Analysis of Communication and Transport Systems

Analysis of Key Performance Indicators for Terminal Maneuvering Areas

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Abstract

The global aviation network is constantly growing and airspaces get more and more crowded, leading to an increased need of a more performance driven Air Traffic Management (ATM) system. This entails the need of developing new methodologies and tools for performance measurement and for the possibility to make an objective evaluation, a set of precise Key Performance Indicators (KPIs) is needed in several areas such as safety, capacity and flexibility. In this paper, a list of proposed KPIs relevant to the performance measurement of Terminal Maneuvering Areas (TMAs) has been developed.

The KPIs *Level-off During Descent* and *Additional Time During Descent* have been numerically analyzed using data from Arlanda Airport during 2018. These analyses resulted in an average level-off time at 3.5 minutes, an average level-off distance at almost 20 nautical miles and an additional time during descent at about 6 minutes.

The numerically analyzed KPIs are useful since they require basic data and are easy to calculate, but without a reference value and a longer period for analysis a more accurate evaluation is hard to perform. It is important to take into account that inefficiency in the descent phase of flight may not have originated in that phase. However, these two KPI measurements cannot be derived to a previous phase.

Keywords: Key Performance Indicator (KPI); Key Performance Area (KPA); Terminal Maneuvering Area (TMA)

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1 Introduction

With the ever-growing global aviation network, airspaces get more and more crowded leading to an increased need of a more performance driven Air Traffic Management (ATM) system. This entails the need of new methodologies and tools for performance measurement, performance evaluation and decision support. For the possibility to make an objective evaluation and correctly characterize ATM operations, a set of precise quantitative Key Performance Indicators (KPIs) is needed (Agüi et al. 2018).

1.1 Background

In the 1940s the aviation network was becoming more global, leading to the founding of the International Civil Aviation Organization (ICAO) at the Chicago Convention in 1944 with the goal to reach consensus on international civil aviation rules. Today, ICAO has 193 member states and industry groups that have to agree on polices and Standards and Recommended Practices (SARPs) to endorse a secure, safe, efficient, environmentally responsible and economically sustainable aviation sector (ICAO 2019a). In 2003, ICAO launched a worldwide initiative to ensure that the future Air Traffic Management (ATM) system is performance driven. According to ICAO (2019b) the ATM system consists of all systems that assist aircraft in their operations, including strategic airspace management such as airspace infrastructure planning and requirements on communications, navigation and surveillance, as well as tactical airspace management meaning the dynamic use of airspace and also Air Traffic Services (ATS) systems.

SESAR is an ongoing modernization project in Europe that builds on this initiative and has proposed a set of enhanced KPIs to measure flight performance and quantify ATM operation efficiency within airspace (Agüi et al. 2018). Most of these KPIs are produced to measure en-route performance, meaning the effectiveness over a large geographical area and over a long period of time. There has not been much focus on the performance of departures and arrivals, and therefore the focus of this project will be to bring forth and develop KPIs suited for Terminal Maneuvering Areas (TMAs), which are controlled airspaces covering only a couple of airports and shorter periods of flight time, as shown in Figure 1.

The purpose of TMAs are to control and guide air traffic in the approach and departure phases. The lower limit of a TMA is often set at a height of about 1 500 feet, but can vary in different zones of a TMA. The airspace closest to the ground, covering only one specific aerodrome, is called Control Zone (CTR) and is a small airspace often only extending from the ground to a height of about 1 500 feet. The purpose of a CTR is to protect traffic during the phases of start and landing (LFV 2019).

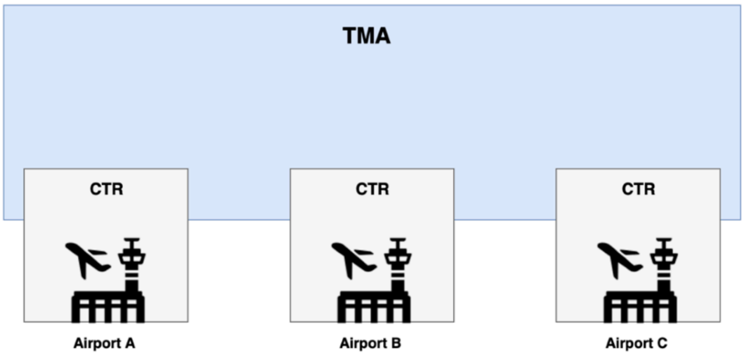

Figure 1 - Terminal Maneuvering Area and Control Zone.

1.2 Aim

The aim of the paper is to produce a list of KPIs relevant for evaluation of TMA performance and analyze their usability, to detect inefficiencies within TMAs.

1.3 Target Audience

This study is a part of the *Towards Multidimensional Adaptive KPIs for Operations Assessment and Optimization* (TMAKPI) project, which is a research project at the ITN department of Linköping University with the aim to delve a deeper understanding of several KPIs and help the authorities with identifying areas of inefficiency to develop improvements. Therefore, the target audience of this paper is narrow and it is firsthand targeted toward the researchers and operational specialists involved in the project.

1.4 Scope of the study

Flight can be divided into five different phases. Performance segments for the five phases of flight are illustrated in Figure 2 and in this project the focus is on TMAs meaning that only phase 2 and phase 4 are of relevance, which are shown in blue – departure and initial climb out, and descent and arrival (CANSO 2015). There is only data available for arrivals and therefore analysis has only been performed on phase 4.

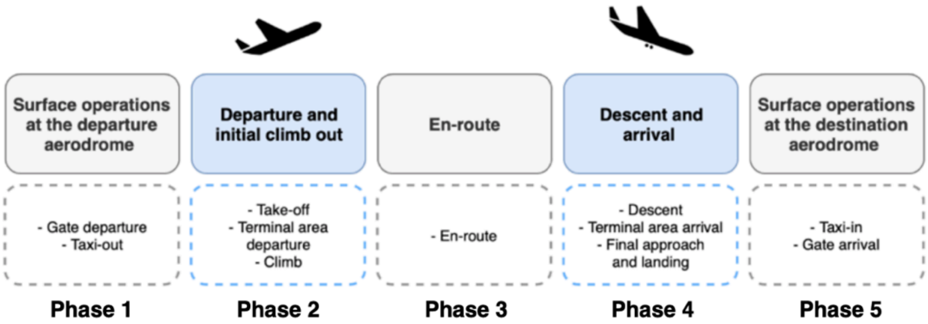

Figure 2 - Phases of flight

The KPIs that have been identified as relevant for measuring the performance of TMAs in this project has been analyzed against data from Stockholm TMA and flights arriving to Arlanda Airport. The CTR of Arlanda is included in the study to cover take-offs and landings. Stockholm TMA covers Bromma Airport, Uppsala Airport, Västerås Airport and Eskilstuna Airport as well, but these are not in the scope of this study. A map of Stockholm TMA is shown in Figure 3, where the orange line is the border of Stockholm TMA and the yellow areas are CTRs.

