

# Capacity requirements analysis of civil air traffic in military controlled airspace

*Capacity estimation Lelystad TMA*

Thesis

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## *Capacity estimation Lelystad TMA*

Thesis

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## Preface

This research report was written to comply with the graduation requirements of the Bachelor of Science degree in the Aviation Engineering program from the Amsterdam University of Applied Sciences. This bachelor focusses on a wide range of Aviation related subjects including Maintenance Repair and Overhaul (MRO) business, theory in automated flight, airframe mechanics, and aircraft performance. This thesis combines all this knowledge and applies it to a capacity requirements analysis for the Lelystad TMA.

This thesis is commissioned by the Knowledge Development Centre – Centre of Excellence (KDC-CoE). Graduating at the KDC-CoE was a unique opportunity to increase my knowledge in air traffic management and airspace capacity. The collaboration with LVNL and CLSK gave me the opportunity to experience both working environments. Additionally, the research into the capacity of Lelystad TMA was an unique project that is very current at the moment.

I would like to thank my supervisors Ton van Kempen and Frenchez Pietersz for their support and guidance during my graduation. Their ideas, vision and expertise help me achieve more knowledge and supported me in my motivation.

Next to my supervisors, I would like to thank Alina Zelenvska for her efforts in guiding me in combination with the weekly SCRUM sessions. Thanks to the sessions I was able to structure my research and work as efficiency as possible. During the sessions she gave advice how to tackle objectives and to work so sufficient as possible.

Moreover, I would like to thank Kees Moerkerk for his input and guidance during the research. Without his guidance during the research it was not possible to achieve the quality of the report and to organize the expert sessions.

Furthermore, I would like to thank the employees of CLSK and LVNL who were willing to contribute to my research with the performed interviews and expert sessions. The information gathered during the interviews and sessions formed the basis of the research.

Finally, I would like to thank the other graduate students Marc Riebeek, Marc Voogt and Casper Moll for creating a professional and enjoyable working environment in the office. Together we formed a team and helped each other, which contributes to the quality and level of this research.

Tessa Rietema

Schiphol, 28-02-2019

## Abstract

The determination of the capacity of the Lelystad Terminal Maneuvering Area (TMA) is complex and brings different challenges. The opening of Lelystad airport (EHLE) for civil air traffic is the motivation to perform research into the capacity of the Lelystad TMA. The Lelystad TMA is controlled by Command Air Force (CLSK) and the tower and Area Control Centre (ACC) by Air Traffic Control the Netherlands (LVNL). CLSK and LVNL have a different way of handling aircraft, CLSK works with flight responsibility and LVNL with area responsibility. When the research started CLSK did not make use of a workload model to determine the capacity of an airspace. The aim of this research is to help CLSK to determine the capacity factors and the capacity of the Lelystad TMA.

At the moment, only the capacity of the TMA is missing in the overall capacity of Lelystad airport. In the Safety Efficiency and Environment Impact Reporting (VEMER) the capacity of the airport, runway and Controlled Traffic Region (CTR) are already determined. When the capacity of the TMA is determined, a total overview of the capacity can be delivered. The number of slots for the airport is based on the total capacity of the handling process. Therefore, airlines have not made flight schedules yet for the airport.

My means of interviews and expert sessions with operational experts of CLSK data is created to use during the research. With the data, the volume and capacity of the TMA is calculated. After this, a bottleneck analysis is conducted for the capacity of the handling process of EHLE. The bottleneck in the handling process is the airport with its aircraft stands. After this, the TMA is the limiting capacity compared with the runway. Additionally, the annual maximum flight movements of 4,000 and 10,000 is feasible with the structure of the TMA. When the airport becomes operational for commercial traffic, the established capacity must be validated.

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## List of Abbreviations

AAS	Amsterdam Airport Schiphol
ACC	Area Control Centre
AMSL	Above Mean Sea Level
AREA	Area Control
ATC	Air Traffic Controller
ATFCM	Air Traffic Flow and Capacity Management
ATS	Air Traffic Service
b	Extra separation – human factor
C	Coefficient – complexity/interaction
CAPP	Approach Controller
CLSK	Command Air Force
CTR	Controlled Traffic Region
d	Separation distance
DBS	Distance Based Separation
EHLE	Lelystad Airport
FMP	Flow Management Position
FT	Feet
h	Aircraft distance to runway
HvA	Amsterdam University of Applied Science
I	Effort
IAS	Indicated Air Speed
IFR	Instrument Flight Rules
I&W	Ministry of Infrastructure and Watermanagement
KDC	Knowledge & Development Centre
KLM	Royal Dutch Airline
kts	knots
LVNL	Air Traffic Control the Netherlands
MILATC	Military Air Traffic Control Centre
nm	Nautical miles
$p_{mix}$	Traffic mix ratio
SID	Standard Instrument Departure
STAR	Standard Arrival Route
T	Task load coefficient
t	Average time
TAS	True Air Speed
TBS	Time Based Separation
TMA	Terminal Maneuvering Area
v	Velocity TAS
VEMER	Safety Efficiency and Environmental Impact Reporting
VEM-model	Safety Efficiency and Environmental model
VFR	Visual Flight Rules
W	Workload
$\rho$	Density

## Definitions of terms

### Capacity ATC sector

Maximum number of aircraft that are controlled in a particular ATC sector within a given time period, while still permitting an acceptable level of controlled workload.

### Aircraft flow

Refers to a group of aircraft that exhibit similar characteristics as they travel through an airspace region.

### Commercial mode

Time periods in the daily distribution of Lelystad airport where IFR flights take place from airlines. Other IFR traffic is rejected in the specified commercial modes.

### Non-commercial mode

Time periods in the daily distribution of Lelystad airport where IFR training flights, MRO flights and business flights take place. The IFR traffic that is rejected in the commercial mode will take place in the non-commercial mode.

### Area responsibility

Air traffic controller is responsible for traffic in a certain area in the airspace. Traffic which want to enter the area must ask permission of the traffic controller. The controller must give clearance to the pilot.

### Flight responsibility

Different air traffic controllers are working in one area of the airspace. Everyone is allowed to enter the area, there is only agreed who has priority in the area.

## Summary

The opening of Lelystad airport (EHLE) for civil air traffic is the motivation to perform research into the capacity of the Lelystad Terminal Maneuvering Area (TMA). The complete airspace of EHLE is controlled by Air Traffic Control the Netherlands (LVNL) and Command Air Force (CLSK). Herein the Tower is controlled by LVNL, the TMA is controlled by CLSK and the Area Control Centre (ACC) by LVNL again. At the moment, only the capacity of the TMA is missing in the overall capacity of Lelystad airport. The capacity of the airport, runway and Controlled Traffic Region (CTR) are already available. When the capacity of the TMA is determined, a total overview of the capacity can be delivered. The number of slots for the airport is based on the total capacity of the handling process. Therefore, airlines have not made flight schedules yet for the airport because no slots are available.

The main objective of this research is to define the capacity factors and the capacity of the Lelystad TMA. This results in the following main research question:

***“What elements determine and influence the capacity of the Lelystad TMA and how much capacity can be realized for civil air traffic which arrive and depart at Lelystad airport?”***

The initial step of the research is to determine which factors influence the capacity of the airspace. In addition, data has to be generated of the Lelystad TMA. There is no data available of commercial IFR traffic, since the airport is not yet operational. The theoretical volume is determined by using expected speeds on final and separation standards. The outcome of the theoretical volume is discussed during an expert session with operational experts of CLSK. The aim of the session was to get an agreement on the capacity factors and the volume of the TMA. During the session was decided to consider two traffic modes in the TMA; commercial mode and non-commercial mode. In addition, there was decided to build in margins in the theoretical volume to absorb failures during the operation. This resulted in the practical volume of the TMA, table 1 and 2.

Table 1 Volumes Commercial mode per hour

Per hour	Theoretical volume	Practical volume
Arriving aircraft	32	21
Departing aircraft	30	27

Table 2 Volumes Non-commercial mode per hour

Per hour	Theoretical volume	Practical volume
Arriving aircraft	17	11
Departing aircraft	18	16

Another expert session was organized with the same operational experts of CLSK to determine the workload and capacity. The total workload of a traffic controller is influenced by the complexity of a traffic route and the interaction between traffic routes. During the session two matrixes are filled in with scores from 0 till 4, where 0 has no influence and 4 has the maximum influence on the effort of the traffic controller. The outcome of the two matrixes results in an effort matrix. The capacity per combination of traffic routes is calculated with the effort matrix and the theoretical volume, table 3.

Table 3 Capacity per hour Commercial and Non-commercial mode

Per hour	Commercial mode		Non-commercial mode	
	Runway 23	Runway 05	Runway 23	Runway 05
Arriving traffic	21	17	8	8
Departing traffic	22	23	12	12
Mix traffic	20 - 25	18 - 21	10 - 14	10 - 12

After this, a bottleneck analysis is performed of the capacity of the TMA, runway and airport of EHLE. First the runway capacity was compared with the capacity of the TMA. In both modes and runways, the capacity of the TMA is limiting to the capacity of the runway. After this, the capacity of the TMA was compared with the capacity of the airport. The airport has 4 aircraft stands, which means approximately 8 movements per hour are possible. This makes the airport infrastructure the limiting factor in the handling process of EHLE. For the non-commercial mode the capacity of the TMA cannot be compared with the capacity of the airport, because there is no information available about the number of aircraft stands for IFR training flights.

In the VEM-Model of EHLE is stated that the maximum number of movements is 10,000 per year in 2023. For this, 17 to 34 flights per day are expected on a daily basis. On one day six hours are designated as commercial mode. The capacity per hour, for the commercial mode, for runway 23 is 21 movements per hour and for runway 05 is 19 movements per hour. In proportion, these numbers are higher than the maximum number of movements that are set. Therefore the 10,000 movements per year are feasible.

Although the research determines the capacity of the TMA, more research is necessary in order to use the capacity figures. The following recommendations result from this research:

- The capacity factors of the TMA have to be verified with the practical situation when EHLE becomes operational.
- The external factor weather is not included in the capacity. CLSK needs to perform a research in the effects of the weather on the capacity.
- The capacity and the traffic mix of the TMA has to be verified with data when EHLE becomes operational.
- CLSK has to gather data of military traffic in the TMA to create more accurate buffers and margins for the TMA.
- Between the commercial mode and the non-commercial mode, a link must be created. When the total capacity of the TMA is not used by commercial traffic, the remaining can be used by the traffic of the non-commercial mode.
- The final recommendation of the research is to make the handling procedure of the entire TMA area responsibility for the traffic controllers.

## 1 Introduction

The capacity estimation of the Lelystad Terminal Maneuvering Area (TMA) is performed for the Command Air Force (CLSK). The capacity estimation is required by the Air Traffic Control the Netherlands (LVNL). The LVNL is currently working on the structure of the airspace from Lelystad airport (EHLE). In the airspace the TMA is controlled by CLSK, they are responsible for handling aircraft in that area. Since LVNL does not control the airspace, it has appointed the Knowledge & Development Centre (KDC) to gain more insight into the capacity requirements of the airspace. The KDC is established throughout the development and improvement of the Mainport Schiphol together with the four main stakeholders; Amsterdam Airport Schiphol (AAS), Royal Dutch Ariline (KLM), Ministry of Infrastructure and Watermanagement (I&W) and the Air Traffic Control the Netherlands (LVNL).

Lelystad airport will be opened to reduce air traffic movements of Schiphol airport. The LVNL is working on the layout of the Lelystad TMA to ensure the Air Traffic Service (ATS) routes fit in the structure of the airspace. One of the requirements of LVNL for the Lelystad TMA is to change the airspace classification from E<sup>4</sup> to D<sup>5</sup>. Airspace classification D ensures the airspace remains free of uncontrolled Visual Flight Rules (VFR) traffic. In figure 1, the structure of the Lelystad TMA is illustrated. (Dekker & Meerburg, 2018)

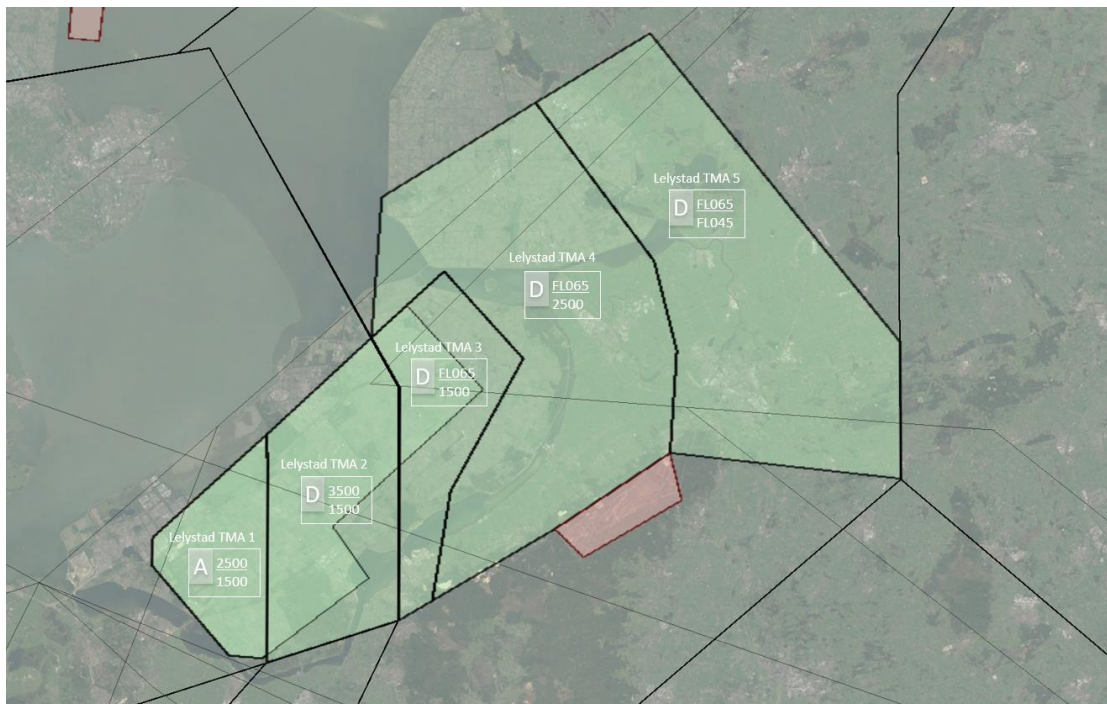


Figure 1 Structure Lelystad TMA (Dekker & Meerburg, 2018)

The complete airspace of EHLE is controlled by LVNL and CLSK. Herein the Tower is controlled by LVNL, the TMA is controlled by CLSK and the Area Control Centre (ACC) by LVNL again. The operational procedure of LVNL and CLSK for handling aircraft are different. LVNL has the responsibility of an air sector and the CLSK has flight responsibility. In the process of handling aircraft at EHLE, capacity information is unavailable of the TMA. There are no capacity figures available, since the airport is not operational for civil air traffic. In addition, CLSK does not make use of historical data and peak hours to determine the airspace capacity. Hereby CLSK has difficulties with determining the capacity needed for civil air traffic next to the military air traffic in the Lelystad TMA. This thesis research will support to determine the capacity needed for civil air traffic which will operate from EHLE.

<sup>4</sup> IFR and VFR flights are permitted in the airspace. Radio contract and clearance are mandatory for IFR traffic. It is not required for VFR-traffic.

<sup>5</sup> IFR and VFR flights are permitted in the airspace. All flights are provided with Air Traffic Control service.

## 1.1 Problem statement

The opening of EHLE for civil air traffic is the motivation to perform research into the capacity of the Lelystad TMA. At the moment, the handling procedure of TMA sector 1, 2 and 3 is area responsibility and of TMA sector 4 and 5 by means of flight responsibility, figure 1. The research is relevant for the opening of EHLE and could provide input for the airspace restructuring in 2023. There are no previous studies performed in respect to the Lelystad TMA, since EHLE is a new airport. At the moment, only the capacity of the TMA is missing in the overall capacity of Lelystad airport. This is because the TMA is controlled by CLSK and the tower and ACC by LVNL. When the capacity of the TMA is determined, a total overview of the capacity is delivered. The number of slots for the airport is based on the total capacity of EHLE. Therefrom, airlines have not made flight schedules yet for the airport because no slots are available. Here fore, it is important the capacity is calculated.

## 1.2 Research Objective

The main objective of this research is to create knowledge on the operational procedure of CLSK to define the factors which determine and influence the capacity of the Lelystad TMA. The operational procedure should provide insight in the factors which determine the capacity of the airspace. The factors which determine and influence the capacity will be defined in cooperation with CLSK. The volume and capacity of the Lelystad TMA is calculated with the found factors in combination with the separation standards for aircraft. In other capacity studies for an airspace, there is determined that the capacity also depends on the workload of air traffic controllers. Therefore, the impact of certain tasks on the workload needs to be determined. By organizing expert sessions with operational experts of CLSK the impact of the tasks on the workload is defined.

The foundation KDC supports the development of the Mainport Schiphol in an innovative and sustainable way. The work program is guided by the Knowledge and Innovative Agenda for Aviation, which is developed in cooperation with the Dutch government. The research could lead to a proposal for a CLSK workload model and could provide input for the airspace restructuring that will happen in the future (2023).

## 1.3 Research relevance/significance

The availability of an airport is defined by the capacity of the overhead layers' airspace. The Tower and ACC are controlled by the LVNL which make use of workload models to determine the capacity in certain time periods. The Lelystad TMA is controlled by CLSK which do not make use of workload models and capacity figures. It is important there are accurate capacity figures of the Lelystad TMA, because it is necessary to determine the capacity of the airport.

The main stakeholders for the research are LVNL and CLSK. For LVNL and CLSK it is important the capacity is determined because it is necessary for the capacity of the handling process of Lelystad. In addition, AAS and EHLE benefit from the research. The ATS-routes of Lelystad run through the Schiphol TMA. The volume of the ATS-route from Lelystad can affect the capacity of the Schiphol TMA. Another stakeholder of the research is the Dutch government. At the moment EHLE has often been in the news about the flight paths that fly over the regional cities. The outcome of the research can be shared with the people living nearby the airport.

## 1.4 Research questions

The main research question is based on the problem statement and research objective. The main question will be answered at the end of the research.

*“What elements determine and influence the capacity of the Lelystad TMA and how much capacity can be realized for civil air traffic which arrive and depart at Lelystad airport?”*

### 1.4.1 Sub-research questions

The main research question is divided into sub-research questions. The combination of the sub-research questions provides the answer of the main research question. For the research the following sub-research questions are made;

- What factors influence the capacity in the airspace of the Lelystad TMA?
- What is the theoretical volume of the Lelystad TMA?
- What is the relation between the factors and the capacity of the Lelystad TMA?
- What are the capacity requirements for civil air traffic in the Lelystad TMA when the airport is opened?
- Is the capacity feasible in the first year when EHLE becomes operational?

### 1.4.2 Background questions

In order to answer the main or sub research questions more background information is needed of the TMA and CLSK.

#### Operational procedures

- What are the operational procedures of CLSK in the airspace of the Lelystad TMA?
- What are the differences between area responsibility and flight responsibility?
- What is the definition of controller workload?
- How is the controller's workload measured in the CLSK and LVNL operation?

#### Capacity factors

- Which factors determine the interaction between traffic flows?
- Which factors determine the interaction within traffic flows?
- Which elements determine the task load of a traffic controller?
- Which capacity factor has the most influence on the capacity?

#### Capacity calculation

- What is the theoretical capacity of the Lelystad TMA, when only the separation distance is considered?
- What is the threshold for the maximum allowable workload of a traffic controller?
- What is the relation between the workload of a traffic controller and the capacity?
- What is the practical capacity of the Lelystad TMA?

## 1.5 Research scope

The research focus will be on determining and defining the factors which influence the capacity of the Lelystad TMA. Since there is a time period of five months not everything is taking into the scope. In this section boundaries are stated of the research.

- The research will consider the airspace structure when EHLE is opened for commercial IFR-traffic.
- The research will only review the Lelystad TMA, sector 1, 2, 3, 4 and 5.
- The research will not change the flight paths of the Lelystad TMA when the airport is operational for civil air traffic.
- The research will not change the operational procedure of CLSK.
- The research will not consider the available number of traffic controllers from CLSK in the calculations.
- The effect of the changes in runway use of Schiphol will not be included in the research.
- The calculation of the capacity of the TMA is based on an ideal situation. No runway changes of EHLE within the hour are included in the calculations. In addition, the external factor weather is not considered.
- The research will only include data on airspace and procedures that were available from the start of the research.

## 1.6 Assumptions, Limitations, and Delimitations

The research into the capacity of the Lelystad TMA applies to the situation when the airport becomes operational for civil air traffic. At the moment of conducting the research, there is no information yet available of airlines which will operate from EHLE. There is expected the airport will serve as leisure airport, with connection to tourist cities in regions in Europe and the Mediterranean. Based on this information there are assumptions made on the type of aircraft and the distribution of commercial traffic to the ACC sectors. (Obbens, Obbink, & van den Bos, 2018)

The civil aircraft types that are expected to operate on EHLE are a Boeing B737 and an Airbus A320. The aircraft will mainly fall under the aircraft category Medium. Most airlines which fly to leisure destinations are using aircraft in the category Medium. In addition to commercial traffic, there is expected that VFR traffic and military traffic will take place in the traffic mix.

A limitation in the research is that there is no data available from the TMA of civil IFR traffic at the airport. Expert sessions are organized to generate data from the TMA. In addition, CLSK has no experience with the Lelystad TMA. CLSK is not yet familiar with factors or air traffic situations in the TMA that can influence their workload. Therefore, it is difficult for the traffic controllers to use their expert judgement.

## 1.7 Thesis structure

This thesis is structured around the sub-questions in the same order as stated in paragraph 4. The methodology of the research is stated in Chapter 2. Chapter 3 presents previous research of capacity estimations of airspaces in relation to capacity factors. Chapter 4 discusses capacity factors and the traffic mix of EHLE. In Chapter 5 the volume of the TMA is calculated based on the traffic mix and input of the expert session with operational experts of CLSK. Chapter 6 presents the capacity of the TMA in relation with the workload of traffic controllers. After this, a bottleneck analysis is made of the capacity in the handling process of EHLE. Additionally, the conclusion and discussion are given on the main question of the research. At last, the recommendations of the research questions are given.

## 2 Methodology

The method used during the research is qualitative, which include interviews and expert sessions with operational experts of CLSK. In the research a main research question is formulated that must be researched. In order to answer the main research question, the research process must first be determined. This process will be held to conclude the research. In this chapter, various methods will be explained which are used during the research. Additionally, the data used during the research is described.

### 2.1 Research Design

In this section the methodology of the research is described based on steps that must be taken during the research, figure 2. The research of the capacity of the Lelystad TMA is a qualitative research where data has been created through expert sessions and interviews. There is no data available from the TMA, since EHLE is not yet operational for civil air traffic. The research is conducted into six steps, based on the sub-research questions.



Figure 2 Research process

The research starts with a literature study to determine which factors influence the capacity of the TMA and how the capacity can be determined. In addition, interviews will be held with traffic controllers from CLSK to gain more insight into operational procedures.

Hereafter, the theoretical volume is calculated based on the expected traffic mix and separation standards. The traffic mix is determined by looking at the flight procedures of EHLE. The separation standards are derived from the expected aircraft categories that take place at the airport. Based on the lectures of “*airport capacity & planning*” of the HvA, calculations are made to determine the average separation time. With the average separation time, the volume per hour is calculated.

The theoretical volume of the TMA is then presented to operational experts of CLSK in an expert session. The aim is to get an agreement with the operational experts about the capacity factors, traffic mix of the TMA and theoretical volume. In addition, agreements are made about the military traffic crossing the TMA and whether there is a need to include buffers in the calculation.

