TACTICAL DEMAND TAILORING

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Summary

Air Traffic Control the Netherlands (LVNL) provides Air Navigation Services in the Dutch National Airspace (AMS-FIR) below 24500 feet. LVNL is characterized as a lower centre, predominantly handling Schiphol traffic, one of the largest European hubs. For LVNL the largest contributor to controller workload is the handling of arriving traffic, which presents itself as an irregular flow at the AMS-FIR boundary. Flights arriving to Schiphol must be navigated into a sequence (the order in which the aircraft will land) before a safe landing can be conducted. This sequencing of arrivals is done by manoeuvring these aircraft within Schiphol's Terminal Manoeuvring Area (TMA). However, the size of this area is relatively small. This means that controllers operating in this area have limited influence over the landing sequence of Schiphol arrivals. The final sequence of arrivals and the runway they land on is therefore partially determined by the order and the entry point which the aircraft use to enter the TMA. This causes LVNL's operation to be influenced by the traffic arriving to Schiphol, both in their quantity and the direction from which these flights approach. LVNL currently has little influence over these factors, leaving controllers to manage the arriving traffic to Schiphol largely as it presents itself. One method that does provide LVNL with influence over traffic outside of AMS-FIR is by issuing traffic flow regulations to parts of its airspace. These regulations cause delays to flights planned to fly through the regulated airspace causing significant economic impact to parties involved. This indicates that benefits to the operation of an Air Navigation Service Provider (ANSP) could be achieved through a method which allows that ANSP to influence traffic outside of its area of operations. One way that might improve the benefits from the airspace is by is the tool called Tactical Demand Tailoring (TDT). TDT is based on the tactical, in-flight re-routing of Schiphol arrivals by re-clearing these aircraft to a different route than what was originally planned. This allows aircraft to approach from a direction more suited to LVNL's operation and allows the organisation to extend its area of influence outside of AMS-FIR. The TDT would allow LVNL to influence the direction of approach of some of the arriving flights to Schiphol. However, re-routing traffic could lead to an important increase in amount of miles flown by these flights.

The main objective of this research is to assess the TDT tool aimed at increasing the influence of LVNL of Schiphol arrivals in terms of increment of miles flown by diverted flights This was achieved by identifying city-pairs suitable for the application of TDT, analysing the effects of a re-route on the distance of the flights affected, and to estimate the volume of traffic LVNL could instruct to approach Schiphol from a different direction than originally planned.

Data on tracks from flights showed that the most promising cluster of airports showing a variation in operated routes was the cluster grouping Italy & Switzerland. Airports inside this cluster were analysed individually by comparing the multiple routes that are flown by airlines between along the city-pair. The change to track length when TDT is applied to a flight was calculated by the comparison of the average length of these routes. The amount of flights to which TDT could be applied was estimated by analysing historical data. This data was used to calculate how many flights inside a period of time originated from identified suitable city-pairs.

The analysis of airports identified 11 city-pairs suitable for the application of TDT. Traffic data from 2019 has shown that, on average, approximately 5 to 13 flights originate from suitable city-pairs TAn analysis of the tracks flown by flights along suitable city-pairs shows that these flights, when re-routed, likely experience a negligible change to the length of their route. On average, the route length of these flights changes with 0,4%-1,4%. This change in track length is caused by the aircraft taking a different route than the one that was originally submitted in the flight plan of these flights. A change to track length of this

proportion is expected not to form an issue for the operator of the aircraft when a re-route is issued to one of their flights.

Despite the increased flight tracks, benefits from this tool emerged. Firstly, the issuing of sector capacity regulations by flow management controllers could be significantly reduced. When these regulations are issued, they cause some flights planned to fly through the restricted airspace to receive a delayed departure. These delays are estimated to cost 100 euros per minute of delay. Cases have been found where re-routing 3 flights in one inbound peak to another IAF could have prevented multiple capacity regulations inside AMS-FIR. This would have saved over 500 minutes of delay. TDT could also significantly reduce the amount of delay produced by regulations issued to Schiphol's Initial Approach Fixes.

Secondly, applying TDT to the operation of LVNL could be realised in the operations inside the TMA. Occasionally, Schiphol arrivals are re-routed to a different runway than initially planned for, inside the TMA. This allows the airport to operate at its maximum landing capacity, but this method of operating is considered more demanding for air traffic controllers. Re-routing Schiphol arrivals would allow these flights to enter the TMA from a different direction, eliminating the necessity of re-routing these flights while inside this busy airspace.

Furthermore, TDT could increase the influence LVNL has over Schiphol's runway load balance. LVNL is submitted to regulations regarding its runway utilisation. However, Runway utilisation is influenced by the direction from which traffic approaches Schiphol. This is something LVNL, currently, has little influence over. Re-routing traffic to approach from a different direction could allow LVNL to achieve a more desirable runway utilisation.

The results of this research indicated that the operation of LVNL could significantly improve from the implementation of TDT. LVNL's operation could benefit on multiple aspects from re-routing 3 to 4 flights inside one inbound peak. Further investments to research the implementation of TDT should be made.

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1. Introduction

Air Traffic Control the Netherlands (LVNL) is responsible for safe, efficient and environment friendly handling of air traffic within the civil parts of the Dutch national airspace (Amsterdam Flight Information Region (AMS-FIR)) (LVNL, n.d.). The Netherlands has a central geographical position within western Europe, one of the world's busiest air traffic regions. Due to the relatively small size of the Netherlands, LVNL has relatively little space in which it can handle the air traffic presented to their air traffic controllers. One of the largest and busiest airports of Europe, Schiphol, is inside LVNL's area of control. These aspects provide LVNL with challenges and constraints to their operation. As flights arriving to Schiphol reach the final stages of their flight, they must be navigated into a sequence (the order in which the aircraft will land) before a safe landing can be conducted. Currently, this sequencing of arrivals is done by Air Traffic Controllers manoeuvring these aircraft within the Terminal Manoeuvring Area (TMA) of Schiphol by providing Airspace Users (AU's) with arrival route clearances or vector navigation. AU's enter the TMA of Schiphol through one of the three Initial Approach Fixes (IAF). An IAF is a predefined point in space used by arrival flights to enter an airport's TMA. During periods with high amounts of inbound traffic (inbound peaks), it is common for the airport to utilize two runways for landing operations. Under this situation, it is usual practice that flights are instructed to land on the runway most conveniently oriented in respect to their point of entry to AMS-FIR while considering conflicts with other traffic. This is illustrated in Figure 1.

Figure 1: Common arrival tracks when landing on runways 18R & 18C

Figure 1 shows the most commonly used arrival paths (in red lines) for runways 18R and 18C using different entry points to AMS-FIR. These lines show how these entry-points can affect the runway an aircraft lands on. It is common practice that flights land on the runway most conveniently oriented relative to the IAF used to enter the TMA. However, it does occur that flights are instructed to approach a different runway than the one most conveniently oriented. This could be due to an uneven distribution of arrivals from the IAF's. This type of operation could be necessary to maintain the maximum landing capacity of the airport. Re-routing arriving traffic inside the TMA is therefore occasionally necessary but also considered more demanding for controllers.

This research will provide insight into a proposed operational tool which could help LVNL improve its operation. This tool will be referred to as Tactical Demand Tailoring (TDT) in this report. TDT is expected to provide the organisation with means to influence the arriving air traffic before it enters AMS-FIR. It would allow LVNL to redirect the flights arriving to Schiphol tactically, after their departure, but before these aircraft enters AMS-FIR. This extends the influence LVNL has over Schiphol arrivals to outside of its area of operations. This tool will rely on the real-time sharing of information between different actors in the global aviation operation including Air Navigation Service Providers (ANSP's), Airline Operations Control Centres (OCC's), the Eurocontrol Network Manager (NM) and others.

This document is organised as follows. After the introduction this document presents Chapter 2, containing a review of relevant literature and a theoretical framework. Chapter 3 defines the methodology of this research. Chapter 4 describes the findings of the research and its potential implications. Chapter 5 contains the conclusion of this report. Lastly, Chapters 6 and 7 describe the recommendations and bibliography, respectively.

1.1 Problem Statement

Traffic entering AMS-FIR usually presents itself at the FIR-entry points according to their filed flight plan. The path taken by these aircraft from the FIR-entry point to the runway is then determined in large part by which entry point they used and the runways that are in use for landing operations at that time. During inbound peaks it is common for two runways to be used for landing operations. AMS-FIR has a relatively high density and complexity of traffic. Therefore, rerouting arriving aircraft inside this airspace to make an approach to a runway, other than the one most conveniently oriented with respect to their FIR-entry point, is considered undesirable. This causes runway utilisation to be influenced by the direction that the arriving traffic presents itself from. Besides, LVNL must also comply with certain regulations with regard to runway usage such as the Nieuwe Normen & Handhavingsstelsel (NNHS) restricting the use of certain runways at Schiphol (Schiphol Group, 2020). Air traffic, however, does not always present itself in equal amounts from each direction. This inequality of arrivals causes LVNL to have to manage traffic as it is presented to it, without any influence over when and where they enter the AMS-FIR (KDC Group, 2022). This can be interpreted as unsynchronised arrivals forming a bottleneck in the efficiency with which arriving flights are handled by LVNL. These bottlenecks are undesirable and might be improved by sequencing traffic outside of AMS-FIR.

LVNL currently has tools that allow the forecasting of traffic multiple hours in advance. LVNL can currently influence the traffic planned to fly through its airspace. This is done by Flow Management Position controllers (FMP) issuing regulations to certain parts of its airspace (Area Control (ACC) sectors). These regulations to airspace capacity are forwarded to the NM. The NM then decides which flights planned to pass through the restricted airspace can continue their flights as filed in their flight plan, and which flights will be subjected to a delayed departure. This method of influencing the traffic flow within AMS-FIR is only applicable at relatively long time in advance as the flights subjected to a delayed departure must still be stationed at their departure airport.

This method of restricting the flow of arriving air traffic to AMS-FIR causes delays and is undesirable due to the effects these delays have to single flights, airline network operations and airports absorbing these delays. Occasionally, these delays are even handed out unnecessarily when evaluating the operation in hindsight. This is necessary as there is a level of unpredictability to estimating when a flight exactly arrives at a point in its route (Eurocontrol, 2022). Due to this unpredictability LVNL gives out regulations to parts of its airspace to ensure that the traffic in its area of responsibility never exceeds safe limits.

Providing LVNL with a tool for influencing arriving flights while they are airborne would increase their level of tactical influence over when and where arriving flights enter the AMS-FIR. LVNL could thus benefit from Tactical Demand Tailoring as this provides means to influence the entry point and time of arrival flights to AMS-FIR. This would effectively allow LVNL to partially synchronise air traffic prior to airspace entry.

1.2 Research question

The main research question for this research is then formulated as follows:

What benefits to the operation of LVNL would Tactical Demand Tailoring provide while considering negative effects on track miles flown?

Answering the main question will be supported by the following sub-questions:

1. What city-pairs are suitable for the application of Tactical Demand Tailoring?
2. What effects would Tactical Demand Tailoring have on total track miles flown?
3. What increases to flexibility in runway load balance could be achieved by applying Tactical Demand Tailoring?
4. What benefits to ACC sector operation could be achieved by applying Tactical Demand Tailoring?

1.3 Objectives

The main objective for this research is to evaluate the benefits of applying Tactical Demand Tailoring to the LVNL operation while considering operational costs in terms of track miles flown. This main objective will be supported by the following sub-objectives.

1.3.1 City-pair identification

The first sub-objective of this research is the identification of city-pairs suitable for the application of TDT at Schiphol. In order to enhance flexibility for arrivals to Schiphol, the traffic flow to each Initial Approach Fix (IAF) would ideally be more easily influenceable than it is now. However, it is expected that not all arriving flights are suitable for the application of TDT. Therefore, the evaluation of TDT for the operation of LVNL requires the identification of aerodromes which meet the requirements for the application of Tactical Demand Tailoring.

1.3.2 Track length analysis

The second sub-objective is to evaluate the effects of Tactical Demand Tailoring to the total amount of track miles flown by re-routed arriving flights to Schiphol. It is expected that a variation to track miles flown by Schiphol arrivals when Tactical Demand Tailoring will take place. The final result of the track length analysis will be a comparison between the amount of track flown with and without Tactical Demand Tailoring applied, shown as a percentage of change for each identified city-pair.

1.3.3 Change to capacity balancing potential

The third sub-objective is to evaluate the number of flights inside one inbound peak can be re-routed outside of AMS-FIR by applying Tactical Demand Tailoring. This amount of flights susceptible for a re-route will be used to evaluate two different aspects of LVNL operation.

The first aspect is the change that Tactical Demand Tailoring could bring to the ratio of utilisation of the two runways (what percentage of flights per inbound peak lands on which runway. This is the runway load balance). The application of Tactical Demand Tailoring is expected to result in a change in runway load balance for Schiphol. The potency of this change in runway load balance will be examined in this study in order to evaluate the potential benefits of implementing Tactical Demand Tailoring at Schiphol.

The second aspect is the change in capacity balancing potential that Tactical Demand Tailoring would bring is the change in arrivals to Schiphol passing through a specific Area Control (ACC) sector. It could be beneficial to the operation of LVNL that traffic planned to arrive at one ACC sector is diverted to another sector. Tactical Demand Tailoring would provide LVNL Flow Management Position (FMP) with more short term (or tactical) influence over traffic numbers through a sector. This change in flexibility could reduce how often regulations to sector capacity are issued.

1.4 Scope & limits

The following section describes the scope and limits of the research. It defines what will be and what will not be included in this research.

1.4.1 City-pairs

The original selection of city-pairs will be made through a ranking of airports with the highest amount of traffic to Schiphol per day. These airports are analysed by their geographical location relative to Schiphol. Although no exact limits will be made for the geographical location of airports, it is expected that the final selection of city-pairs will exclude flights outside a 1,5 to 4 hour window of flight time from Schiphol. Airports that are relatively close to Schiphol are not expected to be suitable for the application of Tactical Demand Tailoring as a re-clearance to a new FIR-entry point would likely result in an inefficient route. Aircraft located too far away from Schiphol are also likely not suitable for the application of Tactical Demand Tailoring due to the relatively low amounts of traffic originating from these airports. Also, these airports have a relatively high level of unpredictability to their time of entry to AMS-FIR due to uncertainties in their flight track such as meteorological conditions or ATC-instructions.