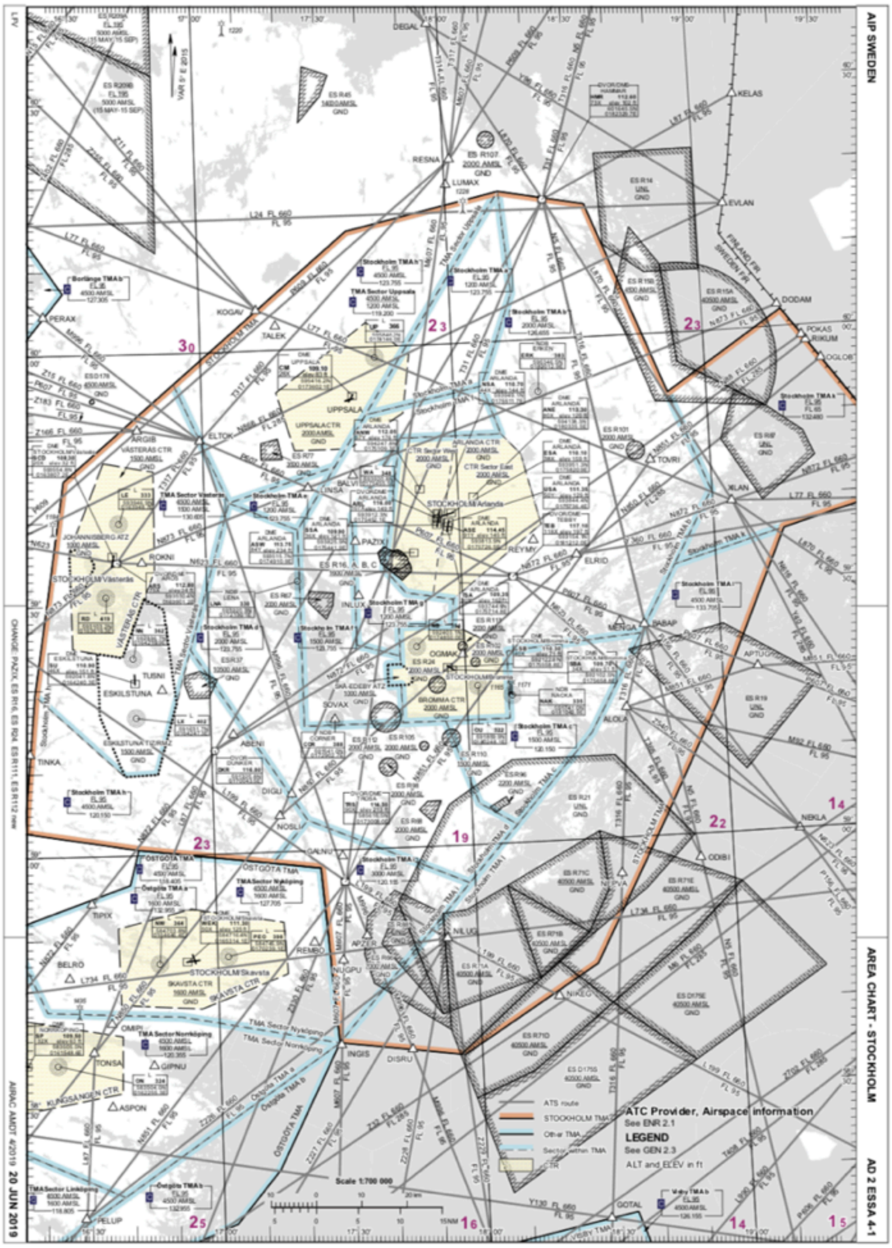

Figure 3 – Stockholm TMA (LFV 2019)

To get a reliable result when only investigating a specific phase of flight, it must be taken into account that different phases of flight has different characteristics and therefore, they do not drive the same costs. For example, regarding fuel burn, the total amount of fuel burn of a flight could not be split over the time spent in a specific phase because different stages of flight contribute to different amounts of fuel burn, e.g. climb burns more fuel than cruise do (Mori 2017). This makes several KPIs more complex when measuring the performance of a phase of flight and not for the whole flight.

1.5 Methodology

At first literature was studied to understand the use of KPIs and what KPIs that are in use today. Then different KPIs suitable for measuring the performance of TMAs were identified and put in a list. Then two of the ones most applicable for evaluating the performance of Stockholm TMA and the traffic at Arlanda Airport were identified to do the analysis.

Data for arriving flights to Arlanda Airport during 2018, extracted from EUROCONTROLs Demand Data Repository (DDR), was loaded into MATLAB for periods of a couple of days at the time. Then the data was filtered so that only data for all flights arriving in one particular day remained. An analysis program was constructed in MATLAB, which contained the calculations needed to be able to analyze the chosen KPIs.

When all relevant KPIs were listed and the analysis program done, the chosen KPIs were analyzed using the historical data from Arlanda Airport, to investigate their usability of measuring performance in TMAs. Lastly, a discussion of the analyzed KPIs was performed.

1.6 Outline of the paper

The paper is structured as follows:

- Chapter 2 consists of a literature review that introduces Key Performance Areas (KPAs) and how these can be quantified by using KPIs. It also consists of tables that lists all KPIs that are of relevance when measuring performance inside TMAs.
- Chapter 3 provides the historical data from Arlanda Airport 2018 as well as a description of how the data is handled, loaded and sorted.
- Chapter 4 describes the KPIs that are analyzed and how these analyzes are performed.
- Chapter 5 consists of the result from the numerical analysis.
- Chapter 6 contains an analysis of the usability of the KPIs and a discussion about the projects results.
- Chapter 7 provides the conclusion of the study.

1.7 Glossary

The definitions of acronyms used in the report is presented in Table 1.

Table 1 - Glossary

Acronym	Definition

ANS	Air Navigation Service
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Services
CAT	Commercial Air Transport
CDQM	Collaborative Departure Queue Management
CDR	Coded Departure Routes
CFIT	Controlled Flight Into Terrain
CNS	Communication, Navigation and Surveillance
CTA	Control Area
CTR	Control Zone
DCB	Demand and capacity Balance
DDR	Demand Data Repository
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
KPI	Key Performance Indicator
KPA	Key Performance Area
MAC	Mid Air Collision
NMAC	Near Mid Air Collision
OPD	Optimized Profile Descent

RAT	Risk Analysis Tool
RBT	Reference Business Trajectory
SARP	Standards and Recommended Practices
SBT	Shared Business Trajectory
SUA	Special Use Airspace
TMA	Terminal Maneuvering Area

2 Key Performance Indicators (KPIs)

The ICAO system has, according to APACHE Consortium (2017), based on the ATM community's expectations on the future ATM system, produced eleven principles to work towards. These principles are called Key Performance Areas (KPAs) and are the following: *Access and Equity, Capacity, Cost-effectiveness, Efficiency, Environmental, Flexibility, Global Interoperability, Participation by ATM Community, Predictability, Safety and Security*. The KPAs are presented in alphabetical order, but *Safety* is always the most important one. The expected progress of KPAs are nowadays more and more quantified by different KPIs, leading to greater opportunities for processing data and analyzing the result. The quantification plays an important role in the development of a more efficient global ATM system. It is important that concerned organizations agree on standardized KPIs for the possibility of consolidating data oversee performance of the ATM system globally (APACHE Consortium 2017).

All KPAs are described in the following chapters 2.1-2.11, also including Tables 2-12 of KPIs proposed relevant for measuring performance in TMAs. These KPIs are relevant because they could be connected to the activities of phase 2 and/or phase 4 of flight (as earlier described in Figure 2 in Chapter 1.4). These activities are take-off, climb, terminal area departure, terminal area arrival, descent and landing. According to CANSO (2015) the performance of departures and arrivals are usually measured inside range rings, where the departure phase is measured from the runway to a 40 nautical miles (radius) ring around the airport and the arrival phase is measured from a 100 nautical miles (radius) ring around the airport to the runway. However, these borders are impacted by the design of a specific airport, its capacity, weather conditions and restrictions necessary for safe operation (CANSO 2015). Some KPIs have been modified to better fit with measuring the performance of TMAs. If this is done, a comment is made. All KPIs covering the other phases of flight (1, 3 and 5) which covers gate departure, taxi out, en-route, taxi in and gate arrival are omitted. However, according to CANSO (2015), it is important to notice that all phases of flight can impact each other and that inefficiencies can be traced back to earlier phases.

2.1 Access and Equity

The purpose of the *Access and Equity* KPA is to ensure that the global ATM system ensures equity of all users. Meaning that all users must have access to the ATM resources needed for their operations and that the sharing of airspace is accomplished in a safe manner (APACHE Consortium 2017). KPIs relevant for measuring the *Access and Equity* performance of TMAs are shown in Table 2. This is especially important in TMAs, because they are often crowded.

Table 2 - KPIs of the Access and Equity KPA

#	KPI	Comment	Source
1	Unsatisfied Demand vs Overall Demand	Measured in volume of airspace times time.	*APACHE Consortium (2017)*
2	Percentage of RBTs which are equal to the first SBTs submitted (per airspace user)	Evaluation of the ability of the ATM system to evenly accept requests of airspace users.	*APACHE Consortium (2017)*
3	Worst Penalty Cost	Compares the maximum penalty cost of all airspace users with the average penalty cost for all airspace users.	*APACHE Consortium (2017)*
4	Total ATM Delay Relative to Reference ATM Delay	Used for planning purposes. Total delay in the TMA in the solution scenario divided by total delay in the ATM in the reference scenario.	*APACHE Consortium (2017)*
5	Percentage of Flights Advantaged or Disadvantaged	Measures if change impacts airspace users in a positive or negative way to represent inequity among airspace users.	*APACHE Consortium (2017)*
6	Airspace User Cost per Flight Relative to Reference Airspace User Cost	Used for planning purposes. Cost of flight per airspace user in the solution scenario divided by the cost of flight per airspace user in the reference scenario.	*APACHE Consortium (2017)*

2.2 Capacity

The global ATM system should utilize its capacity to meet airspace users demand at all times and locations, with minimal restrictions on traffic flow (APACHE Consortium 2017). The capacity is the maximum volume of air traffic (highest number of operations) that an airspace will accept while being able to ensure safe operations in a given period of time during normal conditions (IACO 2019c). The ATM system must also be capable of responding to future growth without any impacts on safety and TMAs are often more crowded airspaces making them critical. To be capable to respond to the growth, the capacity as well as efficiency, flexibility and predictability must increase (APACHE Consortium 2017). KPIs relevant for measuring the *Capacity* performance of TMAs are shown in Table 3.