After this, the practical volume is calculated with the input of the first expert session. The same method is applied as with the theoretical volume, except adjustments are made in the separation standards and the traffic mix.

Before the research started it was already known that the workload of traffic controllers could influence the capacity of the airspace. To determine the workload of the traffic controllers, the Safety Efficiency and Environment Model (VEM-Model) of Air Traffic Controller (ATC) workload from LVNL is used. This requires a second expert session with the same operational experts to apply the method. During the session, the aim is to determine the workload of the traffic flows within the TMA. There also must be checked whether a buffer is needed on the workload. In addition, during the session the capacity per hour must be determined for when the maximum workload is reached.

After the session, a link is made between the workload and the volume to calculate the capacity. This determines the capacity of the TMA per hour for the traffic flows. With the capacity, an analysis is made to determine the bottleneck in the handling process of EHLE. In addition, the maximum annual movements of 4,000 and 10,000 are analyzed to see if it is feasible with the structure of the TMA.

## 2.2 Research instruments

During the research three main research instruments are used to determine the capacity of the Lelystad TMA. The first instrument are interviews with operational experts of CLSK and LVNL. In addition, with CLSK two expert sessions are held to generate data for the calculations of the volume and capacity. The last instrument that is used is the VEM-Model. The VEM-Model creates a link between the workload of the traffic controllers and the capacity of the airspace.

### 2.2.1 Interviews

In the beginning of the research interviews are held with traffic controllers of CLSK to gain more knowledge of the operational procedures. Insight in the operational procedures helps to set factors which can influence the capacity of the airspace. In addition, an interview is held with Mr. Meerburg the Flight Procedure Designer of LVNL. Mr. Meerburg helps to design the TMA and the ATS-route structure of EHLE. During the interview, the focus is on the traffic mix and the ATS-routes that take place in the airspace. The information obtained helps to create a first estimate of the theoretical volume of the TMA. The interviews with traffic controllers of CLSK are stated in Appendix IV and V.

### 2.2.2 Brainstorm session

As EHLE is not yet operational for civil traffic, no data is available of the TMA. By organizing two expert sessions with operational expert's, data is generated based on their expertise. In the first expert session the theoretical volume is discussed by using the Delphi Technique. The Delphi Technique is a method where an estimation is made of the outcome and likelihood of a future event. In the brainstorm session a group of operational experts' exchange views of the topic, each individual give estimates and assumptions. This input is used as data to determine the volume of the TMA for the traffic flows. The questions asked during the session are:

- Which factors could influence the capacity of an airspace?
- What is the expected traffic mix that will take place in the TMA?
- What is the maximum number of aircraft a traffic controller can have at the same time on its frequency?
- What separation standard must be considered for the arriving and departing traffic?
- Is a buffer required in the volume of the TMA to accommodate operational failures?

The second expert session is held with the same operational experts as the first. This is to prevent the same decisions taking twice. The purpose of this session is to determine the workload of the traffic routes based on the expert judgement of the operational experts. The matrixes of LVNL's VEM - Model are used to determine the workload. These are the interaction matrix and the complexity matrix. For each traffic flow or combination of traffic flows, a weighting of 0 to 4 is provided for the expected effort. When both matrices are filled in, the capacity per hour is determined when the maximum workload is achieved. (Haughey, 2018)

### 2.2.3 VEM-Model ATC workload

There is decided to use the LVNL method to establish a link between the workload and the theoretical volume. The LVNL has been working with the VEM-Model for a long time. For the total capacity of EHLE it is better to use one method to determine the capacity. The VEM-Model is used to determine the capacity based on the workload of the traffic controllers. In the analysis chapters the results of the capacity of runway 23 are shown. For the capacity of runway 05 the same method is applied as for runway 23. The outcome is found in Appendix VII.

## 2.3 Sample Expert session

The expert sessions is held with operational experts of CLSK. Herein, it is important at least two traffic controllers are attending, an Approach controller and an Area controller. The Approach controller is responsible for the air traffic in the Lelystad TMA and the Area controller is responsible for the air traffic outside the TMA. When both controllers are attended during the

expert session, the operational procedures and scenario's from outside and within the TMA can be included in the assumptions and calculations. If possible, preference is given to traffic controllers who are designated to operate at Lelystad Airport. In addition, it is important Mr. Moerkerk is attending during the sessions. Mr. Moerkerk is an ex traffic controller of AOCs NM, who was part of Workgroup ATFCM Lelystad from LVNL. In the Workgroup ATFCM Lelystad decisions are made with regard of capacity and structure of Lelystad airport. During the research Mr. Moerkerk is also the contact person of CLSK.

In addition to the expert sessions, interviews are held with traffic controllers of CLSK to gain more information of the operational procedures. Another interview is held with Mr. Meerburg, he is the Flight Procedure Designer of LVNL and is also part of the Workgroup ATFCM Lelystad. Through the interview information is obtained about the structure of the TMA and the departure and approach ATS-routes within the TMA.

## 2.4 Data Collection

At the time of the research, no data was available about the Lelystad TMA. This is because EHLE is not yet operational for civil traffic. Via Mr. Meerburg a table was received of expected arrival and departure speeds for the runway directions. In addition, the rest of the data was collected by means of expert sessions with operational experts of CLSK. The data created during these sessions are used to calculate the volume and capacity of the TMA. In chapter 5 and 6 data of the expert sessions are used. The reliability of both sources is not yet accurate enough. During the expert session two traffic controllers of CLSK and Mr. Moerkerk were attending the session. The outcome of the session could be different when other traffic controllers were attending the session. In addition, the outcome of the session cannot be verified with traffic situation of EHLE.

## 2.5 Data Analysis

For analysis of the data Microsoft Excel Spreadsheets are used. The generated data of the expert sessions is gathered on the spreadsheets to determine the volume and capacity. The volume is calculated by first setting the separation standards and ratio of traffic mix in the matrices. After this, the matrix of the separation standards is multiplied with the ratio of traffic mix. From this, the average time duration is calculated which can determine the capacity per hour. The outcome of the capacity is verified with the practical volume. The data is reliable when the same outcome of the figures is determined.

### 3 Review of the Literature

Many studies are performed on airspace capacity. The relation of airspace capacity with complexity factors and workload is of interest for many researchers. At the moment of the research, there was not much information to be found of estimating the airspace capacity of a new airspace of which no data is available. The goal of the literature study is to find a suitable method for estimating the capacity of the Lelystad TMA. In this chapter, the literature review will discuss the operational procedures of CLSK and the elements which can influence the capacity. In addition, a method is explained which can estimate the capacity of the airspace.

#### 3.1 Operational procedure CLSK

The Military Air Traffic Control Centre (MILATC) is responsible for air traffic control, approach air traffic control, flight information provision and alerts concerning flights in the New Milligen Terminal Control Areas (TMAs). This includes the Lelystad TMA, with sector 1, 2, 3, 4 and 5, figure 3. The MILATC dispatches flights through flight responsibility. During flight responsibility different traffic controllers are working in the same airspace, in which one controller respects the flights of the other controller. The arriving aircraft are on the frequency of the Approach controller and the departing traffic on the frequency of the Area controller. (Anonymous, 2018)

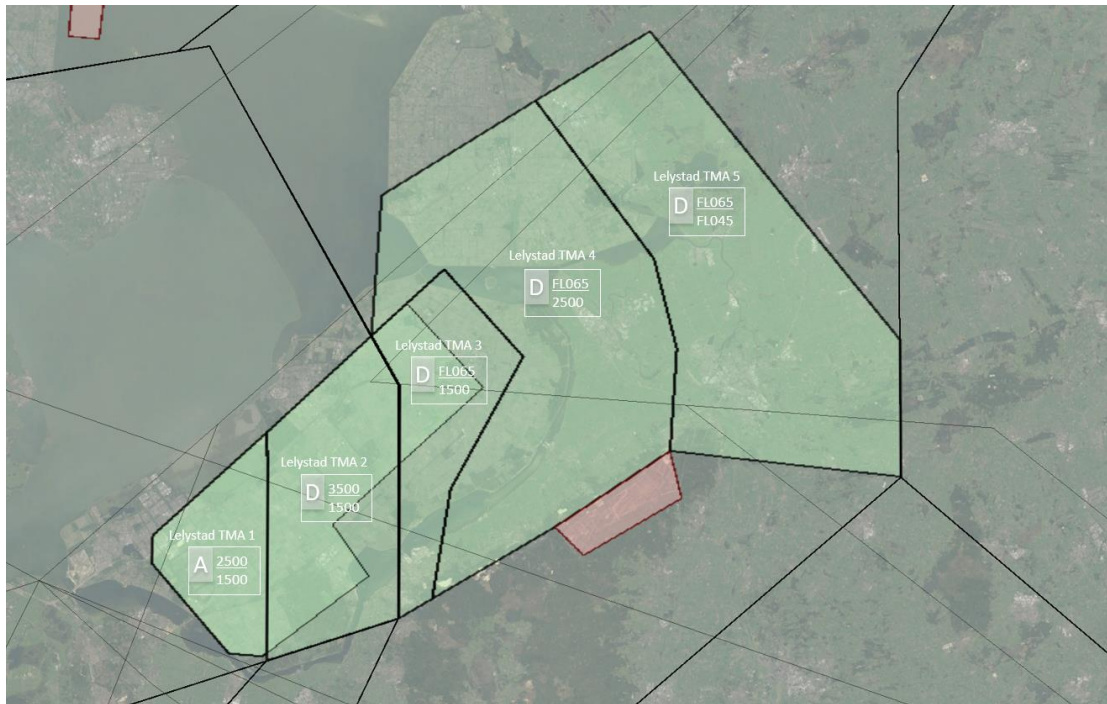


Figure 3 Structure Lelystad TMA (Dekker & Meerburg, 2018)

In the Lelystad TMA two operational units are active;

- Area Control (AREA);
- and Centralized Approach (CAPP).

The Approach controller is operative in the whole TMA and the Area controller in sector 4 and 5. In sector 1, 2 and 3 of the TMA traffic is handled through area responsibility, the Approach controller will keep the arriving and departing flights on its frequency. In TMA sector 4 and 5 traffic is handled through flight responsibility. Herein the area controller will take over the departing flights on its frequency when a 5 nautical miles (nm) separation is achieved between the aircraft. The separation agreement between arrival and departing flights is the landing aircraft stay clear from the departing aircraft. (MILATCC, 2018)

The Amsterdam Flow Management Position (FMP) is responsible for the Air Traffic Flow and Capacity Management (ATFCM) at all civil and military airports. The FMP monitors how many aircraft arrive and departure at the airport. Whereby the coordinator of Area control, the traffic load monitors and clearances provide to aircraft. When the traffic volume exceeds the maximum

capacity of the air traffic controllers, the oversupply will be detected by the FMP. The following restrictions will be entered when the limit of the maximum volume is exceeded. First, the aircraft will be put in a holding pattern. Hereafter, the intentions of the flight are adjusted. When the traffic supply continuous to increase, the supervisor is informed about the situation. The supervisor can contact the airports whose flights have destination EHLE. The airports are informed with the situation at Lelystad and are requested to keep the flights with destination Lelystad on the ground until the maximum volume in the airspace is reduced. (MILATCC, 2018) (Anonymous, 2018)

Agreements are made for military en-route traffic through a particular air sector. The Area controller guides the military aircraft from its start destination to its final destination. During the flight the military aircraft crosses areas where the Approach controller is responsible for the airspace. Twelve minutes before the aircraft enters the airspace, the aircraft will automatically appear on the crossing military air traffic list from the Approach controller. To guarantee the separation standards, the agreement is made the Approach controller keep aircraft clear of military en-route traffic. (MILATCC, 2018)

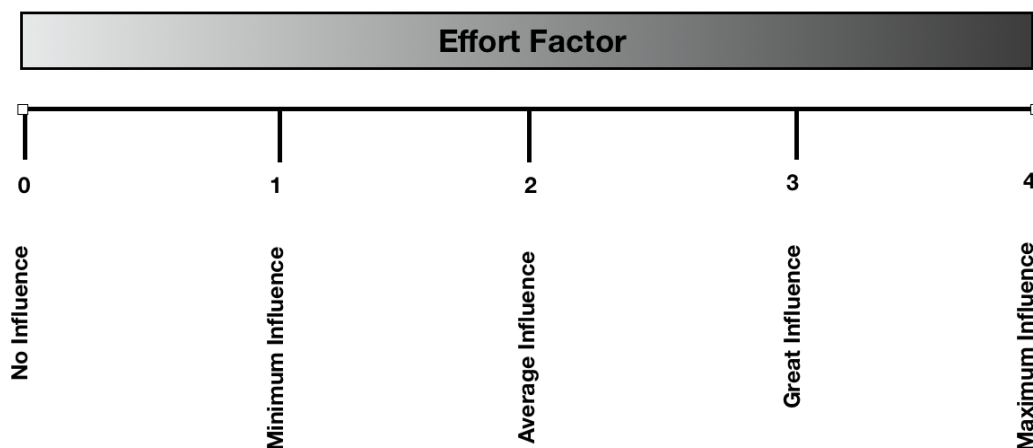
### 3.2 Airspace capacity

The airspace capacity is determined by the maximum number of aircraft that are packed in a given geometric airspace for a given time period, with the permissible separation between the aircraft. In Europe, airspace capacity is based on the workload of the traffic controller. Thus, the capacity of an Air Traffic Sector (ATS) can be defined as the maximum number of aircraft that are controlled in a particular ATC sector in a specific time period, while still permitting an acceptable level of controller workload. Before the workload is calculated one need to determine:

- How the controller workload is measured;
- And what the acceptable level of controller workload is.

(Majumdar & Polak, 2001)

The traffic controllers' workload can be determined by using an effort matrix for the combination of traffic flows. The effort matrix consists of an interaction matrix and a complexity matrix. The interaction matrix determines the interaction between traffic flows. It indicates the amount of effort that is needed to safely manage traffic. By asking operational experts to give an opinion on the elements in the matrices, more insight is obtained in the distribution of the degree of effort. For the assessment, a scale is chosen between zero and four. With a value of zero, no influence is assigned to a factor, with four the maximum influence is being assigned to a factor, figure 4. (van der Groef, 2015)



Figuur 4 Scale weighting effort (van der Groef, 2015)

#### 3.2.1 Interaction matrix

The interaction matrix consists of traffic flows that oppose each other. The interaction between traffic flows is known as the interaction factor. The effort of the controller is also influenced by the

required separation standards between traffic flows. The extent to which traffic flows conflict can contribute to the complexity of a traffic situation, this affects the controller's effort. Another important aspect is if the traffic routes are parallel or diverge. When traffic routes diverge, a conflict arises between the traffic routes, this costs more effort to guide the traffic. In table 4, the interaction matrix is illustrated. (van der Groef, 2015)

Table 4 Interaction matrix (van der Groef, 2015)

		Arriving		Departing	
		Route arriving 1	Route arriving 2	Route departing 1	Route departing 2
Arriving	Route arriving 1				
	Route arriving 2				
Departing	Route departing 1				
	Route departing 2				

The interaction matrix is filled in with the effort weighting factors to assess the effort between the traffic flows. The matrix is symmetrical around the diagonal. The interaction between traffic flow 1 and 2 is equal to the interaction between traffic flow 2 and 1.

### 3.2.2 Complexity matrix

In the complexity matrix the interaction within traffic flows is established. The interaction within a traffic flow is also known as the complexity. The complexity will be determined by the layout of the traffic route and the traffic within the route. Therefore, the complexity consists of three elements:

- Horizontal space: lateral maneuvering space;
- Vertical space: vertical maneuvering space;
- Length airspace: available length within a traffic route (time).

When the complexity for a route is determined, the differences in aircraft performance must be considered.

Another element which is part of the complexity matrix is the task load. The task load is the effort to direct traffic to a destination. In this element the traffic conflicts are not included. During the dispatch of a flight, a standard number of tasks are required. This is seen as the standard job package. The size of the package depends on the type of traffic route and the amount of traffic on the route. In guiding a flight, the traffic controller also uses flight instructions to determine the heading, speed and altitude. This also requires an effort that is expressed as the standard task load. From this come three elements that influence the task load.

- The standard instruction load is the number of required instructions to guide traffic to its destination.
- The standard procedures; is the number of required actions (procedures) that must be completed per traffic route.
- The coordination load; is the degree of coordination of traffic controller with other traffic control centers.

(van der Groef, 2015)

It is possible that during the score of a factor an overlap is created with the other factors. For the outcome of the workload, it does not matter it overlaps. The workload mostly consists of an overlap of factors.

In table 5, the complexity matrix is illustrated. In the matrix only the arriving and departing traffic flows are considered. The operational experts score the matrix with the same scale as in the interaction matrix.

(S&P LVNL; Performance LVNL, 2015) (Szamel, Mudra, & Szabo, 2014)

Table 5 Complexity matrix (van der Groef, 2015)

		Horizontal space	Vertical space	Length airspace	Standard task load
Arriving	Route arriving 1				
	Route arriving 2				
Departing	Route departing 1				
	Route departing 2				

### 3.2.3 Effort matrix

The combination of the two matrixes forms the effort matrix, figure 5. The factors outside the diagonal are the weighting coefficients for the interaction between traffic flows. These are determined in the interaction matrix by operational experts.

The factors on the diagonal express the relative effort for individual traffic flows. These factors are the complexity factors described in complexity matrix, table 5. The diagonal coefficient is calculated by determining the average of the three complexity coefficients horizontal space, vertical space and length airspace (time). The average is the effort coefficient for the interaction within a traffic route. The task load is not included in the average of the diagonal coefficient, but is a separate coefficient for the task load alone. (van der Groef, 2015)

Diagonal	Traffic flow 1	Traffic flow 2	Traffic flow 3	Traffic flow 4	Traffic flow 5
Traffic flow 1	$C_{11}$	$C_{12}$	$C_{13}$	$C_{14}$	$C_{15}$
Traffic flow 2	$C_{21}$	$C_{22}$	$C_{23}$	$C_{24}$	$C_{25}$
Traffic flow 3	$C_{31}$	$C_{32}$	$C_{33}$	$C_{34}$	$C_{35}$
Traffic flow 4	$C_{41}$	$C_{42}$	$C_{43}$	$C_{44}$	$C_{45}$
Traffic flow 5	$C_{51}$	$C_{52}$	$C_{53}$	$C_{54}$	$C_{55}$

Symmetry:  
 $C_{ij} = C_{ji}$

Figure 5 Effort matrix example five traffic flows (van der Groef, 2015)

### 3.2.4 Total workload

The effort of the interaction between traffic flows is expressed by taking the product of the volume of both traffic flows and multiplying it with the interaction coefficient. This creates an effort that depends on both traffic volumes as the interaction coefficient. In this way, the effort is determined for each interaction between traffic flows.

$$I_{ab} = (V_a * V_b) * C_{ab}$$

Equation 1 Interaction effort two traffic flows (van der Groef, 2015)

In equation 1 “ $V_a$ ” and “ $V_b$ ” are the volumes of traffic flow a and b. “ $C_{ab}$ ” in equation 1 is the interaction coefficient. The outcome of equation 1 is the effort of traffic flow a and b. The traffic interaction between stream a and stream b is the same as stream b and stream a. Therefore, only half of the interaction matrix needs to be filled in. It is not necessary to calculate the interaction effort for stream b with stream a.

The internal interaction is determined by the traffic volume and the complexity coefficient. The same approach is chosen as the interaction between traffic flows. The traffic volume is multiplied with the traffic volume minus one. Here is assumed there is a maximum interaction with the traffic. The minus one is a correction, since an aircraft cannot have an interaction with itself. Equation 2 is used to calculate the effort of a traffic flow.

$$I_{aa} = V_a * (V_a - 1) * C_{aa}$$

Equation 2 Effort traffic flow (van der Groef, 2015)

In equation 2 “ $I_{aa}$ ” is the effort of traffic flow a, “ $V_a$ ” is the volume of traffic flow a, and “ $C_{aa}$ ” is the complexity coefficient of traffic flow a.

The standard task load is determined by multiplying the task load coefficient with the traffic volume. The standard task load relates to a standard task load per flight, equation 3. In equation 3 the outcome “ $I_{aa}$ ” is the effort of the task load from traffic flow a. “ $V_a$ ” is the volume of traffic flow a and “ $T_{aa}$ ” is the task load coefficient of traffic flow a.

$$I_{aa} = V_a * T_{aa}$$

Equation 3 Task load effort (van der Groef, 2015)

The total effort of traffic flow “a” is the combination of equation 2 and 3. This results in the following equation:

$$I_{aa} = V_a * (V_a - 1) * C_{aa} + V_a * T_{aa}$$

Equation 4 Total effort traffic flow (van der Groef, 2015)

Equation 5 calculates the total workload ( $W_{total}$ ) for two traffic flows. It is a combination of equation 1 and 4.

$$W_{total} = V_a * (V_a - 1) * C_{aa} + T_{aa} * V_a + (V_a * V_b) * C_{ab} + V_b * (V_b - 1) * C_{bb} + T_{bb} * V_b$$

Equation 5 Total workload two traffic flows (van der Groef, 2015)

## 4 Capacity factor & Traffic mix

In the literature study, of previous chapter, is stated the airspace capacity is not only influenced by the geographic structure but also by the workload and capacity factors. This chapter outlines the factors that may influence the capacity of the Lelystad TMA. In addition to the capacity factors, the traffic mix that takes place in the TMA is also discussed. This is because the capacity is also influenced by the traffic mix.

### 4.1 Capacity factors

The capacity of the TMA is influenced by the workload and the traffic volume. The workload of the traffic flows depends on:

- the task load;
- interaction between traffic flows;
- and the complexity of an ATS-route.

The task load is the effort to guide traffic to a destination without considering possible traffic conflicts. The task load consists of; instruction load, procedures, and coordination load. Instruction load is the number of required instructions needed to guide the traffic to the desired destination over an ATS-route. The element procedures indicate the amount of procedures that is needed to allow the aircraft to safely fly its route. The coordination load is the required degree of coordination of a traffic controller for a traffic route. This also includes communication with other traffic controllers.

The interaction between traffic flows is the extent to which traffic flows conflict. It contributes to the complexity of a traffic situation and thus influences the traffic controller's effort.

The complexity is the interaction within a traffic flow. It depends on the layout of the traffic route and the traffic demand within the route. In addition, the maneuvering space can vary per traffic route. The traffic routes are influenced by:

- the horizontal space;
- the vertical space;
- and the length of the airspace.

The horizontal and vertical space are the available maneuver space of the traffic route. The length of the airspace is the available length within a traffic route. It is also the available time the traffic controller has to fulfill procedures to safely lead the aircraft.

The other factor which determines the capacity of the TMA is the traffic volume. The traffic volume is determined by:

- the traffic mix;
- the separation standards;
- and the aircraft performance.

The traffic mix will consist of:

- Departing aircraft;
- Arriving aircraft;
- and, a mix of departing and arriving aircraft.

The separation standards in combination with the aircraft performance helps to calculate the volume.

Another element that influences the capacity, but is not included in the capacity, is the external factor weather. The weather is a factor that is very inconsistent. Because it is difficult to include a factor whose data can change every day. There is determined to leave it out of consideration in the calculation of the volume and capacity.

(van der Groef, 2015) (Majumdar & Polak, 2001)

In Appendix II, the relation between the factors and the capacity is given.

## 4.2 Traffic demand Lelystad airport

At the time of starting this research, no clear picture was available of the expected traffic at EHLE. No flight schedules of airlines were known yet, the only baseline as reference is the Safety Efficiency and Environmental Impact Reporting (VEMER) of LVNL for EHLE. This report is for the capacity of the airport. Herein, no information is given of the capacity of the TMA. The expected traffic mix of Lelystad is described in the VEMER. Herein, the future traffic of EHLE are:

- IFR traffic;
- VFR traffic;
- and military traffic.

