can be accessible, this is an environment where the agent can get all the current information about the state of the environment.

4.2. The existing MAS model of an airport as humanitarian hub

This section will elaborate on the PJIA Model which is based on the ground handling operations of PJIA after the hurricanes in 2017. The PJIA Model is developed as part of the MSc thesis of van Liere. All of the information in this section is originating from [31]. Section 4.2.1 explains the motivation of the MSc thesis of van Liere. Then, in Section 4.2.2, the model is explained. Afterwards the experiments that were performed and the results are briefly described in Section 4.2.3.

4.2.1. Motivation and Problem statement

The goal of the existing PJIA Model is to explore novel methods for modelling an airport as a humanitarian hub. The scope of the model was to simulate the coordination in the ground handling operations from landing to the terminal building and vice versa. The ground handling operation of PJIA, located on Sint Maarten, after hurricane Irma and José was chosen as case study.

The case study was chosen because Sint Maarten is part of the Kingdom of the Netherlands and as the Technical University of Delft is Dutch as well, information could be more easily gathered. The focus in the model lies on the cargo handling and the evacuation operations at the airport. Particularly, using prioritisation of aircraft in the decision-making of coordinating actors.

The constructed agent-based model has a combination of the bottlenecks concluded in Section 2.4, representing a day in the week after hurricane José. It was not possible to remake a specific day perfectly as the information was gathered two years after date.

4.2.2. The Model

The advantageous aspects of agent-based modelling is that it can be deconstructed in different levels. It can represent the agent characteristics and the different subsystems, but also the system as a whole.

The language used for the model is Netlogo, as it is an intuitive and visual programme. The lay out of the airport grid in NetLogo is shown in Figure 4.2. [31]

Environment Specification

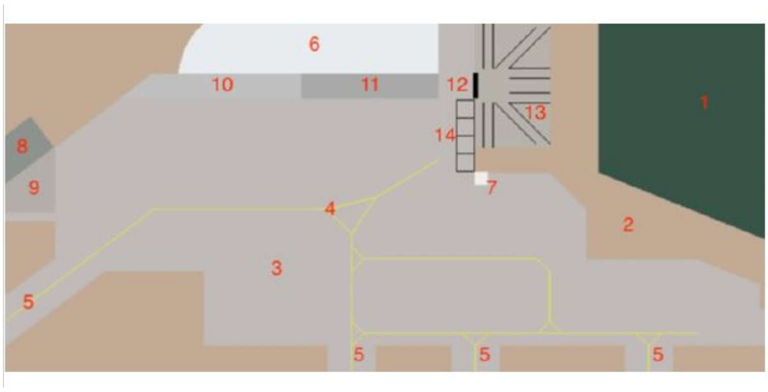


Figure 4.2: Lay Out of PJIA in NetLogo.

Some places of the airport are not shown in Figure 4.2. These were the cargo handling building and the FBO building as they were destroyed. Also the runway and the fire department building cannot be seen as they were out of the scope of the research.

According to [31], the environment is static, deterministic and accessible. Especially the accessibility is an important assumption that has been made, as it has an extensive effect on the realism of coordination.

Agents and Environmental Objects

In order to generalise the model the events and agents are simplified. There are two types of agents in the system: coordinating, or proactive, agents that coordinate the executing, or reactive, agents to perform certain tasks in the cargo and passenger handling operations.

There are four coordinating agents in the system: the MAMD, the MOC, the EC and the MOVCON. Their tasks have been shortly described in Section 2.3.2. The executing agents are: Civilian Handling Personnel (CHP), drivers, Military Handling Personnel (MHP), marines and aircraft agents. The latter are the combined aircraft and crew as the crew itself did not really take part in the ground handling operations. A summary of the amount of agents and objects in the model can be found in Table 4.1.

Ground Support Equipment	**Personnel**	
Objects	Executing Agents	Coordinating Agents
• Beltloaders: 4 • Tugs-Dollies: 8 • High-loaders: 2 • Pax-stairs: 8 • Forklifts: 2	• Driver personnel: 5 • Civilian handling personnel: 4 • Military handling personnel: 4 • Marines personnel: 6 • Pax: indefinite • ATCO: 1 • Aircraft agents: according to an uploaded schedule	• MAMD: 1 • MOC: 1 • EC: 1 • MOVCON: 1

Table 4.1: Agents and Objects in the PJIA model.

Offloading of civilian aircraft is done by the MAMD, the CHP's and the drivers. The MAMD coordinates the GSE, the CHP and the drives. The CHP makes use of the high-loaders, belt loaders and the tugs with dollies. The drivers drive the tugs with dollies and the passenger stairs. When the ATCO has knowledge of an incoming military aircraft, it informs the MOVCON. The MOVCON then reserved the needed GSE with the MAMD. Offloading military aircraft was done by the MHP's, coordinated by the MOC. The MHP can drive forklift trucks and tugs with dollies. When a high-loader is needed for a military aircraft, the CHP will still drive it. The EC, MOVCON and marines were involved in the evacuation operations. The MOVCON by giving the aircraft specifications (nationality, amount of seats and time for boarding) to the EC. And the EC by coordinating the marines and the passengers. The marines checked the passports and helped escorting the passengers to the aircraft.

Aircraft and their crew are considered to be one agent, as the aircraft crew did not play a proactive role in the coordination of ground handling. The specifications of the aircraft agents can be found in Table 4.2. Mil stands for military and Civ for civilian aircraft. L stands for large aircraft and S for small. All aircraft perform evacuation operations, but those that also bring relief cargo are indicated by a C. C* means that the same kind of aircraft is also available without cargo.

Each kind of aircraft and cargo needs specific GSE to get the cargo from the aircraft to the tugs and dollies. It is assumed that each dollie has four tugs attached to it. The equipment needed for LD3 Unit Load Device (ULD), Individual Cargo Unit (ICU) and the 463L Master Pallets are given below:

- **LD3 ULD's** are offloaded by a high loader.
- **ICU** are assumed to be lifted by a person.
  - Large civilian aircraft use a belt loader.
  - Large military aircraft need a high loader. For military aircraft only one of the two high loaders is adapted for military use.
- **463L Master Pallets** are offloaded using a high loader or by combat offload. Combat offload means that everything is shoved out of the aircraft and dropped onto the tarmac. To pick these pallets up the forklifts are used. These forklifts are also used to get the pallets from the dollies to the ground.

Input Category	Affiliation	Aircraft Type	On-board cargo			Seating capacity
			LD3 [kg]	463L [kg]	ICU [kg]	
Mil: L, C	RNLAF	C-130H		13500		22
		C-130H-30		13500		70
		A400M		18000		150
	FAF	A400M		18000		150
Mil: L	USAF	C-130H				80
Mil: S, C	DCCG	DhC MPA-D8			3000	30
Civ: L, C	Samaritan's Purse	DC-8	18000 20000		5000 6000	30
	Delta	B737	15000 20000		5000 8000	40
	KLM	B747	20000 25000		5000 8000	50
Civ: S, C*	WINAIR	DHC Twin Otter			2000 2500	19
	Private	Undefined			500 1000	6

Table 4.2: All aircraft agents in the PJIA model.

Large civilian aircraft also require passenger steps for boarding.

In the evacuation processes only nationality was taken into account. In the actual case there is prioritisation in the following order: medical reasons, family with young children, nationality, age, gender, place in waiting line. There was prioritisation implemented for the cargo handling. Each agent that coordinates chooses the aircraft that is waiting the longest as its next target for its tasks.

4.2.3. Experiments and Results

In order to validate and calibrate the model a couple of experiments were done. Furthermore experts that were present at the time after the hurricanes at Sint Maarten also checked the model.

The parameters that needed to be calibrated were validated by the use of ten PI's (see table 4.3). All the PI's in the model are times, as all the parameters that needed to be calibrated were speeds or times.

#	Performance Indicator	T
1	Waiting time pax steps at aircraft	T_{psaac}
2	Waiting time before offloading starts	T_{BOS}
3	Offloading time	T_{Off}
4	Passport control time	T_{PC}
5	Waiting time pax standby	T_{PS}
6	Conversion to pax configuration	T_{Con}
7	Waiting time before boarding starts	T_{BBS}
8	Boarding time	T_B
9	Waiting time before pax steps removed	T_{BPSR}
10	Turnaround Time	T_{TAT}

Table 4.3: Performance Indicators of the existing model.

In total there were five experiments done. First an experiment was done with the initial parameters, then one with small random variations in the parameters. Afterwards two extra marines were added. Then there was an experiment with new moving speeds. The last run of simulations was done with a corrected offloading and boarding speed. Some of the parameters were changed after the experiments and were checked by an expert who agreed on the values.