Table 3 - KPIs of the Capacity KPA

#	KPI	Comment	Source
1	Number of IFR Flights Able to Enter a Terminal Airspace Volume	Adjusted for TMA.	*APACHE Consortium (2017)*
2	TMA Airspace Capacity	Adjusted to fit TMA. The maximum volume of traffic a TMA will safely accept under normal conditions.	*APACHE Consortium (2017); ICAO (2019c)*
3	Minutes of Delay	Total minutes of delay caused by disruptive events.	*APACHE Consortium (2017)*
4	Number of Cancellations	Total number of cancellations caused by disruptive events.	*APACHE Consortium (2017)*
5	Declared Capacity	Target acceptance rate for facility or sector. Number of departures and landings per hour.	*APACHE Consortium (2017); CANSO (2015); ICAO (2019c)*

6	TMA Throughput, in Challenging TMA Airspace, per Unit Time	Adjusted to fit TMA.	*APACHE Consortium (2017)*
7	TMA Increased Throughput		*APACHE Consortium (2017)*
8	Capacity Efficiency	Percentage of demand accommodated by facility's capacity and actual demand.	*APACHE Consortium (2017); CANSO (2015)*
9	Delay Attributed to Capacity Limits	Total or average delay by airport of facility attributable delay.	*APACHE Consortium (2017); CANSO (2015)*
10	Arrival ATFM Delay	Attributable to terminal and airports ANS and caused by landing restrictions at the destination airport.	*APACHE Consortium (2017); ICAO (2019c)*
11	The Share of Regulated Hours With Over-deliveries	Actual demand / Capacity > 110 %	*APACHE Consortium (2017)*
12	Percent of ATFM Delays due to Avoidable Regulations (No Excess Demand)		*APACHE Consortium (2017)*
13	Declared Peak Arrival Capacity vs Actual Throughput		*APACHE Consortium (2017)*
14	TMA Time to Recover From Non-nominal to Nominal Condition	Adjusted to fit TMA. Time needed to recover airspace lost capacity, i.e. duration of disruption.	*APACHE Consortium (2017)*

15	Percent Loss of TMA Capacity Avoided	Adjusted to fit TMA.	*APACHE Consortium (2017)*
16	Operational Availability	Maximum facility service hours minus outage time, divided by maximum facility service hours. Present in both the Capacity table (#17) and the Efficiency table (#1).	*APACHE Consortium (2017)*
17	Airport Peak Throughput	The 95th percentile of number of rolling hours of operations at an airport sorted from least to most busy.	*ICAO (2019c)*
18	Number of Flights, Flight Hours and Flight Distance That Can Be Accommodated	Requires expert judgement or a modelling approach.	*APCACHE Consortium (2017)*
19	Hourly Number of IFR Arrival Plus Departures Possible During IMC		*APACHE Consortium (2017)*
20	Daily Number of IFR Arrivals Plus Departures Possible During a 15 Hour Day Between 07:00 and 22:00 Local Time During IMC		*APACHE Consortium (2017)*
21	ATFM Slot Adherence	Calculated take-off time compliance. Percentage of flights taking off within their assigned slot. Present in both the Capacity table (#21) and the Predictability table (#11).	*APACHE Consortium (2017); ICAO (2019c)*

22	ATC Pre-departure Delay	Delays take-off which impacts performance of the TMA.	*APACHE Consortium (2017)*
24	Flights Delayed > 15 Minutes in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
24	Peak Runway Throughput	Mixed mode.	*APACHE Consortium (2017)*
25	Peak Departure Throughput per Hour	Segregated mode.	*APACHE Consortium (2017)*
26	Peak Arrival Throughput per Hour	Segregated mode.	*APACHE Consortium (2017)*
27	Number of Flights, Available Plane Miles etc.		*APACHE Consortium (2017)*
28	Percentage of Demand Accommodated by Facility's Capacity and Actual Demand		*APACHE Consortium (2017)*
29	Total or Average Facility Attributable Delay		*APACHE Consortium (2017)*
30	(Maximum Facility Service Hours Minus Outage Time) Divided by Maximum Facility Service Hours		*APACHE Consortium (2017)*
31	Robust Maximum TMA ATFM Delay	Adjusted to fit TMA. Average TMA ATFM delay greater than mean value +	*APACHE Consortium (2017)*

		Standard deviation of TMA ATFM delay.	
32	Average Flow Management Arrival Delay	Average regulated trajectory arrival time – Planned arrival time.	*APACHE Consortium (2017)*
33	Capacity Shortfalls	Adjusted to fit TMA. Number of flights that received a change of their initial flight plan in TMA / Total number of flights in TMA	*APACHE Consortium (2017)*
34	Maximum Throughput Capacity in TMA	Adjusted to fit TMA. Maximum number of aircraft that may be served without degrading system performance.	*APACHE Consortium (2017)*
35	TMA Recovery Period	Adjusted to fit TMA. Time until the system is no longer suffering due to effects of unexpected events.	*APACHE Consortium (2017)*

2.3 Cost-effectiveness

Different interests of the ATM community should be balanced, and the ATM system as a whole should be cost-effective. Principles and policies of ICAO user charges should always be followed, and it is important that the cost of service to airspace users always is taken into account when proposing improvements of quality of service or ATM performance (APACHE Consortium 2017). KPIs relevant for measuring the *Cost-effectiveness* performance of TMAs are shown in Table 4. They are of relevance for measuring the performance of TMAs because they all include ATCO or ANS, which are services used in all phases of flight.

Table 4 - KPIs of the Cost-effectiveness KPA

#	KPI	Comment	Source

1	ATCO Employment Cost per ATCO Hour	Employment costs for ATCO in operations / ATCOs in operations hours	*APACHE Consortium (2017)*
2	ATCO Hour Productivity	IFR flights / ATCO in operations hours	*APACHE Consortium (2017)*
3	Unit ATCO Employment Cost	Employment costs for ATCO in operations / ATCOs in operations	*APACHE Consortium (2017)*
4	Annual Working Hours per ATCO in Operations	ATCOs in operations hours / ATCOs in operations	*APACHE Consortium (2017)*
5	IFR Hours per ATCOs in Operations	IFR flight hours / ATCOs in operations	*APACHE Consortium (2017)*
6	ANS Revenues per IFR Flight Hour	ANS revenues / IFR flight hours	*APACHE Consortium (2017)*
7	Determined Unit Cost (DUC) for Terminal ANS		*APACHE Consortium (2017)*
8	Terminal ANS Costs		*APACHE Consortium (2017)*
9	Terminal ANS Unit Rates		*APACHE Consortium (2017)*
10	Average Cost per Flight at a System Wide Annual Level		*APACHE Consortium (2017)*

11	Total Operating Cost in TMA Plus Cost of Capital Divided by IFR Flights	Adjusted to fit TMA.	*APACHE Consortium (2017)*
12	Total Labor Obligations to Deliver One Forecast IFR Flight in The System	Measured monthly and year-to-date.	*APACHE Consortium (2017)*
13	TMA Actual Unit Cost		*APACHE Consortium (2017)*
14	Actual TMA Unit Cost for Airspace Users (True Costs for Users)		*APACHE Consortium (2017)*
15	Financial Cost-effectiveness Indicator		*APACHE Consortium (2017)*
16	Support Cost Ratio		*APACHE Consortium (2017)*
17	Direct Operating Costs for TMA User	Adjusted to fit TMA. Related to the airplane and passengers, e.g. staff expenses, maintenance, landing fees, navigation charges and repairs.	*APACHE Consortium (2017)*
18	Indirect Costs for TMA Users	Adjusted to fit TMA. Impacts of costs that does not relate to a specific flight, e.g. crew and cabin salary.	*APACHE Consortium (2017)*
19	Overhead Costs for TMA Users	Adjusted to fit TMA. E.g. IT infrastructures and dispatchers.	*APACHE Consortium (2017)*