(Obbens, Obbink, & van den Bos, 2018)

### 4.2.1 IFR-traffic

The IFR traffic consists mainly of leisure, business and Maintenance Repair Overhaul (MRO) traffic, which fly over the ATS-routes. The flights not on the ATS-routes are local IFR-training flights, flying within the CTR and TMA. Within IFR-traffic, it is expected that aircraft will fly with different speed differences. The commercial IFR traffic are mainly leisure flights operated by airlines. Expected is that the airlines will fly with a Boeing B737 or an Airbus A320. There are hardly any differences in performance between these aircraft, which makes it negligible in the calculation of the capacity. However, business aircraft and training aircraft have different performance characteristics than the aircraft used by the airlines. In the VEMER is expected the business flights and the training flights will not take place in the peak hours of the airlines. In the first expert session with operational experts is decided to determine the capacity for two modes;

- the commercial mode;
- and the non-commercial mode.

(Obbens, Obbink, & van den Bos, 2018)

In the commercial mode IFR flight from airlines takes place. Here, all other traffic is rejected to avoid delays for the airlines. Airlines usually aim for maximum deployment of their fleet, which often leads to peaks in the traffic. In the VEMER a scenario is chosen in which three IFR peak moments are anticipated on the day. In these peak moments the commercial mode will take place. When the peak hours are over, traffic takes place that is rejected in commercial mode. This is the non-commercial mode. In the non-commercial mode there are IFR-training flights, MRO flights and business flights. In figure 6, the daily distribution of the airport is displayed with its local times.

(LVNL; CLSK, 2018) (Moerkerk, Lagarde, & Lindeman, 2018)

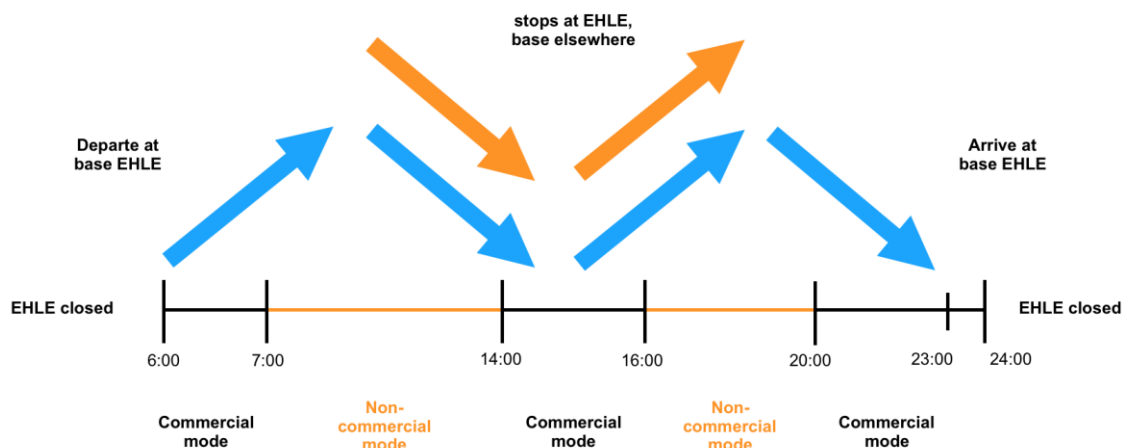


Figure 6 Daily distribution EHLE (local times) (Obbens, Obbink, & van den Bos, 2018)

### 4.2.2 VFR-traffic

VFR traffic at the airport usually flies circuits. There are two circuits for VFR traffic; BRAVO route and MIKE route. The BRAVO route is located southeast of the airport and has a flight altitude of 1000 ft Above Mean Sea Level (AMSL) for both the arrival and departure flights. The MIKE route

is located north of the airport and has a flight altitude of 1500 ft AMSL for both the arrival and departure flights. The VFR-circuits are located in Controlled Traffic Region (CTR) sector 2 of Lelystad and run through Schiphol TMA 1. Sector 2 of the Lelystad TMA has a lower limit of 1500 ft and an upper limit of 3500 ft. The VFR circuits run under the Lelystad TMA, it does not cross the traffic on the ATS-routes. Therefore, the VFR-circuits are not included in the capacity calculation. In addition, the TMA has received airspace classification D. With this classification, air traffic controllers have the right to refuse VFR traffic. In the expert session, the operational experts decided not to include the VFR traffic in the capacity determination. (LVNL; CLSK, 2018)

### 4.2.3 Military traffic

The military routes AWX and BENE run through sector 2 and 3 of the TMA, figure 7. The AWX and BENE routes have a height restriction of 3000 ft. These military routes may conflict with the ATS-routes that run from and to the runway. There is no historical data available on how often the routes are used and with what type of aircraft the routes are flown. Therefore, the future use and the intensity of the routes is difficult to predict. However, it must be considered in the calculation of the capacity. In the session with the operational experts there was decided the TMA is temporary unavailable for civil air traffic when the military cross-over routes, AWX and BENE, become active. The duration of the closing will depend on the intensity of the crossing aircraft. Here for two scenarios are assumed, one where two aircraft cross the TMA and another where six aircraft cross the TMA. According to the flight plan, there must be a separation of five minutes between the crossing aircraft. Therefore, the TMA will be closed for:

- a low intensity for 10 minutes;
- and with a high intensity for 30 minutes.

(LVNL; CLSK, 2018) (Moerkerk, Lagarde, & Lindeman, 2018)

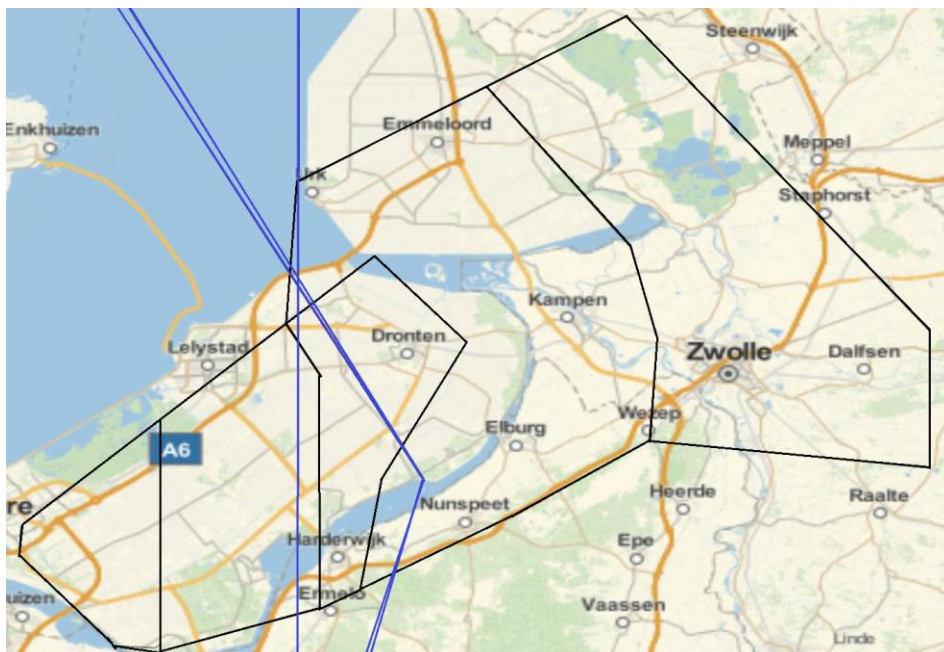


Figure 7 AWX and BENE routes in TMA

## 5 Volume Lelystad TMA

The volume of the Lelystad TMA is the number of movements that is possible in a certain amount of time. The number of movements depend on the separation standards, the aircraft performance and the traffic mix. In Chapter 4 was explained that the research is based on two modes; commercial mode and non-commercial mode. For the calculations of the volume these two modes are included.

### 5.1 Separation standards

To determine the volume of the TMA, the separation standards are required. For the arriving aircraft at EHLE the separation standards of the wake vortex turbulence are used. These separation criteria are defined to ensure the trailing of second aircraft is not at risk by the vortexes generated by the leading aircraft. At EHLE aircraft categories that are expected to operate are Light and Medium, therefor only these two aircraft categories are included in the calculation. In table 6, the Distance Based Separation (DBS) for the aircraft categories are given. The DBS is only used for the arriving aircraft at EHLE. (Skybrary, 2016)

Table 6 Distance Based Separation in nm (DBS) aircraft categories (T070; Knowledge & Development Centre Mainport Schiphol, 2016)

DBS	Follower	
Leader	Medium	Light
Medium	3	5
Light	3	3

For departing aircraft at EHLE, the separation of the average runway occupation time is used. The aircraft are automatically separated on the runway by the occupation time of the previous aircraft. In table 7, the average runway occupation time per type of aircraft are provided. The average occupation time is not based on aircraft categories Medium or Light, but on the type of aircraft.

Table 7 Average runway occupation time at EHLE (Obbens, Obbink, & van den Bos, 2018)

TBS	Follower	
Leader	IFR-start	IFR-training
IFR-start	120	210
IFR-training	300	150

### 5.2 Commercial mode

The theoretical volume is calculated by determining the number of movements per hour in the TMA. The number of movements for arriving traffic is determined by using the separation standards of the wake turbulence categories (table 8) and the average True Air Speed (TAS). The TAS is required to convert the separation standards of nautical miles into time per seconds. At EHLE only aircraft with classification Medium and Light are expected. The Light aircraft consists of IFR-training flights and business jets. Medium aircraft concerns aircraft types such as the Boeing B737 and the Airbus A320, which fly to leisure destinations. For the arriving traffic the expected Indicated Air Speed (IAS) per waypoint is available, table 8 and 9. (Meerburg, 2018 ) (Obbens, Obbink, & van den Bos, 2018)

Table 8 Approach speeds (KIAS) runway 05 (Meerburg, 2018 )

Approach Runway 05	
BADEX / EKNON	Expected speed 250 KIAS
ASBES	Expected speed 230 KIAS
LE137	Expected speed 210 KIAS
XIDES	Speed restriction 185 KIAS
LE134	Final approach 140 KIAS

Table 9 Approach speeds (KIAS) runway 23 (Meerburg, 2018 )

Approach Runway 23	
BADEX / EKNON	Expected speed 250 KIAS
LE122	Expected speed 230 KIAS
LE123	Expected speed 210 KIAS
LE124	Final approach speed 180 KIAS

Before the separation is converted to time, the True Air Speed (TAS) must be determined. The equation for the TAS is:

$$TAS = IAS * \sqrt{\frac{\rho_0}{\rho_h}}$$

Equation 6 TAS

The density ratio and the TAS are unknown in the formula. The values from the ISA table are used as density ratio in the formula.

The average speed of the approach flights to EHLE is calculated by adding up all the speed of the waypoints and dividing it by the number of waypoints. For runway 23 this is an average TAS of 187 knots and for runway 05 an average TAS of 186 knots. The average speed of both runways is close to each other making the differences in speeds negligible. The speed of runway 23 is included in the calculations for the theoretical volume.

For the departing flights the average runway occupation time is used as separation. Here for, the time does not have to be calculated.

### 5.2.1 Theoretical Volume

The separation standard between arrival aircraft depend on the Wake Turbulence Category. In the commercial mode only aircraft category Medium is expected. The standard separation outside the TMA is 5 nm and in the TMA 3 nm. When the aircraft flies at final, the separation must increase to 4 nm. In the expert session is decided to increase the total separation of 3 nm to 4 nm in the TMA. The separation standards are given in table 10. (Moerkerk, Lagarde, & Lindeman, Brainstorm session 1, 2018)

Table 10 Adjusted Distance Based Separation (DBS) in nm

DBS	Follower	
	Medium	Light
Leader		
Medium	4	5
Light	4	4

While providing separation, ATC controllers' and pilots' performance is less than optimum. There is usually more separation provided than the minimum required separation. An assumption is made that an extra of 18 seconds separation is applied. Assuming the data occurs as a normal distribution, when EHLE is opened, there is assumed a five percent risk of having more separation. Equation 7 provided the additional separation margin in seconds. (Hogervorst & J., 2015)

$$b' = 1.96 * 18 \text{ seconds} \approx 35.28 \text{ seconds}$$

Equation 7 Additional separation margin (s)

There was stated that in the commercial modus only category Medium is considered. This means that there is a separation standard of 4 nm. With the separation and the average speed of the aircraft at the ATS-route, the average time is calculated. In equation 8 the “d” is the separation distance in nm and the “Δv” the TAS velocity in knots. The “b” in the equation is the extra time of the human factor. The outcome of the equation is the average time in seconds.

$$\Delta t = \frac{d}{\Delta v} + b$$

$$\Delta t = \left( \frac{4 \text{ nm}}{187 \text{ kts}} \right) * 3600 + 35.28 \approx 112 \text{ seconds}$$

Equation 8 Average time (s) (Hogervorst & J., 2015)

When the formula is filled in, an average time of 112 seconds is achieved. The theoretical volume is calculated by dividing the hour by the average time.

$$\frac{3600}{112} \approx 32 \text{ aircraft per hour}$$

Equation 9 Theoretical volume arriving aircraft

This number indicates how much traffic in the TMA in terms of approaches are possible in an ideal situation. The outcome of the capacity is rounded down. When it is rounded up, the capacity of the TMA will be exceeded.

The theoretical volume for the departures of the airport depends on the average runway occupation time. The average runway occupation time is based on traffic type instead of aircraft category. For departing aircraft, the average runway occupation time of starting IFR-traffic is 120 seconds. The theoretical volume for departure traffic is:

$$\frac{3600}{120} = 30 \text{ aircraft per hour}$$

Equation 10 Theoretical volume departing aircraft

This number indicates how much traffic in the TMA in terms of departures are possible in an ideal situation. The outcome of the capacity is rounded down. When it is rounded up, the capacity of the TMA will be exceeded.

## 5.2.2 Practical Volume

In the first expert session with operational experts the theoretical volume of the arriving and departing traffic of the TMA are discussed. In the session, there is decided to build in margins to absorb failures during the operation. For the arriving traffic, half of the average separation time is used as a buffer. The time of the buffer is also used to ensure two aircraft will not run into each other at the merge point of the arriving routes. For the arriving aircraft the average standard separation time is 112 seconds, meaning a buffer of 56 seconds needs to be added. The total separation then becomes 168 seconds. The practical volume of the TMA, with the margin, is:

$$\frac{3600}{168} \approx 21 \text{ aircraft per hour}$$

Equation 11 Practical volume arriving aircraft

The buffer used on the arriving aircraft is not used on the departing aircraft. The departing aircraft are already separated by the average runway occupation time. In addition, the aircraft diverge of the ATS-route instead of converge. Therefore, it is not necessary to use the same buffer as the arriving aircraft. However, unexpected failures in the operation must be considered. In the expert session was decided to use a margin of 10 percent of the total theoretical volume. This results in a practical volume of:

$$30 \text{ aircraft} * 0.90 = 27 \text{ aircraft per hour}$$

Equation 12 Practical volume departing aircraft

In the calculation of the volume from the TMA, the military traffic must be considered. In the session with the operational experts there was decided the TMA is temporary unavailable for civil air traffic when the military cross-over routes, AWX and BENE, become active. There is agreed to use two scenarios one where two aircraft cross the TMA and another where six aircraft cross

the TMA. According to the flight plan, there must be a separation of five minutes between the crossing aircraft. Therefore, the TMA will be closed at:

- a low intensity for 10 minutes;
- and with a high intensity for 30 minutes.

(Moerkerk, Lagarde, & Lindeman, Brainstorm session 1, 2018)

In table 11, the practical volume of the TMA is given for the two scenarios' when the military routes become active.

Table 11 Practical volume per hour military buffer – Commercial Mode

Practical volume per hour	Low intensity	High intensity
Arriving aircraft	17	10
Departing aircraft	22	13

### 5.3 Non-commercial mode

In the non-commercial modus there is a combination of IFR-flights and IFR-training flights. Just as in the commercial mode, the volume of the arriving traffic is based on the separation standard of the Wake Turbulence categories, table 10. For the non-commercial mode categories Medium and Light are considered in the calculation. For the Medium category the same average speed is used as in the commercial mode, namely 187 knots. For the Light category, an average flight speed of 100 knots is assumed. The average speeds on final are taken from the Diamond DA-42, the Piper PA-28 and the Cessna C-172. The extra separation of the human factor used in the commercial mode is also applied in the non-commercial mode. This is an extra separation of  $b \approx 35.28$  seconds. (Moerkerk, Lagarde, & Lindeman, Brainstorm session 1, 2018)

#### 5.3.1 Theoretical volume

In the non-commercial mode, there is a mix of larger and smaller aircraft. Two situations can occur during the mix:

- Speed of the trailing aircraft is higher than the leading aircraft; they are closing during a final approach ( $V_t > V_l$ )
- Speed of the trailing aircraft is lower than the leading aircraft; they are opening during a final approach ( $V_t < V_l$ ). The separation increases during the final approach.

In order to calculate the airspace capacity of the TMA, the average time separation must know. If the trailing aircraft speed is lower than the leading aircraft, the final approach is flown with more than the minimum separation. To determine the average time separation, four small calculations must be performed to calculate the average time per aircraft.

1. Medium behind Light aircraft
2. Medium behind Medium aircraft
3. Light behind Light aircraft
4. Light behind Medium aircraft.

(Hogervorst & J., 2015)

$$t_{medium-light} = \frac{d}{v_{trailing}} + b$$

Equation 13 Average time – Medium behind Light aircraft (Hogervorst & J., 2015)

$$t_{medium-medium} = \frac{d}{v_{trailing}} + b$$

Equation 14 Average time - Medium behind Medium aircraft (Hogervorst & J., 2015)

$$t_{light-light} = \frac{d}{v_{trailing}} + b$$

Equation 15 Average time - Light behind Light aircraft (Hogervorst & J., 2015)

$$t_{light-medium} = \frac{\left(d + h \left(1 - \frac{v_{trailing}}{v_{leading}}\right)\right)}{v_{trailing}} + b$$

Equation 16 Average time - Light behind Medium (Hogervorst & J., 2015)

The “h” in equation 16 is the distance to the runway in nautical miles. The “d” in equations 13 to 16 is the separation distance in nautical miles and “b” is the extra time in seconds of the human factor. The “v<sub>trailing</sub>” is the TAS velocity in meters per second of the trailing aircraft and “v<sub>leading</sub>” of the leading aircraft. The outcome of the equations is the average time in seconds. The average time per aircraft combination is provided in table 12. (Hogervorst & J., 2015)

Table 12 Time Based Separation (TBS) in seconds - Arriving traffic

TBS	Follower	
	Medium	Light
Leader		
Medium	112	405
Light	112	179

For the non-commercial mode there is chosen for a distribution of traffic of 30% IFR flights and 70% IFR-training flights. The average time separation for the mode is calculated by taking the figures of table 12 and the ratio of the traffic mix.

$$\Delta t = |p_{mix}| |t_{TBS}| |p_{mix}|^t$$

$$\Delta t = |0.3 \quad 0.7| * \begin{vmatrix} 112 & 405 \\ 112 & 179 \end{vmatrix} * \begin{vmatrix} 0.3 \\ 0.7 \end{vmatrix} \approx 206.5 \text{ seconds}$$

Equation 17 Average time separation - Arriving aircraft (Hogervorst & J., 2015)

When the formula is filled in, an average time of 206.5 seconds is achieved. The theoretical volume is calculated by dividing the hour by the average time.

$$\frac{3600}{206,5} \approx 17 \text{ aircraft per hour}$$

Equation 18 Practical volume - Arriving aircraft

This number indicates how much traffic in the TMA in terms of approaches are possible in an ideal situation, in which no faults occur. The outcome of the capacity is rounded down. When it is rounded up, the capacity of the TMA will be exceeded.

The theoretical volume for the departures of the airport depends on the average runway occupation time. The average runway occupation time is based on traffic type instead of aircraft category. For the non-commercial mode the starting IFR traffic and IFR-training traffic is used. The traffic ratio between the IFR traffic and the IFR-training traffic is the same as the arriving traffic of the non-commercial mode, 30% IFR traffic and 70% IFR-training traffic. The average runway occupation time for the mix traffic is given in table 13.

Table 13 Average runway occupation time in seconds – Non-commercial Mode (Obbens, Obbink, & van den Bos, 2018)

Leader	Follower	
	IFR-start	IFR-training
IFR-start	120	210
IFR-training	300	150

The average time separation is calculated with the same formula used for the arriving traffic. The average separation time for the departing traffic is:

$$\Delta t = |0.3 \quad 0.7| * \begin{vmatrix} 120 & 210 \\ 300 & 150 \end{vmatrix} * \begin{vmatrix} 0.3 \\ 0.7 \end{vmatrix} \approx 191.4 \text{ seconds}$$

Equation 19 Average time separation - Departing aircraft

The outcome of the formula is an average separation of 191.4 seconds. The theoretical volume per hour is calculated by the following way:

$$\frac{3600}{191.4} \approx 18 \text{ aircraft per hour}$$

Equation 20 Theoretical volume - Departing aircraft

This number indicates how much traffic in the TMA in terms of departures are possible in an ideal situation, in which no faults occur. The outcome of the capacity is rounded down. When it is rounded up, the capacity of the TMA will be exceeded.

### 5.3.2 Practical volume

The agreements made in the first brainstorm session for the commercial mode also apply to the non-commercial mode. For the arriving traffic, half of the standard separation is used as a buffer. This is used to absorb failures in the daily-operation and to ensure two aircraft will not run into each other at the merge point of the arriving routes. In the calculation of the theoretical volume an average separation time of 206.5 seconds was calculated. The buffer for the arriving aircraft will be 103.2 seconds. The total separation the becomes 309.7 seconds. The practical volume of the TMA in one hour, with the buffer, is:

$$\frac{3600}{309.7} \approx 11 \text{ aircraft per hour}$$

Equation 21 Practical volume - Arriving aircraft

For the departing aircraft an agreement was made that 10 percent of the total volume is used as a margin. This margin is needed to deal with unexpected failures in the operation. The practical volume for the departing aircraft in one hour is:

$$18 \text{ aircraft} * 0.90 \approx 16 \text{ aircraft per hour}$$

Equation 22 Practical volume - Departing aircraft

In the calculation of the volume from the TMA, the military traffic must be considered. The same agreements made in the commercial mode also applies to the non-commercial mode. The low and the high intensity scenarios are applied on the practical volume. The outcome is stated in table 14.

(Moerkerk, Lagarde, & Lindeman, Brainstorm session 1, 2018)

Table 14 Practical volume per hour military buffer – Non-commercial mode

Practical volume per hour	Low intensity	High intensity
Arriving aircraft	9	5
Departing aircraft	14	8

### 5.4 Conclusion

The theoretical volume of the commercial and non-commercial mode differs per arriving and departing traffic flow. For the arriving traffic the theoretical volume depends on the separation standards of the aircraft categories and for the departing traffic it depends on the average runway occupation time. The theoretical volume indicates how much traffic per hour in the TMA is possible in an ideal situation. In reality, an ideal situation will not always occur. This requires a buffer to compensate malfunctions during the daily-operation. For the arriving traffic is chosen to use an extra separation and for the departing traffic is chosen to use 10 percent of the theoretical volume. In table 15, the volumes are given of the commercial mode and in table 16 the volumes are given of the non-commercial mode.