Even though this clearly validates that the retrospective model works, there was no analysis done on the prioritisation processes of the cargo handling. It is mentioned in the recommendations the decision making structure changed in future research.

4.3. Expanding the existing MAS model

Incorporating loosely coupled control means that changes need to be made to some of the agents in the system. This is discussed in Section 4.3.1. In Section 4.3.2, the general design steps in order to include the changes are given.

4.3.1. Expanding an agent

At the moment in the existing model the agents are quite superficial, the complexity lies in the amount of agents and tasks. It would be possible to develop these agents in the model to more complex agents. Complex agents have a simulated approach of reasoning. Depending on how complex these agents become they could be able to anticipate actions of others, or reason which information they need. This would make their decision making, and therefore the overall coordination, different.

Decision Ladder Model

Decision making has multiple layers, in the most basic form there are three main steps:

$$\text{Find options} \longrightarrow \text{Assess options} \longrightarrow \text{Choose option}$$

These three steps use two kind of processes, the front end and the back end processes. They can be seen in Table 4.3, where the ovals are the cognitive processes and the rectangles are the outcomes. The front end takes into account the problem identification and all the external factors like gathering information, assessing the situational awareness etc. The back end process uses the front end processes to make a decision.

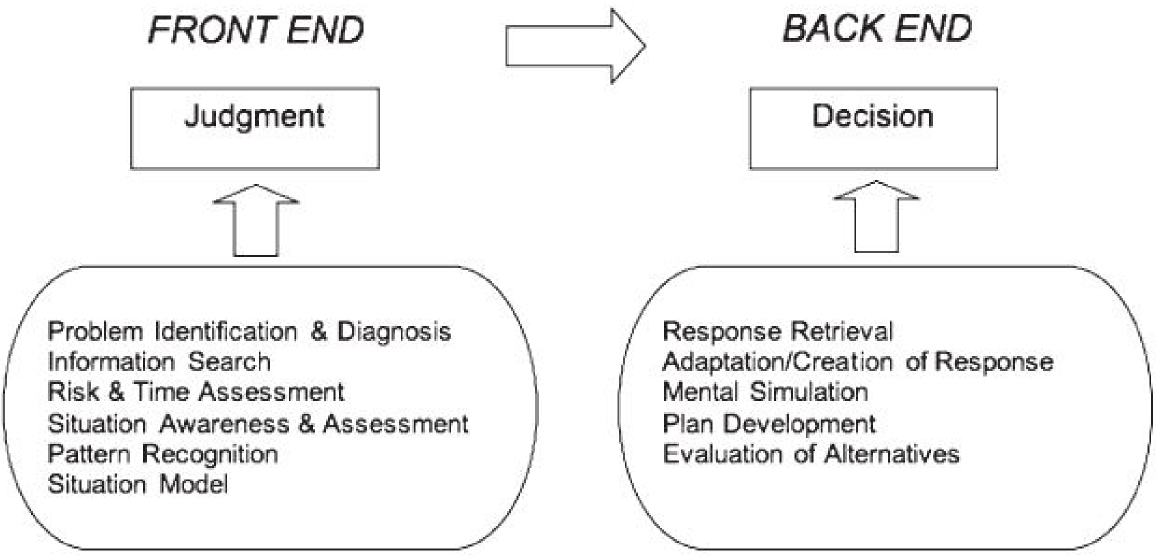


Figure 4.3: Front end and back end processes in decision making. [34]

A more elaborate model has been proposed by [34], called the Decision Ladder Model. The decision ladder model covers almost all aspects and layers of the decision making of an individual. The model, as shown in Figure 4.4, has the front end processes on the left hand side and the back end processes at the top of the ladder. The descending or the right hand part represents the preparation of the action. The boxes in the figure show the information-processing and the ovals represent the resulting knowledge.

This unique model has some advantages over other models. The first is that in the existing model different agents have different expertises, which can be captured by the decision ladder model by making shortcuts in the cognitive processes. These shortcuts can be a 'leap' from one knowledge point to another, or a 'shunt' from an activity to a knowledge state. Furthermore it is also not necessary for an agent to start its decision making process on the left-hand side, an agent can also for example with the identification of the target state.

Reasoning in this case is the process of thinking in a logical way before making a decision on an action [36]. This logic is based on the SA and of the cognitive abilities of an agent. The SA of an agent is defined by the level that an agent understands 'what is going on' [5]. For example, the situational awareness can be

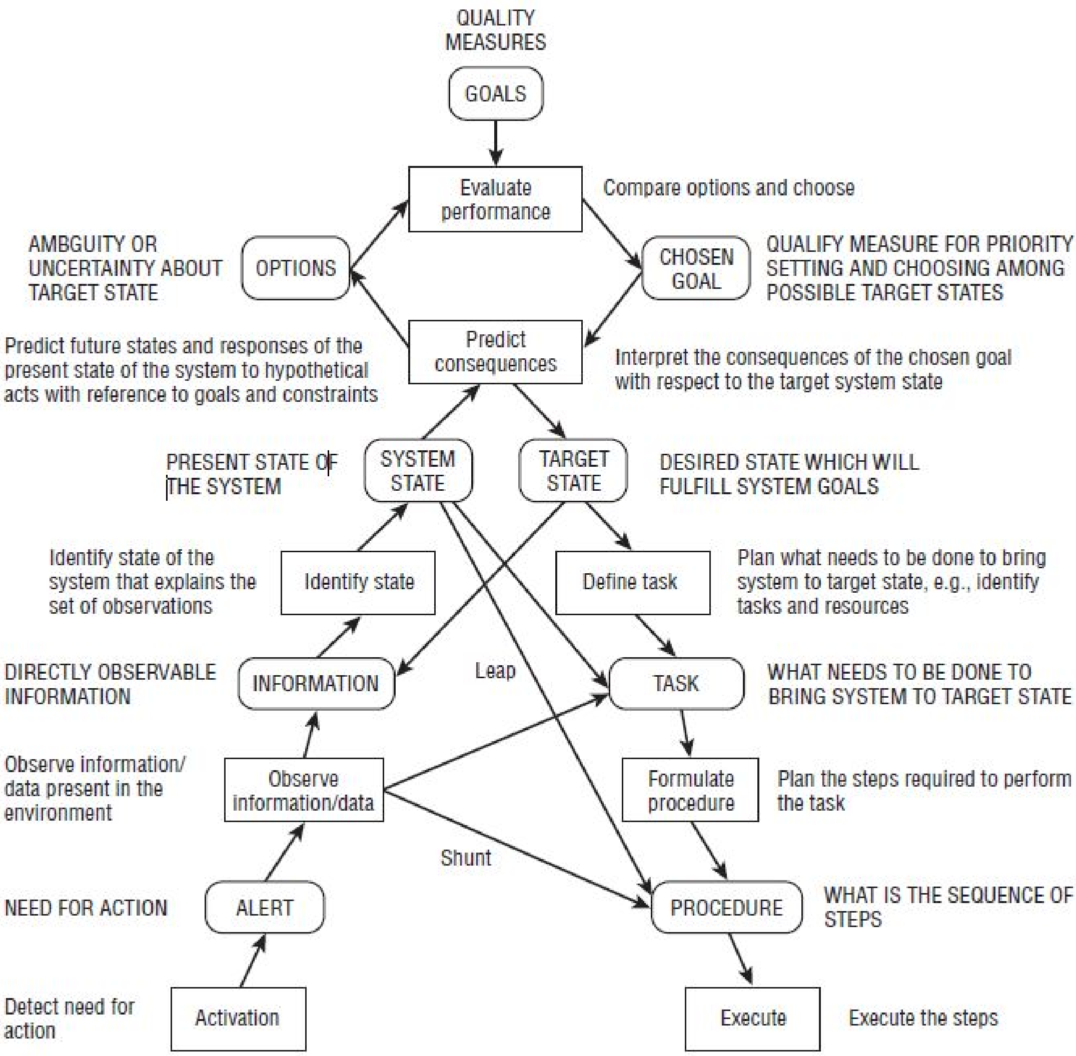


Figure 4.4: Decision Ladder Model [34]

the information the agent can observe, together with remembering earlier knowledge about the system, the agent can then by reasoning put this observed information to a possible state of the system.

These steps can not only be used to reason an optimal solution to an existing ’problem’, but it can also be used for anticipation in order to get potentially more efficient coordination.

Theory of Mind

In order to understand how humans can anticipate the decisions or actions of others, one should look at the Theory of Mind (ToM). The ToM is commonly used in game theory and in a MAS it is part of the SA of an agent.

Agents may create a model of the environment or of other agents based on their own basic knowledge, their observations and the information given by other agents. In this way an agent might be able to anticipate the behaviour of another agent. The ToM incorporates different degrees of anticipation, this is well explained by [17] [18].