20	Average Cost per Flight at a System Wide Annual Level		*APACHE Consortium (2017)*
21	Total Operating Cost in TMA Plus Cost of Capital Divided by IFR Flights	Adjusted to fit TMA.	*APACHE Consortium (2017)*
22	Cost per IFR Flight Hour		*APACHE Consortium (2017)*
23	Cost Excluding ATCO Employment Costs per IFR Flight Hour		*APACHE Consortium (2017)*
24	Cost of Capital and Deprecation as a Percentage of Costs		*APACHE Consortium (2017)*
25	Employment Costs of ATCOs as a Percentage of Total Costs		*APACHE Consortium (2017)*
26	Flights per ATCO Hour on Duty	Count of flights handled / Number of ATCO hours applied by ATCOs on duty	*APACHE Consortium (2017)*
27	Technology Cost in TMA per Flight	Adjusted to fit TMA. Calculated for the time spent in TMA.	*APACHE Consortium (2017)*
28	TMA Unit Economic Cost for The Airspace User	Adjusted to fit TMA. Cost difference between the actual trajectory compared to airspace users preferred trajectory.	*APACHE Consortium (2017)*

29	TMA Unit Economic Cost for The Airspace User - Strategic	Captures only the cost due to strategic ANS actions.	*APACHE Consortium (2017)*
30	TMA Unit Economic Cost for The Airspace User - Tactical	Captures only the cost due to tactical ANS actions.	*APACHE Consortium (2017)*
31	TMA ATM Charges Cost for The Airspace User	Similar to #28 but only considering TMA ATM charges. Focus on impact on ANSP revenues.	*APACHE Consortium (2017)*
32	Sectorization Cost	Captures the referred dependency. Number of optimal sectors and when they are active, divided by actual number of active sectors and time f corresponding activity.	*APACHE Consortium (2017)*

2.4 *Efficiency*

All airspace users want to fly according to their flight plan and optimal trajectories to keep their selected times of departure and arrival. Route efficiency measures how close the actual route is compared to the ideal one and the *Efficiency* KPA addresses operational and economic cost-effectiveness of flight. It is the passengers who are the end users of the ATS and airlines build their schedules according to their passengers demands. If an airline could not be served as required, it can lead to loss in attractiveness for an airline as well as higher costs in the form of for example late arrivals and longer routes (APACHE Consortium 2017). KPIs relevant for measuring the *Efficiency* performance of TMAs are shown in Table 5.

Table 5 - KPIs of the Efficiency KPA

#	KPI	Comment	Source
1	Operational Availability	Maximum facility service hours minus outage time, divided by maximum facility service hours.	*APACHE Consortium*

		Present in both the Capacity table (#17) and the Efficiency table (#1).	*(2017); CANSO (2015)*
2	Calculated Take-off Time Compliance	Percentage of IFR flights taking off within their assigned ATFM slot. Number of early and late departures.	*APACHE Consortium (2017); CANSO (2015); ICAO (2019c)*
3	Terminal Departure Flight Distance / Time Efficiency	Number of departing aircraft delayed in terminal airspace. Average departure delay per flight or average departure delay per delayed flight.	*APACHE Consortium (2017); CANSO (2015)*
4	Airport Throughput Efficiency	Airport throughput (accommodated demand) compared to capacity or demand, whichever is lower.	*ICAO (2019c)*
5	Level-off During Climb	Distance and time flown in level flight before top of climb.	*APACHE Consortium (2017); CANSO (2015); ICAO (2019c)*
6	Arrival Flight Distance / Time Efficiency	Total or average excess time or distance by aircraft group, operating configuration or arrival airport.	*APACHE Consortium (2017); CANSO (2015)*
7	Level-off During Descent	Distance and time flown in level flight before top of descent.	*APACHE Consortium (2017); CANSO (2015); ICAO (2019c)*

8	ATM Attributable Delay	Delay against a schedule or a field time that can be attributable to ATM.	*APACHE Consortium (2017)*
9	Airport/Terminal ATFM Delay Attributed to Arrival Flow Restrictions	ATFM delay at a given airport and/or associated terminal airspace.	*ICAO (2019c)*
10	The Share of Regulated Flights		*APACHE Consortium (2017)*
11	Percentage of Flights With Normal Flight Duration in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
12	Percentage of Flights Departing On-time		*APACHE Consortium (2017)*
13	Average Departure Delay of Delayed Flights		*APACHE Consortium (2017)*
14	Average Flight Duration Extension in TMA of Flights with an Extended Flight Duration in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
15	Percentage of Flights with On-time Arrival at a Predetermined Set of Airports		*APACHE Consortium (2017)*
16	Number of Early Departures		*APACHE Consortium (2017)*
17	Number of Late Departures		*APACHE Consortium (2017)*

18	Number of Departing Aircraft Delayed in The Terminal Airspace		*APACHE Consortium (2017)*
19	Total or Average Excess Minutes or Miles by Aircraft Group, Operating Configuration, or Arrival Airport		*APACHE Consortium (2017)*

2.5 Environmental

Because the global ATM system impacts the environment depending on how efficiently aircraft fly, the system should be protective of the environment by working towards a reduction of emissions, noise and other negative impacts. The ATM system decides an aircrafts' altitude, speed and trajectory, which are all factors that affect the amount of fuel burn, emitted greenhouse gases and level of noise. When in inside a TMA, flying at a low altitude and in a local area with a lot of air traffic, these factors have a bigger impact on the environment and with noise annoyance (APACHE Consortium 2017). Because of higher atmospheric pressure at low altitudes than at high altitudes (SMHI 2013), the fuel consumption of aircraft is higher at low altitudes which makes it important to reach the cruise level as fast as possible at departures and to land as soon as possible at arrivals. Also, another reason for avoiding level flight in TMAs is that noise increases when in level flight (ICAO 2019c). KPIs relevant for measuring the *Environmental* performance of TMAs are shown in Table 6.

Table 6 - KPIs of the Environmental KPA

#	KPI	Comment	Source
1	Amount of Emissions Attributable to Inefficiencies in ATM Service Provision	E.g. CO2, NOx, H2O and particulate.	*APACHE Consortium (2017)*
2	Additional Time in Terminal Airspace	Actual terminal airspace transit time compared to an unimpeded time.	*ICAO (2019c)*
3	Additional Time During Descent	Version of #2 to fit the Descent and Arrival phase of flight (phase 4). Actual descent transit time	*ICAO (2019c)*

		compares to an unimpeded time.	
4	Additional Time During Climb	Version of #2 to fit the Departure and Initial Climb Out phase of flight (phase 2). Actual climb transit time compares to an unimpeded time.	*ICAO (2019c)*
5	Additional Fuel Burn	Additional flight time/distance and vertical flight inefficiency converted to estimated additional fuel burn attributed to ATM.	*ICAO (2019c)*
6	Effective Use of CDR	CDR = Preplanned alternative routes that can be used in case of traffic constraints e.g. thunderstorms or turbulence.	*APACHE Consortium (2017)*
7	Relative Noise Scale		*APACHE Consortium (2017)*
8	Number of People Exposed to Significant Noise as Measured by a Three-year Moving Average		*APACHE Consortium (2017)*
9	Size and Location of Noise Contours		*APACHE Consortium (2017)*
10	Geographical Distribution of Pollutant Concentrations		*APACHE Consortium (2017)*

11	Fuel Efficiency per Revenue Plane-mile as Measured by a Three-year Moving Average		*APACHE Consortium (2017)*
12	Vertical Flight Efficiency	In ascent for departure and descent for arrival phases of flight.	*APACHE Consortium (2017)*
13	Average Fuel Burn in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
14	CO2 Emissions in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
15	Reduction on Average Flight Duration in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
16	ATM Inefficiency on Trip Fuel (or Emissions) in TMA	Adjusted to fit TMA. The sum of fuel burn in TMA for all flights in the analysis– the sum of the estimated optimal trip fuel in TMA for all flights in the analysis.	*APACHE Consortium (2017)*
17	ATM Vertical Trajectory Inefficiency on Trip Fuel (or Emissions) in TMA	Adjusted to fit TMA. Actual trip fuel in TMA – Optimal trip fuel fixing the actual route in TMA.	*APACHE Consortium (2017)*
18	Strategic ATM Inefficiency on Trip Fuel (or Emissions) in TMA	Adjusted to fit TMA. RBT trip fuel in TMA – Optimal TMA trip fuel.	*APACHE Consortium (2017)*
19	Strategic ATM Vertical Trajectory Inefficiency on Trip Fuel (or Emissions) in TMA	Adjusted to fit TMA. RBT trip fuel in TMA – Optimal	*APACHE Consortium (2017)*

		trip fuel fixing the RBT route in TMA.	
20	Tactical ATM Inefficiency on Trip Fuel (or Emissions) in TMA	Adjusted to fit TMA. Actual trip fuel in TMA – RBT trip fuel in TMA.	*APACHE Consortium (2017)*
21	Tactical ATM Vertical Trajectory Inefficiency on Trip Fuel (or Emissions) in TMA	Adjusted to fit TMA. Actual trip fuel in TMA – RBT trip fuel in TMA – (Optimal trip fuel fixing the actual route in TMA – Optimal trip fuel fixing the RBT route in TMA).	*APACHE Consortium (2017)*

2.6 Flexibility

The *Flexibility* KPA aims to measure the ability of the ATM system to accept airspace users to modify their flight in form of e.g. adjusting departure/arrival times and trajectories (APACHE Consortium 2017). KPIs relevant for measuring the *Flexibility* performance of TMAs are shown in Table 7.