Table 15 Theoretical volume per hour - Commercial mode

Per hour	Theoretical volume	Practical volume
Arriving aircraft	32	21
Departing aircraft	30	27

Table 16 Theoretical volume per hour - Non-commercial mode

Per hour	Theoretical volume	Practical volume
Arriving aircraft	17	11
Departing aircraft	18	16

When the military cross-routes, BENE and AWX, becomes active, a reduction in the availability of the airspace must be considered. When there is a low intensity of military traffic, the TMA will be unavailable for civil air traffic for 10 minutes. When there is a high intensity of military traffic, the TMA will be unavailable for civil air traffic for 30 minutes. table 17 and 18, provides the practical volume for arriving and departing traffic when military routes become active.

Table 17 Practical volume per hour military routes – Commercial mode

Practical volume per hour	Low intensity	High intensity
Arriving aircraft	17	10

Table 18 Practical volume per hour military routes – Non-commercial mode

Practical volume per hour	Low intensity	High intensity
Arriving aircraft	9	5
Departing aircraft	14	8

In the first expert session, with operational experts of CLSK, there was not enough time to reach an agreement of the theoretical and practical volume for the mix traffic. Therefore, the volumes of the mix traffic are not determined. In the second expert session the mix traffic is discussed.

## 6 Capacity Lelystad TMA

The capacity of the Lelystad TMA is determined by means of an effort matrix. During the second expert session, the effort matrix is filled in by operational experts of CLSK. The effort matrix consists of two matrices; complexity matrix and the interaction matrix. In the complexity matrix, the traffic flows face the complexity factors and in the interaction matrix, the traffic flows face each other.

In the first expert session was agreed the TMA is temporary unavailable for civil air traffic when the military cross-over routes, AWX and BENE, become active. This only applies to TMA sector 1, 2 and 3, because the traffic is handled through area responsibility. In TMA sector 4 and 5, traffic is handled through flight responsibility. Herein, it is not possible to close the airspace for civil air traffic. In TMA sector 4 and 5, military traffic takes place that does not make use of the AWX and BENE routes. The military traffic can cross the TMA at the same level as the civil traffic. To prevent collisions, the agreement is civil traffic remains free of military traffic. To include the military traffic in the capacity, a buffer is taken on the maximum workload. This ensures when military traffic takes place in TMA sector 4 and 5 the maximum workload is not exceeded. In the session was decided to use five percent of the maximum workload.

(Moerkerk, Lagarde, & Lindeman, Capacity Lelystad TMA, 2018)

When the maximum workload of the traffic controllers is achieved, there must be determined how much capacity is possible to handle. In the second expert session, agreements were made for the traffic flows.

- For the arriving aircraft a maximum capacity of 2 movements per hour can take place with a maximum workload.
- For the departing aircraft a maximum capacity of 4 movements per hour can take place with a maximum workload.
- For a mix of arriving and departing aircraft a maximum capacity of 3 movements per hour can take place with a maximum workload.

(Moerkerk, Lagarde, & Lindeman, Capacity Lelystad TMA, 2018)

In this chapter, the capacity of the Lelystad TMA is derived from the workload per combination of traffic routes. The method that is used applies to both runway directions and modes. In the first section the capacity of the commercial mode is provided and in the second section the capacity of the non-commercial mode.

### 6.1 Commercial mode

In this section, the matrixes are discussed in the same order as they were entered in the session. First the weightings of the interaction matrix are discussed and then the weightings of the complexity matrix. This paragraph only provides the explanation of the results of runway 23. In Appendix VII, the expert session is written out were the explanation is provided for runway 05.

#### 6.1.1 Interaction matrix

During the expert session, the operational experts started to score the interaction matrix, table 19. The matrix is symmetrical around the diagonal. The weighting for the traffic mix BADEX with EKNON is equal to the weighting of EKNON with BADEX. There are six traffic mixes to assessed by the operational experts.

1. BADEX – EKNON
2. BADEX – ERMUR
3. BADEX – ARBEP
4. EKNON – ERMUR
5. EKNON – ARBEP
6. ERMUR – ARBEP

The first traffic mix are two arriving routes, BADEX and EKNON. During the assessment of the factors, the scenario is assumed that two aircraft meet each other in the merge point. There are several possibilities to ensure the aircraft will not conflict with each other. Because of these options, it costs less effort for the traffic controller. Therefore, a weighting of 2 is given.

The second traffic mix is an arriving and departing route, BADEX with ERMUR. The routes are free of conflict. However, the traffic still must be monitored and communication is required. Because of the little effort, it gets a minimal weighting of 1.

The third traffic mix is an arriving and departing route, BADEX with ARBEP. This cost more effort than the traffic mix BADEX with ERMUR. The departing route to ARBEP is longer on the frequency of the approach controller. The area controller may only have the departing flight when a separation of 5 nm is meet between the aircraft. This costs more effort and monitoring, giving it a weighting of 2.

The fourth traffic mix is an arriving and departing route, EKNON with ERMUR. These traffic routes are conflict free, similar to BADEX with ERMUR. Therefore, it has a weighting of 1.

The fifth traffic mix is an arriving and departing route, EKNON with ARBEP. The aircraft are transferred to the area controller very quickly. If there is no conflict from EKNON to the final approach fix and there is no conflict with the departing route going south, transfer of communication and transfer of control can take place on the border of TMA sector 3 and 4. No effort is required for this traffic mix, resulting in a weighting of 0.

The last traffic mix are two departing routes, ERMUR and ARBEP. The aircraft fly sequence with a separation of 5 nm. This is because it is separated by the average runway occupation time. At a given moment, the aircraft diverge from each other. The 5 nm separation between the aircraft must be met to transfer the aircraft to the area controller. This requires minimal effort from the traffic controller, resulting in a weighting of 1.

Table 19 Interaction matrix runway 23 – Commercial mode

		Arriving route		Departing route	
		BADEX	EKNON	ERMUR	ARBEP
Arriving route	BADEX		2	1	2
	EKNON			1	0
Departing route	ERMUR				1
	ARBEP				

### 6.1.2 Complexity matrix

After the interaction matrix is scored, the operational experts continued with the complexity matrix. In the complexity matrix, the interaction within traffic flows is specified. The interaction within a traffic flow is also known as the complexity. There are three complexity factors:

- horizontal space;
- vertical space;
- and Length of airspace (time).

The task load is given in the complexity matrix, but does not belong to the complexity factors. It is another factor, which also influence the workload of traffic controllers.

First, the arriving route BADEX is assessed. In TMA sector 4 and 5, there is not much space to deviate of the route. It is possible, but because the construction of the airspace more coordination is required. For the complexity factors and task load a minimum weighting of 1 is given.

The other arriving route is EKNON. The route has the same structure as BADEX. Therefore, is decided to give EKNON the same weightings as BADEX.

The third route is the departing route ERMUR. There is not much space to deviate from the route. The 5 nm separation between aircraft must be arranged from the runway. During take-off aircraft must be monitored if the separation of 5 nm is achieved. This task is expected every day from the traffic controller. Therefore, is decided to give the complexity factors a minimum weighting of 1. For the task load more effort is needed, since the Schiphol traffic in the adjacent airspace must be considered. It requires more monitoring which results in a weighting of 2 for the task load.

The last traffic route is the departing route ARBEP. The route has almost the same structure as ERMUR. Therefore, it receives a minimal weighting of 1 for the complexity factors and a weighting of 2 for the task load.

Table 20 Complexity matrix runway 23 – Commercial mode

		Horizontal space	Vertical space	Length airspace	Task load
Arriving route	BADEX	1	1	1	1
	EKNON	1	1	1	1
Departing route	ERMUR	1	1	1	2
	ARBEP	1	1	1	2

### 6.1.3 Effort matrix

When both matrices are scored, they are merged as an effort matrix, table 21. The diagonal coefficient expresses the relative effort for individual traffic flows. It is achieved by determining the average of the three complexity factors; horizontal space, vertical space and length airspace (time). The task load is not included in the average of the diagonal coefficient, but is a separate coefficient for the task load. The other coefficients in table 21, are the interaction coefficients from the interaction matrix.

Table 21 Effort matrix runway 23 – Commercial mode

		Arriving route		Departing route	
		BADEX	EKNON	ERMUR	ARBEP
Arriving route	BADEX	1	2	1	2
	EKNON		1	1	0
Departing route	ERMUR			1	1
	ARBEP				1

The capacity is calculated with the effort matrix (table 21) and the theoretical volume of Chapter 5. The theoretical volume is used instead of the practical volume, because otherwise margin on margin is taken. This creates an excessive margin in the day operation, which results more traffic is rejected than necessary. Equation 23 is used to calculate the capacity.

$$W_{total} = V_a * (V_a - 1) * C_{aa} + T_{aa} * V_a + (V_a * V_b) * C_{ab} + V_b * (V_b - 1) * C_{bb} + T_{bb} * V_b$$

Equation 23 Total workload two traffic flows (van der Groef, 2015)

In the Formula  $W_{total}$  is the total workload of two traffic flows. The theoretical volume of the traffic flows is  $V_a$  or  $V_b$ . The  $C$  are the coefficients of the effort matrix. Herein  $C_{aa}$  is the coefficient of traffic flow 'a' and  $C_{bb}$  is the coefficient of traffic flow 'b'. Coefficient  $C_{ab}$  is for the interaction between the two traffic flows and  $T$  is the coefficient of the task load, which was filled in the complexity matrix.

The formula determines the total workload per combination of traffic routes. For example, if two arriving routes BADEX with EKNON are considered. The theoretical volume of both traffic routes must use. For BADEX and EKNON the theoretical volume is 16 movements per hour which makes a total volume of 32 movements per hour. When it is filled in the formula with the coefficient of table 21, a total workload of 1024 is calculated. In addition, the maximum workload is calculated by scoring the matrixes with the highest weighting factor score. The outcome is a maximum workload of 3072.

In the session is decided use a buffer of 5 percent of the maximum workload. The maximum workload is  $3072 * 0.95 \approx 2918$ . At the beginning of the chapter there is explained that two arriving movements are handled by the traffic controller when the maximum workload is achieved. The equation used to calculate the capacity of two arriving route is:

$$Capacity = \left(1 - \left(\frac{1024}{2918}\right)\right) * 30 + 2 \approx 22$$

Equation 24 Capacity - Arriving aircraft

The outcome of the capacity is rounded down. When it is rounded up, the capacity of the TMA will be exceeded. The capacity of two arriving routes of BADEX and EKNON is 22 movements per hour. Here, 50 percent of the traffic comes from BADEX and 50 percent from EKNON. The capacity depends on the weightings filled in the interaction and complexity matrix. In Appendix VIII, a graph is shown in which the corresponding capacity is indicated per workload for the combination of traffic routes.

## 6.2 Non-commercial mode

In the non-commercial mode the traffic may fly that is refused in the commercial mode. All other traffic is allowed in the TMA after the commercial mode. Here, aircraft for the southern area are expected, such as business aircraft and MRO aircraft. The chance of speed differences is greater within this mode. The theoretical and practical volume in this mode is lower than the commercial mode.

In the non-commercial mode, the operational experts also started first with the interaction matrix and then the complexity matrix. In this section only, the outcomes of the matrices of runway 23 are explained. The outcomes of runway 05 are given in Appendix VII.

### 6.2.1 Interaction matrix

The weightings entered in the routes of the commercial mode should also apply to the non-commercial mode, since the ATS routes do not change. But because speed differences occur in this mode, the weights differ with the commercial mode. More effort is needed to monitor the speed differences. The same six traffic mixes are assessed in non-commercial mode as in commercial mode, table 22.

The first traffic mix are two arriving routes, BADEX and EKNON. When there is a slower aircraft on the BADEX route that is slightly further than the aircraft on the EKNON route, there is a chance of conflict. The slower aircraft are placed in the holding to let the faster aircraft pass by. This requires more effort and actions than in the commercial mode. Therefore, the combination of traffic routes received a weighting of 3.

The second traffic mix is an arriving and departing route, BADEX with ERMUR. The routes are free of conflict. The differences in speed also do not affect the combination of traffic. Therefore, this combination of traffic receives the same weighting as the commercial mode.

The traffic mix BADEX with ARBEP, EKNON with ERMUR and EKNON with ARBEP also receives the same weighting as in the commercial mode. The speed differences do not affect the effort of the traffic controllers.

The last traffic mix are two departing routes, ERMUR and ARBEP. Departing aircraft fly sequence, this must be monitored to determine if the separation standard is achieved on the runway. From waypoint DOTIX the traffic is diverging from each other. It takes more effort for the traffic controller to monitor the separation and speed differences. Therefore, a weighting of 2 is scored.

Table 22 Interaction matrix runway 23 – Non-commercial mode

		Arriving route		Departing route	
		BADEX	EKNON	ERMUR	ARBEP
Arriving route	BADEX		3	1	2
	EKNON			1	0
Departing route	ERMUR				2
	ARBEP				

### 6.2.2 Complexity matrix

After the interaction matrix is scored, the operational experts continue with the complexity matrix. In the complexity matrix the traffic routes are assessed on the complexity factors and the task load. The same range of weightings apply as in the interaction matrix.

The results of the complexity matrix from the commercial mode corresponds to the non-commercial mode. The only differences are the weighting of the task load and the maneuvering space for the arriving traffic routes. For BADEX and EKNON the horizontal and vertical space scored a weighting of 2 instead of 1. When speed differences occur on the arriving traffic routes, more effort and actions are required to ensure there is enough separation between the aircraft.

All traffic routes scored a weighting of 3 for the task load. This is because of the speed differences between the Medium and Light aircraft categories. More effort is needed to monitor the speed differences. The result of the complexity matrix is provided in table 23.

Table 23 Complexity matrix runway 23 – Non-commercial mode

		Horizontal space	Vertical space	Length airspace	Task load
Arriving route	BADEX	2	2	1	3
	EKNON	2	2	1	3
Departing route	ERMUR	1	1	1	3
	ARBEP	1	1	1	3

### 6.2.3 Effort matrix

When both matrices are scored, they are merged as an effort matrix, table 24. The diagonal coefficient is calculated by determining the average of the three complexity factors. The task load is not included in the average of the diagonal coefficient, but is a separate coefficient for the task load. The other coefficients are the interaction coefficients from the interaction matrix.

Table 24 Effort matrix runway 23 – Non-commercial mode

		Arriving route		Departing route	
		BADEX	EKNON	ERMUR	ARBEP
Arriving route	BADEX	1.667	3	1	2
	EKNON		1.667	1	0
Departing route	ERMUR			1	2
	ARBEP				1

The same method as in the commercial mode is used to determine the capacity of the non-commercial mode. The capacity is determined with the effort matrix (table 24) and the theoretical volume of Chapter 5. The formula used to calculate the capacity is:

$$W_{total} = V_a * (V_a - 1) * C_{aa} + T_{aa} * V_a + (V_a * V_b) * C_{ab} + V_b * (V_b - 1) * C_{bb} + T_{bb} * V_b$$

Equation 25 Total workload two traffic flows (van der Groef, 2015)

The formula determines the total workload per combination of traffic routes. For example, if two arriving routes BADEX and EKNON are considered. The theoretical volume of both traffic flows must be used. For BADEX the theoretical volume is 8 movements per hour and for EKNON 9 movements per hour which makes a total volume of 17 movements per hour. When it is filled in the formula with the coefficients of table 24, a total workload of 480 is calculated. In addition, the maximum workload is calculated by scoring the matrixes with the highest score. The outcome is a maximum workload of 868.

In the session was decided use a buffer of 5 percent of the maximum workload. Therefore, the maximum workload is  $868 * 0.95 \approx 824$ . At the beginning of the chapter there is explained that two arriving movements per hour are handled by the traffic controller when the maximum workload is achieved. The equation used to calculate the capacity of two arriving route is:

$$Capacity = \left(1 - \left(\frac{480}{824}\right)\right) * 15 + 2 \approx 8$$

Equation 26 Capacity - Arriving aircraft

The outcome of the capacity is rounded down. When it is rounded up, the capacity of the TMA will be exceeded. The capacity of two arriving routes BADEX and EKNON is 8 movements per hour. Here, 50 percent of the traffic comes from BADEX and 50 percent from EKNON. The capacity depends on the weightings filled in the interaction and complexity matrix. In Appendix VIII, a graph is shown in which the corresponding capacity is indicated per workload for the combination of traffic routes.

(Moerkerk, Lagarde, & Lindeman, Capacity Lelystad TMA, 2018)

### 6.3 Results Capacity Modes

This section provides the outcome of the capacity for the commercial mode and the non-commercial mode. The capacity of the TMA differs per runway direction. From the analysis between the weighing's of runway 23 and runway 05, it appears that runway 05 requires more effort.

#### 6.3.1 Commercial mode

First, a comparison is made between the capacity of runway 23 and runway 05 in commercial mode, table 25 and 26. In the interaction matrixes of both runways, the only difference is the weighting of the combination traffic route EKNON with ARBEP. Because the traffic routes intersect at runway 05, it requires more procedures and needs to be more monitored. This costs more effort, resulting in a weighting of 2. At runway 23, the traffic routes do not intersect, this has no influence on the traffic controller's effort. Here for, it received a weighting of 0.

In the complexity matrixes of the runways, there are several differences between the scores. For runway 05 a higher score is given to traffic route BADEX. It has received a weighting of 2 for the complexity factors. There is less maneuver space at runway 05 than at runway 23. In addition, the traffic must be more monitored, resulting in a higher weighting of the task load. For traffic route EKNON, the same weightings and argumentation apply as for BADEX.

Traffic route ERMUR has received a higher weighting for the task load at runway 23. At the departing routes of runway 05 there are height restrictions. This means that the aircraft cannot continue to climb. At runway 23 there are no height restrictions causing the aircraft to continue to climb. In addition, the mix with the Schiphol traffic is considered. This requires more monitoring of the traffic controller, resulting in a higher score for the task load.

The reason the capacity of the TMA of runway 23 is higher than runway 05 is because the routes of runway 05 are more complex. The more complex a route is, the more effort is needed. This results in a decrease in capacity.

Table 25 Capacity per hour runway 23 – Commercial mode

Per hour	Theoretical Volume	Capacity
Arriving traffic	32	21
Departing traffic	30	22
Mix traffic	-	20 – 25

Table 26 Capacity per hour runway 05 – commercial mode

Per hour	Theoretical Volume	Capacity
Arriving traffic	32	17
Departing traffic	30	23
Mix traffic	-	18 – 21

### 6.3.2 Non-commercial mode

In the non-commercial mode, again a comparison is made between the capacity of runway 23 and runway 05, table 27 and 28. The only differences between the runways is the scores in the interaction matrix. The traffic mix of EKNON with ARBEP at runway 05 requires more actions and monitoring than runway 23. The traffic routes intersect each other at runway 05. In the complexity matrixes of the runways, there is no difference between the scores. The complexity matrix therefore has no influence on the capacity difference of the TMA by runway direction.

Table 27 Capacity per hour runway 23 – Non-commercial mode

Per hour	Theoretical Volume	Capacity
Arriving traffic	17	8
Departing traffic	18	12
Mix traffic	-	10-14

Table 28 Capacity per hour runway 05 – Non-commercial mode

Per hour	Theoretical Volume	Capacity
Arriving traffic	17	8
Departing traffic	18	12
Mix traffic	-	10-12

## 7 Airspace Analyses

The capacity of the Lelystad TMA is derived from two expert sessions with CLSK. Before the capacity can be used by CLSK, it must be verified. Since EHLE is not yet operational for commercial air traffic, there is no data available to verify the capacity of the TMA. In this chapter, the capacity is verified with the practical volume. In addition, the capacity of the TMA is compared with the capacity of the runway and airport to find the bottleneck in the handling process of Lelystad. Finally, an analysis is performed whether the 4,000 and 10,000 movements per year is feasible with the structure of the TMA.

### 7.1 Verification data

From the last session with operational experts the capacity is derived for the runway in two directions, 05 and 23. Because the capacity is based on weightings of experts, it needs to be verified. There is no data available of civil traffic in the TMA, since the airport is not yet operational. The values of the capacity are compared with the results of the practical volume. The practical volume is derived in the first expert session with operational experts of CLSK. During the session different traffic scenarios are considered that can occur in the TMA. Based on this, there are buffers and margins created that are inserted in the practical volume. The operational experts agreed to the practical volume for the arriving and departing traffic. In table 29 and 30, an overview is given of the theoretical volume, practical volume and the capacity of the TMA per hour for the commercial mode. For runway 23 the practical volume of the arriving traffic matches the capacity. For the departing traffic there is a difference of 5 movements per hour. This result concludes the buffer which is taken for the practical volume of the departing traffic is not big enough. The departing traffic requires more monitoring and workload than thought. This results in a lower capacity per hour. For runway 05 the capacity is lower than the practical volume. In the first expert session for the calculation of the practical volume, there was not made a distinction between runway directions. The practical volume is based on runway 23, this result in different outcome of the practical volume and capacity per hour. When the runway direction was included, it would more match the capacity like in runway 23.

Table 29 Runway 23 capacity verification per hour – Commercial mode

Per hour	Theoretical Volume	Practical Volume	Capacity
Arriving traffic	32	21	21
Departing traffic	30	27	22
Mix traffic	-	-	20 – 25

Table 30 Runway 05 capacity verification per hour – Commercial mode

Per hour	Theoretical Volume	Practical Volume	Capacity
Arriving traffic	32	21	17
Departing traffic	30	27	23
Mix traffic	-	-	18 – 21

When verifying the capacity with the practical volume in the non-commercial mode, the results of the capacity are lower than the practical volume (table 31 and 32). Here from, is concluded that the buffers taken during the first experts' session are too low.

Table 31 Runway 23 capacity verification per hour – Non-commercial mode

Per hour	Theoretical Volume	Practical Volume	Capacity
Arriving traffic	17	11	8
Departing traffic	18	16	12
Mix traffic	-	-	10 – 14

Table 32 Runway 05 capacity verification per hour – Non-commercial mode

Per hour	Theoretical Volume	Practical Volume	Capacity
Arriving traffic	17	11	8
Departing traffic	18	16	12
Mix traffic	-	-	10 – 12

**7.2 Airspace comparison**

The aim of the research is to determine the capacity of the Lelystad TMA. The capacity and volume are determined in chapters 5 and 6. The next step is to determine the bottleneck in the handling process of EHLE. In this section the capacity of the TMA, the runway and the airport are compared with each other.

**7.2.1 Runway capacity**

The capacity of the runway is determined with the same method used in the calculation for the volume. For the runway capacity, the average runway occupancy time per aircraft category is used from the VEMER of LVNL, table 33.

Table 33 Average runway occupation time (seconds) (Obbens, Obbink, & van den Bos, 2018)

	Follower		
Leader	IFR-start	IFR-landing	IFR-training
IFR-start	120	120	210
IFR-landing	120	180	240
IFR-training	300	240	150

**Commercial mode**

For the mix of arriving and departing aircraft for the commercial mode, the category IFR-start and IFR-landing are required. There is expected the ratio of the departing and arriving traffic is equal to each other. There is a mix ratio of 50 percent starting traffic and 50 percent landing traffic. With the average runway occupation time and the mix ratio, the capacity for the runway is calculated.

$$\Delta t = |p_{mix}| |t_{TBS}| |p_{mix}|^t$$

$$\Delta t = |0.5 \quad 0.5| * \begin{vmatrix} 120 & 120 \\ 120 & 180 \end{vmatrix} * \begin{vmatrix} 0.5 \\ 0.5 \end{vmatrix} \approx 135 \text{ seconds}$$

Equation 27 Average runway time (s) (Hogervorst & J., 2015)

The runway capacity per hour is calculated with the average runway occupation time. The outcome of the capacity is rounded down. When it is rounded up, the capacity of the runway will be exceeded.

$$\text{runway capacity} = \frac{3600}{135} \approx 26 \text{ aircraft per hour}$$

Equation 28 Capacity - Runway

The capacity of the runway is 26 movements per hour. It does not matter from which direction the runway is used, because the average runway occupation time remains the same.