1.4.2 Track length

The track length evaluation will include the parts of track from the point of deviation of the original route until the FIR-entry point in question. This means that only the changing parts of the flown track will be evaluated. Specific differences in departures out of the origin aerodrome will not be included as they are not influenced by the application of Tactical Demand Tailoring. Also, the analysis of track length stops at FIR-entry point. This is due to the assumption that the routes from FIR-entry point to the runway are, as a result of radar vector navigation inside the TMA, very unpredictable and relatively insignificant. Hence, this section of the track is not considered worthwhile to analyse. Although individual flight tracks will be evaluated to establish change in track length flown, the results from this analysis will only show overall change in track length and not evaluate the consequences to individual flights. This analysis will not consider the commercial aspects of an increased track length and will thus not include an analysis of change in fuel burn caused by the change in track miles flown.

1.4.3 Change in flexibility

Runway load balance and runway utilisation analyses will be limited to a situation where runways 18R and 18C are used for landing operations. The runway system of Schiphol has 6 different runways that can be used in different combinations for both landing and starting operations. Analysing the effects on Tactical Demand Tailoring on each different runway combination is expected to result in a high complexity in the analyses. This is not considered worthwhile as the goal of this research is to evaluate the potential that Tactical Demand Tailoring could bring to LVNL. This is expected to show from an analysis of landing on only 18R and 18C. Hence, the runway utilisation analyses for this research will be limited to a parallel landing operation in southern direction using beforementioned runways.

2. Literature review

The following chapter describes literature and documentation relevant to this research. The theoretical framework describes different terminologies and systems and concepts relevant to this research.

2.1 Theoretical framework

Air Traffic Control the Netherlands (LVNL) is responsible for the management of the civil airspace of the Netherlands. Besides managing this airspace LVNL is also involved in the modernisation and management of technological systems, providing aeronautical information to airspace users and providing aeronautical maps and publications (LVNL, n.d.).

Currently, LVNL handles all flights inside Dutch national airspace (AMS-FIR) under flight level 245. This includes flights arriving to Schiphol, the country's largest airport. LVNL does not have influence on exactly when expected traffic flies into its region of responsibility. Currently, LVNL lacks the ability to synchronise arriving traffic prior to airspace entry, and thus must manage traffic bunches within the small airspace that surrounds Schiphol (KDC Group, 2022). This leaves air traffic controllers to have to manage the air traffic as it is presented to them. This indicates that the operation of LVNL contains inefficiencies. In an attempt to resolve some of these inefficiencies LVNL has decided to look into the potential of a new method of managing Schiphol arrivals. LVNL currently has access to an operational tool that helps them anticipate the traffic heading for their area of responsibility: the Arrival Manager (AMAN). This tool shows LVNL what traffic it might expect in certain sectors a few hours in advance. It also provides recommendations on actions that a controller might take to enhance the arrival sequence of inbound traffic with e.g. a delay instruction. These delay instructions would advise the controller that the arrival sequence is more efficient if a certain flight arrives at a point on its route a few minutes later than its currently estimated time overhead of said point. It is then up to the controller to manifest this delay if possible. AMAN assists the ANSP with the sequencing of arrivals but is not able to extend the area of influence of the ANSP outside of its area of control. Its recommendations are also limited to sequencing and time based instructions. It does not provide advised changes to the route of the arriving traffic (Eurocontrol, 2010).

Unlike AMAN, Tactical Demand Tailoring would be an application of Trajectory Based Operations (TBO). This concept is described as a four-dimensional (4D) flight trajectory, collaboratively developed, managed and shared (KDC Group, 2022). This includes the sharing of flight information between processes interacting with a flights 4D trajectory, maintaining flight information from flight planning to arrival gate, and using flight information in all levels and processes for collaborative decision making (Eurocontrol, 2022). Currently, it is generally agreed upon by most actors in the aviation sector that operational benefits would arise if interorganisational information sharing is applied. For example, Airlines (today) do not have all information to propose the NM an acceptable trajectory. Likewise NM is missing some airline/flight specific information for decision making (ICAO, 2022).

The concept of TBO, its enablers, applications and advices for implementation as described by Knowledge & Development Centre mainport Schiphol (KDC). Although a lot of information has been written about the concept of TBO, there is not yet a single definition of its operational concept (KDC Group, 2022). However, TBO is reliant on the accurate predictability of the 4D trajectory of air traffic.
A trajectory is a four dimensional (latitude, longitude, altitude and time) description of an aircraft's flight path (FAA & Eurocontrol, n.d.).

This accurate predictability can only exist if different parties within the system share their own information with other parties and relevant actors. Timely, valid and accurate Information sharing is the key to cooperative processes. The best solutions to local problems come from the situational awareness of local actors fairly applied across the ATM network (Eurocontrol, 2022).

The described collaborative 4D flight trajectory requires a digital infrastructure capable of communicating relevant information regarding the 4D trajectory from and to relevant stakeholders. This will be based on the ICAO concept of FF-ICE (Flight & Flow Information for a Collaborative Environment). FF-ICE defines information requirements for flight planning, flow management and trajectory management (ICAO, n.d.). The concept of FF-ICE consists of two separate releases. The first is FF-ICE R1. This concept focusses on the pre-flight aspect of information sharing. It can be used for mostly predictions on traffic flow and management which can be applied to optimalisation of flight paths. The FAA (2019) describes FF-ICE R1 as s a collaboration process between the eAUs (enabled Airspace Users) and the eASPs (enaibled Air Service Provider) to support the eAU in optimizing the filed flight plan prior to departure. The FAA (2019) states that FF-ICE R2 includes strategic negotiations and stakeholder interaction. It does so by supporting Trajectory-Based Operations (TBO) through ground-to-ground and Air-to-Ground (A/G) SWIM exchanges distribution, and synchronization of trajectory information. FF-ICE/R2 envisions the systematic data sharing for all applicable flights, between air and ground systems, and across relevant stakeholders in support of collaborative operations. The key difference in R1 vs R2 is the timeframe in which the information sharing takes place. Where R1 focusses, as mentioned, on the sharing of information pre-flight (pre-tactical), R2 focusses on the in-flight sharing of information (tactical). FF-ICE R2 would provide operational actors in aviation with a more detailed image of flights relevant to their operation. It allows for the intention of an aircraft to be visible in four dimensions to all actors interested in this information. This 4D image is created by the interorganisational sharing of live traffic information, such as position, altitude, speed, planned procedural information (such as planned arrival route at destination airport) and meteorological information. FF-ICE R2 allows for the uniform sharing of information by creating a live, more detailed flight plan of each flight and shares this flight plan to relevant parties.
The context of this thesis is regarding applications provided by the R2 version of FF-ICE as Tactical Demand Tailoring is based on in-flight re-routing of eAU's.

It is important to note that the exact method of exchanging information such as re-clearances using FF-ICE R2 is not defined in any of the official documents describing it. This is because describing this flow of information is outside of the scope of FF-ICE R2.

The exchange of information that FF-ICE finds its foundations in are based on System Wide Information Management (SWIM). SWIM consists of standards, infrastructure and governance enabling the management of the ATM-related information exchange between qualified parties via interoperable services. Also, SWIM will combine human-to-human with machine-to-machine communication, and improve data distribution and accessibility. This will be done in terms of the quality of the data exchanged. SWIM is explained in detail in ICAO doc 10039 (ICAO, 2015). This document describes the concept of SWIM, the framework it resides on, transitions to be made to facilitate the use of SWIM and future developments. This research will mostly make use of its description of the concept of SWIM as a possible basis for the exchange of information necessary for the execution of TBO. The implementation of SWIM is internationally mandated by the EU as stated by CANSO in the document titled "System Wide Information Management v2" as "European regulation IR 2021/116 also called Common Project 1 (CP1) is mandating the use of SWIM by 31st of December 2025 for Aeronautical, Meteorological, Cooperative network, flight and AMAN-E-AMAN information exchanges by all European relevant stakeholders" (CANSO, n.d.).

Further information on the infrastructure and governance that SWIM is based on can be found in a document by Skeyes titled SWIM (SKEYES, n.d.). This document contains a multitude of diagrams and illustrations showing how information and communication flows between different organisations and models.

2.2 Related studies

Tactical Demand Tailoring is a new concept within international Aviation. The concept bases itself on recent and conceptual developments such as Trajectory Based Operations and FF-ICE R2. However, the idea of in-flight re-routing is not entirely new.

Mukherjee and Hansen (2008) have described a systematic model for in-flight tactical re-routing using algebraic formulas to reduce Air Traffic Flow Management (ATFM) delays . They describe situations where an aircraft and its route are subjected to adverse weather conditions. They described two forms of re-routing; dynamic and statical. Both forms of re-routing increase efficiency more effectively the earlier predictive information is available. Dynamic re-routing is concluded as the most effective method for avoiding delays while static re-routing is easiest to implement. The research showed clear benefits from inflight re-routing. The research is not specific for any particular airport or area but analyses the general concept of inflight re-routing in a broader sense.

A study by Bertsimas (1999) showed benefits from the tactical re-routing of airborne traffic. This research provides a systematic analysis of different routes through a section of airspace. This was done by changing navigation points with nodes and used an algorithm to solve for the most efficient route when constraints along the route arise, such as route congestions or adverse weather. This research concluded that the idea of using algorithmic calculation for in-fight re-routing has potential to solve constraints in route usage in restricted sections of airspace.

Further research into in-flight re-routing was performed by Liu et al. (2021). The authors evaluated the potential for an algorithmic approach to in-flight re-routing while considering constraints in an airspace such as meteorological conditions, en-route capacity constraints and special airspace activity. This research focussed on the potential of optimising track miles while considering meteorological constraints. The method used for optimisation of track miles flown showed potential. A key finding from this research is that although an alternative route might reduce the amount of track miles flown by an aircraft, its travel time or fuel usage might not decrease accordingly as meteorological conditions across different route segments might vary. This phenomenon should be considered for the eventual operational implementation of Tactical Demand Tailoring.

A research performed by Taylor and Wanke (2009) aimed at generating operationally acceptable re-routes for air traffic management when a weather event is encountered. The results showed how the different metrics and associated weighting factors that define the operational acceptability of the re-route are impacted by the quality of the reroute. Metrics to determine what makes a re-route operationally acceptable included the re-route distance, measured from relevant waypoints, and how consistent a new route was when comparing against historical routing.

Expected acceptability of proposed re-routes research was performed by Evans et al. (2017). In this study a predictor of operational acceptability for route changes during a flight was developed using data mining techniques. Its results indicated that the operational acceptability of a proposed re-route are becoming increasingly predictable and are expected to require human input as time progresses. The paper hinted at the automation of the generation of re-routes in the near future.

Research into airspace congestion in European airspace was performed by Bilimoria & Lee (2005) This paper discussed the growing airspace problem in Europe by influencing ATC navigation charges and proposed a new method for determining the ATC charge for AU’s. This method would reverse the way the aircraft weight influences ATC pricing and introduces an ATC congestion cost. In the paper this proposed method appears to be efficient at tackling the congestion problem.

However, it is expected that this new rule might become unpopular as it would likely affect some types of airline more negatively than others. This paper showed that there are multiple ways to tackle the airspace congestion problems faced by European ANSP’s, besides re-routing flight through an instruction by ATC.
Research into practical applications of TBO was performed by Radišic et al. (2014). They studied the potential for a reduction in perceived workload for air traffic controllers when traffic is flying by TBO. This analysis was performed by choosing a group of air traffic controllers and selecting an airspace sector familiar to them to allow them to assess the complexity of traffic as accurately as possible. These air traffic controllers were when asked to manage simulated air traffic with varying ranges of TBO enabled aircraft. The results of this study suggested that TBO can significantly reduce complexity perceived for air traffic controllers when at least 70% of air traffic is flying under TBO. The lack of consistency of perceived complexity for the same air traffic controller and between different controllers in their experiments indicates the necessity to repeat these experiments on a larger scale. However, this perceived reduction in complexity by controllers in a controlled simulated environment shows the potential for TBO to increase the overall capacity of an air traffic network.

The beforementioned literature covers concepts related to Tactical Demand Tailoring such as inflight re-routing and tactical applications of TBO. However, none cover the idea of tactically rerouting of aircraft that are under control of a different ANSP than the ANSP desiring the reroute.

3. Methodology

The methodology for this research will be separately described per deliverable. It includes what steps will be performed per objective in order to achieve the desired results and how these will be performed. This will be a quantitative research. Its findings are based on observations drawn from LVNL data archives.

3.1 City-pair identification

Tactical demand tailoring relies on the in-flight re-routing of arriving traffic to Schiphol. Not every city-pair is expected to be suitable for the application of this re-routing. This is caused by limitations to the amount of routes considered feasible to fly between Schiphol and the departure airport. Certain restrictions and limitations lie in the way, such as ATC routes, constrictions to airspace such as military areas and areas with unfavourably high navigation charges. The identification of city-pairs that could be viable for Tactical Demand Tailoring will be selected using a data sample retrieved from LVNL databases. This data sample consists of data fulfilling the following conditions:

- Inbound traffic during an inbound peak
- No restrictions to traffic capacity to sectors or waypoints were active
- From July 2019 (due to traffic representability, high season and no COVID-19 influence)
- Operating runways 18R and 18C for landing (due to complexity of full runway configuration analysis)
- Timeframe of 07:00 to 12:00 (busiest period of short-haul arrivals to Schiphol)
- Includes track information from departure aerodrome

The first property that will be used for the selection of suitable city-pairs is the quantity of traffic that regularly flies from the departure airport to Schiphol during the selected inbound peaks. Airports with higher amounts of traffic are considered more favourable for the application of Tactical Demand Tailoring. This is due to the potential effect that applying Tactical Demand Tailoring to flights from these airports might have on the division of traffic over AMS-FIR-entry points. Airports responsible for larger shares of arriving traffic to Schiphol have larger impact on the traffic load through an ACC sector or to runway load. The most common departure airports will be placed in order from most traffic to Schiphol to least during inbound peaks. This will provide an initial sequence in the potential of selected aerodromes.