Zero-order theory of mind (ToM_0), the agent does not realise that another agent has not the same goal. It is unable to create the mental model of another agent. With mental model is meant the goals and intentions. In Figure 4.5, an example is given, with two people playing the game rock-paper-scissors. It illustrates a person anticipating another player to play 'paper' as that is what the other player has played the most. Its response, in order to win over paper, should then be to play scissor.

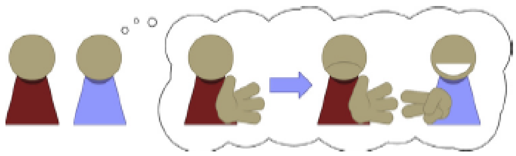


Figure 4.5: Example of zero-order theory of mind, while playing rock paper scissors. [18]

First-order theory of mind (ToM_1), the agent realises that another agent might have a goal of its own. Therefore it will make a decision, by placing itself in the position of the other agent. In Figure 4.6, an example is given building on the previous example. It illustrates a person anticipating that the other person anticipates her reasoning. So the person considers that the other player has a ToM_0.

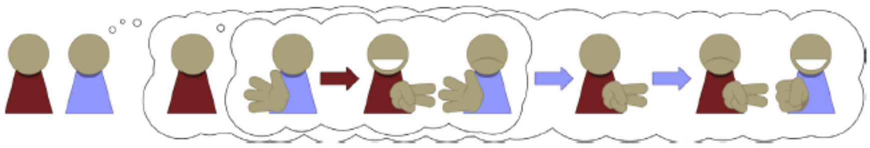


Figure 4.6: Example of first-order theory of mind, while playing rock paper scissors. [18]

Second-order theory of mind (ToM_2), the agent realises that another agent might know that it knows that they have different goals. Therefore it will anticipating the reaction of the other agent on its most logical decision and then make a decision based on this reaction. In Figure 4.7, an example is given building on the previous example. It illustrates a person anticipating that the other person anticipates her reasoning one step further. So the person considers that the other player has a ToM_1.

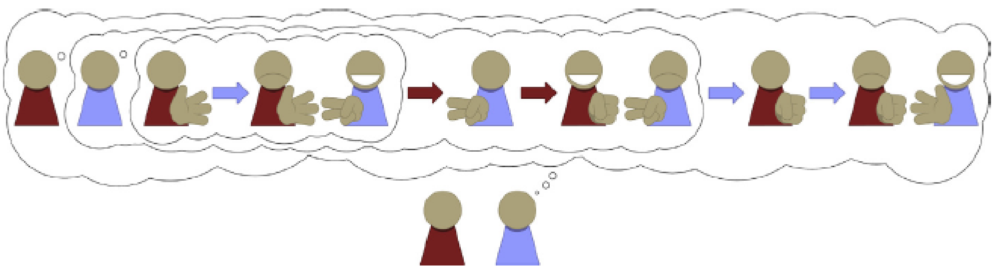


Figure 4.7: Example of second-order theory of mind, while playing rock paper scissors. [18]

This can go on to higher orders. In this theory it is important to note two things. First is that this theory does not incorporate a notion that its own reasoning might be false. Furthermore, in a competitive or semi-competitive environment this theory works best for an agent if that agent has one order higher than the other agents. In a cooperative environment two agents should have the same order in order for it to work best.

Agents may thus create a model of the environment or of other agents based on their own basic knowledge, their observations and the information given by other agents. In this way an agent might be able to anticipate the behaviour of another agent, or a state of the environment.

4.3.2. Expanding an existing Agent-Based Model

When creating any model certain steps need to be performed, these steps are the same when one is expanding an existing model.

Design Steps

These can be divided in four main steps: designing, implementing, evaluating and conclusion. A more detailed model of these steps is described by [11] and can be found in Figure 4.8.

The first phase, design and preparation, mainly exists of preparing the next phases. When building the model, the steps as prepared by the previous phase are implemented. Afterwards model evaluation is done in three steps: verification, calibration and validation. Verification is checking whether or not there are any mistakes in the model. If there are, changes need to be made in the model. Calibration is adjusting some parameters to make the model fit historical data or an experts knowledge. Validation is there to make sure the model is not overfitted to one case, by applying the model to new data. Calibration and validation have a feedback loop to the design phase in order to check if the aim of the model has been satisfied. The last phase is done by running the model and understand the insights.

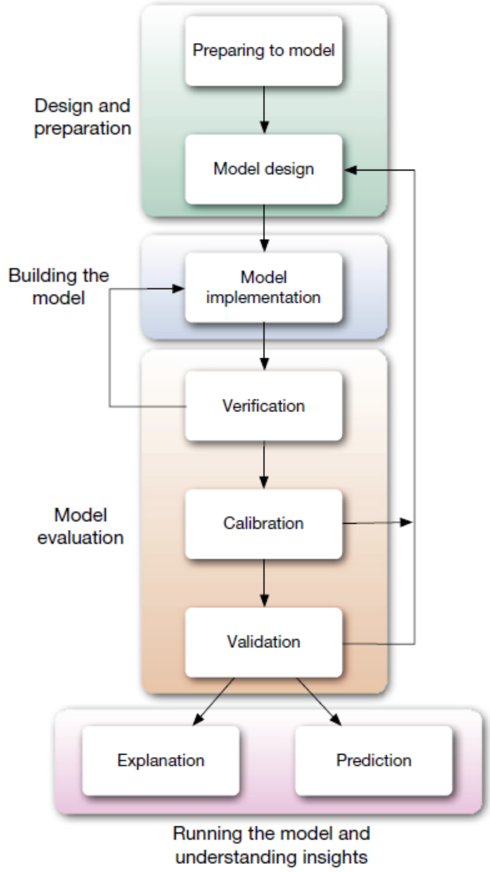


Figure 4.8: General steps taken when creating an Agent Based Model. [11]

This whole reports lays the foundation for the design phase. At the end of this report the following questions should be answered:

- What is the aim of the model?
- What will the model look like?
- What is the methodology?

The answers to these questions will be the guideline for the further course of the thesis.

Programme

As the goal is to expand an existing agent-based model, the programme in which this expansion is done can already be decided upon. The existing agent-based model is made in Netlogo, however that does not mean that the model cannot be converted. MESA is a new programme from Python which is based on Netlogo. As Python is a more general language, converting the model might be worth it.

As there was not too much information to be found on both programmes, the opinions of eight people who have worked with both programmes was gathered. To make a comparison between the two, the general remarks are put in Table 4.4.

Netlogo	***Python MESA***
Advantages	
• Very visual • Elaborate library with example models • Simple	• For Python the documentation is very elaborate • Pre-defined class and object structures for model, agents, schedule, grid and visualisation • Possibility for data import and export and external functions • Works as modular framework
Disadvantages	
• From code to visual part takes more than a minute to load • Hard to debug • Small community • No skewed lines • Simple program, difficult for complex models • One big file	• Making the model visual takes more time • Not a lot of documentation for MESA yet

Table 4.4: Summary of advantages and disadvantages of Netlogo and Python MESA

Considering all the advantages and disadvantages it can already be decided that converting the model to Python MESA is the best choice. The reason is that, even though converting might be time consuming and Netlogo is easy to understand and very visual, Python MESA has a better potential to expand the model. This is especially important because there will be parts added to the existing model, the modular framework will make it more understandable. Furthermore as the model might be used in more research, more expansions might be done to it. The downside to Python MESA is that MESA is a young programme, so there is not a lot of documentation yet. However this is countered by the fact that the Netlogo community is also not very big, so the same problem there. The only difference is, is that the Python language itself is very well known with a very large community.

4.4. Conclusions

An airport, as humanitarian hub, is a complex and sociotechnical system. Agent-based modelling has been chosen as the paradigm to model this humanitarian hub. The existing PJIA Model can be used as the basis for implementing the coordination mechanisms.

When looking more closely to the PJIA Model it can be said that it is very elaborate, but there is room for more depth. It simulates very standardised processes, where all information is accessible. These are two very large assumptions which can be researched more thoroughly. The model can be expanded in two ways. On the one hand the assumption that the environment is fully accessible can be changed, by not giving all the (correct) information. On the other hand the agents themselves can have deeper cognitive properties, using the theory of mind. These deeper cognitive properties can make an agent anticipate certain actions and react on that, this will make the cargo handling processes and the information processes less standardised. In both cases changes need to be made to the existing agents. The decision ladder model could be used in order to change an agent's behavioural and cognitive characteristics. The research questions could incorporate the analysis of the effect of:

- The knowledge of the agent about the environmental state.
- The knowledge of the agent about other agents state.
- The knowledge of the agent about other agents cognitive abilities.
- The knowledge of the agent of what it does not know.
- The resistance of the model in case of misinformation/communication.