The capacity of the runway can now be compared with the capacity of the TMA. The capacity of the TMA differs per runway because the complexity of the routes differs. The capacity of the TMA is 20 to 25 movements per hour on runway 23. The number depends on the mix combination of arriving and departing routes. For runway 05, the capacity of the TMA is 18 to 21 movements per hour. To determine the most common traffic mix of the arriving and departing traffic route, there is looked at the expected flight directions. The VEMER report expects the following:

- 35% of the traffic goes to ACC sector 2;
- 65% of the traffic goes to ACC sector 3;
- 5% of the traffic goes to the other sectors.

(Obbens, Obbink, & van den Bos, 2018)

Most traffic goes to ACC sector 2 and 3, because these are the routes that go south. EHLE will mainly handle leisure flights, there is expected the airlines will fly most to warmer climates. The combination of arriving and departing routes of BADEX with ARBEP is the most similar. Therefore, the capacity of this combination of traffic routes is compared with the runway capacity.

The capacity of the combination of BADEX with ARBEP is 21 movements per hour, when runway 23 is used. For runway 05 the capacity of the combination BADEX with ARBEP is 19 movements per hour. The capacity of the TMA is lower than the capacity of the runway, resulting the capacity of the TMA is limiting to the capacity of the runway.

**Non-commercial mode**

For the non-commercial mode the same table of the average runway occupation time is used, table 33. Herein, all aircraft categories are used. The same mix ratio for traffic is used as in the calculation of the volume, namely 30% IFR traffic and 70% IFR training flights. Because IFR starts and IFR landings are separated in the average runway occupation, the percentage of IFR traffic has to be split. This provides a traffic ratio of 15% IFR starts, 15% IFR landings and 70% IFR training flights. The capacity of the runway is calculated with the average runway occupation time and the traffic mix.

$$\Delta t = |p_{mix}| |t_{TBS}| |p_{mix}|^t$$

$$\Delta t = |0.15 \quad 0.15 \quad 0.70| * \begin{vmatrix} 120 & 120 & 210 \\ 120 & 180 & 240 \\ 300 & 240 & 150 \end{vmatrix} * \begin{vmatrix} 0.15 \\ 0.15 \\ 0.70 \end{vmatrix} \approx 189.6 \text{ seconds}$$

Equation 29 Average runway time (s) (Hogervorst & J., 2015)

The runway capacity per hour is calculated with the average runway occupation time.

$$\text{runway capacity} = \frac{3600}{189.6} \approx 18 \text{ aircraft per hour}$$

Equation 30 Capacity - Runway

The capacity of the runway are 18 movements per hour. It does not matter from which direction the runway is used, because the average runway occupation remains the same.

The capacity of the runway is compared with the capacity of the TMA. In the non-commercial mode, the capacity of the runways hardly differs. The capacity of the mix arriving and departing routes BADEX with ARBEP will be compared with the runway capacity. The traffic mix BADEX with ARBEP has a capacity of 11 movements per hour for runway 23 and runway 05. The capacity of the TMA is lower than the capacity of the runway, resulting the capacity of the TMA is limiting to the capacity of the runway.

**7.2.2 Airport capacity**

For the capacity of the airport, the number of aircraft stands is analyzed. EHLE has four aircraft stands available for commercial aircraft. The average turnaround time is not less than an hour, so 8 movements per hour can take place at the airport. For the capacity of the airport it is expected that there will be an equal distribution of starting and landing aircraft. The capacity of the airport with 8 movements per hour is lower than the capacity of the TMA. This makes the airport infrastructure in the commercial mode the limiting factor in the handling process of EHLE, compared with the TMA and runway. Figure 8 displays the capacity of the commercial mode of the runway, TMA and airport. (Obbens, Obbink, & van den Bos, 2018)

There is no information available on how many aircraft stands are available for IFR training flights. As a result, no comparison is made between the TMA and the airport for the non-commercial mode.

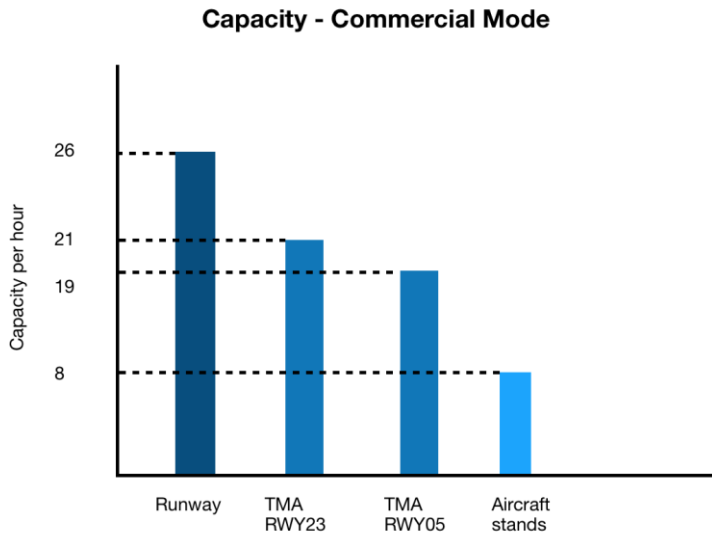


Figure 8 Capacity comparison handling process – Commercial mode

### 7.3 Movements per year

This section determines whether the target for maximum traffic movements is feasible with the route structure of the TMA. For IFR traffic, 4,000 movements per year are set in 2019 and 10,000 movements in 2023. The number of movements for the IFR-training flights are not included in the 4,000 and 10,00 movements. There is no maximum number set for the traffic movements of the IFR-training flights per year. As a result, the number of movements per year for the non-commercial mode cannot be compared with the maximum number of traffic movements. (Obbens, Obbink, & van den Bos, 2018)

#### Commercial mode

Based on the VEMER of LVNL, the day distribution of figure 9 is used. On one day six hours are designated as commercial mode.

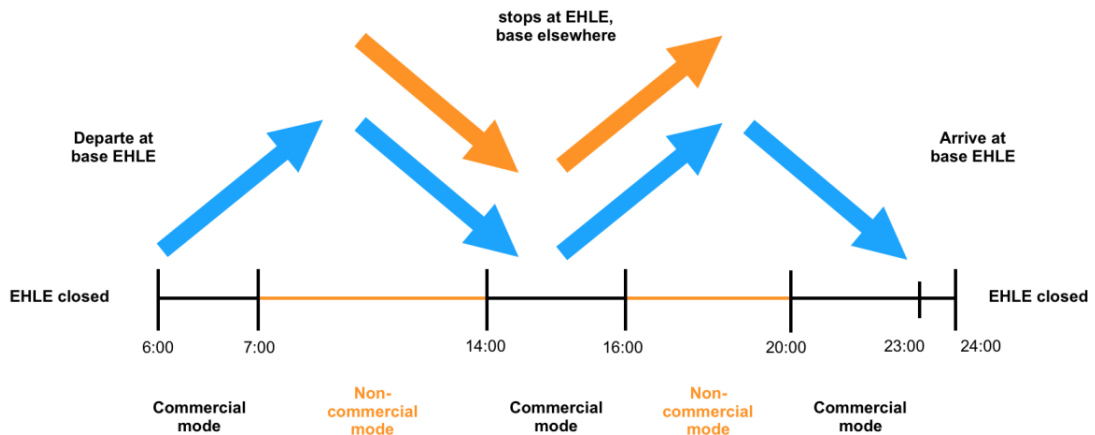


Figure 9 Daily schedule operational modes EHLE (Obbens, Obbink, & van den Bos, 2018)

The capacity per hour, for the commercial mode, for runway 23 is 21 movements per hour and for runway 05 is 19 movements per hour. This is when the mix traffic BADEX with ARBEP is used. When the total capacity will take place in the designated commercial mode, 126 movements per day can take place on runway 23 and 114 movements on runway 05. In the VEMER of EHLE is determined that the maximum number of movements is 4,000 per year in the first years EHLE is operational. For this, 7 to 14 flights per day are expected. When looking at the capacity of the mix traffic of runway 23 and runway 05, the number of movements in the first year is possible. For 10,000 movements per year (in 2023), 17 to 34 flights per day are expected on a daily basis. The expected flight movements on daily basis of the TMA is higher than the

expected flights determined in the VEMER to reach the 10,000 movements. (Obbens, Obbink, & van den Bos, 2018)

To calculate how many movements per year are possible, the summer and winter schedules of 2019-2020 are considered. The summer period runs from 31-03-2019 till 26-10-2019 and the winter period run from 27-10-2019 till 28-03-2020. In total, this is 362 days that the airport will probably be operational. It may be that in the first years the airport is not open on all the days of the winter and summer period for commercial traffic. In this calculation the assumption is made that the airport is open on all the days of the summer and winter period. For runway 23 the annual capacity will be  $126 * 362 = 45,612$  movements and for runway 05 the annual capacity will be  $114 * 362 = 41,268$  movements. This calculation also determines the 4,000 and 10,000 movements is feasible with the structure of the TMA. (IATA, 2018)

### **Non-commercial mode**

The non-commercial mode takes place outside the peak hours of the commercial mode. In figure 8, 11 hours are indicated as non-commercial mode. In practical, this will vary due to the difference in daylight periods during the year. In the VEMER an average of 8,5 hours per day is considered. The capacity is 11 movements per hour when runway 23 or runway 05 is used. For the daily capacity in the TMA there are 93 movements per day possible. On an annual basis when the summer and winter period are considered, a capacity of 33,847 movements is possible in the TMA. There are no maximum movements determined in the VEMER for the non-commercial mode. Therefore, no comparison could be made. (Obbens, Obbink, & van den Bos, 2018)

## **7.4 Conclusion**

In this chapter the capacity of the handling process of EHLE is analyzed. Herein, the capacity of the TMA, the runway and the airport are considered. The analyses of the commercial mode and the non-commercial mode showed the TMA is the limiting factor compared with the capacity of the runway. Hereafter, the capacity of the TMA was compared with the capacity of the airport. For the commercial mode, a comparison is made based on the number of aircraft stands for civil aircraft. The outcome of the analysis is the capacity of the airport is the bottleneck in the handling process of EHLE. There is no information available on how many aircraft stands are available for IFR training flights. Therefore, no comparison could be made between the capacity of the TMA and the capacity of the airport for the non-commercial mode.

After the bottleneck analysis of the handling process of EHLE, the annual movements were calculated to compare it with the maximum flight movements. For the IFR traffic, 4,000 movements per year have been set for the first years EHLE is operational and 10,000 movements in 2023. The number of movements for the IFR-training flights are not included in the 4,000 and 10,000 movements. For the IFR training flights, no maximum number of movements is set per year. As a result, the number of movements per year for the non-commercial mode cannot be compared with a maximum number of aircraft movements. For the commercial mode the capacity of the TMA is 21 movements per hour or 19 movements per hour, depends on the runway use. There are six hours per day appointed as commercial mode, allowing 126 or 114 movements per day at the airport. The VEMER of Lelystad determines that 7 to 14 flights per day are expected when a maximum of 4,000 movements per year may take place. For the 10,000 flights per year, it is expected that 17 to 34 flights per day will take place. The daily capacity of the TMA is higher than the expected flights on daily basis in order to reach the 4,000 and 10,000 movements. Therefore, the 4,000 and 10,000 movements are feasible with the structure of the TMA.

## 8 Conclusions and Discussion

In this chapter the conclusions and discussion of the research are discussed. The conclusions of the research are explained per sub-research question, in the end the main research question is answered. In the discussion, the methods and assumptions used during the research are critically examined and analyzed.

### 8.1 Conclusions

The aim of the research is to answer the research question: “*What elements determine and influence the capacity of the Lelystad TMA and how much capacity can be realized for civil air traffic which arrive and depart at Lelystad airport?*”. The conclusion of the research question is derived by answering the sub-research questions:

- What factors influence the capacity in the airspace of the Lelystad TMA?
- What is the theoretical volume of the Lelystad TMA?
- What is the relation between the factors and the capacity of the Lelystad TMA?
- What are the capacity requirements for civil air traffic in the Lelystad TMA when the airport is opened?
- Is the capacity feasible in the first year when EHLE becomes operational?

#### 8.1.1 Capacity factors

The first sub-question is: “*What factors influence the capacity in the airspace of the Lelystad TMA?*”. The capacity of the Lelystad TMA is influenced by two main factors, the workload of the traffic controllers and the volume of the TMA. The workload is influenced by the complexity, the interaction and the task load. The complexity is the interaction within a traffic flow. It depends on the layout of the traffic route and the traffic demand within the route. The following factors determine the complexity of an air traffic route:

- the horizontal space;
- the vertical space;
- and the length of the airspace.

The interaction is the extent to which traffic flows are conflicting. It contributes to the complexity of a traffic situation and thus influences the traffic controller’s effort. The task load is the effort needed to guide traffic to a destination without looking at possible traffic conflicts. It consists of the element’s:

- instruction load;
- procedures;
- and coordination load.

The other main factor which influences the capacity of the Lelystad TMA is the volume. The volume is determined by:

- the traffic mix;
- the separation standards;
- and the aircraft performance.

Another element that influences the capacity, but is not included in the calculations of the volume and capacity, is the external factor weather. The weather is a factor that is very inconsistent. Because it is difficult to include a factor whose data can change every day, it has been decided to leave it out of consideration in the calculation of the volume and capacity.

#### 8.1.2 Theoretical volume

The second sub-question is: “*What is the theoretical volume of the Lelystad TMA?*”. The average TAS, separation standards and traffic mixes are included in the calculation of the volume. Two modes are included in the report, the commercial mode and non-commercial mode. In the commercial mode IFR traffic from airlines are considered. Herein, other air traffic is rejected. In the non-commercial mode traffic takes place that is rejected in the commercial mode. This mode includes 70% IFR training flights and 30% IFR flights.

For the theoretical volume calculations are made for the arriving traffic and the departing traffic. The theoretical volume is not calculated for the traffic mix departing and arriving traffic. In the first expert session, with operational experts of CLSK, there was not enough time to reach an agreement on the theoretical volume for the mix traffic. The results of the theoretical volume of the arriving and departing traffic of both modes are shown in table 34.

Table 34 Results theoretical volume per hour

Per hour	Commercial mode	Non-commercial mode
Arriving traffic	32	17
Departing traffic	30	18

No margins or buffers are included in the theoretical volume to compensate for failures in the operation. During the first expert session, it was agreed to add half of the separation time to the separation to use as a buffer for the arriving traffic. For the departing traffic, the separation is automatically applied in the operation. The separation taken is equal to the average runway occupation time. However, failures can occur in the operation. Therefore, a 10% margin is taken on the total volume. By adding the margin and buffers in the theoretical volume, the practical volume is derived. In table 35, the results of the practical volume are shown.

Table 35 Result practical volume per hour

Per hour	Commercial mode	Non-commercial mode
Arriving traffic	21	11
Departing traffic	27	16

In sector 3 of the TMA military traffic take place on the AWX and BENE routes. This traffic must be included to the volume. Because there is no data available on the intensity of the flights, it was agreed to consider two scenarios. One scenario assumes an intensity of 2 military flights per hour and the other scenario assumes an intensity of 6 military flights per hour. According to the flight plan, there must be a separation of five minutes between the crossing aircraft. Therefore, the TMA will be temporary unavailable for civil air traffic at:

- a low intensity for 10 minutes;
- and with a high intensity for 30 minutes.

This results in the following practical volume for the modes, table 36.

Table 36 Results practical volume per hour - Military routes

Per hour		Commercial mode	Non-commercial mode
Arriving traffic	Low intensity	17	9
	High intensity	10	5
Departing traffic	Low intensity	22	14
	High intensity	13	8

### 8.1.3 Capacity

After the theoretical volume is calculated, a link is established between the capacity factors and the theoretical volume. This answers the sub-question of: “**What is the relation between the factors and the capacity of the Lelystad TMA?**”. The capacity of the TMA is calculated by combining the workload with the theoretical volume. The total workload is assessed by means of two matrices; the complexity and interaction matrix. In the two matrices the factors of the workload are stated. The matrices are filled in by operational experts of CLSK based on their expertise. In the session was decided to use a 5% margin on the total workload. This creates a buffer to consider the military traffic in TMA sector 4 and 5. The result of the capacity per hour is given in table 37.

Table 37 Capacity per hour

Per hour	Commercial mode		Non-commercial mode	
	Runway 23	Runway 05	Runway 23	Runway 05
Arriving traffic	21	17	8	8
Departing traffic	22	23	12	12

The capacity is verified because it is based on scores of operational experts from CLSK. Since there is no data available of civil traffic in the Lelystad TMA, the data is verified with the practical volume. In the first expert session the practical volume of the TMA is determined by including margins and buffers in the calculations. The margins and buffers are derived by considering practical situations that can occur in the airspace. The operational experts of CLSK agreed to the practical volume for the arriving and departing traffic.

For runway 23 the practical volume of the arriving traffic matches the capacity in the commercial mode, table 38. For the departing traffic there is a difference of 5 movements per hour. This result concludes the buffer which is taken for the practical volume of the departing traffic is not big enough. For runway 05 the capacity is lower than the practical volume. In the first expert session, there was not made a distinction between runway direction. The practical volume is based on runway 23, this result in different outcomes between the practical volume and the capacity per hour. When the runway direction was included, the practical volume would match the capacity like runway 23.

Table 38 Data verification per hour – Commercial mode

Commercial mode per hour	Runway 23		Runway 05	
	Practical volume	Capacity	Practical volume	Capacity
Arriving traffic	21	21	21	17
Departing traffic	27	22	27	23
Mix traffic	-	20 - 25	-	18 - 21

When verifying the capacity with the practical volume in the non-commercial mode, the results of the capacity are lower than the practical volume (table 39). Here from, is concluded that the buffers taken during the first experts' session are too low.

Table 39 Data verification per hour – Non-commercial mode

Non-commercial mode per hour	Runway 23		Runway 05	
	Practical volume	Capacity	Practical volume	Capacity
Arriving traffic	11	8	11	8
Departing traffic	16	12	16	12
Mix traffic	-	10 -14	-	10 - 12

### 8.1.4 Handling process

The fourth sub-question is: **“What are the capacity requirements for civil air traffic in the Lelystad TMA when the airport is opened?”**. In order to answer this question, a bottleneck analysis is performed on the capacity of the handling process of EHLE. The capacity of the TMA is compared with the capacity of the runway and airport. First the runway capacity is compared with the capacity of the TMA. In both modes and runway direction, the capacity of the TMA is limiting to the capacity of the runway. The capacity of the runway was determined based on the average runway occupation time from the VEMER of EHLE. After this, the capacity of the TMA was compared with the capacity of the airport. The airport has 4 aircraft stands, which means that 8 movements per hour are possible. In the commercial mode it is possible to achieve 19 movements per hour. This makes the airport infrastructure the limiting factor in the handling process of EHLE. For the non-commercial mode the capacity of the TMA cannot be compared with the capacity of the airport, because there is no information available about the number of aircraft stands for IFR training flights. In figure 10, a comparison is given of the different capacities in the commercial mode.

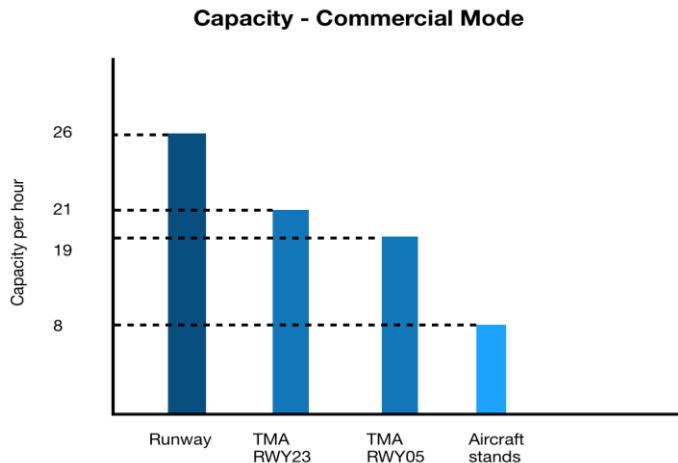


Figure 10 Capacity EHLE – Commercial mode

### 8.1.5 Capacity feasible

The last sub-question in the research is: ***“Is the capacity feasible in the first year when EHLE becomes operational?”***. In the VEMER of EHLE is stated that the maximum number of movements is 4,000 per year. For this, 7 to 14 flights per day are expected according to the VEMER. When looking at the capacity of the traffic mix of runway 23 and runway 05, the annual flight movements in the first year is possible. For 10,000 movements per year (in 2023), 17 to 34 flights per day are expected according to the VEMER on a daily basis. On one day six hours are designated as commercial mode. The capacity per hour, for the commercial mode, for runway 23 is 21 movements per hour and for runway 05 is 19 movements per hour. When the total capacity will take place in the designated hours of the commercial mode, 126 movements per day can take place on runway 23 and 114 movements on runway 05. The capacity of the TMA is higher than the expected flights on daily basis. Therefore the 4,000 and 10,000 movements per year are feasible.

### 8.1.6 Final conclusion

The answers to the sub-questions indicate that the bottleneck in the handling process of the commercial mode is the infrastructure of the airport. For the non-commercial mode, no comparison is possible with the airport, because there is no information available of the number of aircraft stands for IFR training flights. The bottleneck analysis from the non-commercial mode concludes the TMA is the limiting factor compared with the runway. Additionally, an analysis is performed to determine if the annual flight movements of 4,000 and 10,000 is feasible with the structure of the TMA. In the annual flight movements only IFR flights are considered. The IFR training flights are not included. The outcome of the analysis concludes the annual flight movements of 4,000 and 10,000 are feasible with the structure of the Lelystad TMA.

The main research question that has to be answered is:

***“What elements determine and influence the capacity of the Lelystad TMA and how much capacity can be realized for civil air traffic which arrive and depart at Lelystad airport?”***

In the first sub-question, the first part of the main question has been answered. There are 3 main factors that influence the capacity of the TMA;

- The volume of the airspace;
- The workload of the traffic controller;
- And the weather.

These three main factors are subdivided into several factors. In the research there was chosen to leave the weather out of consideration, because of its variety per day.

In the second part of the main research question there is asked how much capacity can be realized for civil air traffic of EHLE. In the VEMER six hours of commercial mode are indicated. In Section 8.1 the practical volume per hour is given for the commercial mode. By multiplying the number of hours with the capacity per hour, the capacity per day in commercial modus is calculated, table 40. However, IFR traffic can also take place in non-commercial mode. The number of movements for civil traffic is expected to be higher than the established values in the table.

Table 40 Capacity TMA per day – Commercial mode

Per day	Commercial mode	
	Runway 23	Runway 05
Arriving traffic	126	102
Departing traffic	132	138
Mix traffic	120 - 150	108 - 126

## 8.2 Discussion

The research analysis and results provide insight in the volume and the capacity of the Lelystad TMA. For this research certain assumptions are made to determine the capacity and volume of the Lelystad TMA. In this section, the decision that are taken per sub question are reconsidered and further explained. In addition, the limitation during the research are reviewed.

The first sub question is: **“What factors influence the capacity in the airspace of the Lelystad TMA?”**. In order to answer this question a literature study is performed. In this study, research is carried out into the capacity in relation to factors that can influence the capacity. Many factors of the articles correspond to each other. The outcome of the capacity factors from the literature study is verified in the first expert session with operational experts from CLSK. However, these factors still have to be tested in practice when commercial traffic take place in the TMA.