The second property that will be used to select aerodromes suitable for the application of TDT will be their geographical location relative to Schiphol. Firstly, their distance, or approximate flight time to Schiphol is considered. Aerodromes located too close or too far from Schiphol are excluded from the selection in accordance to the defined scope discussed in section 1.4. Another key aspect of the geographical location of aerodromes is their vicinity to other potentially suitable airports. Some airports could have a suitable location but not produce enough volume for the application of TDT. E.g. an airport with only one or two flights to Schiphol per week would not provide an effective amount of flights to produce a meaningful effect to the operation of LVNL. However, this airport could be located in a group, or cluster, of airports which all have a suitable location. In this case, potentially, multiple airports in the same cluster could produce enough traffic to provide useful traffic numbers. All the airports inside one cluster would then be analysed individually to form a final selection of suitable city-pairs.

The evaluation of city-pairs is performed with an analysis of the routes aircraft fly from departure airport to Schiphol. When assessing potentially suitable city-pars, it is useful to know that there is a limited amount of approach routes that traffic arriving to Schiphol can take. Namely, these arrivals are limited to three IAF’s that must be passed when making an approach. These points are all located inside the ACC sectors of AMS-FIR and provide structure to the traffic before it enters the TMA.

While this 3-IAF system provides structure to the Schiphol arrivals, it also limits the amount of arrival routes that an aircraft can take. When analysing if a city-pair is suitable for the application of TDT, is convenient to know the location of these points in AMS-FIR. The location of these waypoints is shown in figure 2 below where SUGOL, ARTIP and RIVER are the IAF's.

Figure 2: IAF locations and corresponding common arrival routes of AMS-FIR

A suitable city-pair would show multiple different routes that are frequently operated between Schiphol and the departure airport. This shows that more than one route is operable for airlines along one city-pair, indicating a level of flexibility in the operation. The airlines have a choice of which route to take. These routes also must use more than one IAF to enter the Schiphol TMA for TDT to have its desired effect. If the possible routes to Schiphol all use the same IAF for their approach, then there is little to no difference to the operation of LVNL regardless of the route flown. For a re-route to have influence over the operation of LVNL, the routes must enter AMS-FIR from different directions and use different IAF's for their approach.

Furthermore, the multiple routes from one city-pair must also visually contain a significant amount of overlap in the first part of the flight. The amount of overlap in routes is determined by plotting all possible routes along one city-pair, and overlapping these routes onto one another. Overlapping sections of tracks then show as a single line, splitting off from one another at some point along the track. The point where these lines split off from each other is identified as the 'point of divergence'. The section of track between departure airport and point of divergence is deemed the area in which an instruction for a re-route can be given to the crew of the aircraft in question. If an in-flight re-route is to take place, then the aircraft must still be able to switch from one route to the other without this leading to operational constraints, such as a large amount of miles needed to be flown to switch from one route to the other. If the two routes diverge in the first stages of the flight, then switching from one route to another could result in the aircraft flying large distances to pick up the track of the other route. This would cause the city-pair in question to not be suitable for the application of TDT. This effect can be seen in figure 3. This figure shows tracks from Catania Airport to Schiphol passing ARTIP and RIVER as IAF's. These routes diverge nearly immediately after departure. This divergence causes the distance between the tracks to increase as the flight progresses.

Figure 3: Routes from LICC to EHAM passing ARTIP and RIVER

3.2 Track analysis

The following section discusses the method for assessing the change to track length flown when TDT is applied to flights along the identified city-pairs. The potential costs of the application of TDT will be evaluated through the extra track miles flown when a flight is re-cleared onto a new route.

The first step in this method is to identify if the routes flown by aircraft originating from each airport arrive to Schiphol using one single IAF every time, of if there is an inconsistency in the IAF used for the approach. An inconsistency in this context would mean that the routes of one city-pair don't consistently pass the same IAF on their arrival to Schiphol. If flights from a city-pair show high consistency in the IAF used for its approach, then this city-pair is likely unsuitable for the application of TDT. This consistency would indicate that a route to a different IAF would be too inconvenient for an airline to fly (e.g. due to extra track miles or higher navigation charges). If flights from a city-pair do show an inconsistency in the IAF used, then this city-pair possibly is suitable for the application of TDT. This fluctuation would indicate that a route to more than one IAF is deemed to be viable by the operator. This indicates relatively low differences in operational costs (e.g. track miles or navigation charges) when comparing the routes to either IAF. The benefits of applying TDT should not exceed the operational costs caused by the re-route. Therefore, it is these types of city-pairs that are deemed suitable candidates for the final list of suitable city-pairs. Airports that do not show an inconsistency in the IAF used for an approach to Schiphol are excluded from the selection of city-pairs and will not be analysed further.

The second step in the analysis of tracks is the evaluation of change to track miles flown when TDT would be applied. For each airport, 10 flight tracks have been selected. Where possible, 5 tracks have been selected that use one IAF and 5 that use the other. The data used for the analysis of each airport was from the period between 20-06 and 17-07 of 2019.

The method for calculating the changes to track length is supported by the illustration in Figure 4. This figure shows a schematic view of the multiple approaches from one departure airport to a destination airport using the coloured arrows. The colours of the arrows indicate in what phase of the flight the aircraft is at that point along its track. The combination of the blue and orange arrows show the most often filed path to IAF 1. The combination of blue and green arrows show the same, but for IAF 2. The section of arrows shown in blue form the part of the routes that overlap. Thus, regardless of which IAF is filed for the approach to the destination airport, the aircraft is certain to fly over this part of the route. While a flight is on the 'blue' section of its flight, it could then still be re-routed to make its approach to the destination airport using the other IAF than it originally filed for, while still flying a route that is operated regularly between the two airports. The point where the routes to either IAF split is called the 'divergence point'. As the divergence point of the routes is closer to the destination airport, the window in which TDT can be applied increases. The most suitable city-pairs for TDT will have a divergence point closest to Schiphol. This would provide the receiving ANSP with more tactical or 'short-term' influence over arriving traffic.

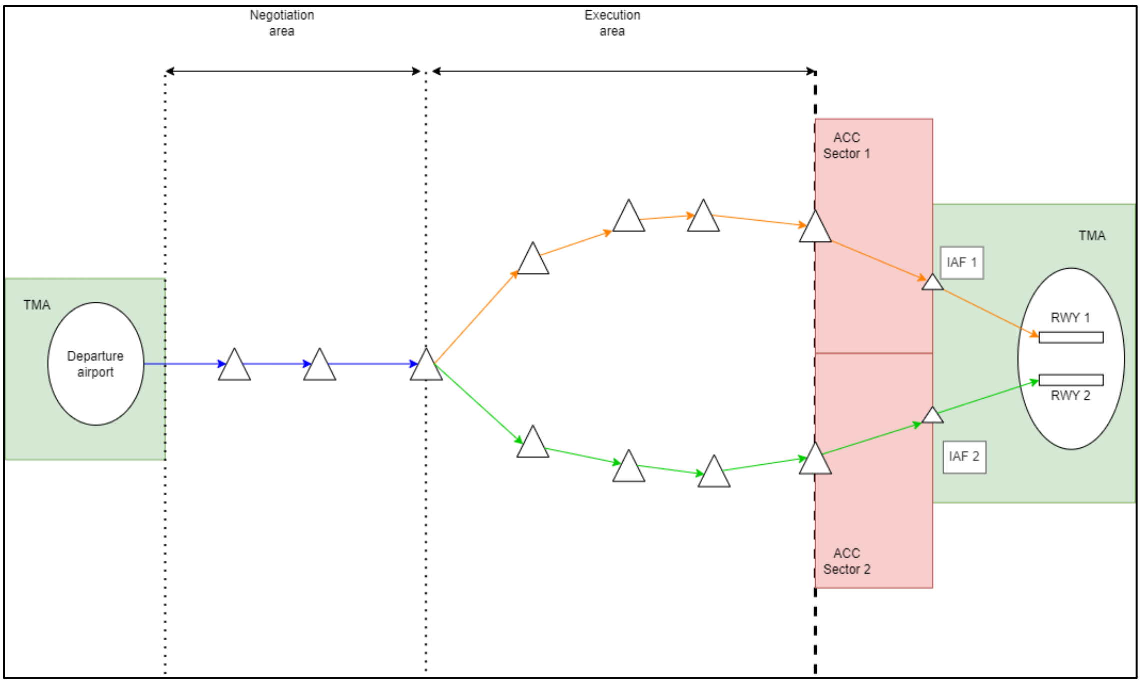

Figure 4: Schematic illustration of Tactical Demand Tailoring

The added amount of track miles will be calculated by measuring the original length of the track and comparing it to the new route. The average track length for each possible route will be calculated, using the data from the 5 tracks per city-pair per IAF. Subtracting the average track lengths of these routes provides the amount of change to a track length. This number shows the amount of change in track length that the re-route will cause in the same unit as the track length was expressed in (e.g. NM's or Km's). This number is then divided by the original track length to provide the change in track length as a percentage point.

- The track shown by the blue and orange arrows show route 1.
- The track shown by the blue and green arrows show route 2.
- The track in blue arrows is the section of track where route 1 and 2 overlap.

Using figure 4 as an example, the following steps show how such a track length analysis calculation is performed.

1. Calculate average track length for route 1 from departure airport to destination airport.
2. Calculate average track length for route 2 from departure airport to destination airport.
3. Subtract length of route 2 from length of route 1 to provide the change in track length.
4. Divide change in track length by track length of route 1 (multiply by 100 for percentage point).
5. This provides the change in track length expresses as an amount of distance as well as a change in percentage point.

The calculated change in track miles provides insight into the potential operational costs (or benefits, as new track length could be shorter than original length) when applying TDT to a flight. This comparison only looks at the change to the operation of the aircraft in track length and excludes other potential influences to their operation such as navigation charges or fuel consumption.

3.3 Gains to capacity balancing potential

The aim of Tactical Demand Tailoring is to provide LVNL with a tool to synchronise or redirect the arriving traffic before it reaches the boundaries AMS-FIR. This increase in flexibility will be expressed as a number of flights per inbound peak. The identification of suitable city-pairs will provide a selection of routes on which flights could potentially be re-cleared to a different FIR-entry point, IAF, and runway. This selection of routes will be compared to the traffic samples drawn from representable operational periods. This traffic sample will likely contain a number of flights originating from one or more of the previously identified city-pairs. The number of flights originating from these city-pairs will provide how many flights inside that traffic sample are applicable for a re-clearance using Tactical Demand Tailoring.

The first step in estimating the level of flexibility that could be gained by TDT is by analysing how many flights are originating from the 11 selected city-pairs relative to the total number of inbound traffic to Schiphol. This number can be estimated using a data sample of past traffic flown from a representative period of operations towards Schiphol. The same data has been used as for the identification of city-pairs in section 3.2. This dataset has been filtered to show how much traffic approaches the airport during inbound peaks. Inbound peaks the periods in the operation of LVNL where TDT would show its greatest benefits as it is at these times where the demand on the operation is greatest. The dataset used for this analysis was the same as described in section 3.1 This selection ensures that the data used for this analysis is only of inside the inbound peaks and is therefore suitable for the estimation of the volume of suitable traffic. Once the relevant periods have been identified, the data can be filtered to show how many flights inside this period originated from suitable city-pairs. This number of flights from suitable city-pairs provides an indication to how much more flexibility to runway load is created by applying Tactical Demand Tailoring. The tracks of the arrival flights provide insight into how many flights are landing on a particular runway (18R or 18C). The gain in flexibility of runway utilisation can be indicated by calculating how many flights had the potential to land on the other runway had Tactical Demand Tailoring been applied. This number provides insight into the added flexibility by using Tactical Demand Tailoring.

The other aspect of increased flexibility is in the load per ACC sector. This load will be expressed in the number of Schiphol arrivals passing though the sector in question during the analysed operational period. The number of flights inside the analysed period that originated from previously selected city-pairs will form an indication as to how many of the Schiphol arrivals that passed through the sector could have been diverted to other ACC sectors. This provides the added flexibility that Tactical Demand Tailoring could have to traffic load for individual ACC sectors. This flexibility will be expressed as a number of flights inside one operational period.

4. Results

The following chapter discusses the results obtained from the methodology described in Chapter 3. It contains the results from the identification of city-pairs, the track analysis and the evaluation of flexibility gain.

4.1 City-pair selection

The following section discusses the results from the methodology described in section 3.1.

4.1.1 Traffic analysis

The identification of city-pairs was supported by an analysis of traffic samples as described in section 3.1. This selection of data provides insight to the composition of inbound traffic to Schiphol. It's been used to identify what airports provide the most flights to Schiphol. It also provides what IAF they used to approach the Schiphol TMA and what runway they used to land.
The data selected contains information on the following topics:

- Landing time
- Runway used
- IAF used
- Aircraft type and callsign
- Operator
- Departure airport

This data was filtered to accurately represent the conditions as discussed in the methodology. This filter ensures flights are only included when the following conditions are met:

- Landing operations using 18R and 18C
- Between 07:00 and 12:00 Local Time (LT)
- Without active capacity regulations to air traffic

Firstly, in order to identify airports with a large volume of traffic to Schiphol, a ranking of the most common departure airports for flights to Schiphol was made. Airports with higher amounts of traffic could potentially provide the greatest influence to the distribution of inbound peaks. However, inside one inbound peak, it is rare to find more than one flight arriving from the same airport. It is assumed that re-routing about 3 or 4 flights inside one inbound peak to a different IAF could have significant consequences for the utilisation of the sectors or for the flow through a sector of airspace. This number of flights amounts to about 10% of flights that land on a single runway in one hour during an inbound peak. The airports responsible for the most amount of arriving flights to Schiphol in one day are shown in Table 1.