Table 7 - KPIs of the Flexibility KPA

#	KPI	Comment	Source
1	Number of Rejected Changes to The Number of Proposed Changes to The Number of Flight Plans Initially Filed Each Year		*APACHE Consortium (2017)*
2	Proportion of Rejected Changes for Which an Alternative Was Offered and Taken		*APACHE Consortium (2017)*
3	Average Delay in TMA for Civil/Military Flights with Change Request and Non-scheduled / Late Flight Plan Request		*APACHE Consortium (2017)*

4	Percentage of Flights Not Subjected to Constraints	On system level.	*APACHE Consortium (2017)*
5	Percentage of Flight Operator Requests Granted	On system level.	*APACHE Consortium (2017)*
6	Percentage of Position Swaps Over The First-come-first-serve Approach (CDQM)	On medium level.	*APACHE Consortium (2017)*
7	Percentage of Non-scheduled IFR Flights That Can Depart on Time	On medium level.	*APACHE Consortium (2017)*
8	Percentage of Altitude/Vertical Change Requests Accommodated	On medium level.	*APACHE Consortium (2017)*
9	Percentage of Route Change Requests Accommodated	On medium level.	*APACHE Consortium (2017)*
10	Percentage of OPDs Granted	On medium level.	*APACHE Consortium (2017)*
11	Percentage Utilization of SUA	On medium level.	*APACHE Consortium (2017)*
12	Departure Delay for Business Trajectory Updates	Flights requesting departure time change.	*APACHE Consortium (2017)*
13	Non-scheduled Flight Departures		*APACHE Consortium (2017)*

14	ATM Service Provision at New Locations		*APACHE Consortium (2017)*
15	Suitability for Military Requirements		*APACHE Consortium (2017)*
16	Average Delay for Non-scheduled Civil/Military Flights Delayed		*APACHE Consortium (2017)*
17	Percentage of Non-scheduled Civil/Military Flights Arriving on Time		*APACHE Consortium (2017)*
18	ARES Allocation at Short Notice		*APACHE Consortium (2017)*
19	Percentage of RBTs Equal to First Submitted SBTs	Number of RBTs equal to the number of first submitted SBTs / number of SBTs submitted.	*APACHE Consortium (2017)*
20	Spare Capacity in TMA	Adjusted to fit TMA. (The time during which the TMA is active – The time during which over 90% of TMA capacity is utilized) / The time during which the TMA is active.	*APACHE Consortium (2017)*
21	Flexibility of DCB Solutions	Number of different DCB solutions / Number of regulated trajectories.	*APACHE Consortium (2017)*
22	The Percentage of Demand Handled Over Declared Capacity	(demand handled – declared capacity) / Declared capacity.	*APACHE Consortium (2017)*

2.7 Global Interoperability

The ATM system should be based on international standards and uniform principles in order to ensure homogeneous and non-discriminatory traffic flows (APACHE Consortium 2017). KPIs relevant for measuring the *Global Interoperability* performance of TMAs are shown in Table 8.

Table 8 - KPIs of the Global Interoperability KPA

#	KPI	Comment	Source
1	Number of Filed Differences with ICAO SARPs		*APACHE Consortium (2017)*
2	Level of Compliance of ATM Operations with ICAO CNS/ATM Plans and Global Interoperability Requirements		*APACHE Consortium (2017)*

2.8 Participation by ATM Community

Aviation community should be involved in the global ATM system to ensure that the evolution at all times fulfils its expectations (APACHE Consortium 2017). KPIs relevant for measuring the *Participation by ATM Community* performance of TMAs are shown in Table 9.

Table 9 - KPIs of the Participation by ATM Community KPA

#	KPI	Comment	Source
1	Number of Early Meetings Covering Planning, Implementation and Operation, and Covering a Significant Estimated Proportion (e.g. 90%) of The Whole of The Regional Aviation Activity		*APACHE Consortium (2017)*
2	Number of Yearly Meetings for Planning		*APACHE Consortium (2017)*

3	Number of Yearly Meetings for Implementation		*APACHE Consortium (2017)*
4	Number of Yearly Meetings for Operations		*APACHE Consortium (2017)*
5	Collaborative SBT Updates	Number of SBT update requests / Number of RBTs different from first submitted SBTs.	*APACHE Consortium (2017)*
6	Collaborative RBT Updates	Number of RBT update requests / Number of RBTs updated.	*APACHE Consortium (2017)*

2.9 Predictability

The *Predictability* KPA means the ability of airspace users and ATM service providers to provide consistent and dependable levels of performance (APACHE Consortium 2017). KPIs relevant for measuring the *Predictability* performance of TMAs are shown in Table 10.

Table 10 - KPIs of the Predictability KPA

#	KPI	Comment	Source
1	Capacity Variation in TMA	Adjusted to fit TMA. Difference between the 85th and 15th percentile declared capacity for facility.	*APACHE Consortium (2017); CANSO (2015)*
2	Flight Time Variation in TMA	Adjusted to fit TMA. Difference between the 85th and 15th percentile travel time inside TMA.	*APACHE Consortium (2017); CANSO (2015); ICAO (2019c)*
3	Flight Plan Variation in TMA	Adjusted to fit TMA. Difference between the 85th	*APACHE Consortium*

		and 15th percentile flight plan distance or time inside TMA.	*(2017); CANSO (2015)*
4	Departure Punctuality	Adjusted to fit TMA. Percentage of flight departing (taking off) on time compared to schedule.	*ICAO (2019c)*
5	Arrival Punctuality	Adjusted to fit TMA. Percentage of flights arriving (landing) on time compared to schedule.	*ICAO (2019c)*
6	Percentage of Flights Within 15 Minutes of Scheduled Departure or Arrival		*APACHE Consortium (2017)*
7	Percentage of Departures < +/- 3 Minutes vs Schedule Due to ATM Causes		*APACHE Consortium (2017)*
8	Departure Delays Caused by Weather or ATM		*APACHE Consortium (2017)*
9	Knock-on Effect (Reactionary Delays)		*APACHE Consortium (2017)*
10	Variance of Differences Between Actual Flight and Flight Flan or RBT durations		*APACHE Consortium (2017)*
11	ATFM Slot Adherence	Calculated take-off time compliance. Percentage of flights taking off within their assigned slot. Present in both the Capacity table	*APACHE Consortium (2017); IACO (2019c)*

		(#21) and the Predictability table (#11).	
12	Flight Operation Time Variability		*APACHE Consortium (2017)*
13	Compliance With RBT	Actual time of arrival over critical waypoints in TMA – planned time of arrival over critical waypoints in TMA.	*APACHE Consortium (2017)*
14	Adherence with RBT/CTA Tolerance Window	Number of RBT updates / number of flights, due to inconsistence with RBT/CTA tolerance windows.	*APACHE Consortium (2017)*
15	Predictability of Demand	100 * absolute value of ((real demand – predicted demand) / predicted demand).	*APACHE Consortium (2017)*
16	Slots Left Over	100 * (number of slots not used / number of slots assigned).	*APACHE Consortium (2017)*
17	Tactical Predictability	100 * (Number of RBT updates / Number of RBTs).	*APACHE Consortium (2017)*
18	Difference Between Actual Delay and Assigned Delay	100 * absolute value of ((actual delay – assigned delay) / assigned delay).	*APACHE Consortium (2017)*

2.10 Safety

Of all KPIs, *Safety* is always the most important one and the highest priority in aviation and the global ATM system is ensuring overall safety. Uniform safety standards and safety management should be systematically applied in the system (APACHE Consortium 2017).

Two of the most important factors in flight when it comes safety are high altitude and high speed, making the phases of departure and arrival vulnerable and the phases of flight that are most exposed. Approximately 50 percent of all fatal accidents occur during descent, approach and landing and about 30 percent of all fatal accidents occur during take-off and climb (Boeing 2020), which makes safety extra important when measuring performance in TMAs. KPIs relevant for measuring the *Safety* performance of TMAs are shown in Table 11.