As this literature study is part of the preparation phase of the thesis, in section 5 the following questions need to be answered:

- What is the aim of the model?
- What will the model look like?
- What is the planning for the next phases (implementation, evaluation and explanation)?

One thing has already been decided on and that is the programme in which the model will be implemented. Even though the existing model is made in Netlogo, it has been decided that it will be first converted to Python MESA. This is decided despite the fact that it might be time consuming, but with the eye its future use and expansion. Python MESA has as main advantages over Netlogo that it is a language used for more than Agent-Based Modelling and that its has a modular coding style.

5

Research Proposal

This chapter concludes the literature study with in Section 5.1 a summary of this report. Following from that the proposed research questions are presented in Section 5.2. Section 5.3 elaborates on the work that needs to be done for each question. Afterwards, in Section 5.4, the planning for the proposed research is given.

5.1. Summary of Literature Study

Natural disasters can have a significant impact on human lives. More and more natural disasters will occur in the future due to climate change. The research focuses on:

Airports as a humanitarian hub in the response phase after a sudden onset emergency because of a natural disaster.

Airports can play an important role in humanitarian relief operations. As humanitarian hubs they can bring relief aid into a stricken area and evacuate people out of there. However these airports can also become bottlenecks in the relief operation. A literature study on the subject showed that the cargo flow and the coordination are one of the problems for becoming a bottleneck. However there is no research combining the two. Coming to a first question:

Can the cargo flow become more efficient by changing the informational processes or by changing the organisational structure?

An agent based model exist that simulates such ground handling operations in a detailed and retrospective way. The model is simulates the coordination in the ground handling operations from landing to the terminal building and vice versa. The case study used was Princess Juliana International Airport, located on Sint Maarten, after the hurricanes in 2017. The case study itself fits problems that are also mentioned in other case studies and literature, namely the lack of available resources and overall coordination between the different entities. Before checking if the model suits the research as well, it was first investigated how these coordination mechanisms could be implemented in the case study.

Coordination is "The act of managing interdependencies" [12], in this research coordination is investigated in terms of information processes and organisational structures. An organisational structure can be defined by its complexity, its degree of centralisation (who has what amount of authority) and its degree of standardisation (who has what amount of control). In the case study the structure is of distributed authority with standardised control. Looking at the preliminary research question, the literature and the case study it would be best to compare standardised control with less standardised control, while keeping the same complexity and a distributed authority. This less standardised control is also called 'loosely coupled control', which means that there are still standardised rules, but the rules are giving a boundary rather than the exact process. In other words there is room for reasoning.

In order to reason the situation awareness of individual needs to change. When two individuals enter a joint activity, they need to have common ground. Common ground is achieved when the two individuals are aware of each others situation and situational awareness. This common ground can also be lost and most of the time that is were coordination fails. The resilience of the system against such loss of common ground should be tested. The theory of implicit coordination can be used to go a step further in the model and make agents be able to anticipate certain events. However first the research method should be defined and then how these theories could be implemented.

An airport as a humanitarian hub is a complex sociotechnical system. Often these systems are modelled using a Multi-agent System modelling paradigm. Using the definition it was found that this is also suitable to use for this research, therefore not only the case study can be used for the research, but also the existing PJIA Model. In the model there are four different coordinating agents for the ground handling operations and seven different kind of executing agents. The agents are a mix of the passengers, Dutch military, civil aviation and an airport subcontractor called Menzies Aviation. There are five different types of ground support equipment, all owned by Menzies Aviation, and three different kinds of cargo. The services that are modelled are the cargo offload from the aircraft to the terminal building and getting the passengers from the terminal building to and in the aircraft. At the moment the model has a lot of elements, but the agents are relatively shallow. Only the coordinating agents can make a basic form of reasoning.

How these aforementioned reasoning and anticipation can be further implemented in an agent based model, one should look at the decision ladder model and the theory of mind. The decision ladder model is a useful technique to simulate decision making and reasoning. One of its main advantages is that this model can be adapted according to the expertise and situation awareness of an agent. Furthermore the theory of mind can be applied when wanting to implement anticipating properties in an agents.

The PJIA model can be expanded by using the same steps when building a model. The next sections will elaborate on the aim of the model, the design steps and the planning. It is already decided that the existing PJIA model will be converted from Netlogo to Python MESA, because of the modularity and prospect of possible expansion. Furthermore the existing scope of the model does not have to change, it can keep the same agents and processes. It is possible to further simplify the model, however the effect of the changes need to be evaluated first.

It is established that the organisational structure and information processes in a system are dependent on each other. When making room for reasoning in the rule setting, there is room for experimenting with different information processes. The information processes include all direct and indirect communication between the agents. First the coordinating agents will be assessed, in a later stage it would be possible to give more depth to the executing agents.

It is established that the organisational structure and information processes in ground handling operations can have an influence on the cargo flow. The structure can be changed to a less standardised rule setting, called loose-coupling. The exact change in information processes still need to be researched. But a loss of common ground can be used to check the resilience of the system.

Whether these changes makes the cargo flow more efficient, leads directly to the following research objective:

Analyse and understand the information flow and the effect of less standardised control on the performance of ground handling operations at an airport as humanitarian hub.

5.2. Research Questions

The research objective is formulated in the previous section. From this research objective the main question becomes as follows:

What is the effect of changes in the information flow processes on the performance of ground handling operations at an airport as humanitarian hub.

Part I - Identify the information flow processes of the PJIA model.

WP 1 - **How can the information flow processes of the PJIA model be analysed?**

1A. What are the information processes in the PJIA model?
1A. What are the PI's that are influenced by the information processes?
1A. What are relevant scenarios in which the resilience of the system is tested using the PI's?

WP 1 - **How can the current model be changed to incorporate the identified method of analysis?**

2A. How does the model need to be transferred to Python MESA?
2A. Is the PJIA model in Python MESA modelled correctly?

Part II - Analyse and understand information flow processes in the PJIA model.

WP 1 - **What are the bottlenecks in information flow of the current system?**

3A. How does the current system perform under different circumstances, using the PI's?
3A. WP 3B - Where are the bottlenecks in the information flow of the ground handling operations?
3A. What are the possible shortcuts that can be taken in the information flow?

WP 1 - **Are shortcuts in the information flow more efficient when looking at the PI's?**

4A. How does the system perform when implementing the defined shortcuts in the information flow?
4A. How does the system perform compared to the original PJIA model?

Part III - Analyse and understand information flow processes when agents are allowed to anticipate

WP 1 - **What effect does anticipating properties in coordinating agents have on the total system?**

5A. What can the coordinating agents anticipate?
5A. What information do the coordinating agents need in order to anticipate?
5A. What is the effect on the PI's when anticipation is implemented in the proactive agents?

WP 1 - **What effect does anticipating properties in executing agents have on the total system?**

6A. What can the executing agents anticipate?
6A. What information do the executing agents need in order to anticipate?
6A. What is the effect on the PI's when anticipation is implemented in the executing agents?

5.3. Methodology

The research will consist of three parts, first there is the identification of the current processes and how the analysis will be done will be defined. Then the current system will be analysed and evaluated. Afterwards changes will be implemented in the system, making the rules of the system less standardised. These changes will also be analysed and compared.

All questions build on each other, meaning that a question cannot be answered when the answer of a previous question is incomplete. Each part can contain a relevant conclusion, in case the estimated timeline is proven to be incorrect in practice. Furthermore, after each part, the relevance and possibilities of the next part should be first checked before starting on this new part. This might cause certain subquestions to change over the course of the research.

Part I - Identify the information flow processes in the PJIA model.

This part has as goal to determine the information processes in the PJIA model and to establish the way the system will be analysed. Furthermore this part aims to transfer the PJIA Netlogo model to a PJIA Python MESA model, using the modularity of the last to its advantage without changing the simulation runs.

WP 1 - How can the information flow processes of the PJIA model be analysed?

After this Work Package, the full PJIA model should be understood and the method of analysis defined.

WP 1A - What are the information processes in the PJIA model?

The first subquestion is used to get a general understanding of the current system. In this Work Package the following subquestions need to be answered, by using the current PJIA model:

- Who are the actors in the current system?
- What are the interactions and interdepencies between the identified actors and the environment?
- How are the actors, environment and interactions defined and implemented in the model?
- What is the best way to map the actors, interactions and interdependencies?

After all this the information flow processes should be fully identified and the PJIA model in Netlogo should be fully understood.

WP 1B - What are the PI's that are influenced by the information processes?

This subquestion has as goal to understand which part of the ground handling operations are possibly influenced by a change in information flow processes. Also this question should define what is understood with 'good' communication.