The second sub question is: **“What is the theoretical volume of the Lelystad TMA?”**. In the calculation of the volume the expected speeds (IAS) per waypoint are used. The expected speeds are obtained from Mr. Meerburg of LVNL. The speeds are used because at the time of the research there was no data available nor simulations of commercial air traffic in the. The calculation of the volume was more accurate when data from simulations or actual data were used.

In addition, the human factor of the traffic controllers and pilots were included in the calculation of the theoretical volume. There is usually more separation provided than the minimum required separation. An assumption is made that an average of 18 seconds more separation is applied. Assuming the data occurs as a normal distribution, when EHLE is opened. These assumptions are made based on the lecture of HvA (Hogervorst & J., 2015). When data was available on the airspace, a more accurate human factor could be considered in the research.

In the first expert’s session with CLSK was decided to use two modes; commercial mode and non-commercial mode. This principle is derived from the traffic modes of the VEMER; IFR and VFR mode. Within the modes, assumptions are made about the distribution of traffic. In the commercial mode there is only IFR traffic from airlines expected and in the non-commercial mode a traffic mix of IFR and IFR training flights. For the traffic mix of the non-commercial mode a distribution of 70% IFR training flights and 30% IFR flights are expected. This is an assumption based on the expected traffic of Lelystad airport. The distribution of traffic is not based on data, because there was no data available. If the distribution was based on data, the capacity would be more accurate.

The third sub question is: **“What is the relation between the factors and the capacity of the Lelystad TMA?”**. The capacity of the Lelystad TMA is calculated by means of the VEM-model ATC workload of LVNL. This method is chosen to determine the capacity in the same way as LVNL. The capacity is derived from the workload of different traffic flows within the TMA. In order to determine the workload for the traffic flows a second expert session with CLSK is conducted.

In this session was decided to use a buffer of 5% on the maximum workload. The buffer ensures the maximum workload is not exceeded when military traffic takes place in TMA sector 4 and 5. However, there is no data available on the intensity of military traffic in TMA sector 4 and 5. It may be that the buffer is too small or too large, which results in a too large or too little capacity. When data was available from the military traffic, a more accurate margin could be taken, making the capacity of the TMA more accurate.

In addition, the workload per combination of traffic flows is determined in an expert session with three man of CLSK. It could be that if there was another CLSK composition during the session, there would be a different outcome in terms of capacity.

Lastly, the capacity of the TMA is verified with the practical volume. There was no data available of commercial traffic in the TMA. The alternative was to verify the outcome of the capacity with the practical volume. During the first expert session with CLSK buffers and margins are chosen based on traffic situations that can occur in the TMA. The verification with the practical volume is not as reliable as verification with data, but it was the only option in the research.

The fourth sub question is: ***“What are the capacity requirements for civil air traffic in the Lelystad TMA when the airport is opened?”***. For this question a bottleneck analysis is performed of the handling process of EHLE. Herein, data from the VEMER Lelystad are used to determine the capacity of the runway and airport. For the commercial mode it was possible to determine the bottleneck in the handling process. However, for the non-commercial mode it was not possible to determine the capacity of the airport. In the VEMER there was not defined how many aircraft stands were available for IFR training traffic. The bottleneck analysis in the non-commercial mode is only made between the runway and the TMA.

The last sub question is: ***“Is the capacity feasible in the first year when EHLE becomes operational?”***. In the VEMER is stated the maximum number of movements is 4,000 per year for IFR flights when Lelystad airport becomes operational and 10,000 movements per year in 2023. These numbers do not include IFR training flights. With the commercial mode hours, it is possible to conclude if the movements per year are feasible. For the non-commercial mode it was not possible to compare the annual movements. Since the IFR training flights are not included in the maximum number of movements per year.

### ***Limitations***

Because EHLE is not operational yet for civil air traffic, there is no data available of the airspace. To cope with this problem, data was created by organizing expert sessions with operational experts of CLSK. The disadvantage of this approach is that there are assumptions made and the outcome cannot be verified. Another limitation in the research was the intensity of the military traffic. No data is available from the traffic how often it occurs. This may cause the buffer that is taken to be too large or too small which can result in less capacity.

## 9 Recommendations

The discussion of previous chapter states certain assumptions or decisions in the research could be performed differently when more data of the airspace was available. This chapter builds on the discussion to give recommendations regard to the research and possible follow-up research.

The first sub question of the research is: “**What factors influence the capacity in the airspace of the Lelystad TMA?**”. In the chapter of the conclusion the capacity factors for the Lelystad TMA are defined. These factors are determined based on the literature study and are verified during the first expert session with CLSK. However, the capacity factors also must be verified when Lelystad airport becomes operational for commercial air traffic. The first recommendation of the research is to verify the list of capacity factors with the practical situation of Lelystad airport.

In the research is decided to not include the external factor the weather in the volume and capacity calculations. Because the weather is not a constant factor, it was decided to leave it out of consideration in the research. However, the weather is a factor that influences the capacity. Visibility is the most limiting factor, this affects the minimum separation distance on final. When visibility gets worse, the separation becomes greater which reduces the capacity. It is therefore important to do research in the relation between the external factor and the capacity. There is agreed LVNL will provide the capacity for Lelystad airport with regard to the weather. However, CLSK has to research the effects of weather on the volume and capacity of the TMA.

The second sub question is: “**What is the theoretical volume of the Lelystad TMA?**”. Two modes are included in the research to determine the capacity of the TMA; the commercial mode and the non-commercial mode. In the non-commercial mode a traffic mix of 30% IFR flights and 70% IFR training flights are considered in the research. When EHLE becomes operational, the traffic mix must be verified. In addition, there is decided in the first expert session to not include the VFR traffic in the research because it can be rejected. A recommendation is to perform a research in the VFR traffic.

In addition, the human factor of the traffic controller and pilot is considered in the calculation of the volume. The assumption is made that the data would occur in a normal distribution and an average of 18 seconds more separation is given. When EHLE becomes operational data must be gathered regarding the extra separation of the human factor.

The third sub question is: “**What is the relation between the factors and the capacity of the Lelystad TMA?**”. The research of the capacity factors has shown that the workload is a major influence on the capacity. In the VEM-model of LVNL, the workload includes effort of the complexity interaction factors. The same method is used in the report to determine the capacity of the TMA. After this, the capacity is verified with the practical volume. This must also be verified with the practical situation when EHLE is operational for commercial traffic. A recommendation for the research is when EHLE becomes operational for commercial traffic, the capacity must be verified.

The capacity is derived from the workload of different traffic flows within the TMA. In order to determine the workload for the traffic flows a second expert session with CLSK is conducted. In this session there is decided to use a buffer of 5% on the maximum workload. The buffer is based on expert judgement of the traffic controllers from CLSK who were attending the expert session. Since, no data is available of the intensity of military traffic it is possible the buffer is too large or too small. A recommendation of the research is to gather data of military traffic in TMA sector 4 and 5 to create a more accurately buffer of the workload.

In the second expert session, the capacity per hour is determined for the maximum workload. These numbers are also based on expert judgement of the traffic controllers from CLSK who were attending the expert’s session. A recommendation of this research is to define how many movements are possible when the maximum workload is achieved and what is considered as a normal workload.

The fourth sub question is: “**What are the capacity requirements for civil air traffic in the Lelystad TMA when the airport is opened?**”. In the VEMER of EHLE is stated that the

maximum flight movements are 4,000 in the first years EHLE is operational and 10,000 per year expected in 2023. The conclusion states the number of movements are possible within the TMA. However, the determined capacity of this research is a first indication. A recommendation for CLSK is to analyze the capacity with the available data when EHLE becomes operational.

The last sub question is: ***“Is the capacity feasible in the first year when EHLE becomes operational?”***. Due to the short time period for the research, no link is created between the commercial mode and the non-commercial mode. Before the capacity model is used, a link must be made between the two modes. Based on the link, the influence of the traffic in the non-commercial mode on the commercial mode in terms of capacity can be determined. In addition, it can occur the total capacity of the TMA is not used by the commercial traffic. The remaining capacity could be filled by the traffic of the non-commercial mode. Here for, the link is required between the two modes.

The final recommendation of the research is to use area responsibility to handle traffic in the TMA. At the moment TMA sector 1, 2 and 3 is area responsible and TMA sector 4 and 5 is flight responsible. For the capacity it is better to consider the area as one responsibility. When the TMA is considered as area responsibility, the unpredicted military traffic is not considered in the capacity figures. The reason flights in TMA sector 4 and 5 are handled by flight responsibility is because of the military traffic. The military traffic flies through the TMA in sector 4 and 5, where they do not make use of the flight routes. When the complete TMA is handled by area responsibility, the military traffic must be handed over to the frequency of the approach controller of Lelystad. Since the traffic only flies through the TMA for a few minutes, it is unfavorable to switch frequencies. When the TMA has area responsibility, it is expected that military traffic will plan a different route that will not go through the TMA.

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## Appendix I Reflection

The research report is written to complete the bachelor of Science degree in Aviation Engineering. A reflection is written to evaluate the secondary and primary research skills. Additionally, an overall reflection is written of the entire research.

### Secondary research skills

Nowadays, a lot of data is available of research topics. During the research on the capacity of the Lelystad TMA it was difficult to find data related to the TMA. In addition, it was difficult to find a suitable method which also considers the unexpected military traffic in an airspace. The literature study in the research has cost a lot of time and could be in the end more efficiency. The reason for this is that I mainly focused on finding a method where no historical data is used. It appears that few articles are available.

### Primary research skills

During the research expert sessions are conducted with CLSK to generate data for the calculations of the volume and the capacity. It was challenging because of the sensitivity of the research topic. In addition, the TMA is not yet operational for civil air traffic which makes it difficult for the traffic controllers to give their expertise. In the first expert session the operational experts of CLSK found it difficult to determine the volume per hour for the mix of arriving and departing traffic. Thereby, the volume of the mix was not defined. This was a learning point in terms of preparation and construction of the session. During the session I found it difficult to be concrete and to lead the conversation well. The second expert session went better than the first. It was much clearer and decisions were made faster. In addition to the data collection, I found it difficult to choose a method to determine the volume per hour. In the end I have choose to use the average TAS in combination with the different separations' standards for aircraft categories. The difficulty in the calculations are making the assumptions. Since there is no data it is hard to make assumptions. During the expert session, the assumptions were verified by the operational experts, making it more sustainable.

### Improvement time management skills

In the beginning phase of the research I lost a lot of time writing my project plan and gathering information of CLSK. CLSK has its own intranet where documents such as working method and procedures are found. Because I did not have access to the intranet, it took a long time before I had the documents of CLSK. During the research period two SCRUM meetings were weekly planned. During the meeting every student has five minutes to present what he is doing at the moment and what he is planned to do. On the SCRUM board task were placed which has to be finished within a two-week period. These tasks led to the results of the sprint reviews. The SCRUM meetings were attended by the students and the SCRUM master, who helped the students to keep on schedule of the graduate track. Because of the SCRUM meeting and board, I had a good overview of the tasks I had to perform. The sprint reviews helped me to determine whether I was on the right track during the research. Overall, the SCRUM is a good method and I tent to use it more often.

### Organization

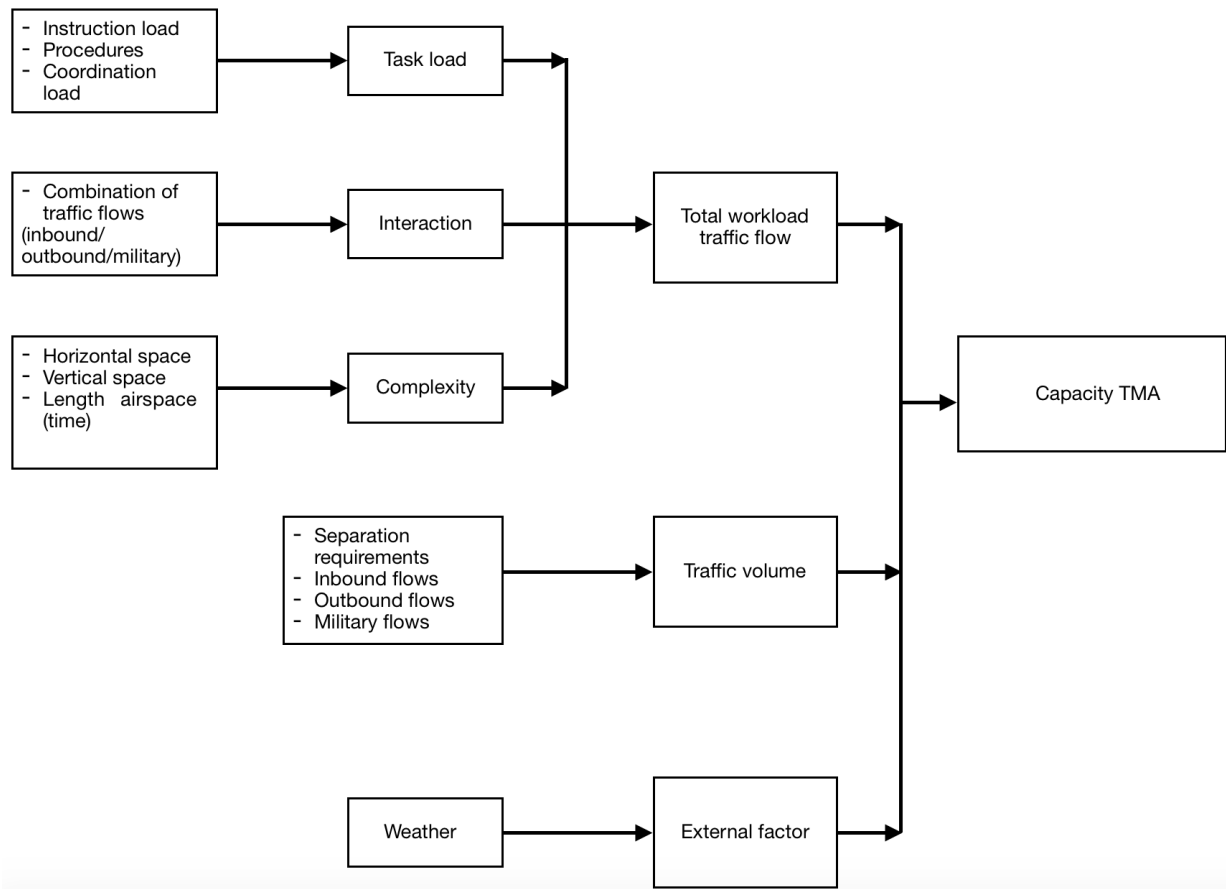
The KDC CoE is a unique working environment to graduate from. By means of the cooperation with Schiphol Airport and KLM different aspects of the aviation industry are considered in the research. During the research I found it hard to make a connection with Schiphol and KLM. Lelystad airport and Schiphol certainly have a connection because of Schiphol's growth potential. However, it is difficult to include this connection in the research. In the organization of LVNL and CLSK is Lelystad airport an important project. During my research period, I did miss the involvement in the entire Lelystad project. It did not affect my results, but it might be good to have more insight in the other topics regarding the Lelystad project.

### Overall reflection

Looking back on my graduation research at KDC I very much enjoyed the working environment and the involvement of the stakeholders in the research. I have learned a lot of the different working methods and procedures within CLSK and LVNL. In addition, I have learned more of the

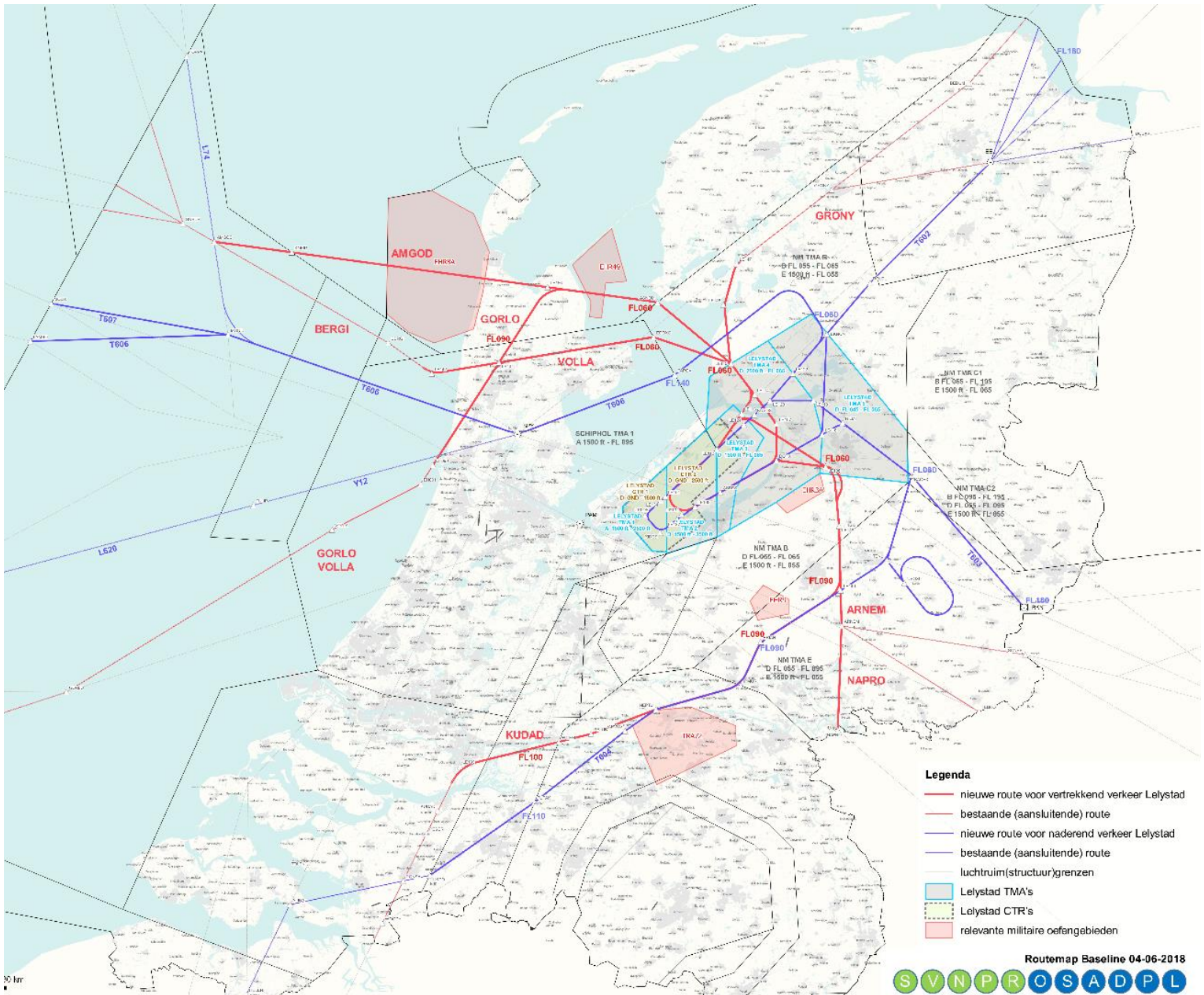
airspace structure and the difficulties to reach an agreement of the volume and capacity of an airspace. This research helped me to think creative and have an open mind for innovative ideas or method.

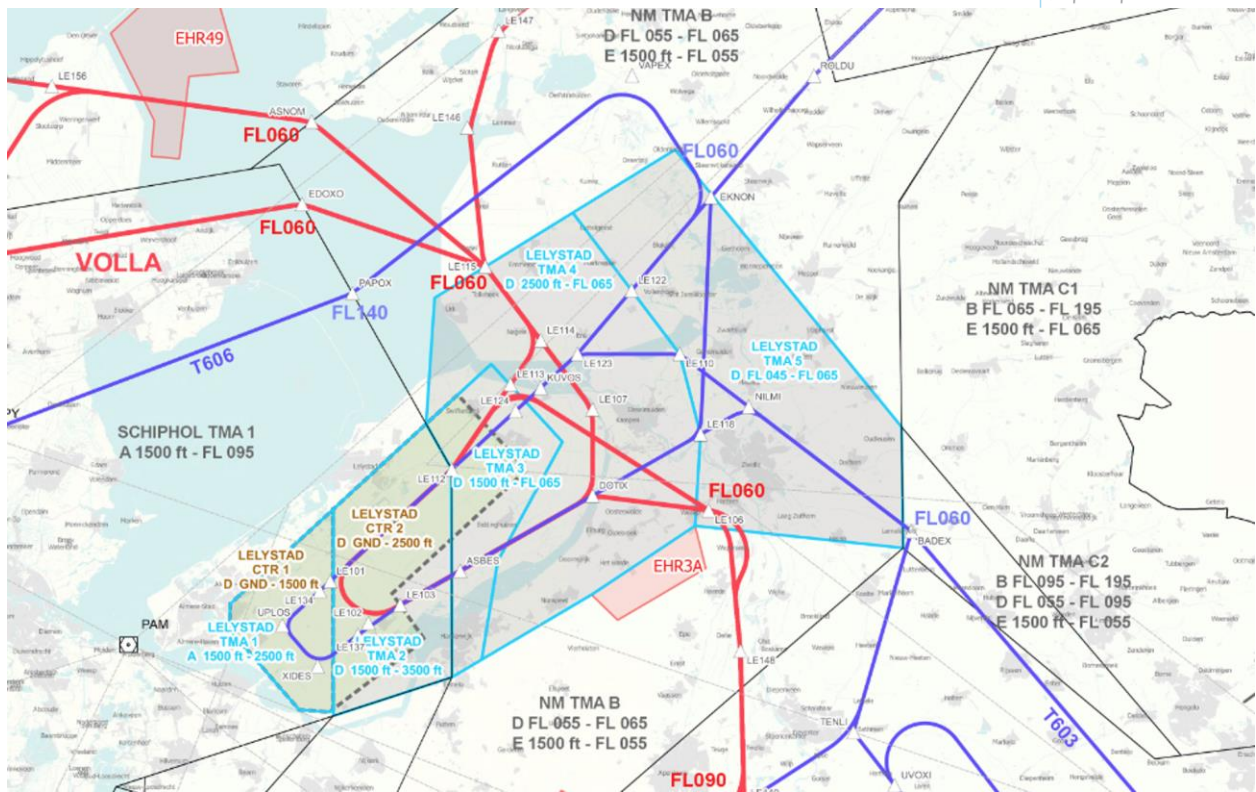
## Appendix II Capacity in relation to factors



Appendix III

Routes Lelystad TMA





## Appendix IV Interview anonymous 1 09-10-2018

The interview is held with anonymous 1, someone who is working for CLSK. The date of the interview is 09-10-2018.

### ***What is the difference between an approach and area controller?***

At Lelystad airport the approach controller is working in TMA sector 1, 2 and 3. Sector 4 and 5 are used by the approach and area controller. TMA sector 4 and 5 have flight responsibility. Herein area traffic can fly through but is obliged to coordinate with the approach controller. In TMA sector 1, 2 and 3 the area traffic cannot fly through without asking permission. When it is not possible area traffic flies through the sector, the initiative is with the approach controller of Lelystad.

The coordinator of CLSK only works for the area controllers, he or she conducts coordination meetings for the executive controllers and is the contact point. All coordination that takes place runs through this person. The approach controller is an individual who does its own coordination.

### ***Where are the restrictions of Eindhoven Airport (EHEH) based on?***

Restrictions are based on the current traffic situation. If the traffic does not currently fit into the operation, the aircraft are placed in the holding. At Eindhoven airport (EHEH) the approach controller and the EH1 controller are always occupied. On these positions you cannot set up two people. So, when it is busy, these people are literally busy. It is possible to do something about the preliminary process by adding an extra traffic controller that does all coordination.

The coordinator has an overview of the traffic that arrives at EHEH on daily distribution. When too much traffic is expected at the airport, the coordinator determines whether to add an extra traffic controller. When there is no extra traffic controller available, the traffic is still brought in.