Table 11 - KPIs of the Safety KPA

#	KPI	Comment	Source
1	Effectiveness of Safety Management (EoSM)		*APACHE Consortium (2017)*
2	Application of Severity Classification Based on the RAT	The risk analysis tool (RAT) is a methodology to classify safety related occurrences in the ATM system.	*APACHE Consortium (2017)*
3	Level of Presence of Absence of Just Culture	A just culture emphasizes that mistakes are a product of organizational cultures (generally) and not solely individually brought.	*APACHE Consortium (2017)*
4	Total CAT Accidents		*APACHE Consortium (2017)*
5	ANS-related Accidents and Accidents With ANS Contribution		*APACHE Consortium (2017)*
6	Serious Incidents in CAT		*APACHE Consortium (2017)*
7	ANS-related Serious Incidents and Serious Incidents With ANS Contribution		*APACHE Consortium (2017)*

8	ATM-related Incidents		*APACHE Consortium (2017)*
9	Count of Accidents Normalized Through Either Number of Operations or The Total Flight Hours in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
10	Controlled CFIT accidents		*APACHE Consortium (2017)*
11	Wake Turbulence Related Accidents		*APACHE Consortium (2017)*
12	Number of MACs in TMA		*APACHE Consortium (2017)*
13	Application of Automated Safety Data Recording for Separation Minima Infringement Monitoring		*APACHE Consortium (2017)*
15	Number of Separation Minima Infringements, Runway Incursions, Airspace Infringements and ATM-Specific Occurrences		*APACHE Consortium (2017)*
16	Level of Occurrence Reporting in TMAs	Adjusted to fit TMA.	*APACHE Consortium (2017)*
17	Accidents and Incidents in TMA With ATM Contribution per Year	Adjusted to fit TMA.	*APACHE Consortium (2017)*

18	Number of Traffic Alert Warnings in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
19	Number of Resolution Advisors Issued in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
20	Number NMACs in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
21	Number of Separation Violations in TMA	Adjusted to fit TMA.	*APACHE Consortium (2017)*
22	Severity of Separation Violations in TMA	Adjusted to fit TMA. (Separation minima – Actual separation) / separation minima.	*APACHE Consortium (2017)*
23	Duration of Separation Violations in TMA	Adjusted to fit TMA. Time during which separation minima is being violated.	*APACHE Consortium (2017)*
24	Risk of Conflicts/Accidents	Possible to calculate based on #22 and #23.	*APACHE Consortium (2017)*

2.11 Security

The *Security* KPA aims at the protection of aircraft, people, devices and systems on the ground against different threats. In the event of threats, the ATM system should provide authorities with information and assistance (APACHE Consortium 2017). KPIs relevant for measuring the *Security* performance of TMAs are shown in Table 12. These KPIs are of relevance because security threats could appear in any phase of flight.

Table 12 - KPIs of the Security KPA

#	KPI	Comment	Source

1	Number of Acts of Unlawful Interference Reported Against ATS Provider Fixed Infrastructure		*APACHE Consortium (2017)*
2	Number of Incidents in TMAs Involving Direct Unlawful Interference to Aircraft That Required ATS Provider Response	Adjusted to fit TMA. E.g. Bomb threat, hijack or imitative deception.	*APACHE Consortium (2017)*
3	Number of Incidents in TMA Due to Unintentional Factors That Have Led to An Unacceptable Reduction In ANS capacity.	Adjusted to fit TMA. E.g. human error or natural disasters.	*APACHE Consortium (2017)*
4	Personnel Safety Risk After Mitigation		*APACHE Consortium (2017)*
5	Capacity Risk in TMA After Mitigation	Adjusted to fit TMA.	*APACHE Consortium (2017)*

3 Data and data handling

In order to analyze the usability of the KPIs, we use data for all arriving IFR flights to Arlanda Airport during 2018, extracted from EUROCONTROL's Demand Data Repository (DDR). The data consists of two files, one which describes the 4D flight trajectories for the last updated flight plans and one with equivalent information updated with radar data from the actual flights. The files contain data from 121 526 flights in total, which is about 7.5 million segments from the actual flight data and 5.4 million segments in the flight plans. For each segment, there are several data fields. The data fields we use in this project are presented in Table 13.

Table 13 - Data fields

#	Data Field	Description
1	Segment Identifier	Description of which points a segment is bounded by
2	Origin of Flight	ICAO code
3	Destination of Flight	ICAO code
4	Aircraft Type	Aircraft type
5	Time Begin Segment	Time when the aircraft enters the segment, in HHMMSS
6	Time End Segment	Time when the aircraft leaves the segment, in HHMMSS
7	FL Begin Segment	Flight level when the aircraft enters the segment
8	FL End Segment	Flight level when the aircraft leaves the segment
9	Status	Describes whether the aircraft is climbing, descending or cruising
10	Callsign	Unique identifier for each flight
11	Date Begin Segment	Date when the aircraft enters the segment
12	Date End Segment	Date when the aircraft enters the segment

13	Latitude Begin Segment	Latitude when the aircraft enters the segment
14	Longitude Begin Segment	Longitude when the aircraft enters the segment
15	Latitude End Segment	Latitude when the aircraft leaves the segment
16	Longitude End Segment	Longitude when the aircraft leaves the segment
17	Flight Identifier	Unique identification number for each flight
18	Sequence	The sequence number in the flight
19	Segment Length	Length of segment, in nautical miles

The massive amount of data requires strategies to divide it into smaller parts in order to be able to work with it. We therefore perform all data handling on one day at the time.

The first step is to load all beginning and ending dates from both files into MATLAB, which results in two arrays with about 7.5 and 5.4 million elements. We then set a date where data is wanted from. A flight is considered to belong to the date that it is landing on, since all KPIs calculated in this project regard arriving flights. We then generate a list with all indices where the chosen date and the day before is found in the large date arrays. Since a flight can start at one day and end on another, the day before needs to be included.

When we have found all indices for the chosen date and the date before, all data fields described in Table 13 are imported, starting at the lowest index found and ending at the highest index. Since there are no possibility to import separate parts of the data in a simple way, we import all data from the lowest to the highest found index uninterrupted. This results in tables with 20 columns and approximately 50-100 000 rows, depending on the date. These tables contain all data from the chosen date and the date before, but since the data is not sorted on ending time/date, flights from other dates are also included. We therefore need to clear these tables so that only flights ending the chosen date remain.

The first step in clearing the data is to sort out flights that does not end at Arlanda Airport. After this, we generate a list of all the unique flight numbers that end at Arlanda Airport. The number of flights in this list is about 960-1 400. To know which flights that end the chosen day, we need to find the last segment of each flight. Since all flights have different number of segments, we let the program check whether the next segment has the sequence number 1 or not. If the sequence number is a 1, the segment in the current position must be the last in the flight, and we then save the flight number. If the sequence number of the next segment is anything else than a 1, we let the program move on to next segment. When this procedure is done, we obtain a list with all unique flight numbers that end the chosen date, which for the evaluated dates were about 340-400 flights/day.

We now have a large data table with about 960-1 400 flights and 50 000-100 000 segments, which needs to be filtered so it only contains data for the 340-400 flights that end the chosen date. We do this by comparing the flight numbers in the large table with the list of the unique flight numbers that we produced in the previous step. Only the segments that belong to flights in this list are saved, so that a table with 20 columns and 15-30 000 rows remains, corresponding to the 340-400 flights that end at Arlanda Airport the chosen date.

When this is done for both the flight plan file and the file with data from actual flights, we save the resulting tables so we can use them when calculating the KPIs.

4 KPI Analysis

In this project, we choose two KPIs to analyze further. The data we have available are for descent and arrivals (phase 4 of flight) to Arlanda Airport during 2018 and for both the flight plans and the actual flights, meaning that it is possible to do a comparison of these. All KPIs measuring quantity of flights, flight time and flight distance of arrivals are possible to analyze. The ones that we choose to analyze are *Level-Off During Descent* (*Efficiency* #7, see Table 5) and *Additional Time During Descent* (*Environmental* #3, see Table 6). We choose these because they both give a good overall picture of TMA performance and *Level-off During Descent* has a high grade of maturity because it is already implemented and used by ICAO. *Additional Time During Descent* is a rewrite of the ICAO (2019c) *Additional Time in Terminal Airspace* (which is also of high maturity because it is implemented and in use by ICAO) we make to be able to measure the performance of only the descent phase and not both the descent and arrival phases together. Because we lack data for departures, we consider this a better option to analyze.

4.1 Level-Off During Descent

This KPI measures the time and distance flown in level flight from the point of top of descent to touch down. It is intended to indicate the amount of level flight during the phase of descent. The less the level flight the better the performance, because ideally there should be no level flight at all after top of descent. The reason for this is that level flight results in higher fuel burn and produces more noise than descending (ICAO 2019c).