Therefore the following subquestions should be answered in this Work Package:

- What are the PI's for the ground handling operations?
- What are the PI's that define 'good' communication'?
- What services or actors do not or have little influence on these PI's (e.g. how can the model be even more simplified).

These questions can be answered by using the identified information flow processes and the understanding of the model found in WP 1B.

WP 1C - What are relevant scenarios in which the resilience of the is tested using the PI's?
The point of these scenarios should be to test the resilience of the whole system. These circumstances should thus be defined so that they are applicable to test the performance of the system when a change in information process is implemented.

- What are realistic 'Problematic' circumstances, that have a possible influence on all the PI's?
- What are realistic 'Improved' circumstances, that have a possible influence on all the PI's?

An example of problematic circumstances would be when wrong or incomplete information is given, without the recipient knowing this.

An example of improved circumstances would be when the MOVCON would have a bike. Or there was a schedule for incoming aircraft. Even the implementation of walkie talkies is possible.

WP 2 - How can the current model be changed to incorporate the identified method of analysis?

After this Work Package the PJIA model should be transferred from Netlogo to Python MESA and validated. The new model should represent the simulation, however the build up of the model is allowed to change.

WP 2A - How does the model need to be transferred to Python MESA?
In this part of Work Package 2 it should be considered in what way the model should be build and how the modularity of Python MESA can be incorporated with an eye to future changes and/or expansion.

- What are the procedure functional blocks of airport emergency operations?
- How can the modularity of Python MESA be used to improve the model towards future changes/expansions, while keeping the simulation itself the same?
- How can the newly defined PI's be implemented in the model?
- How can the defined scenarios easily be turned on or off in the model?

After answering the three questions, the model should be transferred from Netlogo to Python MESA.

WP 2B - Is the PJIA model in Python MESA modelled correctly?
Here there are two main things that need to be determined first:

- How can verification and validation of the transferred model is done?
- How often should the simulations be ran in order to be able to make the right conclusions?

After answering these questions verification and validation of the new PJIA model can be done and conclusions can be made.

PART II - Analyse and understand the information flow processes in the PJIA model.

From this point onwards the PJIA model is the Python MESA version of the PJIA model. This part aims to understand how the information processes happen in the model and what the resilience in the system is.

WP 3 - What are the bottlenecks in information flow of the current system?

This Work Package has as aim to identify the points in the information process that cause a delay or a detour of the information.

WP 3A- How does the current system perform under different circumstances, using the PI's?
In this subquestion the information processes of the system will be analysed by comparing the different circumstances.

- How does the current system perform?
- How does the system perform under 'Problematic' circumstances?
- How does the system perform under 'Improved' circumstances?

WP 3B - Where are the bottlenecks in the information flow of the ground handling operations?
Using the answers to previous question the delays or detours in the information process are determined.

WP 3C - What are the possible shortcuts that can be taken in the information flow?
This subquestion directly follows from the previous. Where WP 3B determines the bottlenecks, here the possible improvements are identified.

WP 4 - Are shortcuts in the information flow more efficient when looking at the PI's?

In Work Package 3 the bottlenecks and possible shortcuts are identified. In this Work Package these possible shortcuts will be analysed and compared to the original system of the PJIA model.

WP 4A - How does the system perform when implementing the defined shortcuts in the information flow?
Each defined shortcut that might have a possible positive impact on the system will be implemented in the system. After which the simulations will be run for each of the three circumstances. Then, using the PI's, the following questions will be answered:

- How does the system perform with a single shortcut?
- How does the system perform under 'Problematic' circumstances?
- How does the system perform under 'Improved' circumstances?

WP 4B - How does the system perform compared to the original PJIA model?
Compare the answers of WP 4A with the answers of WP 3A. Is taking a shortcut really more efficient when looking at the PI's? If multiple shortcuts are identified and analysed, the results should also be compared to each other.

Part III - Analyse and understand information flow processes when agents are allowed to anticipate.

This part aims to analyse the system in the same way as is done with the shortcuts. Only here the effects of anticipating properties in agents is investigated. Implementing anticipated actions means that the agent has more room to choose its course of actions. This automatically implies more control and less standardisation of the job of the anticipating agent. Therefore the rules are more loosely-coupled keeping a distributed organisation.

WP 5 - What effect does anticipating properties in pro-active agents have on the total system?

This Work Package aims to analyse the effects of anticipating properties in coordinating agents.

WP 5A - What can the proactive agents anticipate?
This subquestion needs to be answered using the understanding and evaluation of previous Work Packages.
WP 5B - What information do the proactive agents need in order to anticipate?
After answering the question in WP 5A, a list of all the information an anticipating actor needs should be made. Including a detailed explanation of the influence this anticipation has on the other agents and the environment in the system.

WP 5C - What is the effect on the PI's when anticipation is implemented in the proactive agents?
The anticipating properties will be implemented and the simulation will be run for the following circumstances:

- How does the current system perform?
- How does the system perform under 'Problematic' circumstances?
- How does the system perform under 'Improved' circumstances?

Afterwards the performance of each circumstance is compared to the original scenario.

WP 6 - What effect does anticipating properties in executing agents have on the total system? (those agents become proactive then)

This Work Package aims to analyse the effects of anticipating properties in coordinating agents.

WP 6A - What can the executing agents anticipate?
This subquestion needs to be answered using the understanding and evaluation of previous Work Packages, while also answering the following question:

- Which service or process can be less standardised while keeping a distributed organisation?
- How can these ground handling operations be less standardised?

WP 6B - What information do the executing agents need in order to anticipate?
After answering the question in WP 6A, a list of all the information an anticipating actor needs should be made. Including a detailed explanation of the influence this anticipation has on the other agents and the environment in the system.

WP 6C - What is the effect on the PI's when anticipation is implemented in the executing agents?
The anticipating properties will be implemented and the simulation will be run for the following circumstances:

- How does the current system perform?
- How does the system perform under 'Problematic' circumstances?
- How does the system perform under 'Improved' circumstances?

Afterwards the performance of each circumstance is compared to the original scenario.

5.4. Project Planning

In Figure 5.1 the complete project planning can be found. The full questions of the Work Packages can be found in Section 5.2. As can be seen, the midterm presentation is planned right after Work Package 3. The green light meeting is planned for the beginning of March. This means that there might be no time for Work Package 6. The decision for that will be made at the midterm presentation.

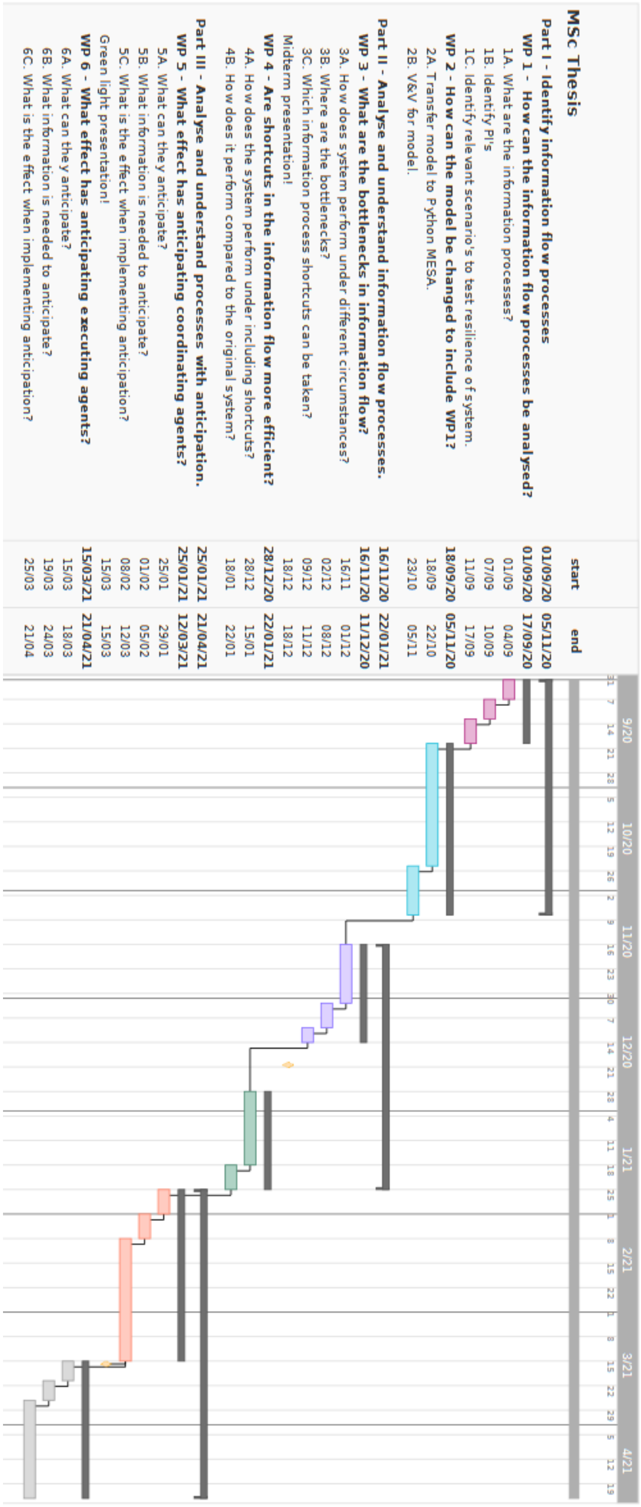


Figure 5.1: Full Gantt chart of Master thesis planning.