CLSK does nothing with the flight plans of civil traffic. The civil traffic simply arrives at EHEH and no restrictions are imposed there. They assume they can handle more traffic in the air than EHEH can handle on the ground. EHEH has 10 VOPs, so 10 aircraft can start and 10 aircraft can land on EHEH. In the switching moment, of aircraft on the VOPs, there is expected that more traffic will take place. The starting aircraft will go directly to the area controller and the landing traffic is on the frequency of the approach controller. So, in principle the controller does not have more than 10 aircraft on its frequency. This is handled by means of flight responsibility.

CLSK works as a team where you do not get in each other's way. When the approach controller is very busy and an aircraft is coming to the airport, the area controller tries to reduce the workload of the approach controller. It is a game the traffic controllers are trained in. You help each other in their work. Actually, the arriving traffic has priority, but because the approach controller is busy the area controller places the aircraft in the holding or try to reduce the aircraft. This is in consult with approach controller.

The approach controller handles multiple flights simultaneously, despite the flight responsibility. Everything that arrives at EHEH arrives at the approach controller. The approach controller has several aircraft on the same frequency.

**Area responsibility:** area is of particular person, you must ask permission to enter the area. Controller must give clearance to the pilot in order to fly into it.

**Flight responsibility:** Everyone is allowed to enter the area, there is only agreed who has priority in the area and how they inform each other. It used to be through strips, but it is nowadays through electronic coordination with electronic strips and military cruiser lists. Certain parameters are attached, such as 12 minutes before the aircraft enter the area, the cruiser strip must be in the cruiser's list of the controller who is responsible for the area. If the aircraft is stated in the cruisers list, the pilot has to adhere the route and altitude. The intersecting military traffic of the cruiser's list has precedence over the traffic of the approach controller. If the traffic of the cruiser's list wants to deviate from its route, he must first coordinate with the approach controller and ask

permission. This must be within the 12 minutes. During area responsibility the separation is guaranteed because one person coordinates in the area.

Flight responsibility is an open area where all traffic can take place in. Agreements and procedures are made to guarantee the separation standards between aircraft.

The electronic strips of the cruiser's lists are stored. When there is an entry or exit waypoint the aircraft fly over, they can define the times within the area. However, the military traffic does not fly via the waypoints. The waypoints are not defined making it difficult to determine the time.

***If there was no research in the capacity of the TMA, how would the capacity have been addressed?***

What may be a disadvantage of the research is that a certain number of movements per hour is determined, but the number of movements could also occur in 10 minutes of the hour. The traffic controller cannot handle these number of movements. It is difficult to indicate the capacity of the TMA since the OIT (Operational Air Traffic) traffic is not predictable and military exercises are not fixed.

A possible method for the research is to determine the capacity by means of expert judgement. By organizing sessions with traffic controllers of CLSK and using the capacity figures of the runway of EHLE as baseline. This will be the starting point. Hereafter, you can determine what an acceptable number is per hour. At final 4 nm separation is required, this is approximately equal to 2 minutes. This must be again derived from the calculation. Starting traffic can be a problem for arriving traffic, so they have to be pulled apart. This increases the separation to 4 minutes. The unexpected factor of OIT traffic must also include. You can say for example to take 70% of the maximum capacity and use a buffer of 30% for the OIT traffic.

CLSK also wants the TMA as complete area responsibility, but there are some issues. The problem is mainly in the machine part of LVNL. The AAA system needs to be adjusted, but there is no space for it. The UCO cycles must be adapted. When OIT traffic flies to an area with flight responsibility it will be on the cruiser's list. When the area is area responsibility the OIT traffic will be on the active list. The approach controller has to take the traffic on its frequency. In the AAA system things must change when the entire TMA operates as area responsibility, so the OIT traffic that crosses the area still remains in the cruiser's list and does not have to be transferred.

To solve this problem, CLSK wants to try to make a flight notification on the OIT traffic. Communication by means of calling is needed when OIT traffic takes place in the area. It is possible to fly through an area without a flight plan, only you have to coordinate verbally. That is always possible, only verbal coordination increases the workload. A safety case is needed to see if it is acceptable to coordinate verbal. In addition, there must be examined how often OIT traffic takes place in the year.

When military flights are handled by means of area responsibility, the aircraft has to change its frequency. This is not needed when there is a flight notification attached to the military flight. A F-16 flies 420 kts / 6 = 7 kilometers per minute. It takes about 3 minutes to fly through the area. When military flights go through range, there are usually 2 or 4 aircraft, depending on how they fly.

If you want to make KPI's from EHLE, you would have to look for similar airports. Rotterdam airport is the basis of the procedures of EHLE, except no military traffic takes place at Rotterdam. Rotterdam is also near the Schiphol TMA. There is looked if the procedures of Rotterdam correspond with EHLE. If there is no match, it is changed.

If you put area and flight responsibility together, the separation is not guaranteed. When switching to area responsibility more coordination is needed. Safety case is needed to see how the workload of the controllers can be reduced.

## Appendix V Interview anonymous 2 15-10-2018

The interview is held with anonymous 2, someone who is an approach controller of CLSK. The date of the interview is 15-10-2018.

### ***What is the difference between area and flight responsibility?***

In area responsibility the traffic controller has its own area of airspace, where he has control and responsibility over. Everyone who wants to enter the airspace must ask permission of the traffic controller. The responsibilities are different with flight responsibility. Different traffic controllers are working in one area of the airspace, the controllers respect each other's flights. At Eindhoven airport (EHEH), the landing aircraft are on the frequency of the approach controller and the starting aircraft at the frequency of the area controller. The agreement is the landing aircraft remain free from the starting aircraft. The traffic controller with the landing aircraft separates the flights and keeps the distance between the departing traffic. In area responsibility the aircraft flying in the traffic controller's area are on his frequency.

### ***How do you separate the landing and starting traffic?***

The separation between landing and starting traffic goes through agreements. When a traffic controller must deviate from a route, it is mandatory to coordinate. In a normal situation the traffic controller knows what to do. When he has to deviate from the route the traffic controllers coordinate with each other.

### ***Approach controller, landing traffic***

Anonymous 2 is an approach controller of CLSK at Eindhoven airport (EHEH). The approach controller handles all incoming traffic at the airport. Since, CLSK has a difficult method, it is difficult to explain who handles the outgoing traffic at the airport. The airspace is built up as boxes with pieces of military areas in it. Around EHEH there are several military fields laying close together. There are good agreements made and the traffic is divided.

**Example:** When a flight departs from a field in an approach area, the first responsibility is with the approach controller. In order to work as efficient as possible, the flight usually goes straight to the area controller. The area controller is responsible for the en-route traffic through the Netherlands.

### ***Are there civil flights at Eindhoven airport when there is a military practice in the same area? Has civil traffic priority over the military traffic?***

Not per definition. CLSK allows as many civil aircraft as possible to follow their procedure. A civil aircraft is difficulted to set a side than a military aircraft, but this depends on the operation at that moment. Air traffic control is a dynamic play. F-16 usually do their own thing in a certain airspace. When a civilian B737 arrives who wants to land, the F-16 usually fly higher or deviates. So, the civil aircraft can follow its procedures. There are also situations where an F-16 must start from Volkel, in this case the civil aircraft deviates from its route so the F-16 can start. It is not per definition the civil aircraft has priority.

### ***Is a distinction made between traffic controllers handling military traffic and civil traffic?***

Nowadays, CLSK handles 90% civil traffic and 10% military traffic. Military and civil traffic are intertwined. At EHEH you can have a civil aircraft on your frequency, but also a military aircraft (for example an F-16 that is going to make a practice approach). There is no rule the military traffic must be on the frequency of a CLSK controller or a civil aircraft must be on the frequency of a LVNL controller. It is overlapping.

### ***How do the military cruiser's list work? If a military aircraft becomes on the list do you consider its route and keep clear from the aircraft?***

Exactly. There are three approach areas (3 clusters):

- West;
- South;
- And North.

The area controller handles aircraft from for example Beek to Eelde. You will fly through a South cluster. The agreement is made the approach controller keeps aircraft clear of the en-route traffic to the south. When area responsibility would apply, the approach controller must put the military flight on his frequency and guide the aircraft through the area. During flight responsibility the approach controller has its own traffic. The military traffic which cross the area of the approach controller will be on the frequency of the area controller. The area controller coordinates the aircraft from Beek to Eelde. By means of cruiser strips and lists the approach controller knows the intentions of the flight and can plan around it and remain clear of it.

***How far in advance will the aircraft appear in the cruiser's list?***

12 minutes in advance, sometimes earlier but at least 12 minutes. When there is a spontaneous cruiser, it is coordinated.

***For example:*** Budo (small airport near Eindhoven) is a green field where you can only depart and land on sight (VFR). When the aircraft departs it is called up by a traffic controller, at that moment the aircraft has IFR status. The aircraft is not stated in the cruiser's list at that time. There is coordinated the aircraft has IFR status, the controllers know they must remain clear from it. It is also stated on the radar, but extra coordination is needed because there is a difference in time between the VFR and IFR status.

***How is the separation in the air guaranteed?***

On the airspace structure of the radar, you know as traffic controller what approximately 5nm is. This is based on the experience of the traffic controller, but there is also the Tools program in the system to measure the exact distance. By experience you know the separation distance of 6-7 nm between a departing aircraft from Eindhoven till a certain waypoint. If you are not sure you can measure the distance with the Tools program.

***How many aircraft has a controller approximately on its frequency?***

There is not a maximum number. CLSK has a Flow Control measure that cannot take more than 20 landing or departing aircraft at EHEH. But regardless of the Flow Control measure, everything is free and possible. It is up to the traffic controller what he can handle. At certain moments in the hour there is no traffic and a moment later there are 8 aircraft on your frequency. It depends on the situation.

***Which restrictions are used when too many aircraft enter the airspace?***

In tools you can see the number of aircraft arriving in time. There are several options to respond.

1. Calling the supervisor, tell him you reached you maximum workload and cannot take anymore aircraft.
2. Putting aircraft in the holding.
3. Adapt the intentions of the flight. Suppose an F-16 wants to make a touch and go, then you can tell him he has to land because you do not have time for him anymore.
4. Or add an extra traffic controller to the operation.

***Does Eindhoven airport (EHEH) make use of flight plans or peak hours?***

EHEH has released slots, there are 13 VOPs at Eindhoven for aircraft. The civil sight of EHEH, determines how many aircraft can come. EHEH sells slots, because of this they know how many aircraft can land or depart at a certain moment. In addition, they know when the VOPs are full. Everything is regulated.

***So, by means of slots there is determined how busy it is in a period of time. No exact figure but an indication based on the slots?***

Yes. There are no more than 13/14 VOPs, so it is not possible to land 20 aircraft. At a certain point you know how busy it gets. This happens automatically because of the number of slots that are issued. When it is very busy with 20 aircraft at the same time, there is the Flow Control monitoring tool that alerts when it gets very busy. The counter is then reversed and there is coordinated in advance with other countries (e.g. France) to stay aircraft on the ground. The aircraft will receive new slots. So, it has become quieter in the air.

***What is a complex traffic situation in an airspace?***

A complex situation is when the traffic is not standard. Standard means the number is not exceeded, but also not the boundary conditions. The weather must be good and an aircraft should not be in trouble, because then you will create a complex situation. When, for example, a traffic controller gets ill, another traffic controller has to take over the traffic which creates a complex situation. Another complex situation is when an aircraft with problems is standing on the runway and the traffic controller has five more aircraft on his frequency. You have to do something with those aircraft because they cannot keep flying. Then it becomes complex. Another situation is if special areas are active where you cannot fly through. Your area will then become smaller, making it more difficult to monitor everything effectively.

***During the operation you have a coordinator, is this part of the approach or area controller?***

Difficult to explain, because CLSK has a complex method. The coordinator actually belongs to the area department. All traffic from outside the Netherlands or goes abroad from the Netherlands first goes to the coordinator. He coordinates the traffic. If he and his assistant have given permission to enter or leave the country, he will distribute the traffic to his traffic controllers.

Sometimes aircraft depart from a field that is in an approach area, where the approach controller is responsible for. Because the aircraft goes abroad, the coordinator of the area department has control over what happens to the flight. The approach controller has the flight on its frequency and transfer it to the area controller. In first instance the coordinator of the area department gave the clearance. Transfer of an aircraft is only possible when there are standard transfer conditions.

***Is the workload included in your operation?***

CLSK follows the ATW, they have to adhere it. But there is the human aspect as job satisfaction, you cannot measure this. There is a lot of demand and pressure on the controllers these days. The more pressure you put on them, the less energy people get from their work.

Factors which may influence the capacity are:

- Weather (dynamic);
- Active military areas;
- Number of traffic controllers;
- Military practices.

***Who is responsible for the restrictions in the airspace?***

In first place the traffic controller, but it is actually teamwork with the supervisor. Many things are taken care of in advance by the supervisor, for example if someone calls in sick, adjustments are made to the traffic. The number of practice areas can be reduced from 2 to 1. The restriction can be made the airport is not available for foreign flights as a diversion airport. The supervisor is already busy with the prevention. In addition, the traffic controller who is responsible for his / her own area / activities is responsible for ensuring everything is performed safely. If something occur that is not safe, he has to inform the supervisor. The supervisor then determines the restrictions.

**Organization:** the coordinator is at the head, here under is the coordinator of area and RAPCOM. RAPCOM (reder approach controller of relevant cluster) is the team captain of a certain approach area, he also handles traffic. The coordinator is responsible for the planning, he does not handle traffic. The supervisor keeps an overview of the entire operation. This is the operational duty manager.

***Is it possible to have area responsibility in TMA sector 4 and 5 in combination with flight responsibility?***

I think it is how you describe it in the working method. If you describe it watertight then it does not matter. If it is closed in the process then everyone is obliged to adhere to this working method. It does not matter whether the area is flight or area responsibility. For example, if the area is handled by means of area responsibility and it states that the area controller coordinates the military traffic through the area on its frequency then there is nothing wrong.

You could also describe it differently. That everything is area responsibility. Then describe in the method military traffic can cross the area and the approach controller remains free of the traffic.

***You do not have to switch frequency as a cruiser? If you describe it correctly in the Operational Manual? That's right***

***Suppose it is area responsibility, does the flight enter the cruiser list or should this be adjusted?***

If area responsibility is accordance with the system, you have to come into cycles. The traffic controller is forced to do something with the aircraft in the area. There are two separate lists; active list and cruiser list.

On the active list are aircraft that come on your frequency and in the cruiser's list are the aircraft of which you must remain free of. But if the entire area is area responsibility according to the system, then you do not have a cruiser list only an active list.

The interviewee argued for the same equal procedure as LVNL, because the north and the south would otherwise no longer match each other. Traffic controllers of CLSK have no fixed areas in which they operate. Some people have 3 different areas. But a certificate for each cluster is needed in order to work in an area.

## Appendix VI Summary expert interview 12-11-2019

The aim of the expert's session is to receive input of the operational experts of CLSK on the capacity factors and the volume in certain traffic scenarios. During the session traffic scenarios are discussed that may take place when Lelystad airport (EHLE) becomes operational for commercial traffic. The participants who participated during the session are:

- Kees Moerkerk: Ex traffic controller AOCS NM
- Yoram Obbens: Senior capacity management & analytics expert LVNL
- Kevin Lagarde: Approach Controller CLSK
- Michel Lindeman: Area Controller CLSK

The agenda of the session consists of:

1. Capacity factors
2. Traffic flows in the Lelystad TMA
3. Indication workload traffic controller
4. Theoretical capacity arriving traffic
5. Theoretical capacity departing traffic

### 1. Capacity factors

The capacity factors in Chapter 4 of the thesis are presented to the operational experts. According to the experts, there were no other factors that could affect the capacity of the Lelystad TMA.

### 2. Traffic flows

Before the theoretical volume of the Lelystad TMA is calculated, the traffic flows within the TMA has to be determined. When EHLE becomes operational, the primary traffic flow is civil IFR traffic. The civil IFR traffic includes traffic of airlines, MRO traffic and business traffic. In the first years of the airport a maximum of 4,000 movements is established. In the VEMER the 4,000 movements are the traffic that makes use of the ATS-routes. This is only IFR-traffic, it does not include military and IFR – training traffic.

In addition to the IFR traffic, military and IFR-training traffic will take place in the TMA. In TMA sector 2 and 3 the AWX and BENE routes of the Air Force take place. At the moment, the AWX and BENE routes are hardly flown. Over time, the frequency of the routes may change. VFR-traffic will not be included in the capacity calculation. The TMA has airspace classification D. IFR and VFR traffic needs a clearance of the traffic controller to fly within the airspace. In addition, the traffic controller has the right to reject traffic. Therefore, VFR traffic is not considered in the calculations and research.

### 3. Workload approach controller

During the session was asked what the maximum number of aircraft is a traffic controller can have at the same time on the frequency. The comparison is made with Eindhoven airport. On an average day, 4 or 5 aircraft are on its frequency of a traffic controller. During the day there are peak hours for commercial traffic, at certain moments 6 or 7 aircraft are on the frequency. In the numbers that are mentioned, the departing traffic is not included. At Eindhoven airport, departing traffic usually goes straight to the Area controller, this is not possible at Lelystad. In sectors 1, 2 and 3 of the TMA, traffic is handled by area responsibility. As a result, the departing and arriving traffic will be on the frequency of the approach controller.

In the TMAs the approach controller may return to 3 nm, but the Area controller must consider 5 nm separation. When there are conflicts between aircraft, the Approach controller has to keep the aircraft on its frequency until the conflicts are resolved. Before the arriving traffic enters the TMA, the aircraft must be separated. The TMA is too small to resolve conflicts, the Area controller must solve the conflicts in advance.

When the situation and route structure of EHLE is considered, 7 aircraft at the same time on the frequency feels like a high number. The complexity is expected in the mix of arriving and departing traffic.

#### 4. Theoretical volume

For both runway directions the theoretical volume is calculated for the arriving and departing traffic. In the calculation the expected IAS of an A320 and B737, the length of the route and the separation distance of 2 minutes are considered. The separation of two minutes is roughly equivalent to a separation of 4 nm at final. When the separation over the whole route is considered, a theoretical volume of 30 aircraft is handled in one hour.

##### **Arriving aircraft from 1 STAR**

In principle, there is a minimum separation of 3 nm in the TMA, but at final 4 nm must be achieved. At final there is an expected speed of 140 kts, 2 nm is approximately flown in one minute. The theoretical volume of 30 aircraft per hour is achieved when the aircraft have the same performance characteristics and the aircraft comes from one Standard Arrival Route (STAR).

##### **Arriving aircraft from 2 STARs**

There may be a situation where aircraft come from two STARs, EKNON and BADEX. Two minutes of separation is needed between the aircraft to achieve the separation standard of 4 nm. When the worst transfer takes place between the Area and the Approach controller, the aircraft of two STARs can conflict in the merge point. Extra separation is required to ensure the aircraft will not meet in the merge point. There are two scenarios made, an ideal and not ideal situation.

- In the ideal situation, zero separation is required.
- In the not ideal situation, an extra separation of two minutes is required.

There is chosen to add an extra separation of one minute, when the arriving aircraft come from two STARs. The total separation of aircraft is set to three minutes. In one hour, a theoretical capacity of 20 aircraft is handled.

##### **Military AWX and BENE route active**

In the following scenario the AWX and BENE routes of the Dutch Air Force become active for Military Mission Effectiveness (MME) traffic in the TMA. An agreement is that MME traffic has priority to the civil traffic of EHLE. In practice this will not happen since the TMA is not large enough to allow civil traffic to divert. In addition, area responsibility applies in sectors 1, 2 and 3 of the TMA, a clearance of the approach controller is required to cross the TMA.

For the MME traffic on the AWX and BENE route scenarios are made when the routes become active. The separation between the MME traffic is according to the flight plan five minutes. For the scenario is chosen to express the MME traffic in a period in the hour the TMA is not available for civil traffic. The time the TMA is not available depends on the intensity of MME traffic. There are two scenarios used, low and high intensity.

- Low intensity: two aircraft make use of the AWX and BENE routes, resulting in an availability of 50 minutes for civil traffic.
- High intensity: six aircraft make use of the AWX and BENE routes, resulting in an availability of 30 minutes for civil traffic.

When the theoretical volume of civil traffic is considered there will be a volume of 16 aircraft per hour when the low intensity is used and a volume of 10 aircraft per hour when the high intensity is used. For the calculation there is expected the aircraft comes from two STARs, a separation of three minutes is used.

##### **Margins/buffers arriving aircraft**

During the flight of arriving aircraft a technical issue or missed approach can take place. At Eindhoven airport a missed approach is approximately 1 or 2 per month. A buffer is needed of 1 or 2 extra aircraft to handle traffic in certain circumstances.

In the theoretical volume of arriving aircraft from two STARs, the separation of 3 minutes is used. There was determined two minutes is enough separation to comply to the 4 nm separation standard at final. When a technical issue takes place there is assumed the extra separation of 1 minute is enough to absorb the failure in the operation. In the first years EHLE is operational there is expected the volume will not be exceeded. In the separation of arriving aircraft of two STARs there is enough margin taken to absorb failures in the operation.

**Arriving aircraft Commercial and Non-commercial mode**

EHLE will work in two modes; Commercial mode and Non-commercial mode.

- In the commercial mode only traffic takes place of airlines.
- In the non-commercial mode traffic as IFR-training flights and IFR flights take place. Herein the MRO traffic and business traffic are considered. The non-commercial mode takes place outside the peak hours of the commercial mode.

In the commercial mode the performance characteristics between the aircraft are small. There are no adjustments made of the margins mentioned before. The performance differences between an A320 and B737 is immersed in the 3 nm separation. In the non-commercial mode, business traffic and IFR-training traffic takes place. Herein, the different performance characteristics must be considered. For the margin in the non-commercial mode there is agreed on a double separation. Between the aircraft a separation of 6 minutes is agreed.

**5. Theoretical volume departing traffic**

For the theoretical volume of the departing traffic the same traffic flows are considered as in the arriving traffic.

In the volume of the departing traffic no distinction is made between one or more Standard Instrument Departure routes (SID). There are no restrictions in the routes for the approach controller to handle the traffic. The average runway occupation time declares 2 minutes are needed between 2 starting IFR aircraft. The average runway occupation time will be held as separation for the departing traffic in the TMA. In one hour, a volume of 30 aircraft is possible.

**Margins/buffers departing traffic**

For the departing traffic no margin yet is taken to absorb failures in the operation. There is decided use a buffer of 10% of the volume. By taking 10% of the volume, 27 aircraft per hour is handled.

**Military AWX and BENE route**

When the AWX and BENE route become active the same intensity scenarios as in the arriving traffic are considered. During a low intensity, 10 minutes of the hour capacity is unavailable for civil traffic. Instead of 27 aircraft, 22 aircraft is handled. During a high intensity, 30 minutes of the hour capacity is unavailable. This results in a volume of 13 aircraft.

**Departing aircraft Commercial and Non-commercial mode**

During the commercial mode the same volume is retained as at the margins/buffer for departing traffic. For the non-commercial mode, a double separation is taken as a margin for the performance differences within the mode. The separation becomes four minutes, here also the 10% margin must consider. Due to the separation and the margin, 13 aircraft is handled per hour.

## Appendix VII Summary expert interview 19-12-2018

In the second expert session the practical volume of the arriving and departing traffic is verified by the operational experts. The same participants take part of the expert session as in the first session.