In the calculations for this KPI, we use the description from ICAO (2019c) as a base, but with some modifications. Since our data already contain information about whether a segment is flown in level flight or not, we disregard all calculations aiming to calculate this in the description from ICAO (2019c).

This KPI requires data from the actual flight. The algorithm we use is:

1. We choose a date and load the data from the actual flight this date into the software (as described in Chapter 3).
2. We calculate the times in each segment. For this step, we use data field #5, #6, #11 and #12; times and dates for when the segment begins and ends. See Table 13 for a description of the data fields. We divide the times into three separate variables; hours, minutes and seconds and convert them from doubles to durations, to make calculations possible. For segments starting and ending the same date, we calculate the time in each

segment as the difference between the segments ending time and beginning time. For segments starting and ending different dates, we add 24 hours to the difference between the times.

3 We make a list with all the unique flight numbers and calculate the number of unique flights. For this we need all flight numbers, data field #17.

4 By using the list of unique flight numbers (calculated in step 3) and flight numbers for all segments (data field #17), we calculate the number of segments in each flight. To be able to save distances and times, we create arrays and put them in a table.

5 We calculate the distances from the start of the descent to touch down. For each flight, we consider the descent to begin at the first found segment with descending status and this point to be top of descent. From this point, we add the distances for all remaining segments in the flight together, to get the total distance for the descent. In this calculation we use the segment length (data field #19), the status (data field #9), the duration of each segment (calculated in step 2) and the number of segments in each flight (calculated in step 4).

6 We calculate the distance and time in level flight. For all segments after top of climb that are flown in level flight, we add together the distances and times. In this calculation we use the segment length (data field #19), the status (data field #9), the number of segments in each flight (calculated in step 4) and the duration for each segment (calculated in step 2).

7 We clear the result from outliers. We disregard all flights where the descent starts before 250 nautical miles before the touch down, as well as all flights with a level flight time less than 20 seconds.

8 We calculate the average level-off times and distances for the chosen date.

4.2 Additional time During Descent

This KPI measures the additional time during descent by comparing the planned flight trajectories to the actually flown trajectories. It is intended to give an overview of average queuing (speed reduction, path extension and holding) as a result of sequencing. It can also, together with *Level-off During Descent*, be used to calculate excess fuel burn and emissions due to inefficiency in the descent phase.

This KPI requires data from both the flight plans and the actual flights. The algorithm we use is:

1 We choose a date, and load the data for both the flight plans and actual flights from this date (as described in Chapter 3) into the software.

2 We calculate the times in each segment. In this step, we use data field #5, #6, #11 and #12; times and dates for when the segment begins and ends. See Table 13 for a description of the data fields. We divide the times into three separate variables; hours, minutes and seconds and convert them from doubles to durations, to make calculations possible. For segments starting and ending the same date, we calculate the time in each segment as the difference between the segments ending time and beginning time. For segments starting and ending different dates, we add 24 hours to the difference between the times. We do everything in this step for both flight plans and actual flights.

3 We make a list with all the unique flight numbers for both the flight plans and actual flights. We then compare these numbers, save the flight numbers that appear in both columns and calculate the number of unique flights. These calculations require all flight numbers (data field #17).

4 By using the list of unique flight numbers (calculated in step 3) and flight numbers for all segments (data field #17), we calculate the number of segments in each flight for both the flight plans and actual flights. We then create arrays for saving distances and times for both flight plans, actual flights and a comparison of these and put the arrays in a table.

5 We calculate the times from start of descent to touch down for both flight plans and actual flights. For each flight, we consider the descent to begin at the first found segment with descending status and this point to be top of descent. From this point, we add together the times for all remaining segments in the flight to get the total time for the descent. For this calculation we use the segment length (data field #19), the status (data field #9), the duration of each segment (calculated in step 2) and the number of segments in each flight (calculated in step 4).

6 By subtracting the time in the flight plan from the actual time we get a comparison between the descent times for each flight in the flight plan and the actual flight. We add the times for the flight plans, the actual flights and the comparison to a table. For these calculations we use the times from top of descent to touch down (calculated in step 5).

7 We clear the result from outliers. We disregard all flights with a descending phase longer than 40 minutes in the flight plan, or 90 minutes in the actual flight.

8 We calculate the average descent times and average additional times during descent for the chosen date.

5 Results of the KPI Analysis

The results from the numeric analysis of the KPI *Level-Off During Descent* are presented in Table 14. The total average descent distance is the distance from top of climb to touch down, in nautical miles. The part of this distance flown in level flight is presented in column three as *Average level-off distance*, and the corresponding times are presented in column four. In the last column, the percentage of the level-off distance compared to the total distance is presented. An arbitrary week without holidays is chosen.

Table 14 - Resulting level off values for 180409-180415

Date	Total average descent distance (nautical miles)	Average level-off distance (nautical miles)	Average level-off time (hh:mm:ss)	Level-off distance in percent of total
180409	122.9263	16.6329	00:03:06	13,5%
180410	121.9739	15.6441	00:03:22	12,8%
180411	121.7105	17.0622	00:03:02	14,0%
180412	118.1099	15.5625	00:02:57	13,2%
180413	126.0541	22.3424	00:03:44	17,7%
180414	130.5327	19.6764	00:03:32	15,1%
180415	139.1790	31.2847	00:04:46	22,5%

In Table 15, the average values from the week in Table 14 are presented.

Table 15 - Average level off values for 180409-180415

Total average descent distance (nautical miles)	Average level off distance (nautical miles)	Average level off time (hh:mm:ss)	Level off distance in percent of total
125.7838	19.7436	00:03:30	15,5%

As seen in Table 14, the averages for both the distances and times are quite similar from day to day. Six of the seven analyzed level-off distances differ between 15.5624 nm and 22.3424 nm, and the last one (180415) is 31.2847 nm. The same pattern can be seen for the times, which differ between 02:57 and 03:32 minutes, while 180415 have 04:46 minutes.

If the distribution over one day is examined, the distribution around the average value can be seen for both the distances and times. This is showed in Figure 4 for the distances on 180409, and in Figure 5 for the times on 180409. As seen, the distances and times are exponential distributed.