Departure airport	City	Max. # of flights in one day
London City Airport	London	6
Frankfurt international airport	Frankfurt	4
Ringway	Manchester	4
Heathrow Airport	London	4
Dublin	Dublin	4
Kastrup	Copenhagen	4
Arlanda	Stockholm	4
Charles De Gaulle	Paris	4

Table 1: most common departure airports inside Schiphol inbound peaks (July 2019)

Although the airports listed in Table 1 are some of the largest and busiest airports in Europe, their geographical location is operationally inconvenient for making approaches to Schiphol from more than one IAF. All airports listed in Table 1 approach Schiphol from only one IAF. According to available data, a flight from London City will make an approach passing SUGOL in 99% of flights, whereas a flight from Frankfurt Airport will make an approach passing ARTIP 99% of the time. This indicates a low amount of flexibility in the routes that are available for an approach to Schiphol. Also, these airports are all relatively close to Schiphol with a flight from one of these airports to Schiphol taking between one and two hours. The combination of these factors make that the airports listed above are unsuitable for the application of TDT.

4.1.2 Cluster selection

To identify airports that are more suitable for the application of TDT, another approach is necessary. Instead of using individual airports as potential candidates for city-pairs suitable for TDT, airports should be clustered into groups. This would combine the traffic from the individual airports inside this group, providing enough traffic volume for TDT to provide benefits to the operation of LVNL. These groups have been selected by their geographical location. This enables the selection of airports within the optimal range of flight duration as specified in section 1.4. Also, these clusters are selected so that flights from airports within one cluster approach Schiphol from the same direction. This would allow for flights from different airports within this cluster to follow a similar path when being re-routed from one approach path to Schiphol to another. When determining what clusters are suitable for further analysis, a limit has been set to the amount of time it takes for a flight from inside this cluster to fly to Schiphol. This limit was set at over 4 hours of flight time. The reason for the exclusion of airports outside of this 4 hour flight time window is the unpredictability to arrival times for flights from these airports. The unpredictability in estimated time of arrival to AMS-FIR is caused by fluctuations in ATC instructions and meteorological conditions. The fluctuations in ATC instructions could be caused by the presence or absence of other air traffic in the area leading to longer routes or to shorter (direct) routes than originally filed by the operator of these flights. The fluctuations to arrival time caused by meteorological conditions are for example caused by differences in actual wind velocity or in adverse weather conditions such as rainclouds. This caused areas with airports from outside this region to be excluded from the selection of clusters.

The following clusters have been selected using flight time criteria as discussed above as well as natural geographical boundaries. The locations of these clusters are illustrated in figure 5:

- **Scandinavia:** Containing all international airports in Sweden, Norway and Denmark
- **British Isles:** Containing all international airports inside of the British Isles. This includes all of the United Kingdom and Ireland
- **Spain and Portugal:** Containing all international airports within the mainland of Spain and Portugal
- **Italy and Switzerland:** Containing all international airports inside Switzerland and Italy including the islands of Sicilia and Sardegna
- **South-eastern Europe:** Containing all international airports within the following countries: Albania, Austria, Bosnia and Herzegovina, Bulgaria, Greece, North Macedonia, Serbia and Slovenia.

Figure 5: Approximate location of clusters

Countries directly to the east of the Netherlands have not been joined in a cluster. This is due to the low amount of traffic originating from these countries. Analysis of the data from arriving traffic originating from these clusters provides insight in the potential each cluster has for the application of TDT. The estimated suitability for of each of the clusters is discussed below.

4.1.2.1 Scandinavian cluster

The cluster of Scandinavia contains all international airports in Sweden, Norway and Denmark. Airports in this cluster with frequent traffic to Schiphol are the following:

Denmark:
- Billund Airport
- Copenhagen Kastrup Airport
- Aalborg Airport

Norway:
- Ålesund Airport
- Bergen Airport
- Kristiansand Airport
- Oslo Gardermoen Airport
- Sandefjord Airport
- Trondheim Airport
- Stavanger Airport

Sweden:
- Göteborg Landvetter Airport
- Stockholm Arlanda Airport
- Linköping/Saab Airport

The traffic originating from these airports fluctuates between 6 to 13 flights per inbound peak. This amount of traffic is assumed to be sufficient to provide LVNL with influence over its overall arriving traffic during an inbound peak. This would indicate that the Scandinavian cluster of airports is a suitable candidate for the application for TDT. However, the potential for alternate routes to Schiphol provide an obstacle in this area. As the cluster is located north of the airport, the most logical IAF's used for flights originating from these airports are the two most northern IAF's in AMS-FIR, ARTIP and SUGOL. However, an obstacle lies in the way of these flights. 99% of all flights originating from these airports make its approach to Schiphol passing ARTIP, the most Eastern located IAF of the two.

The reason that these flights are nearly always planned for an approach passing this IAF is due to the military area located north of the Netherlands mainland (Nieuw Millingen CTA North). This area is reserved for military exercise and is unavailable for commercial air traffic. The location of this area is illustrated in Figure 6. This provides a large obstacle that any aircraft originating from any airports in the Scandinavian cluster must fly around if it intends to make an approach to Schiphol using SUGOL as its IAF. This provides an operational constraint when applying TDT to flights from this cluster. Therefore, airports from this cluster are excluded from the selection of TDT suitable city-pairs.

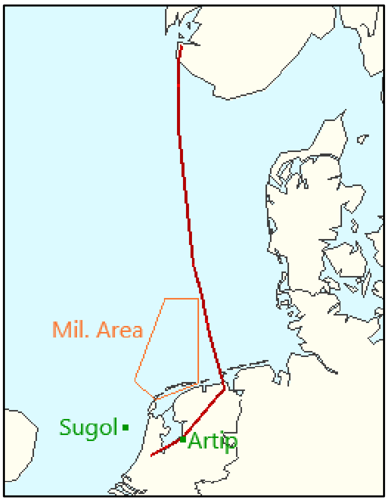

Figure 6: Illustration of track from Scandinavian cluster with IAF locations and Mil. Area

4.1.2.2 British Isles cluster

The cluster of the British Isles includes all international airports located on the British isles with frequent traffic to Schiphol. This includes the following airports:

- Belfast International Airport
- Birmingham Airport
- Manchester Airport
- Cardiff Airport
- Bristol Airport
- Liverpool John Lennon Airport
- London Luton Airport
- Southampton Airport
- London Gatwick Airport
- London City Airport
- London Heathrow Airport
- London Southend Airport
- Humberside Airport
- Leeds Bradford Airport
- Newcastle Airport
- Durham Tees Valley Airport
- Aberdeen International Airport
- Inverness Airport
- Glasgow Airport
- Edinburgh Airport
- Norwich International Airport
- London Stansted Airport
- Cork Airport
- Dublin Airport

The amount of airports inside the British Isles makes it the largest cluster out of the selection. This is also reflected in the volume of traffic flying to Schiphol on a daily basis. The amount of flights originating from the British Isles cluster ranges from 10 to 25 flights per inbound peak. This volume of traffic would provide LVNL flow controllers with high influence over the inbound traffic if all these flights are suitable for an in-flight re-route using TDT. However, the geographical location of this cluster provides operational constraints when evaluating the potential for TDT to be applied. The British Isles are located West of the Netherlands. This means that the IAF's that could potentially be used by these flights when making an approach to Schiphol is limited to the two western located IAF's, RIVER and SUGOL. However, data shows that 99% of flights from inside this cluster make their approach to Schiphol using SUGOL as their IAF.

This would mean that an in-flight re-route using TDT would diverge flights from their approach to SUGOL to an approach to RIVER. However, when analysing the lay-out of AMS-FIR, it becomes clear that re-routing traffic from this cluster to RIVER requires an inefficient route. RIVER is located in Sector 3 of AMS-FIR. ACC Sector 3 is located in the southwest of AMS-FIR. An aircraft originating from the British Isles arriving to Schiphol using RIVER would have to approach AMS-FIR from a southern direction. This would require the aircraft to fly with an initial southern heading to then turn north in order to approach Schiphol using RIVER as its IAF, resulting in an inefficient route.

Furthermore, the geographical location of the British Isles relative to the Netherlands causes the traffic from this area to be unsuitable for influencing the runway load balance of Schiphol when operating 18R and 18C for landing. As all traffic from this cluster approaches AMS-FIR from the West, re-routing traffic to the eastern most located runway (18C in this case) would be disrupting to the operation of LVNL to the point where the negative consequences to the operation would outweigh the benefits of the improved runway load balance (Eurocontrol, 2019). This leads to the conclusion that airports inside the cluster of the British Isles are not suitable candidates for the application of TDT.

4.1.2.3 Spain & Portugal cluster

The cluster of Spain & Portugal includes all international airports located in these countries with frequent traffic to Schiphol. This includes the following airports:

- Barcelona–El Prat Airport
- Bilbao Airport
- Francisco Sá Carneiro Airport
- Girona–Costa Brava Airport
- Ibiza Airport
- Lisbon Portela Airport
- Adolfo Suárez Madrid–Barajas Airport
- Menorca Airport
- Santiago de Compostela Airport
- Valencia Airport
- Porto Airport

The cluster of Spain & Portugal is responsible for a significant amount of traffic to Schiphol. The amount of flights originating from these airports within one inbound peak on a representative day in summer ranges from about 7 to 13 flights. This amount of traffic would be enough to provide LVNL with a significant amount of influence over its sector utilisation and its runway load balance. However, data shows that traffic from the airports within this cluster make their approach to Schiphol using RIVER as their IAF for the majority of the time. This indicates that the traffic from these airports is responsible for a significant portion of the traffic in sector 3. A high percentage of flights from this cluster use RIVER as their IAF.

The lack of other IAF’s being used for approaches to Schiphol indicates that flying from these airports to SPL using different IAF’s might have operational constraints such as higher fuel costs, higher navigation charges (as these increase with track miles flown) (Eurocontrol, 2022) or unfavourable effects on traffic flow in the airspace these flights would pass.

When analysing the airspace between Spain/Portugal and AMS-FIR, it becomes apparent that the most conveniently located IAF for an approach to Schiphol is RIVER, as it is located southwest of the airport. The route to this IAF is relatively straightforward, flying north along the French Atlantic coast until entering the Belgian and then Dutch national airspaces. When considering TDT for these flights, the tracks to the other two IAF’s should be considered. And approach to ARTIP is quickly dismissed as an appropriate IAF for an approach to Schiphol departing from inside this cluster.

Using this IAF would require flights to fly straight over the north of France (a relatively busy sector of airspace), to enter German airspace and fly north over Germany to make an approach to AMS-FIR from the east. This would create a high amount of extra track miles and provides operational constraints to ANSP's having to facilitate this re-route through their airspace (Eurocontrol, 2019). A re-route to using SUGOL as IAF would potentially be more suitable. An approach to this IAF would require aircraft to continue their flight heading north for slightly longer. When analysing the routes flown from airports inside this cluster, there are two airports that stand out. These are Porto airport and Lisbon Portela airport. These airports, both located in Portugal, make approaches to Schiphol using SUGOL as their IAF on a regular basis. This indicates that the potential routes that can be flown between these airports and Schiphol is diverse and could provide a basis for the application of TDT for these routes. Analysing the tracks between these airports and Schiphol should provide an indication on if these airports form city-pairs suitable for TDT. The details to the tracks for these two city-pairs will be analysed in the next chapter.

4.1.2.4 Italy & Switzerland cluster

The cluster of Italy & Switzerland includes all international airports within these two countries, both mainland and off-shore (e.g. airports on Sicilia and Sardegna). This includes the following airports:

- Olbia Costa Smeralda Airport
- Milan-Malpensa Airport
- Turin Caselle Airport
- Genoa Cristoforo Colombo Airport
- Milan Linate Airport
- Bologna Guglielmo Marconi Airport
- Verona Villafranca Airport
- Venice Marco Polo Airport
- Pisa International Airport
- Rome Fiumicino Airport
- Florence Airport
- Geneva Airport
- Zurich Airport

The cluster of Italy & Switzerland, similarly to the other clusters, is responsible for a significant portion of traffic to Schiphol. The amount of traffic from these airports within one inbound ranges from a 7 to 19 flights. This would provide LVNL with more than enough traffic to have a significant influence over the flexibility of its operation. However, this assumes that all airports within this cluster are suitable for an in-flight re-route using TDT. This is unlikely to be the case. Traffic data shows that this cluster is different from the others in the route used to fly to Schiphol, or more accurately, in the consistency of the routes used. When observing the IAF used by aircraft from this cluster when approaching Schiphol, it shows that the flights from these airports don't have a clearly dominant IAF that they use for their approach. Instead, it shows that there is a mix of IAF's used. Namely, the flights departing from airports inside this cluster seem to alternate in using either RIVER or ARTIP to make their approach to Schiphol, with approximately 30-40% of flights passing ARTIP. This is different from what is observed in the traffic from the other clusters where a clear preference was observed in IAF used for an approach to Schiphol. This indicates a possible potential for applying TDT to the flights from the Italy & Switzerland cluster.

However, this does not indicate that all airports inside this cluster form suitable city-pairs for the application of TDT. Therefore, each airport inside this cluster will be analysed individually to assess their suitability. This analysis is discussed in section 4.2.

4.1.2.5 South-eastern European cluster

The cluster of Southeaster Europe consists of all international airports with regular traffic to Schiphol within a number of countries along and near the eastern coastline of the Adriatic sea. The airports in these countries that are included in this cluster are the following:

- Sofia Airport (Bulgaria)
- Belgrade Airport (Serbia)
- Vienna International Airport (Austria)
- Innsbruck Airport (Austria)
- Thessaloniki Airport (Greece)
- Corfu International Airport (Greece)
- Eleftherios Venizelos International Airport (Greece)
- Samos International Airport (Greece)
- Zakynthos International Airport (Greece)
- Ljubljana Jože Pučnik Airport (Slovenia)

The South-eastern Europe cluster is responsible for a relatively small section of arriving traffic to Schiphol. The average amount of flights inside one inbound peak originating from airports within this cluster lays between 6 and 10 flights. This number would be sufficient to provide LVNL with a significant level of control over its arriving traffic. However, this number of flights per peak is the lowest of all clusters, indicating that this cluster is likely not the most suitable option for the application of TDT. Further complications for the suitability of this cluster arise when looking at the consistency of the routes that are flown from these airports to Schiphol. 99% of all flights originating from this cluster make their arrival to Schiphol through one single IAF, ARTIP. This indicates operational constraints when attempting to re-route these flights to a different IAF.