- Kees Moerkerk: Ex traffic controller AOCS NM
- Kevin Lagarde: Approach Controller CLSK
- Michel Lindeman: Area Controller CLSK

The input of the first expert session is included in the calculations of the practical volume for the arriving and departing traffic. The aim of this session is to determine the capacity of the TMA by means of the workload of traffic controllers. The workload of traffic controllers is determined by assessing the complexity and interaction matrix of LVNL. The explanation of this method is described in Chapter 3. The agenda of this session is:

1. Verification practical volume
2. Volume mix arriving and departing traffic
3. Assessing matrices
4. Threshold value
5. Capacity

### 1. Verification practical volume

Firstly, the calculated practical volume is presented to the operational experts. There were no comments on the outcome of the practical volume. The results of the practical volume are stated in Chapter 5.

### 2. Volume mix

In the first expert's session the volume of the mix arriving and departing traffic is not included. The experts find it difficult to determine the volume for the mix traffic. There is suggested to use the basis of the VEM-model of LVNL to assess the workload of traffic routes. The workload is determined by scoring the complexity and interaction matrices by the operational experts with weighting scores. The scores are based on the expertise of the experts.

### 3. Assessing matrices

In the effort matrix the military traffic flow is not included. In previous session was decided to close the TMA for a period of time when Military Mission Effectiveness (MME) traffic takes place. This is not entirely correct, because it only applies to TMA sector 1, 2 and 3. In these sectors area responsibility applies. In TMA sector 4 and 5 flight responsibility applies, these sectors cannot be closed. Military traffic can fly through the sectors at the same height as civil traffic. In previous session military traffic through TMA 4 and 5 is not discussed.

The military traffic in TMA sector 4 and 5 may not be rejected. When the military traffic is in the cruisers list 12 minutes in advance, the military traffic has priority. In the TMA sectors there is not enough maneuver space for a mix of military and civil traffic. When the military traffic is considered in the matrices of interaction and effort, it creates a distorted outcome. The military traffic will not take place every hour of the day. Therefore, it is decided to use a marge on the total workload to use as buffer. The buffer is necessary in order not to exceed the maximum workload when military traffic takes place. The marge taken is 5% of the total workload.

#### **Commercial mode**

The matrices are filled in for the commercial and non-commercial mode. In the commercial mode only civil IFR-traffic of airlines are considered. MRO and business traffic are considered in the non-commercial mode. There is expected the workload in the non-commercial mode is higher than in the commercial mode. The speed differences are included in assessing the matrices.

First, the interaction matrix of runway 23 is assessed. There are six traffic mixes assessed by the operational experts.

- BADEX – EKNON
- BADEX – ERMUR
- BADEX – ARBEP

- EKNON – ERMUR
- EKNON – ARBEP
- ERMUR – ARBEP

The outcome of the matrix is given in table 41.

**Interaction matrix runway 23 – commercial mode**

The first mix traffic is BADEX with EKNON. In this traffic mix is assumed the traffic will meet in the merge point of the two arriving routes. Actions are required to ensure the aircraft will not meet. There are multiple options, such as reducing the speed or giving a course. This reduces the effort for the traffic controller. The experts agreed with an average score of 2.

The second traffic mix is BADEX with ERMUR. This is an arriving traffic flow from South-East and a departing traffic flow to the North. At DOTIX and BADEX the aircraft are arriving and departing at FL060. This requires monitoring, since both aircraft are at FL060. The only burden is the monitoring of the traffic, at the beginning this requires more effort than at the end. The experts agreed to a score of 1.

The third traffic mix is BADEX with ARBEP. It requires more work than the traffic mix BADEX with ERMUR. The route separation of 7 nm is not achieved at the departing route. The departing aircraft must stay longer on the frequency, because the area controller may only have the aircraft when 5 nm separation is achieved. In TMA sector 4 and 5 the departing and arriving traffic is on the frequency of the approach controller. Before the departing aircraft are transferred, there must be 5 nm separation between the aircraft. This costs more effort and monitoring. Therefore, the experts scored a weighting of 2.

After this, the traffic mix EKNON with ERMUR was discussed. The arriving and departing routes are conflict free, similar to BADEX with ERMUR. It received a score of 1.

The traffic mix EKNON with ARBEP are conflict free. The departing aircraft are quickly transferred to the approach controller. When there is no conflict from EKNON to the final approach fix and there is no conflict with the departing traffic, transfer of communication and transfer of control can take place on the border of TMA sector 3 and 4. Here for, the experts gave a score of 0.

The last traffic mix is ERMUR with ARBEP. The aircraft fly in sequence with a separation of 5 nm. The aircraft are separated by the average runway occupation time. The approach controller still has to monitor the aircraft and must consider the 5 nm separation to transfer the aircraft to the area controller. A weighting score of 0 is too low for this traffic mix, therefore a score of 1 is given.

Table 41 Interaction matrix runway 23 – Commercial mode

		Arriving route		Departing route	
		BADEX	EKNON	ERMUR	ARBEP
Arriving route	BADEX		2	1	2
	EKNON			1	0
Departing route	ERMUR				1
	ARBEP				

**Complexity matrix runway 23**

After the interaction matrix is assessed by the operational experts, the complexity matrix is filled in. In the complexity matrix, the complexity within a traffic route is considered. The following four traffic routes are assessed:

- BADEX;
- EKNON;
- ERMUR;
- and, ARBEP.

BADEX: There is enough maneuver space at traffic route BADEX. For the vertical space there are two Flight Levels available, FL050 and FL060. In TMA sector 4 and 5 there is not much space.

There is room to deviate from the route, but because of the construction of the airspace more monitoring is needed. In addition, communication with other traffic controllers is necessary. For the complexity factors and task load a score of 1 is given.

**EKNON:** The traffic routes BADEX and EKNON have almost the same structure. Therefore, the same score as BADEX is given.

**ERMUR:** In terms of horizontal space at ERMUR, there must ensure the 5 nm separation is maintained. This is a task that must be performed every day. For this it is not necessary to give an average weighting. For the complexity factors; horizontal space, vertical space, and length airspace a score of 1 is given. The task load receives a score of 2. Departing traffic of runway 23 has a small interaction with the traffic mix of Schiphol. Therefore, departing traffic of runway 23 requires more monitoring then runway 05.

**ARBEP:** The departing traffic to ARBEP received the same scores as ERMUR. Herein is also in the task load the traffic mix of Schiphol considered.

Table 42 Complexity matrix runway 23 – Commercial mode

		Horizontal space	Vertical space	Length airspace	Task load
<b>Arriving route</b>	<b>BADEX</b>	1	1	1	1
	<b>EKNON</b>	1	1	1	1
<b>Departing route</b>	<b>ERMUR</b>	1	1	1	2
	<b>ARBEP</b>	1	1	1	2

**Interaction matrix runway 05**

In the arriving traffic of runway 05, there is a higher weighting score expected for the complexity, this because of the traffic from the Schiphol TMA. The outcome of the interaction matrix of runway 05 is almost equal to runway 23.

The first traffic mix is BADEX with EKNON. At runway 23 a score of 1 is given for the traffic mix. The arriving traffic of runway 05 has the same problem as the departing traffic of runway 23. The traffic must continue to fly underneath the Schiphol TMA. More effort is required in monitoring the traffic. Here a score of 2 is given.

The second traffic mix is BADEX with ERMUR. The routes are conflict free from each other. But the traffic controllers still have to monitor the procedures and ensure the aircraft do not interfere with the Schiphol TMA. Therefore, a score of 1 is given.

The third traffic mix is BADEX with ARBEP. The traffic mix requires more effort than the traffic mix BADEX with ERMUR, because the traffic routes conflict with each other. At LE120 the departing traffic has a height restriction of FL060. For the arriving traffic a Flight Level of 50 or 60 is expected at LE118. These two waypoints are within the 5 nm separation. This is the reason the experts agreed to a score of 2.

Next is the traffic mix EKNON with ERMUR. The routes are similar to BADEX with ERMUR, conflict free. The traffic controllers only have to monitor the procedures. For this the same score is given as BADEX with ERMUR.

The traffic mix EKNON with ARBEP has the same traffic situation as BADEX with ARBEP. The routes are conflict free of each other. The same score applies here as BADEX with ARBEP.

The last traffic mix are two departing routes, ERMUR with ARBEP. There is no conflict between the routes. In addition, the separation is achieved by the average runway occupation time. Only the 5 nm must consider when the aircraft is transferred to the Area controller. The traffic mix scored a 1.

Table 43 Interaction matrix runway 05 – Commercial mode

		Arriving route		Departing route	
		BADEX	EKNON	ERMUR	ARBEP
Arriving route	BADEX		2	1	2
	EKNON			1	2
Departing route	ERMUR				1
	ARBEP				

**Complexity matrix runway 05**

For traffic route BADEX and EKNON the same score is given as at runway 23. The routes and complexity situation do not differ much from each other.

ERMUR: For traffic route ERMUR, the complexity factors and task load receive a score of 1. At runway 23 the task load received a score of 2. There are no height restrictions on the route of runway 23. This allows the aircraft to continue to climb, which results in more monitoring by the traffic controller.

ARBEP: At the departing route to ARBEP there is height restriction of FL060. By the departing route to ERMUR is no FL060 restriction. After the height restriction of 3000 ft, there is expected the aircraft will continue to climb to FL060. The height restriction has more influence on the task load than on the complexity factors. This results in a score for the complexity factors of 1 and for the task load of 2.

The differences between the departing routes is that by ERMUR there is not a FL060 restriction and at ARBEP there is. This results in a difference in score.

Table 44 Complexity matrix runway 05 – Commercial mode

		Horizontal space	Vertical space	Length airspace	Task load
Arriving route	BADEX	2	2	1	2
	EKNON	2	2	1	2
Departing route	ERMUR	1	1	1	1
	ARBEP	1	1	1	2

**Non-commercial mode**

In the non-commercial mode there are speed differences in the traffic mix. The expected traffic are aircraft for the southern area; business aircraft and MRO aircraft. This could be a B737 or a BEACH200. The chances of speed differences are higher than in the commercial mode. The volume, determined in the previous session, is there for lower than in the commercial mode.

The scores that are filled in for the routes in the commercial mode should also apply to the non-commercial mode, because the routes do not change. But the speed differences in the non-commercial mode could affect the task load of the traffic controllers. There will be an increase in the task load, because the speeds need to be more monitored. Therefore, in the non-commercial mode the task load receives for all routes a score of 3.

In the session the assumption is made the Light categories aircraft will not deviate of the routes. Official the Light aircraft can deviate of the route when a height of 3000 ft is received. This would result in more maneuverer space. The request to deviate of the route can be rejected by the traffic controller. In this session it was assumed that the request to deviate from the route was refused by the traffic controller.

**Interaction matrix runway 23**

In the interaction matrix, the same combination of traffic routes is discussed as in the non-commercial mode.

In the first traffic mix BADEX with EKNON the scenario can take place the slower aircraft at BADEX is slightly further than the aircraft at EKNON. In order to prevent a conflict, the slower aircraft are

placed in the holding to let the faster aircraft pass by. In the commercial mode a weighting of 2 is scored. For the non-commercial a higher score is needed, therefore the traffic mix scores a 3.

The second traffic mix is BADEX with ERMUR. In the non-commercial mode there are no conflicts with speed differences. In the arriving route more monitoring is required, because of the Schiphol traffic. The same score is given as in the commercial mode.

The traffic mix BADEX with ARBEP, EKNON with ERMUR and EKNON with ARBEP also receives the same weighting as in the commercial mode. The speed differences do not affect the effort of the traffic controllers.

The last traffic mix is ERMUR with ARBEP. The aircraft fly in sequence with a separation of 5 nm. The aircraft are separated by the average runway occupation time. The approach controller still has to monitor the separation and speed differences. Here for, the traffic mix receives a score of 2.

Table 45 Interaction matrix runway 23 – Non-commercial mode

		Arriving route		Departing route	
		BADEX	EKNON	ERMUR	ARBEP
Arriving route	BADEX		3	1	2
	EKNON			1	0
Departing route	ERMUR				2
	ARBEP				

**Complexity matrix runway 23**

The results of the complexity matrix from the commercial mode corresponds to the non-commercial mode. The only differences is the weighting of the task load and the maneuvering space for the arriving traffic routes. For BADEX and EKNON the horizontal and vertical space scored a weighting of 2 instead of 1. When speed differences occur on the arriving traffic routes, more effort and actions are required to ensure there is enough separation between the aircraft.

All traffic routes scored a weighting of 3 for the task load. This is because of the speed differences between the Medium and Light aircraft categories. More effort is needed to monitor the speed differences. The result of the complexity matrix is given in table 46.

Table 46 Complexity matrix runway 23 – Non-commercial mode

		Horizontal space	Vertical space	Length airspace	Task load
Arriving route	BADEX	2	2	1	3
	EKNON	2	2	1	3
Departing route	ERMUR	1	1	1	3
	ARBEP	1	1	1	3

**Interaction matrix runway 05**

In the first traffic mix BADEX with EKNON the same score is given as at runway 23. The worst scenario is assumed that a slower aircraft is further on the route than the faster aircraft. More actions and monitoring are required, resulting in a score of 3.

The second traffic mix is BADEX with ERMUR. The traffic routes do not conflict with each other and the speed differences has no influence on the traffic mix. The same score is given as in the commercial mode, a score of 1.

The next traffic mix is BADEX with ARBEP. The traffic routes conflict with each other. At waypoint LE118 and LE120 the aircraft fly at an altitude of FL050. When the leading aircraft flies with a lower speed than the trailing aircraft, it takes longer to climb from FL050 to FL060. Here for, the traffic mix scores a 2.

After this the traffic mix EKNON with ERMUR is assessed. The traffic routes do not conflict with each other. Therefore, it receives the same score as BADEX with ERMUR.

The fifth traffic mix is EKNON with ARBEP. It is almost the same traffic mix as BADEX with ARBEP. The only differences are the arriving route. This does not make a difference for the effort of the traffic controller. Therefore, it scores a 2.

The last traffic mix is ERMUR with ARBEP. The tower is responsible for the separation of the departing traffic. The only differences with the commercial mode are the speed differences. Because of the monitoring of the 5 nm separation and the speed differences, it receives a score of 2.

Table 47 Interaction matrix runway 05 – Non-commercial mode

		Arriving route		Departing route	
		BADEX	EKNON	ERMUR	ARBEP
Arriving route	BADEX		3	1	2
	EKNON			1	2
Departing route	ERMUR				2
	ARBEP				

**Complexity matrix runway 05**

Runway 23 and runway 05 are not different from each other in terms of complexity.

Table 48 Complexity matrix runway 05 – Non-commercial mode

		Horizontal space	Vertical space	Length airspace	Task load
Arriving route	BADEX	2	2	1	3
	EKNON	2	2	1	3
Departing route	ERMUR	1	1	1	3
	ARBEP	1	1	1	3

**4. Threshold value**

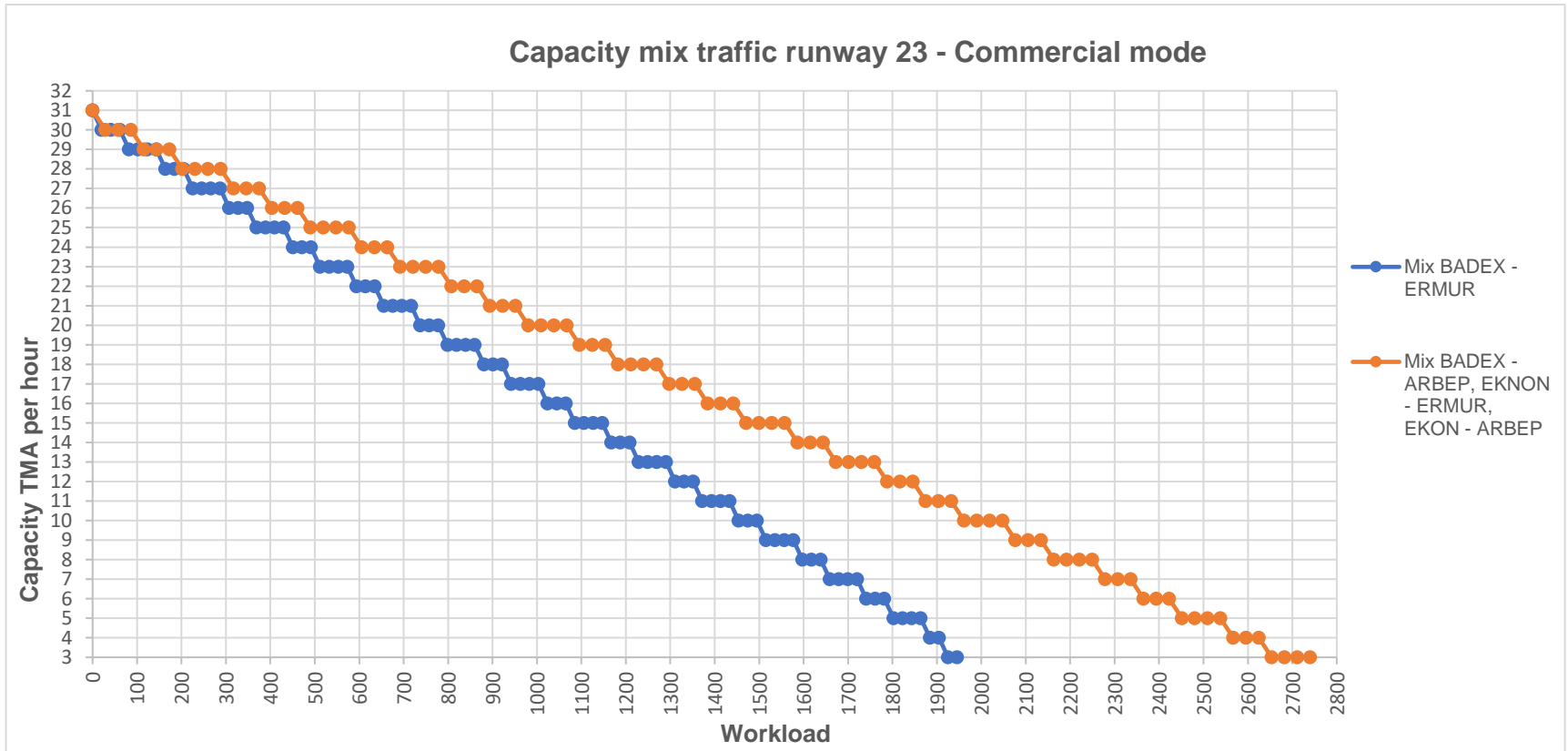
In the session there is previously determined a percentage of the total task load is taken, because of the military traffic in sector 4 and 5 of the TMA. A marge of 20% is too large, then in 12 minutes of the hour military traffic will cross the TMA. When a marge of 5% is taken, in 3 minutes of the hour military traffic is expected.

In order to calculate the capacity, the minimum volume must determine when the maximum workload is achieved. The established minimum volume is for one hour and must consider the worst scenarios in the operation. There is expected an aircraft will be for approximately 10 minutes on the frequency of the traffic controller.

For the arriving traffic is a maximum volume of 21 aircraft per hour calculated and with the departing traffic a maximum of 27 aircraft. These are the outcome of the practical volume. The volume of the departing traffic is higher than the arriving traffic. Therefore, is decided the minimum volume is 4 aircraft per hour for the departing aircraft and 2 aircraft for the arriving traffic. In de traffic mix of arriving and departing traffic an average is taken from the minimum volumes.

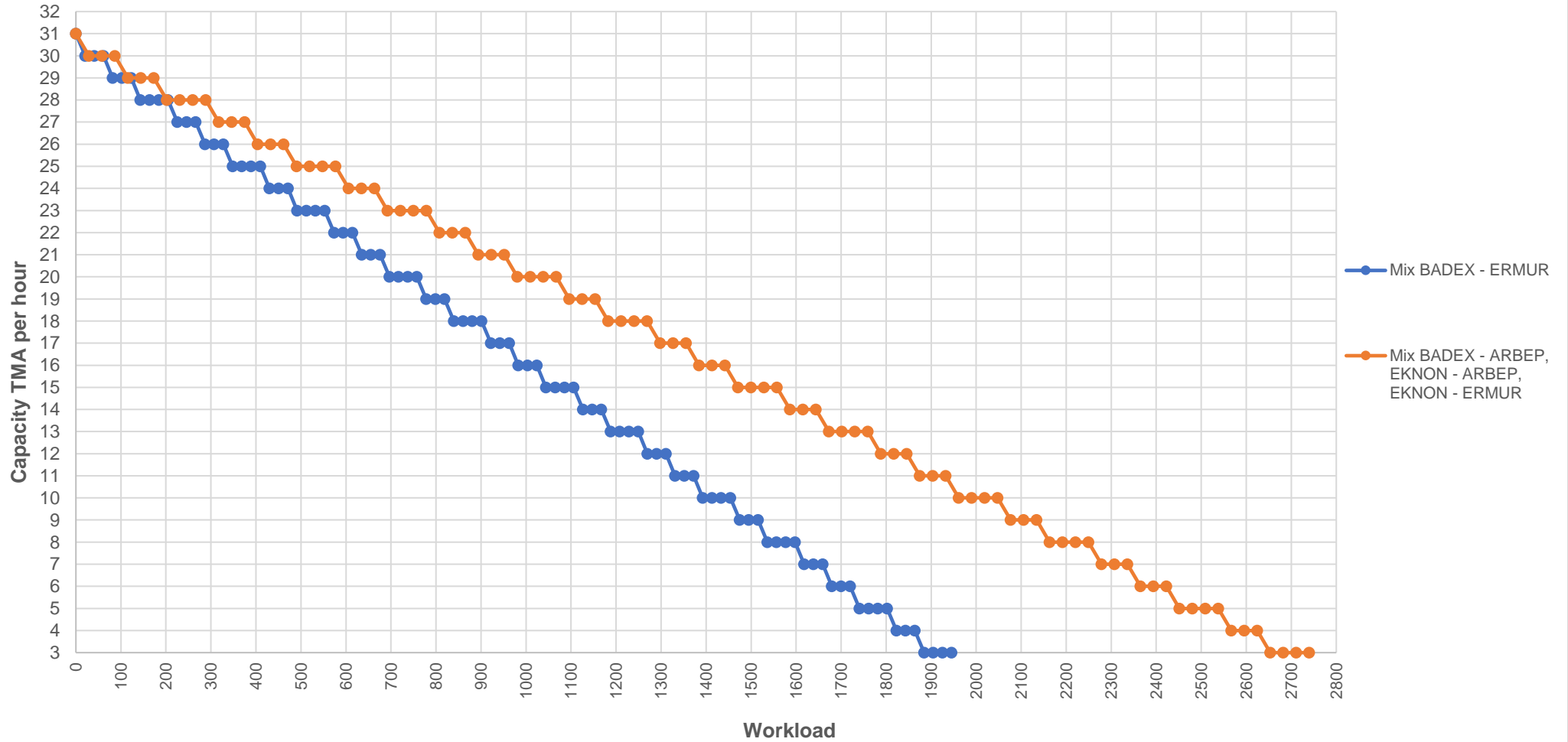
By determining the capacity of the TMA, it is important the theoretical volume is inserted into the formula. When the practical volume is filled in, there will be a marge on a marge. This makes the buffer twice as big, which means less traffic is handled. This is not the intention.

Appendix VIII Capacity in relation to workload



In the graph the workload is compared with the capacity. The VEM model ATC workload is used in the research to determine the capacity. The total workload is determined with equation 5 in Chapter 3. To determine the capacity, a comparison is made in the second expert session. Herein, the maximum workload is linked to the minimum capacity and vice versa. In the graph, only the mix traffic is stated, the combination of departing and arriving traffic. It shows that with a maximum workload there is a minimum capacity of 3 movements per hour. Using the graph, the capacity per hour can be deflected for each workload. Please note that the capacity is rounded down.

Capacity mix traffic runway 05 - Commercial mode



Capacity mix traffic runway 23 - Non commercial mode