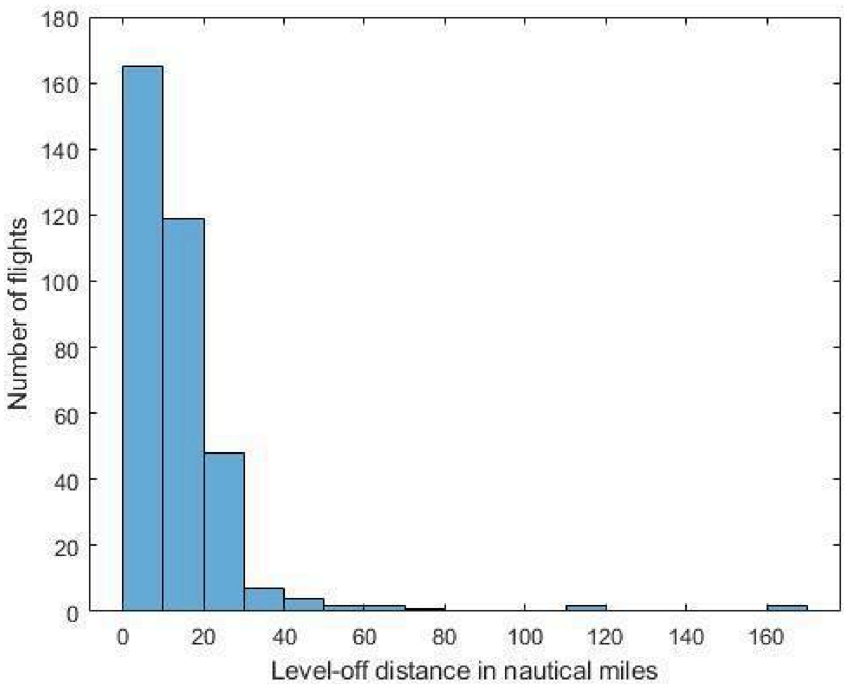

Figure 4 - Distribution of the level-off distances 180409

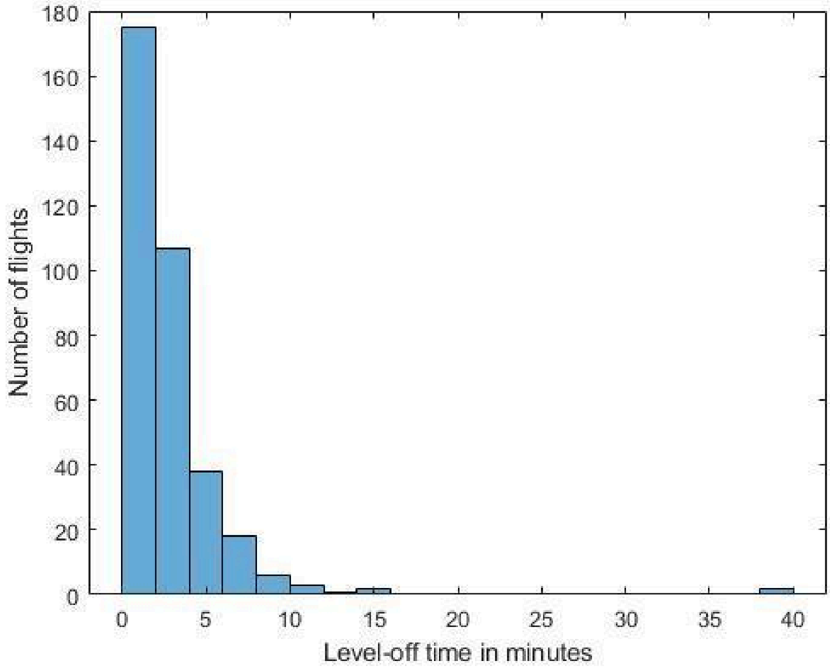

Figure 5 - Distribution of the level-off times 180409

The results from the analysis of the KPI *Additional Time During Descent* are presented in Table 16. Column two and three present the planned and actual times from top of descent until touchdown. The difference between these two is the KPI and presented in the last column. The same arbitrary week as in previous KPI is chosen.

Table 16 - Resulting additional time in TMA values for 180409-180415

Date	**Average time during descent, planned (hh:mm:ss)**	**Average time during descent, actual (hh:mm:ss)**	**Additional time during descent (hh:mm:ss)**
180409	00:19:16	00:26:19	00:07:02
180410	00:19:08	00:27:38	00:08:30
180411	00:19:02	00:24:53	00:05:50
180412	00:19:04	00:25:04	00:05:59
180413	00:19:23	00:24:11	00:04:47
180414	00:20:28	00:25:27	00:04:58
180415	00:19:29	00:25:47	00:06:18

In Table 17, the average values from Table 16 are presented.

Table 17 - Average additional time in TMA for 180409-180415

Average time in TMA, planned (hh:mm:ss)	**Average time in TMA, actual (hh:mm:ss)**	**Average additional time in TMA (hh:mm:ss)**
00:19:24	00:25:37	00:06:12

As seen in Table 16, the average times from both the flight plan and the actual flight are very similar from day to day. The average time for the flight plan differs between 19:02 and 20:28

minutes, and the actual time differs between 24:11 and 27:38 minutes, which means that there is a difference of 01:26 minutes between the days in the flight plans, and 03:27 minutes in the actual flights.

Table 16 also shows that the *Additional Time During Descent* differs between 04:47 and 08:30 minutes. To get an idea of how these time differences are distributed, an example of the distribution of the *Additional Time During Descent* for one day, 180409, is presented in Figure 6. The x-axis shows the times, and the y-axis describes how many flights that end up in the particular time interval.

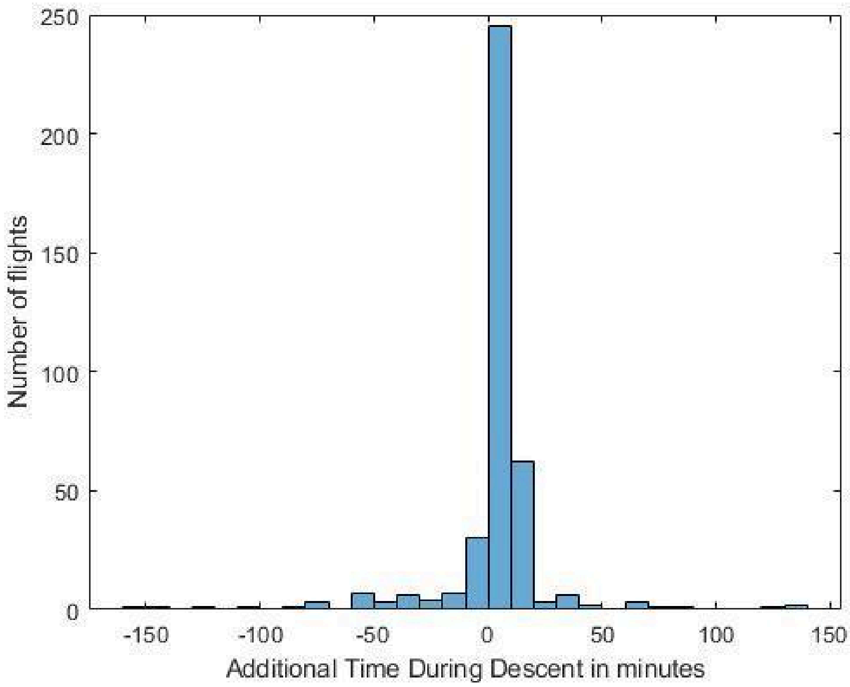

Figure 6 - Distribution of the Additional Time During Descent 180409

6 Analysis and Discussion

It is not always easy to measure the performance of only one phase of flight since, as earlier mentioned in Chapter 2, what happens in all phases of flight can impact each other and, for example, a delay in one phase can be traced back to an earlier phase (CANSO 2015). This makes it hard to define whether an inefficiency has its source in the specific phase of flight where the performance is measured. For example, the *Capacity* KPI #3 *Minutes of Delay* (see Table 3) is a KPI where this is likely to happen, because it is not necessary that the reason for the delay happened inside of the TMA, it might as well be derived to an earlier event of another phase of flight. Hence, this KPI might not be the most usable of measuring the performance of only a phase of flight but better when measuring the performance as a whole.

Also, some KPIs in Chapter 2 are originally covering whole flights and not only parts of flights. Some can be modified to fit TMAs better, or other specific phases of flights, but are in fact a better fit for flights in whole. For example, the *Cost-effectiveness* KPI #27 about technology costs (see Table 4), is a KPI that probably would make a better fit for the whole flight, measuring an average cost including all different phases.

It is important to highlight that we have chosen the actual point of Top of Descent when analyzing the *Level-off During Descent* and *Additional Time During Descent* KPIs. Otherwise, a gap between the en-route phase of flight and the flight inside of the TMA would appear, because the descent starts earlier on and the en-route phase is when an aircraft is in cruise only. In this way we can emit the gap and we get the performance for the whole phase 4 of flight, *Descent and Arrival.*

When the unique flights are listed in the data handling, a flight is not added to the list until next segment is a 1 (i.e. a new flight starts), which results in that the last flight is not included in the list if the import happens to end just at the border between two flights. Since there are 300-400 flights/day, this is not considered to affect the result.

The results from the KPI analysis are done on only one (arbitrary chosen) week. If these analyses covered a longer time period, for example all days during the whole year, it would be easier to analyze their usability and draw conclusions from them. In that case, trends over time could have been analyzed, which would have made it easier to get an idea about what affects the results. The week that the KPIs are analyzed over is arbitrary chosen, with intention to pick such a normal week as possible. That is, we tried to avoid holidays and periods with an obvious high or low amount of flights. Without analyzing more days, there is no way of knowing if the chosen week is actually a good representation of the data or not.

The KPIs that are possible to analyze numerically depend a lot on what data that are available. Many KPIs require data that can be hard to access, which may decrease their usability even if they in other ways are good. Some KPIs are also very advanced to calculate, which may lead to that it takes too much work and time to do the calculations, making it more expensive and therefore the usability decreases. In this project, the choice of KPIs to analyze was done both with respect to required/available data and the level of maturity and complexity. When performing the numerical analysis of our chosen KPIs, we get clear results that seems to indicate a well-functioning TMA. But without some kind of reference value of what makes a phase of flight efficient or inefficient, it is hard to interpret the results and also the usability of measuring the performance.

7 Conclusion

Even though most of the currently enhanced KPIs are developed to measure the performance of the en-route phase of flight, a lot of them are possible to adjust and adapt to enable performance measuring of other phases of flight, including inside of TMAs. However, it is important to take into account that inefficiency in a phase of flight might not have originated in that phase. Hence, a performed measurement might give an uncertain result and does not have to give a precise indication of where the source of inefficiency is located.

The KPIs *Level-off During Descent* and *Additional Time During Descent* require accessible, historical flight data and are relatively simple to calculate, which makes them useable choices of KPIs. Also, the result of the efficiency measurements of these KPIs is accurate because it cannot be traced back to earlier phases of flight. They seem to give good indications on how good the TMA performs, but without analyzing more data or having a reference value it is hard to make an accurate evaluation of their usability.

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