III

Supporting work

1

van Liere's Model

In Figure 1.1 the interactions and cognitive specifications of van Liere's model are given.

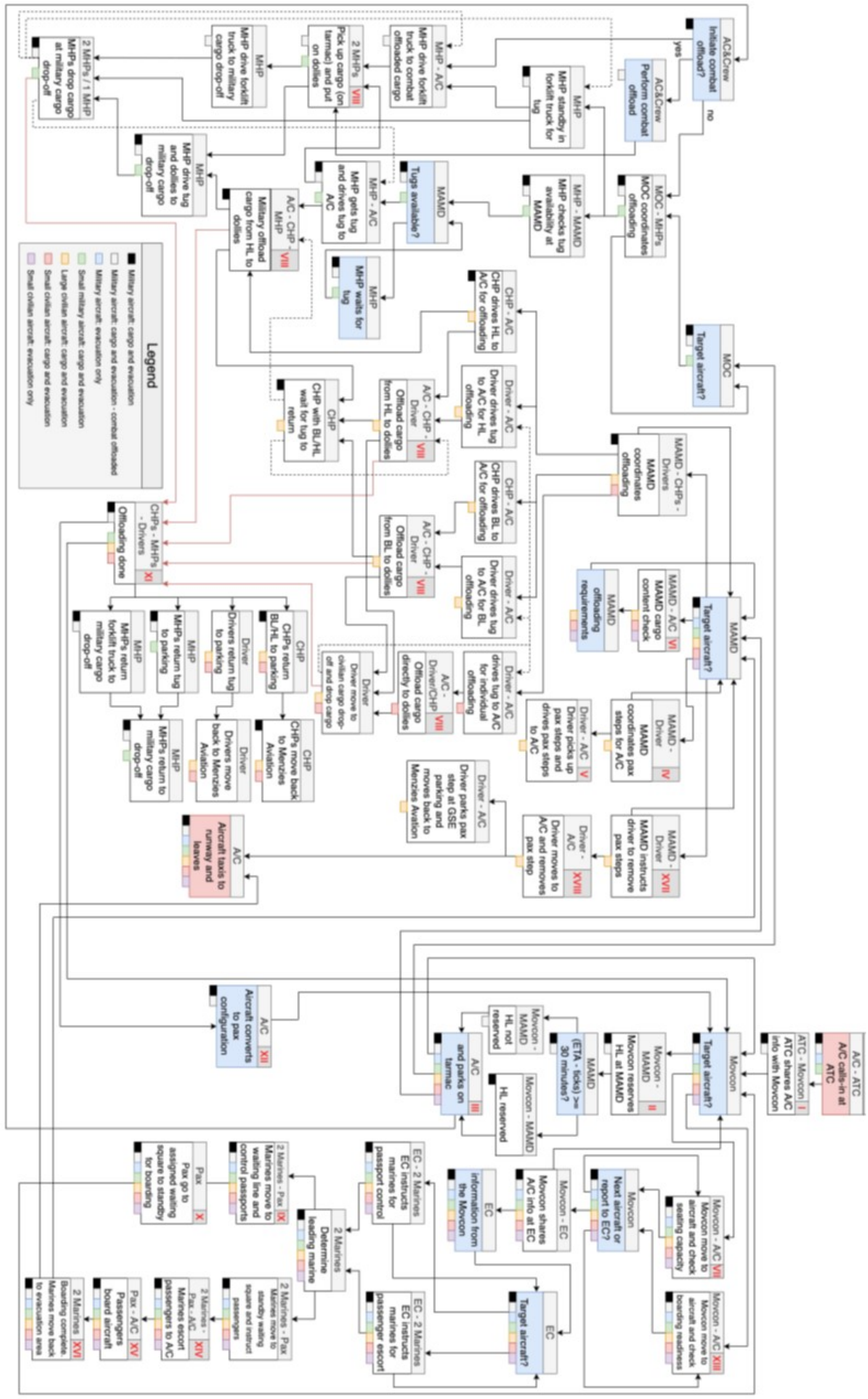


Figure 1.1: van Liere's model coginitive and interaction specifications [31].

2 Calculations

2.1. Time Penalty Calculations

The time penalty for boarding is shown in Equation 2.1. It is calculated as the boarding rate ($R_{boarding}$), in seconds/pax, times the amount of passengers that could board the aircraft (N_{pax}), this results in T_{board}.

$$T_{board} = R_{boarding} \cdot N_{pax} \tag{2.1}$$

The time penalty for offloading civilian aircraft is calculated by the amount of cargo (N_{cargo}), in kilograms, divided by the offloading rate (R_{Offl}), in kg/s. This is shown in Equation 2.2. On one TD, there can be maximally 6400 kg of ULD cargo, 2000 kg of ICU cargo or 18000 kg of 463L cargo.

$$TP_{Offl} = \frac{N_{cargo}}{R_{Offl}} \tag{2.2}$$

This calculation is used for getting the cargo from the aircraft onto the tug with dollies, as well as from the TD on the cargo drop off point. The difference is the R_{Offl} used.

For military offloading the time penalty takes all cargo at once into account. This is similar to the calculation as in Equation 2.2. Only the whole offloading is calculated at once, as can be seen in Equation 2.3. Where $R_{Offl_{AC}}$ is the offloading rate from the airport onto the TD and the $R_{Offl_{TD}}$ from the TD onto the cargo drop off point.

$$TP_{Offl} = \frac{N_{cargo}}{R_{Offl_{AC}}} + \frac{N_{cargo}}{R_{Offl_{TD}}} \tag{2.3}$$

The calculation above is done for the 463L cargo, as well as the ICU cargo. The time penalty is chosen as the largest of the two time penalties.

2.2. Calibration Calculations

The calculations for the boarding and offloading rate are as shown in Equation 2.4. Where $R_{Boarding}$ is the boarding rate, $N_{pax_{AV}}$ is the average amount of pax per aircraft and $T_{board_{EXP}}$ is the average boarding time according to experts.

$$R_{Boarding} = \frac{N_{pax_{AV}}}{T_{board_{EXP}}} \tag{2.4}$$

The recalibration of the offloading is rate is done by experimental approach until the offloading rate matched the experts' offloading time.

3

Coefficient of Variation

The Coefficient of Variation (CV) per run of the TAT, offloading and boarding time for civilian aircraft can be found below. The average TAT, offloading and boarding time for military aircraft are constant, these are not given.

As can be seen in Figures 3.1 and 3.2, all CVs for large civilian aircraft are constant for every test case after 120 runs. The TAT and boarding time have similar CV of around 4. The CV of the offloading time is slightly higher with 6, however it is still constant. In Figures 3.3 and 3.4, the CVs for small civilian aircraft is given per run. Also here it can be seen that they are constant after 120 runs, even though the CV for boarding is really high. The reason for this is that the amount of pax in small aircraft differs a lot, between 6 and 30 pax. Also the amount of cargo has a relative large range, between 500 and 800 kilograms.