When analysing the geographical location of these countries relative to the Netherlands, some of the constraints become obvious. Flights form this cluster approach AMS-FIR from a South-eastern direction. The IAF located most conveniently for an approach to Schiphol for these fights is, unsurprisingly, ARTIP. The second most conveniently oriented IAF for flights from this cluster would be RIVER, as SUGOL is located in a North-Western direction from Schiphol. This would cause flights form this cluster wanting to make their approach using SUGOL as its IAF to fly all the way around AMS-FIR (either along its north-, or southside). However, the IAF RIVER, located in the southwestern direction relative to Schiphol provides a more realistic approach route. This would require flights from this cluster to fly in a more western direction after departure and make their approach to Schiphol from the South-West. This route however is undesirable for airlines for a different reason. This route would require aircraft to either fly over or around Switzerland in an inefficient manner. Flying over Switzerland is undesirable due to the relatively high navigation charges imposed in this airspace when compared to Eurocontrol member states. Flying around Switzerland to approach Schiphol using RIVER would result in an inefficient route, taking more track miles and thus more fuel costs and travel time. Also, due to the high traffic load and complexity in Sector 3 of AMS-FIR, re-routing aircraft from different IAF's to RIVER is deemed undesirable. This would only further complicate the traffic situation in this area and increase workload for controllers responsible. The combination of relatively low traffic volume from this cluster and the lack of flexibility in IAF's available for a feasible approach make this cluster the most unfit for the application of TDT. None of the airports inside this cluster will be analysed individually for the identification of suitable city-pairs.

4.2 Assessment of individual airports

The following section discusses the suitability for application of TDT for each individual airport inside the only promising cluster; Italy & Switzerland, as well as the two potentially suitable airports in Portugal. The selection of airports has been reduced to the ones listed in Table 2:

Airport name	ICAO-code	Country
Bari Karol Wojtyła Airport	LIBD	Italy
Catania–Fontanarossa Airport	LICC	Italy
Olbia Costa Smeralda Airport	LIEO	Italy
Milan Malpensa Airport	LIMC	Italy
Turin Airport	LIMF	Italy
Genoa Cristoforo Colombo Airport	LIMJ	Italy
Milan Linate Airport	LIML	Italy
Bologna Guglielmo Marconi Airport	LIPE	Italy
Verona Villafranca Airport	LIPX	Italy
Venice Marco Polo Airport	LIPZ	Italy
Rome Fiumicino Airport	LIRF	Italy
Pisa International Airport	LIRP	Italy
Florence Airport	LIRQ	Italy
Porto Airport	LPPR	Portugal
Lisbon Portela Airport	LPPT	Portugal
Geneva Airport	LSGG	Switzerland
Zurich Airport	LSZH	Switzerland

Table 2: List of city-pairs potentially suitable for TDT

4.2.1 Comparison of IAF's used

As discussed, the first step of the selection of city-pairs is the selection of airports wherefrom flights consistently use more than one IAF to make an approach to Schiphol. This selection can be made by assessing the data used to identify the list of airports above.

The data shows that from the list above the following airports use only one IAF consistently. These airports are:

- LIEO: Olbia Costa Smeralda Airport, Italy
- LIMF: Turin Airport, Italy
- LIMJ: Genoa Cristoforo Colombo Airport, Italy

As flights from these airports show no fluctuation in the IAF used for their approach to Schiphol, they are not suitable for the application of TDT and will not be analysed further. The remaining airports will be analysed by comparing the tracks of the flights from these airports to Schiphol and evaluating the amount of overlap in the routes flown to each of the IAF's they use frequently.

4.2.2 Track analysis

When individually analysing the tracks from the remaining selected city-pairs, it became clear that a pattern emerges. The selected city-pairs can be divided into three categories. These categories are the following; city-pairs suitable for the application of TDT, city-pairs unsuitable for the application of TDT, and city-pairs where the suitability is dependent on the flight plan that has been filed for that specific flight. City-pairs in these three categories will be titled as Suitable, Unsuitable and Flight Plan (FPL-) Dependant city-pairs respectively. One example of each category is discussed in detail below. The rest of the city-pairs have been sorted according to these three categories.

4.2.2.1 Suitable city-pairs

Example: Bari Karol Wojtyła Airport, LIBD, Italy

Data of flights between Bari and Schiphol show that the flights on this route tend to use a mixture of two routes, using two different IAF's. These IAF's are ARTIP and RIVER. Figure 7 below shows tracks from Bari Airport to Schiphol using ARTIP (left) and RIVER (Right) as the IAF used for the approach. This Figure shows that the routes between these two airports, regardless of which of the IAF's is used, contain a large amount of overlap in their routes. This indicates that LIBD-EHAM is a city-pair with high suitability for the application of TDT. The LIBD-EHAM city-pair will continue to the final selection of city-pairs suitable for TDT.

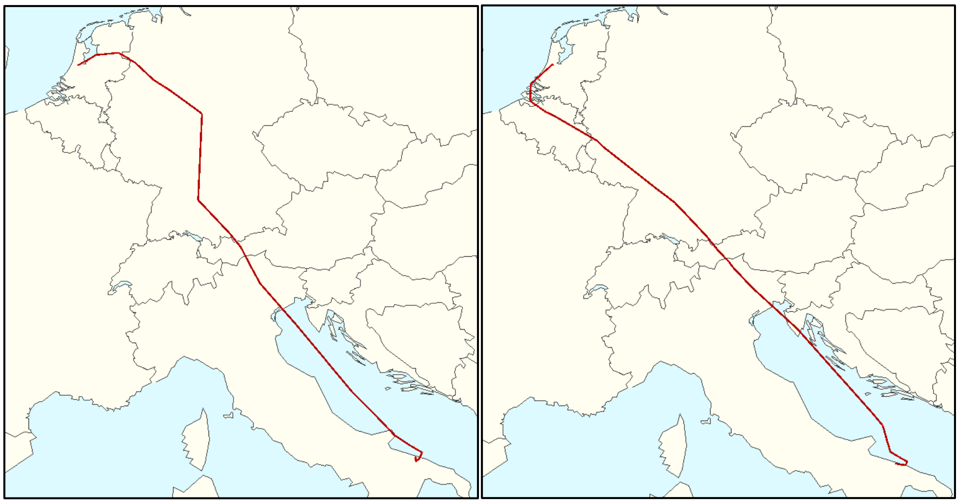

Figure 7: tracks between LIBD & EHAM passing ARTIP (L) and RIVER (R)

4.2.2.2 Unsuitable city-pairs

Example: Milan Malpensa Airport, LIMC, Italy

Milan airport is located in the northern part of Italy, close to the border with Switzerland. Data shows that routes from this airport to Schiphol can be divided into two separate groups. One group makes its approach to Schiphol via ARTIP, initially heading north into German airspace. The other group makes its approach to Schiphol via RIVER, initially heading Northwest into French airspace. The two different routes show no overlap between them as they diverge almost immediately after departure. Figure 8 below shows examples of the different arrival routes to Schiphol from these airports. The lack of overlap in these tracks indicates a low level of suitability for this city-pair to apply TDT. Transitioning from a RIVER route to an ARTIP route would be undesirable. Such a manoeuvre would result in significantly more track miles flown. This would reduce the environmental performance of the European traffic network as well as increased navigation charges for the operator. Also, a re-route from one of these routes to another would likely be performed around the Karlsruhe area (around the French-German border). This is a very high traffic area of the European aviation network. Re-routing traffic through this area to improve the runway load balance performance of an airport would be disruptive to the European network as a whole. Due to these constraints, the suitability of city-pairs such as Milan Malpensa is insufficient to validate further analysis. This causes Milan Malpensa Airport and airports following this pattern to be excluded from the selection of city-pairs.

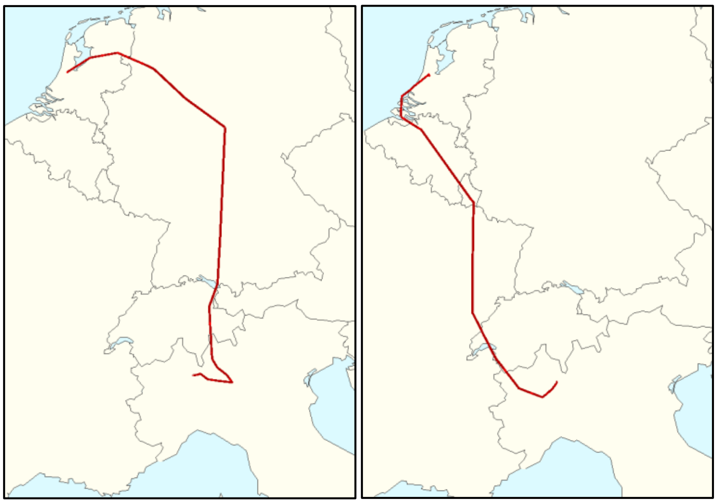

Figure 8: Arrival routes from LIMC to EHAM through ARTIP (L) and RIVER (R)

4.2.2.3 FPL-dependant city-pairs

Example: Catania–Fontanarossa Airport, LICC, Italy

Similarly to Bari Airport, Catania Airport also operates both RIVER and ARTIP as their preferred IAF's. However, unlike Bari Airport, flights from Catania airport are observed to take more than one route to the same IAF. Figure 9 below shows different approach routes for originating from Catania airport. Namely, this is the case when flights from this airport approach using RIVER as IAF. The middle and right sections of Figure 9 show the different approach routes taken by these flights when an approach is make using RIVER. The middle section shows the route when passing Switzerland on the north side and the right section shows the route when passing Switzerland on the south side.

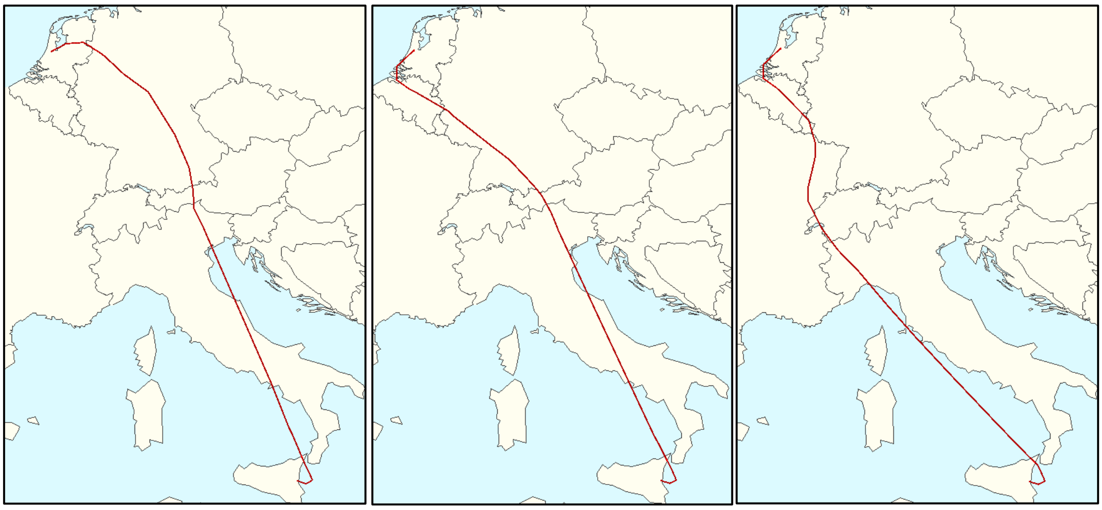

Figure 9: Tracks between LICC & EHAM passing ARTIP (L) and RIVER (M & R)

This fluctuation in routes indicates that multiple routes to the same IAF are deemed viable by the operator of the aircraft. However, this does create a challenge when assessing the suitability of LICC for the application of TDT. When the operator has filed for a route over to ARTIP, it is sure to have filed for a route northbound of Switzerland. When the filed route passes RIVER, it is not immediately clear if the filed route passes north of Switzerland or south of Switzerland. As shown in figure 9, the route to RIVER passing north of Switzerland has a large overlap with the route passing ARTIP, overlapping all the way until passing the Austrian-German border. However, if the flight filed for a route to RIVER passing on the South of Switzerland, its route would diverge from a route to ARTIP nearly immediately after take-off.

The different routes to RIVER will be indicated using the RIVER North (RIVER N) for the route northbound of Switzerland and RIVER South (RIVER S) for the route southbound of Switzerland.

Operationally, this would mean the following: when a flight is filed for an approach over ARTIP, it could be re-routed using TDT for an approach to RIVER by instructing it to change its planned route from an ARTIP route to a RIVER N route. This would allow for the pilot to remain on its planned course until reaching the point of divergence near the Austrian-German border, and pick up the RIVER N route when these two routes diverge. However, when a flight has filed for a RIVER route, and LVNL would prefer this aircraft to approach using ARTIP as its IAF, the option of applying TDT becomes dependant on what route the operator has filed for this flight. If the filed route is a RIVER N route, applying TDT for an ARTIP route is possible. The operation would continue as described when changing from a ARTIP route to a RIVER N route, as described above only with the routes switched. However, when a route has been filed for a RIVER S route, diverging the aircraft for an approach to ARTIP becomes much less convenient. This is due to the RIVER S route diverging from the RIVER N and ARTIP routes nearly immediately after take-off. This means that when LVNL desires to apply TDT to a flight from LICC filed for a route passing RIVER and wanting it to approach using ARTIP, it must first be verified if the filed flight plan passes Switzerland on the south or the northside. This means that the city-pair LICC-EHAM is partially suitable for the application of TDT, depending on the route that has been filed. The city-pair of LICC-EHAM will continue to the final selection of city-pairs suitable for the application of TDT.

Airports suitable for the application of TDT:

Airport	ICAO-code	Country
Bari	LIBD	Italy
Verona	LIPX	Italy
Venice	LIPZ	Italy
Porto	LPPR	Portugal
Lisbon	LPPT	Portugal

Table 3: List of TDT Suitable city-pairs

Airports where suitability is FPL-dependant:

Airport	ICAO-code	Country
Roma Fiumicino	LIRF	Italy
Florance	LIRQ	Italy
Zurich	LSZH	Switzerland
Catania	LICC	Italy
Milan Linate	LIML	Italy
Bologna	LIPE	Italy

Table 4: List of FPL-dependant city-pairs

Airports that are not suitable for the application of TDT:

Airport	ICAO-code	Country
Milan Malpensa	LIMC	Italy
Olbia Costa Smeralda	LIEO	Italy
Turin	LIMF	Italy
Genoa Cristoforo Colombo	LIMJ	Italy
Pisa	LIRP	Italy
Geneva	LSGG	Switzerland

Table 5: List of city-pairs unsuitable for TDT

4.3 Track length analysis

This section discusses the change in track miles flown by flights where TDT is applied. This analysis is performed to evaluate the negative (or positive) consequences to the track length for each of the identified city-pairs. This is done to estimate if the expected benefits of applying TDT to these flights is not outweighed by the potential negative consequences that arise from the in-flight re-routing of air traffic. The data provided by Eurocontrol includes the track length of the filed routes. The length of a route is expressed in Nautical Miles (NM), which gives an accurate distance in NM of miles flown by an aircraft operating this route. These track lengths have been used to estimate the difference in track length between the different routes that are flown between city-pairs.

4.3.1 Track length comparison of TDT suitable city-pairs

The results of the calculations of track miles as discussed in 3.2 are expressed in NM and as a percentage of change of IAF 2 relative to IAF 1. For example, a route from Bari to Schiphol passing RIVER is 7,4NM or 0.83% longer than a route from Bari to Schiphol passing ARTIP. Table 6 shows the result of the track length analysis of the city-pairs found to be suitable for the application of TDT.

Airport	ICAO-code	IAF 1	Avg. length (NM)	IAF 2	Avg. length (NM)	Difference (NM)	Difference (%)
Bari	LIBD	ARTIP	902	RIVER	910	+7,4	+0,8%
Verona	LIPX	ARTIP	582	RIVER	584	+2,2	+0,4%
Venice	LIPZ	ARTIP	589	RIVER	594	+4,2	+0,7%
Porto	LPPR	RIVER	909	SUGOL	966	+56,6	+6,2%
Lisbon	LPPT	RIVER	1050	SUGOL	1111	+61,2	+5,8%

Table 6: Track length analysis of TDT Suitable city-pairs

The amount of increase in track length for the city-pairs shown in Table 6 is less than one percent for the first three city-pairs. The mount of increase expressed as a percentage point for all three city-pairs is less than one, indicating that the amount of extra track miles flown for each route is nearly negligible. This comes as little surprise since the routes that are compared in this table are both frequently filed by airlines. If there was a clear preference for either route to be operated over the other, then the mixture of both routes would likely not be observed. An assumption can be made that an increase of less than one percent is unlikely to form a relevant consideration for an airline when a re-route is proposed for one its flights. Also, the change in track length in Table 6 shows that for the first three rows the route passing RIVER is longer than the route passing ARTIP. This means that a re-route from ARTIP to RIVER would increase the track miles flown by the numbers shown in the last two columns and vice versa. That provides the operator with an extra incentive to support the application of TDT to their operation. Overall, the track length analysis for the airports depicted in the first three rows indicate that the track length does not change significantly when applying TDT to any of these routes. Thus, applying TDT to these city-pairs does not cause significant negative consequences to the operation of the airline.

The bottom two rows in Table 6 show larger amount of change in track miles. These two rows show the routes from two airports in Portugal. The routes that are compared in this table pass over either RIVER or SUGOL. Due to the geographical location of these airports (south of the Netherlands), RIVER is the most conveniently oriented IAF when approaching Schiphol. Flight plans along this city-pair show that the route passing RIVER is significantly more popular than the route passing SUGOL. The route passing SUGOL initially heads more towards the north after departure until it reaches Great Brittan.

It then turns right to head East towards the Netherlands. Examples of these tracks can be found in figure 10. As can be seen in Table 6, this route produces an increase in track miles flown. The route passing SUGOL for either city-pair is about 6% longer.

The change in track miles flown for these city-pairs is larger than in the previously discussed airports. These two city-pairs might therefore be less favourable than the other city-pairs when considering e.g. environmental objectives. However, this does not immediately dismiss this city-pair as a candidate for the application of TDT. Flights from these city-pairs could still be worthwhile to consider as re-routable flights. Despite this relatively larger change in track miles flown, these two city-pairs could still be considered suitable city-pairs for the application of TDT.

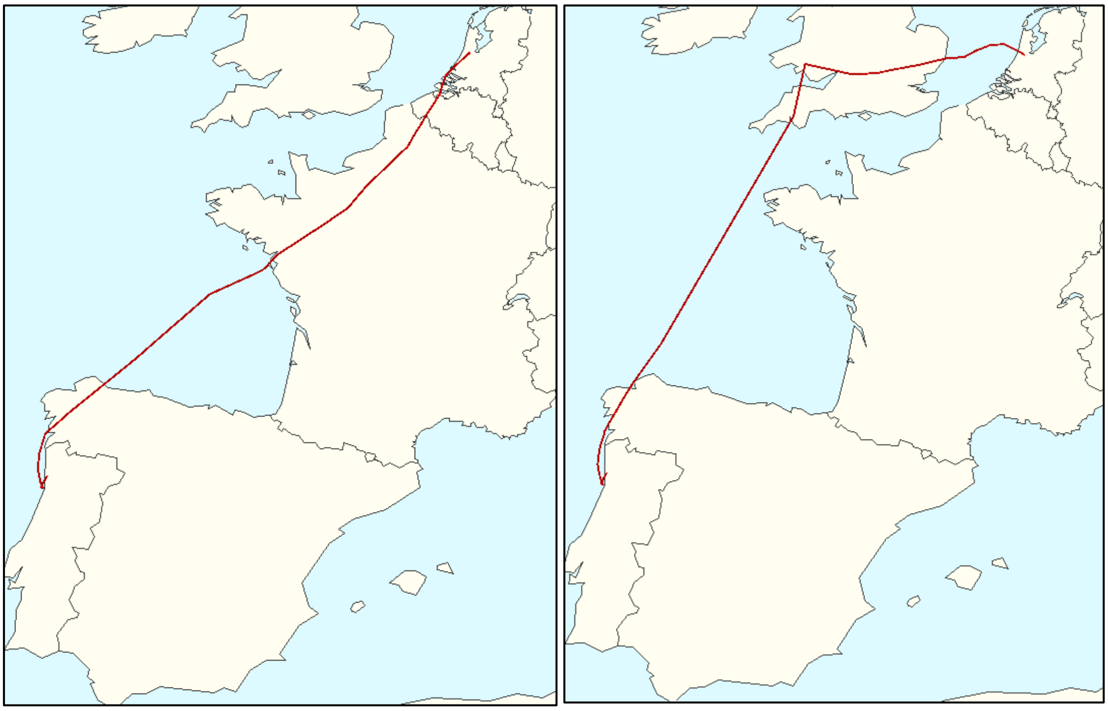

Figure 10: Tracks between LPPR & EHAM passing RIVER (L) and SUGOL (R)

4.3.2 Track length comparison of FPL-dependant city-pairs

When analysing the difference in track length for FPL-dependant city-pairs some tracks have been excluded in order to make a meaningful comparison. As described in section 4.2.2.3, FPL-dependant city-pairs have three commonly operated routes. These are an ARTIP route, a RIVER N route and a RIVER S route. As described, applying TDT to these city-pairs is only feasible along the ARTIP and RIVER N route as these routes overlap. Therefore, to make a meaningful comparison to track length on this city-pair, only ARTIP routes and RIVER N routes have been considered. RIVER S routes have been excluded. The rest of the calculation consists of the same steps as described in section 10.1 for TDT suitable city-pairs.

Airport	ICAO-code	IAF 1	Avg. length (NM)	IAF 2	Avg. length (NM)	Difference (NM)	Difference (%)
Roma Fiumicino	LIRF	ARTIP	796,3	RIVER	793,8	+2,5	+0,3%
Catania	LICC	ARTIP	1080,1	RIVER	1079,6	+0,6	+0,1%
Milan Linate	LIML	ARTIP	542,9	RIVER	535,3	+7,6	+1,4%
Florance	LIRQ	RIVER	683,2	ARTIP	673,1	+10,1	+1,5%
Zurich	LSZH	RIVER	473,9	ARTIP	462,7	+11,2	+2,4%
Bologna	LIPE	RIVER	629,6	ARTIP	621,7	+7,9	+1,3%

Table 7: Track length analysis of FPL-dependant city-pairs

The results shown in Table 7 show that the change to track length for the FPL-dependant city-pairs is relatively small. These results are similar to those of the Italian city-pairs Table 3. This similarity of change in track length is unsurprising as these airports are all located in the same geographical cluster (Italy & Switzerland). The change in track length is smaller than 12NM for all listed city-pairs and the change in percentage rises as the distance between cities in one city-pair becomes smaller. Departure airports closer to Schiphol have a shorter total track length. Therefore, a change to track length results in a higher percentage of change. A change in track length of less than 12 NM is unlikely to form an issue when considering the application of TDT for these flights. The worst case scenario for these flights would be a re-route for a flight from Zurich passing ARTIP to a RIVER N route. In this case, the aircraft would fly an additional 11,2NM and increase its track length by 2,44%. This re-route would slightly decrease the environmental performance of the operation. However, the additional gains to the total operation of LVNL or European air travel as a whole would likely result in a nett gain. Therefore, the change in track length to the city-pairs listed above is unlikely to form an obstacle for the application of TDT.

An analysis of the change in track length for all previously selected city-pairs shows that this change is nearly negligible for most analysed city-pairs. With the exception of two city-pairs form Portugal, no change in track length exceeds 2,5%, with most city-pairs having a change smaller than 1. Thus, increase in NM flown by applying TDT is unlikely to outweigh the potential benefits to the operation as a whole. Therefore, applying TDT to the operation of LVNL should not be dismissed on the basis of potential negative effects to track length.

4.4 Capacity balancing potential

The goal of Tactical Demand Tailoring is to provide LVNL with a tool that allows the organisation to have more influence over the traffic arriving to Schiphol. By applying an in-flight re-route to Schiphol arrivals before they enter AMS-FIR LVNL could influence which ACC sectors, IAF's and runways are used by these arrivals. The following section is dedicated to the evaluation of the influence that LVNL could achieve over Schiphol arrivals. The city-pairs that have been found to be suitable for the application of TDT can now be used to create an estimate of how much gain in flexibility might be realized when TDT is applied to LVNL's operation.

4.4.1 Estimating volume of suitable traffic

The composition of inbound traffic at Schiphol differs from day to day, especially during periods of high traffic volumes in July. This causes the amount of re-routable traffic per day or per inbound peak to differ from day to day. It was found that between the periods of 07:00 and 12:00 from the specified dates the amount of flights suitable for the application of TDT was between 5 and 13 flights. For most identified airports only a single flight took place during this timeframe. However, the collection of identified airports creates a combined volume of traffic that would be considered valuable for the operation of LVNL.

4.4.2 Effects on ACC-sector operation

The operation of the ACC section of LVNL air traffic controllers includes guiding Schiphol arrivals to the appropriate IAF to continue their descend to the airport. All Schiphol arrival will pass an ACC sector on its way to the airport. During inbound peaks this arriving traffic can present itself in large numbers at a given time. Combined with other traffic inside the ACC sectors, the workload for air traffic controllers can become demanding. Demand on air traffic controllers exceeding set limits could cause inefficient and potentially unsafe operations. It is therefore necessary that LVNL predicts and monitors the traffic flow and resulting demand on its controllers closely. This prediction is made multiple hours in advance and is continually monitored as the inbound peak approaches. This monitoring is done by LVNL's Flow Management Position (FMP) controllers.

When an FMP controller observes the traffic flow for an inbound peak is likely to exceed the set limit for that section of airspace, the flow controller will issue a sector capacity regulation. This is a regulation that limits the amount of traffic that can fly through a certain part of airspace and is usually issued several hours in advance. This regulation is then forwarded to the Eurocontrol Network Manager (NM). The NM then selects flights that have filed their route through the restricted airspace and issues an ATFM delay for some of these flights. This delay would keep the flight in question on the ground at the departure airport, not allowing it to leave the apron. Handing out these delays to multiple flights inside one inbound peak effectively spreads out the flow of Schiphol arrivals, reducing the peak load to the airspace and to the operation of LVNL. However, handing out these ATFM delays is disruptive to the operation of the airports and airlines involved. The costs of these ATFM delays is estimated at an average of 100 euros per minute of delay (Cook & Tanner, 2015). Therefore, these delays could be viewed as a 'necessary evil' aimed at keeping the operation safe while sacrificing efficiency and profits. Thus, reducing the amount of ATFM delays handed out is beneficial for LVNL as well as for the overall European aviation network and its players.

Cases have been found where re-routing traffic in-flight could reduce the amount of sector capacity regulations issued. This could be done by pre-emptively applying TDT to airborne flights from suitable airports planned to fly through a sector with a higher demand to one with lower demand. Flow controllers are provided with tools to predict to how much traffic is expected to arrive during an inbound peak. These predictions are made for the airport as a whole as well as for individual sectors or waypoints. If any of these predictions exceed the limit for the capacity of that sector a flow controller will take action to ensure that the sector is not overloaded. However, the predicted amount of traffic has some level of uncertainty to it as it is impossible to predict the amount of incoming traffic with absolute accuracy. It can then happen that the prediction shows levels of traffic where it is not immediately clear if the traffic will exceed safe limits or if it will stay inside the safety parameters. When such a situation occurs, a flow controller might be inclined to pre-emptively issue a regulation to the sector capacity, even when in hindsight the traffic might have stayed within safe limits. This is done to ensure that the operation stays safe at all times. However, it is assumed that if the flow controller observes that the incoming inbound peak contains about 3 or 4 flights that could be re-routed to a different ACC sector before entering AMS-FIR, then the flow controller might restrain from issuing a sector capacity regulation. These flights that could be re-routed provide the FMP controller with more tactical influence over the arriving traffic, reducing their tendency to issue a regulation. This indicates that applying TDT could directly decrease the amount of ATFM delays created by regulations issued by LVNL. At an estimated 100 euros of cost per minute of ATFM delay, reducing the amount of these delays by applying TDT is beneficial to LVNL as well as the European aviation network as a whole.