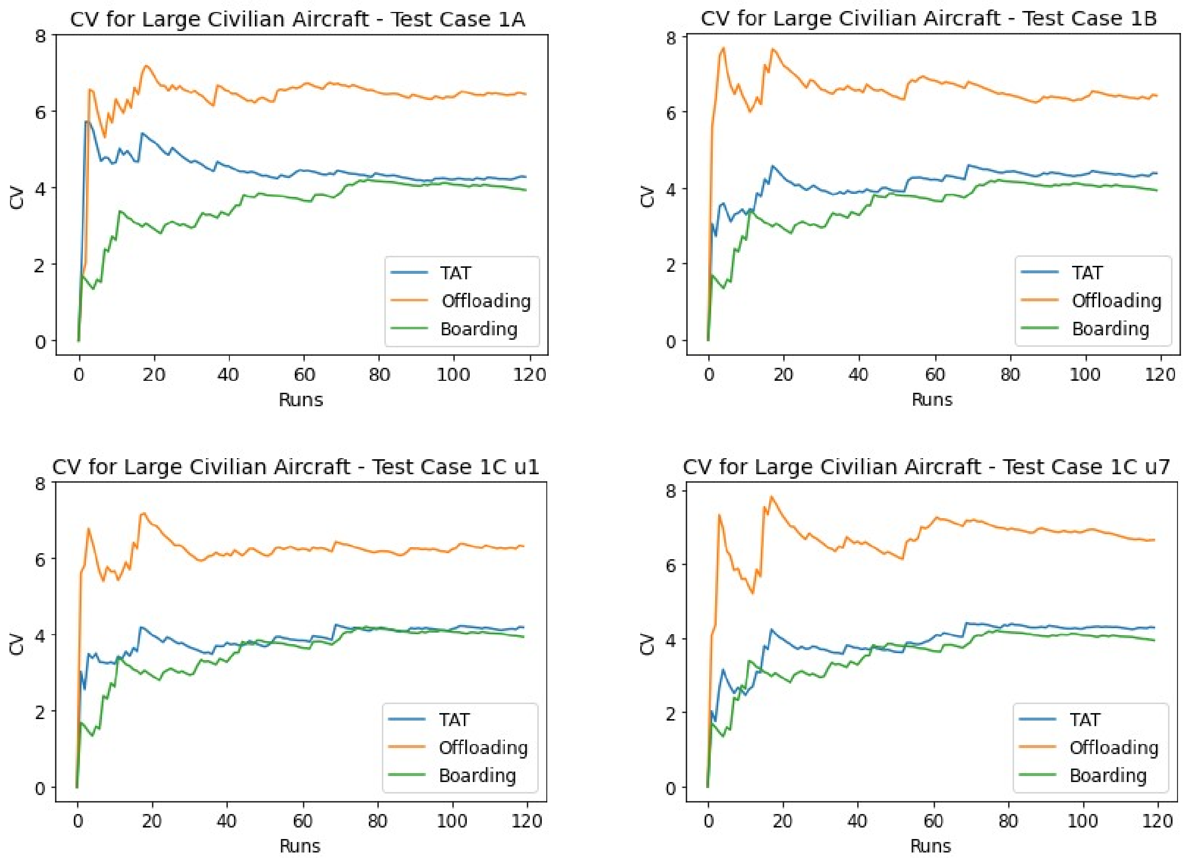


Figure 3.1: Coefficient of Variation for TAT, offloading time and boarding time of large aircraft for strategy 1.

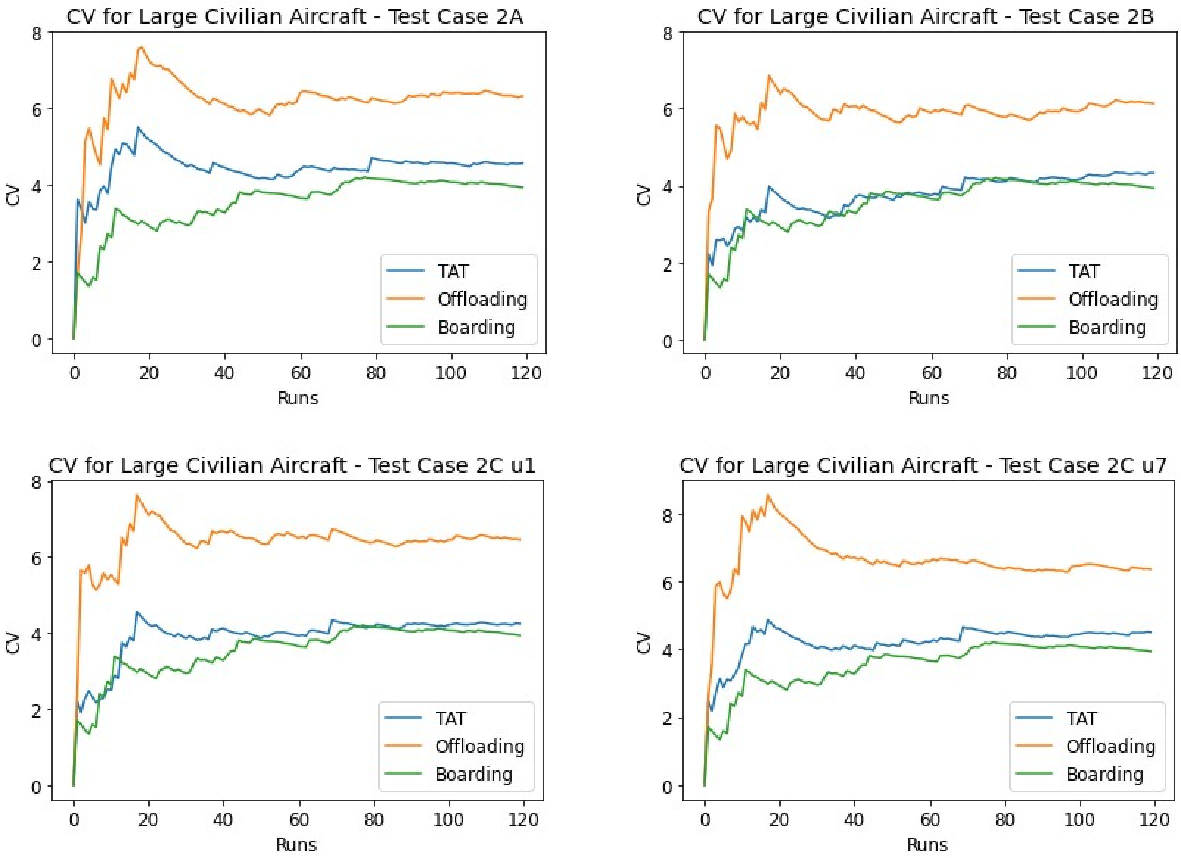


Figure 3.2: Coefficient of Variation for TAT, offloading time and boarding time of large aircraft for strategy 2.

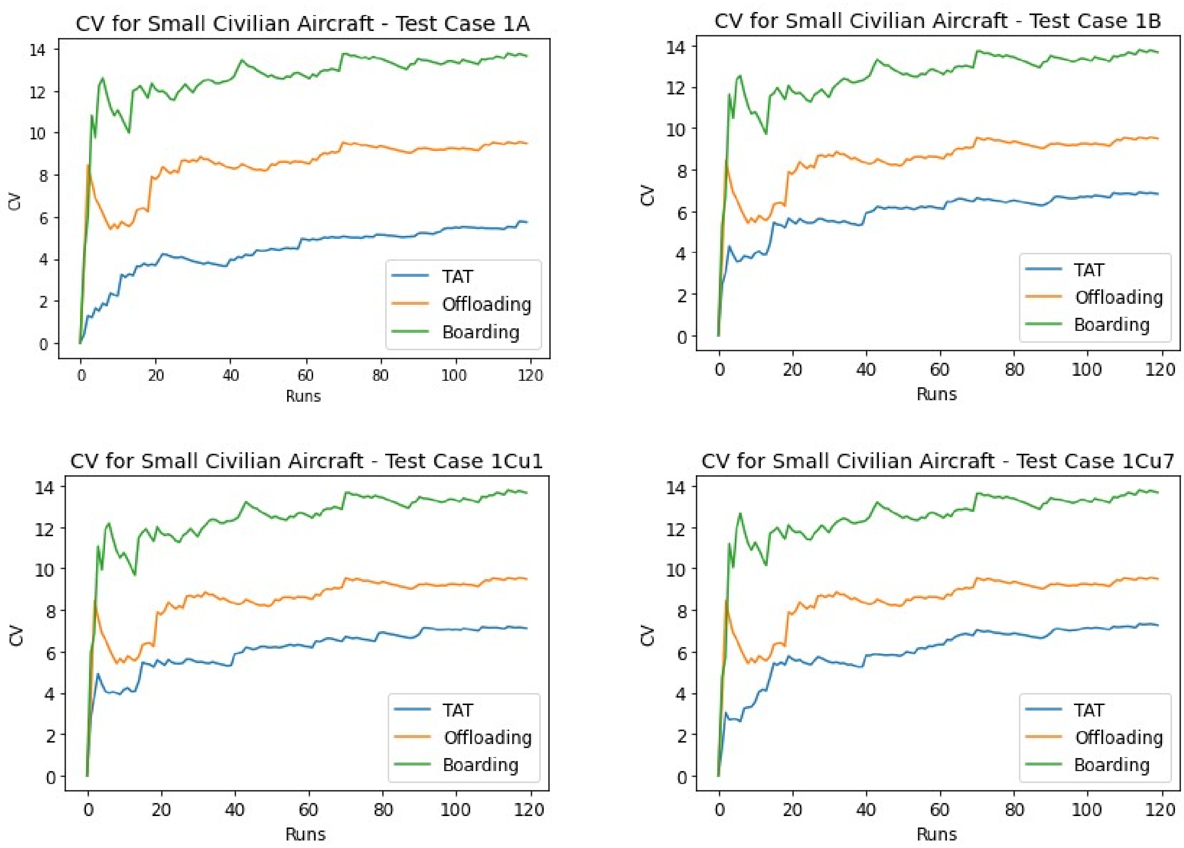


Figure 3.3: Coefficient of Variation for TAT, offloading time and boarding time of small aircraft for strategy 1.