4.4.2.1 Preventing ATFM delay with TDT

An analysis of traffic prediction data from 2022 provided multiple cases where an issued capacity regulation to an IAF could have been avoided by re-routing flights to a different IAF. One of these cases is explained in detail below.

Case study: Capacity regulation to ARTIP, 15-05-2022
The following analysis is based on data retrieved from LVNL's Decision Support Tool (DST). This tool helps to predict traffic flow in AMS-FIR multiple hours in advance. These predictions support flow controllers in deciding if (parts of) AMS-FIR require a traffic regulation to ensure traffic flow does not exceed LVNL's or Schiphol's operational capacity. Predictions on traffic flow by DST are recorded for post-operational analysis.

On 15-05-2022 at 10:11 UTC, LVNL issued a regulation to the traffic flow over ARTIP. This regulation reduced traffic load over this IAF to 30 aircraft per hour between 12:50 and 14:00 UTC. Figure 11 shows the predicted traffic over ARTIP at 10:10 UTC, before the regulation was issued.

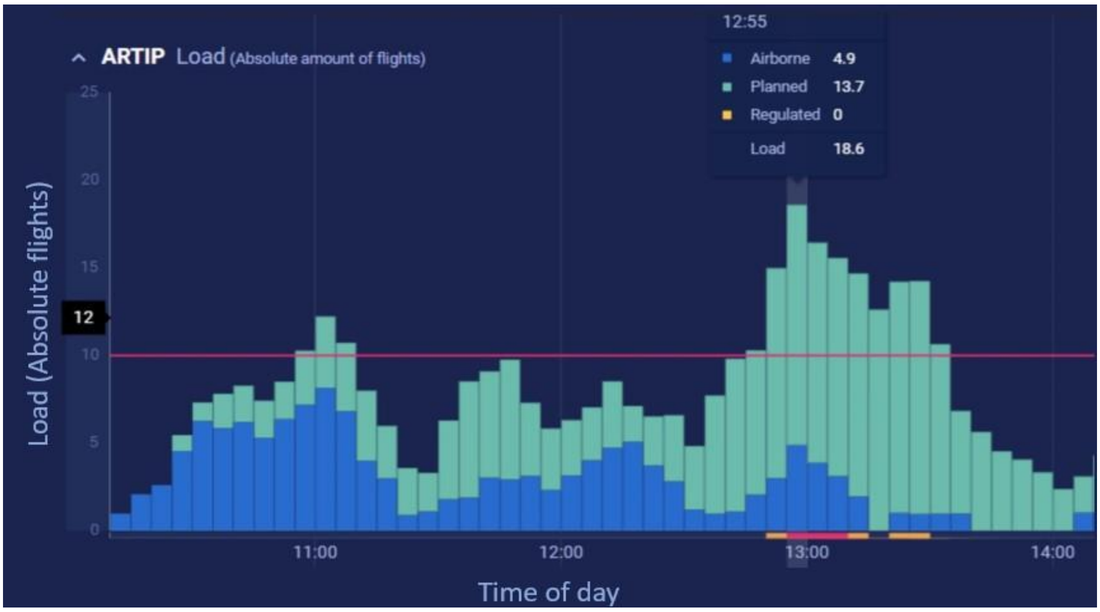

Figure 11: Predicted traffic load over ARTIP on 15-05-22

Each bar in this graph represents the traffic inside a 20 minute window, with 5 minutes separating each bar. The highlighted bar in this graph shows that on this day between 12:55 and 13:15, approximately 18 aircraft were expected to fly over ARTIP. This amount of flights exceeds the advised limit for this waypoint, which is set at 15 flights per 20 minutes. If traffic predictions exceed this value it does not automatically mean that a regulation is issued, but serves more as support for the flow controller to make a decision. DST indicated that this amount of traffic would likely result in a delay for the 18 flights planned to fly over ARTIP in this 20 minute window. This means that, if no action is taken, too much traffic would be approaching ARTIP in this window. This would require the air traffic controller of the ACC sector preceding ARTIP to manifest a delay for some of these flights, as the demand of traffic for this waypoint exceeds its capacity. In order to avoid this, the flow controller on duty at 10:11 issued a capacity regulation over ARTIP for a maximum of 10 aircraft per 20 minutes. This regulation lead to several aircraft scheduled to pass ARTIP during the restricted period to receive an ATFM delay. The regulation resulted in a total of 90 minutes of ATFM delay to be issued. The delayed flights were effectively pushed back to enter AMS-FIR at a later point in time. This reduced the demand of traffic over ARTIP, but also resulted in a change to the expected traffic demand for Schiphol arrivals (EHFIRAM), which can be seen in Figure 12 and 13.

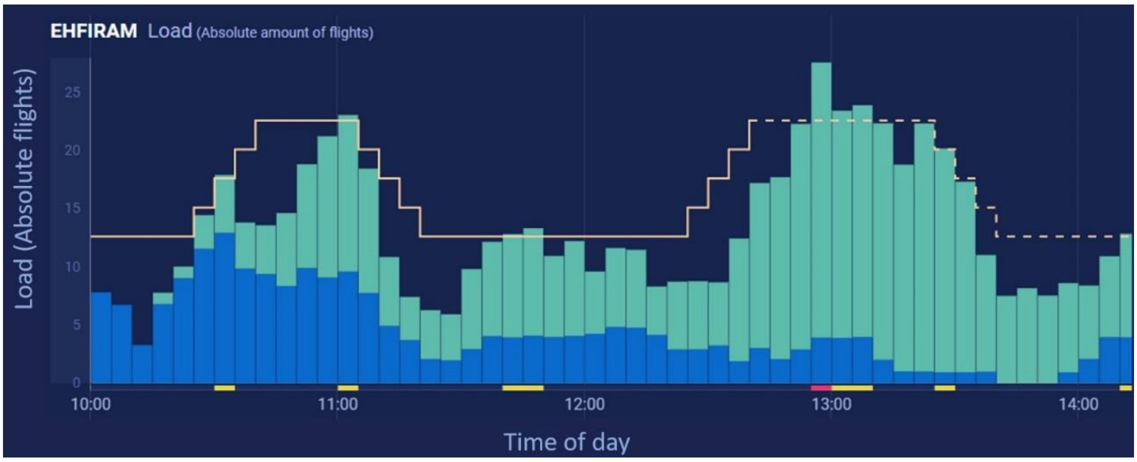

Figure 12: Traffic prediction for Schiphol arrivals on 15-05-2022 without ARTIP regulation

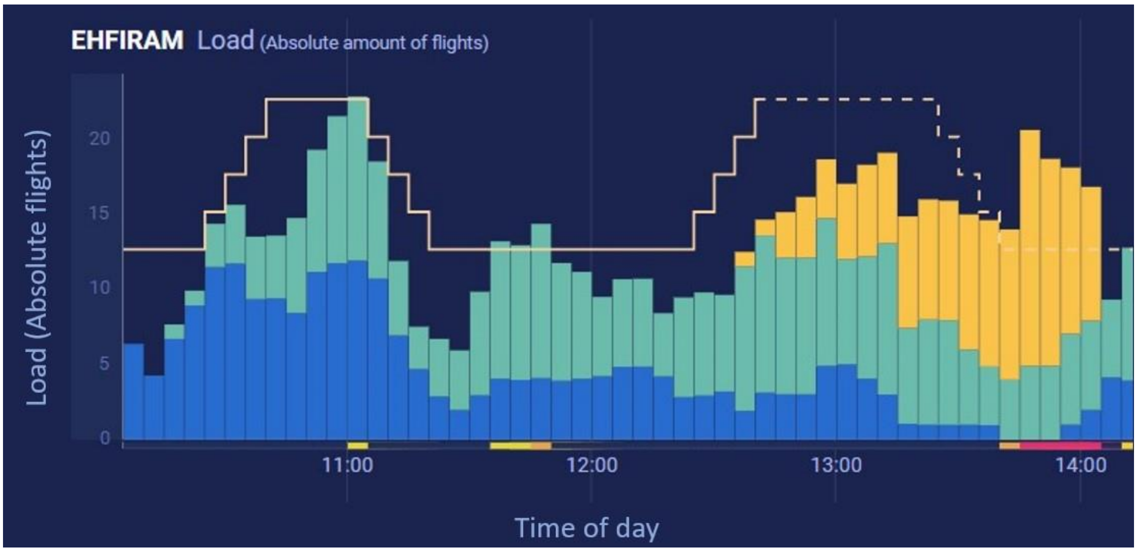

Figure 13: Traffic prediction for Schiphol arrivals on 15-05-2022 with ARTIP regulation

These graphs show the effect of the regulation to ARTIP traffic for the traffic prediction to all Schiphol inbounds. Figure 12 shows the forecasted inbound traffic to all of Schiphol, before the regulation over ARTIP was put into effect. It shows that from 12:30 to 13:30 traffic demand roughly matched the capacity of Schiphol, indicated with the yellow (partially dotted) line. This capacity changes depending on i.e. active runway configuration. Figure 13 shows the forecasted demand of Schiphol inbounds after the regulation over ARTIP was put into effect, showing how this forecast was affected by the regulation. The flights represented with the yellow bars are the ones affected by the regulation over ARITP. The peak in traffic seen at roughly 13:45 was directly caused by the issued regulation over ARTIP, delaying the arrival of a number of flights. This peak in traffic exceeded the airports maximum capacity. This led LVNL to issue another capacity regulation. This regulation was issued at 10:55, restricting traffic flow for EHFIRAM between 14:00 to 16:00 and resulted in a total of 442 minutes of ATFM delay to be issued. In this situation, the issuing of a capacity regulation to ARTIP cascaded to create a total of 532 minutes of ATFM delay to be issued. However, this regulation could potentially have been avoided if TDT had been applied to arriving traffic originating from suitable city-pairs. Between 12:55 and 13:15 18 flights were predicted to fly over ARTIP. Of those 18 flights, 3 departed from airports suitable for the application of TDT (LIPE, LIRF and LIRQ). Re-routing these flights to approach Schiphol passing RIVER instead of ARTIP would have reduced the traffic load over ARTIP to 15 flights between 12:55 and 13:15. Figure 14 shows the predicted traffic over RIVER at that time.

Figure 14: predicted traffic load over RIVER on 15-05-22

This figure shows that between 12:55 and 13:15 the predicted load over RIVER was 4 flights. This is within the advised limits to capacity for this IAF, indicating that the three flights from suitable city-pairs planned for ARTIP could make an approach using RIVER without exceeding advised limits.

It is assumed that the reduction in predicted traffic over ARTIP from 18 to 15 flights between 12:55 and 13:15 would have influenced the decision made by the FMP controller on duty. Since the limit for traffic load over ARTIP is defined at 15 flights per 20 minutes, the predicted traffic load reached this limit, but was it not exceeded. If the controller had decided not to issue a capacity regulation over ARTIP, then this would have prevented the delayed departure for flights affected by this regulation. This, in turn, would have removed the necessity for the AMS-FIR regulation from 14:00 to 16:00. In total, 532 minutes of ATFM delays could potentially have been avoided if three flights from TDT suitable city-pairs had been instructed to make their approach to Schiphol passing RIVER instead of ARTIP.

Reducing ATFM delay under regulated operations

TDT could provide means to actively reduce or prevent the amount of ATFM delay issued when a regulation is put into place. This could be done by re-routing flights to a different IAF than initially planned for. A situation could arise where traffic demand for one IAF significantly exceeds the capacity of that IAF. For example, imagine a situation where the estimated traffic demand for ARTIP is at 20 flights per 20 minutes. This exceeds the advised limit for this IAF, which is set at 15, by 5 flights per 20 minutes. This would require the LVNL flow controller to issue a regulation over ARTIP. When this happens, the Network Manager will hand out slot times for the flights planned to fly over ARTIP with 2 minute intervals, to achieve the desired traffic flow of 10 flights per 20 minutes. Each flight then receives their new time window to fly over ARTIP (ARTIP slot). These flights then receive a new Calculated Take-Off Time (CTOT), ensuring they arrive at ARTIP at their allocated ARTIP slot time. These new CTOT are often later than the original estimated take-off times of these flights, resulting in an ATFM delay. TDT could provide means to reduce the amount of ATFM delay issued in this kind of situation. This would be possible if the traffic planned to approach ARTIP includes flights that could be re-routed using TDT, but not enough to prevent the regulation entirely. In this case, these flights could be removed from the sequence of ARTIP and inserted in the sequence for another IAF, i.e. RIVER, provided this IAF has sufficient capacity. This would reduce the amount of traffic planned to approach through ARTIP, effectively emptying ARTIP slots for following flights to fill. An illustration of this can be seen in Figure 15 below.