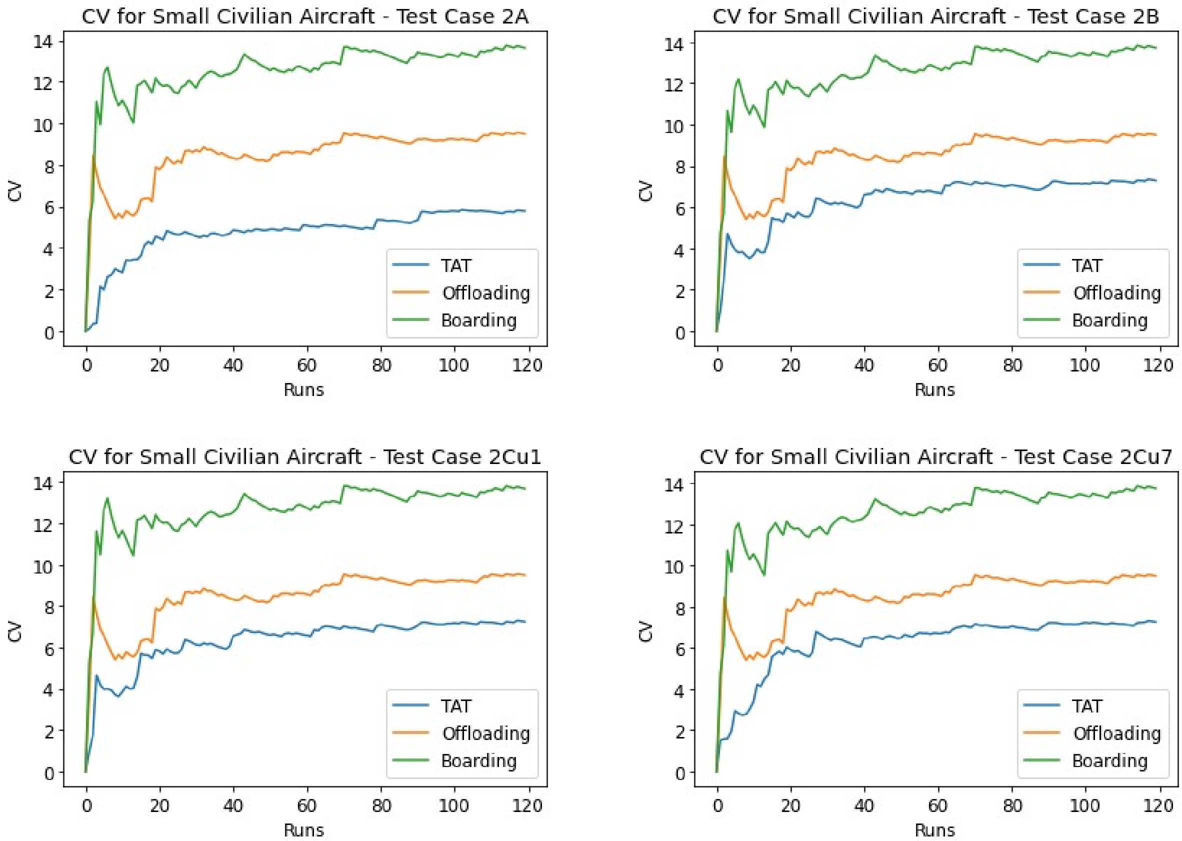


Figure 3.4: Coefficient of Variation for TAT, offloading time and boarding time of small aircraft for strategy 2.

4

Experiment Results of Small Aircraft

4.1. Calibration Results

The results of the calibration for small civilian aircraft with cargo and pax are given in Table 4.1. The values of van Liere's model are estimations as they are taken from histograms [31].

Table 4.1: The average TAT, offloading time and boarding time in minutes for small civilian aircraft with cargo and pax.

	TAT	Offloading	Boarding
van Liere's model	47.5 (est.)	7.5 (est.)	9 (est.)
PJIA model C0	48.6	7.0	12.5
PJIA model C3 (old strat)	45.3	7.0	10.0
PJIA model C3 (strat. 1)	45.9	7.0	10.0
PJIA model C6 (strat. 1)	48.7	7.8	10.0

4.2. Test Cases Results

In Table 4.2, the results for all test cases, for small civilian aircraft with cargo and pax are given. The average time as well as the standard deviation are presented for the TAT, offloading and boarding. Furthermore, Table 4.2 shows the average waiting times for small civilian aircraft with pax and cargo. There are only two waiting times, the before cargo is checked time (T_{BC}) and the before offloading starts time (T_{BO}), as small aircraft do not need pax steps.

Table 4.2: The average TAT, offloading time and boarding time in minutes for small civilian aircraft with cargo and pax.

	TAT		Offloading		Boarding		T_{BC}	T_{BO}
Case 1A	48.7	± 2.8	7.8	± 1.1	10.0	± 0.9	7.2	10.7
Case 1B	34.1	± 2.3	7.7	± 1.1	10.0	± 0.9	0	3.4
Case 1C u1	34.3	± 2.4	7.7	± 1.1	10.0	± 0.9	0	3.6
Case 1C u7	35.5	± 2.6	7.7	± 1.1	10.0	± 0.9	0.2	4.6
Case 2A	49.3	± 2.9	7.8	± 1.1	10.0	± 0.9	7.2	11.3
Case 2B	34.6	± 2.5	7.7	± 1.1	10.0	± 0.9	0	3.9
Case 2C u1	34.6	± 2.5	7.7	± 1.1	10.0	± 1.0	0	3.9
Case 2C u7	35.8	± 2.6	7.7	± 1.1	10.0	± 0.9	0.2	4.9

5

Results Strategy 2

Figure 5.1, gives the distribution of the TAT per test case for strategy 2. The TAT can be divided in offloading time (T_{Offl}), boarding time (T_{Board}) and waiting time. The distribution of the waiting time for all test cases of strategy 2 is given in Figure 5.2. The waiting time can be divided in before paxsteps are ready time (T_{BPS}), before cargo content is checked time (T_{BC}), before offloading starts time (T_{BO}), and before paxsteps are removed time (T_{BPSR}). These results are similar to those of strategy 1, which are presented in the paper.

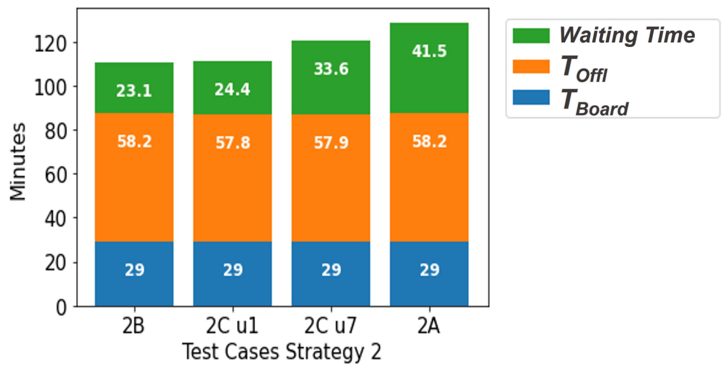


Figure 5.1: Distribution of the turn around time of large civilian aircraft for all test cases of strategy 2 in order of decreasing knowledge.

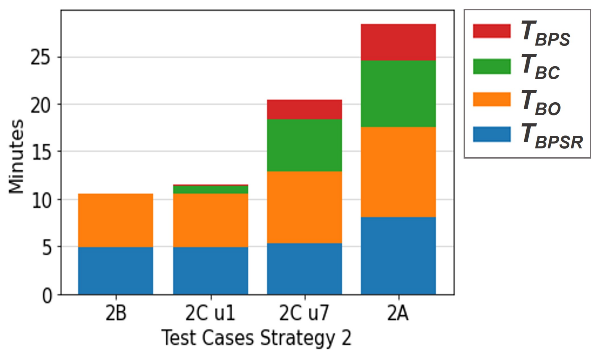


Figure 5.2: Distribution of the waiting times of large civilian aircraft for all test cases of strategy 2 in order of decreasing knowledge.

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