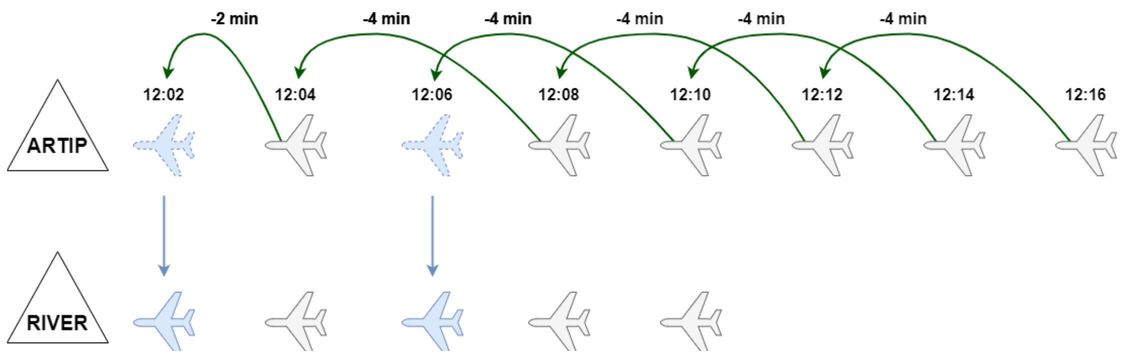

Figure 15: Illustration of ATFM delay reduction using TDT

In this illustration, two flights from the ARTIP sequence are moved to RIVER, indicated by the blue aircraft and arrows. The slots vacated by these flights can now be filled up by flights further down the order. These flights would then receive a CTOT closer to their originally planned take-off time, resulting in less ATFM delay being issued.
This reduction in ATFM delay can be calculated by multiplying the ARTIP interval by the amount of positions gained by aircraft left in the sequence. Here, the ARTIP interval is 2 minutes, and the number of positions gained is 11 (one position by one aircraft, 2 positions by 5 aircraft). The reduction in delay is 22 minutes in this case: $(2 * 1 * 1) + (2 * 5 * 2) = 22$.
This calculation shows that preventing ATFM delay with TDT is most effective when the re-routable flights are planned early in the sequence of the congested IAF. This example shows that TDT could reduce the amount of ATFM delay produced when a capacity regulation is issued to an IAF, provided that flights to that IAF can be re-routed using TDT. The amount of ATFM delay that is issued could be significantly reduced if TDT is applied to the operation of LVNL.

4.4.3 Effects on runway load balance

The runway that an arriving aircraft uses to land is in large part dependant on the ACC sector it flies through and the IAF it uses to enter the TMA. This is due to the increased workload that re-routing these flights inside the ACC sectors or inside the TMA would have on the air traffic controllers working these areas. Therefore, to change the runway that an arrival uses for its landing, it would ideally be re-routed to a different ACC sector and IAF before entering AMS-FIR.

During an inbound peak the runways are often utilised to their maximum capacity (approx. 34 landings per hour). When traffic presents itself in higher numbers than what can land on the currently active runways, then ACC controllers will hold traffic inside the ACC sectors using holding patterns or vector navigation. They will then send aircraft into the TMA at the maximum rate of landing for the active runway configuration. This allows the airport to operate at maximum capacity without exceeding the airports landing capacity. Traffic can present itself in such away where traffic arriving for one runway exceeds that runways maximum capacity and traffic arriving for the other runway is below that runways maximum capacity. In this case air traffic controllers will manually instruct aircraft originally intended to land on the busy runway to make an approach on the less busy runway. the airport can then still operate at its maximum landing capacity, but it does provide a more demanding operation from approach controllers as they must guide aircraft through the TMA to approach a different runway than initially planned. TDT could help to prevent this more demanding method of work for air traffic controllers. If traffic predictions indicate that more traffic is presented to a runway than can land on it in a period of time, then LVNL could identify flights from TDT suitable airports planned for a landing on that runway. These flights could then be re-cleared for a different route to Schiphol, passing a different IAF. This would allow LVNL to pre-emptively avoid having to re-route arrivals to a different runway inside the TMA. An illustration of re-routing inside the TMA can be seen in Figure 15.

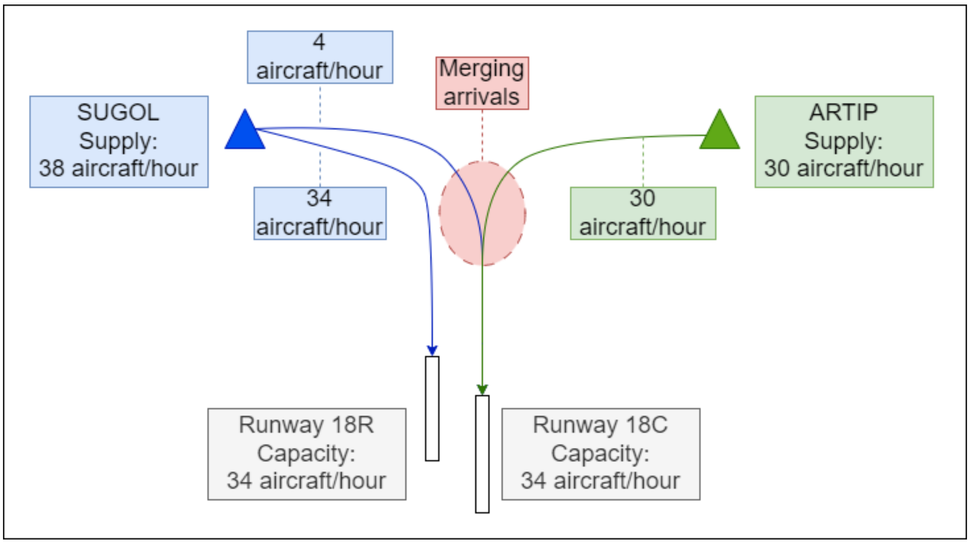

Figure 15: Illustration of re-routing traffic inside TMA

Figure 15 shows a hypothetical situation with 2 active IAF's and 2 active runways. The area in red shows where the arrivals from both IAF's converge. This situation would require more effort from an arrival controller. Further benefits from TDT to LVNL's runway load balancing could show in the form of the organisation's environmental performance. For LVNL to limit its impact on the surrounding residents, its obligated to use certain runways more often than others. However, aircraft can present themselves in such a way where they could more conveniently land on a runway with a relatively higher impact on the airport's environment. This could have negative consequences for the environmental performance of LVNL. For example, a landing on the Buitenveldertbaan (runway 27) has a higher impact on the airports surroundings than a landing on the Polderbaan (runway 18R) or the Kaagbaan (runway 24) (Schiphol Group, 2020). Although meteorological conditions play a large role in the allocation of active runways, the supply of arriving and departing traffic also influence the configuration of active runways. Pre-emptively re-routing aircraft to a different IAF oriented for a runway with a lower environmental impact could help LVNL improve its environmental performance with less effort from air traffic controllers. Re-routing as few as 3 or 4 flights from one runway to another could change that runways utilisation with 9%-12% during an inbound peak.

5. Conclusion

This paper aims at analysing the potential benefits of re-routing Schiphol arrivals in-flight to approach from a different direction. This operational method has been called Tactical Demand Tailoring (TDT). The analysis of city-pairs suitable for a re-route resulted in the identification of 11 departure airports to which TDT could be applied. Arrivals from 5 of these city-pairs are suitable for a re-route at all times. For the other 6 airports suitability is dependent on the flight plan that was filed. Most identified city-pairs are located in Italy. Two airports are found in Portugal and one is located in Switzerland.

Data on traffic from July 2019 shows that, on average, a 5 hour period with high amounts of inbound traffic contains between 5 and 13 flights originating from TDT suitable city-pairs. This would allow LVNL to influence the direction of approach of 5 to 13 flights to better fit its operation. The analysis of the change to flying distance of these flights shows that for flights from most of the identified city-pairs, the change to route length is negligible. Often, the change to the length of the route of these flights is between 0,4 and 1,4%.

Changing the direction of the approach of 3 or 4 flights during one inbound peak could have consequences for the operation of LVNL in multiple areas. Firstly, TDT could significantly reduce the amount of ATFM delays caused by regulations to IAF's. Currently, LVNL can manage traffic flow through its Area Control (ACC) Sectors by issuing sector capacity regulations, limiting the amount of traffic that is allowed to pass through a sector. Flights planned to fly though this airspace then receive a delayed departure. The resulting delays are approximated to cost 100 euros per minute of delay issued. These delays could thus be viewed as a 'necessary evil' required to ensure safe operations. The in-flight re-routing of Schiphol arrivals moves flights to a different ACC sector, effectively clearing the congested airspace. Multiple cases from 2022 have been found where re-routing a number of flights to a different IAF could have prevented a capacity regulation. In one case, up to 532 minutes of delay could have been avoided by re-routing 3 flights to a different IAF during one inbound peak, saving up to €53.200 of costs.

Furthermore, TDT could also change LVNL's operations inside the Terminal Manoeuvring Area (TMA). Currently, a situation can arise where arriving traffic must be re-routed inside the TMA to allow the airport to operate at its maximum landing capacity. This operation is considered to be more demanding for air traffic controllers. TDT could reduce the necessity for this operation. Re-routing some traffic to a approach the airport from a different direction allows these flights to land on a different runway than originally planned without requiring a re-route inside the TMA.

Lastly, the application of TDT could help LVNL gain more influence over the balance of its runway load. LVNL is subjected to regulations regarding its utilisation of Schiphol's runways. TDT could help LVNL guide Schiphol arrivals to approach from a direction that better fits their desired runway utilisation with respect to these regulations. Moving 3 to 4 aircraft to land on a different runway could change that runway's utilisation by up to 12%.

Overall, the application of TDT to Schiphol arrivals from identified city-pairs provides LVNL with a useful amount flights per inbound peak that can be re-routed to approach the airport form a different direction. The negative effects to the amount of track miles flown is often negligible for the identified city-pairs. Therefore, TDT would likely benefit the operation of LVNL. Further investments into research on the implementation of TDT should be made.

6. Recommendations

This research has aimed to investigate the potential benefits of applying TDT to the operation of Schiphol. Multiple areas that could benefit from this operational tool have been identified. However, the concept of TDT still requires more research and investment before it can be used operationally. This chapter aims to make recommendations for future research and discusses ideas and findings related to this research.

6.1 Re-evaluation of TDT after airspace redesign

Another aspect that could be researched in the future is the application of TDT after the Dutch airspace redesign. This redesign could significantly affect the applicability of TDT to the operation of LVNL. Specifically, this redesign could lead to an active 4th Initial Approach Fix in AMS-FIR. Another IAF would likely affect the amount of routes that are considered plausible to fly from certain departure airports. It is assumed that the 4th fix would likely be located in a south-eastern location relative to Schiphol. This would likely allow for many more flights from departure airports located in the south or east of the Netherlands to have a larger amount of options when filing a route to Schiphol. Specifically, it is expected that the clusters of Spain & Portugal, South-eastern Europe and countries in eastern Europe would have more options feasible routes for approaching Schiphol. This increase in plausible routes would likely significantly increase the amount of traffic approaching Schiphol that could potentially be re-routed. This would lead to a larger amount of influence that LVNL would have over the direction of approach of its arriving traffic. This would further increase the positive effects of TDT as detailed in chapter 4.

The application of TDT to the operation of LVNL could prove to become more beneficial in the future. It is expected that aircraft will be operating more fixed arrival routes. Specifically, these flight would be operating Continuous Decent Operations (CDO's). These types of operations are based on aircraft descending towards their destination airport at a constant rate (Eurocontrol, 2020). This would result in a more environmentally friendly and cost efficient operation. However, this method of operations is expected to reduce the level of flexibility that air traffic controllers have when deconflicting traffic. Arrivals and departures would be flying along a fixed route. Once arriving flights establish these fixed routes, it is considered undesirable to remove them from these routes. This would remove the flexibility provided by navigating aircraft using vectors. This constraint could be (partially) mitigated by applying TDT to arriving traffic. Re-routing arrivals outside of AMS-FIR would allow LVNL to influence the fixed approach route of these flights. This would allow these flights to be (partially) sequenced and deconflicted from another by re-routing these flights to different approach routes.

6.2 Continued research

The implementation of TDT would face operational challenges. These challenges would include establishing some form of communication between affected parties. This information sharing would likely have to be automated to some degree, as manually exchanging this information e.g. over radiocommunications would likely result in a higher demand on operational personnel. Also, the parties involved are expected to act in their own interest. The commercial aviation industry is partly driven by a sense of competitiveness. The information that is shared to enable an application like TDT by a party is likely to be accessible for its competitors. This would necessitate the identification of what information these parties are willing to share. TDT becoming operational will be dependent on the willingness of parties to publicly share information regarding their operations. Further research should thus be aimed at identifying what information is necessary for TDT, what parties are involved/affected by its application, and if these parties are willing to make this information publicly available.

Future research will need to focus on the operational processes with the NM manager, the adjacent ANSP's, e.g. Maastricht UAC and Karlsruhe UAC. Furthermore, the airlines operational Centre (e.g. KLM-OCC) and cockpit processes need to be fully described.

A potential main research question for continued research could then be formulated as follows:

What are the informational and operational requirements for Tactical Demand Tailoring in the European aviation industry?

This main question could then be supported by the following sub-questions:

1. Which parties are involved in Tactical Demand Tailoring?
    a. What parties should be involved in decision making, and why?
    b. How much influence should each party have?
    c. What parties should only be informed of a change in operation, and why?
2. What legislation is relevant for Tactical Demand Tailoring?
    a. What party has jurisdiction over the path of the flight (OCC/pilot or ANSP)?
3. What information is required for Tactical Demand Tailoring?
    a. How is this information acquired?
    b. What information are these parties willing to make public?
    c. Under what circumstances are parties willing to share information?
4. How would this information be exchanged by parties involved?
    a. What systems are underlie the exchange of information?
    b. What applications do these concept offer?
    c. How does the communication between parties travel?
5. To what extend could decision-making be automated?
    a. Can automation be used to suggest tactical re-routes?

Ideally, the information shared by parties involved in TDT would be accessible instantaneously, for any party requesting it. Any change to this information would then be updated automatically and is available for any party requesting it. Some of these parties might be:

- The Eurocontrol Network Manager
- Relevant ANSP's
    - ANSP requesting re-route
    - ANSP executing re-route
    - En-route ANSP's
- Airline OCC's
- Flight crew
- Airport receiving flight
- Ground handling parties (for e.g. new gate allocation)

In order to evaluate if a re-route is possible, info from e.g. en-route ANSP's would be required such as their predicted traffic demand. All en-route ANSP's would need to have the operational capacity to handle an extra flight through their airspace. One extra flight might not seem like a lot, but one flight could significantly change the experienced workload for a controller. This effect can be observed by predictions from LVNL's Werklastmodel (WLM), calculating the experienced workload to a controller. The output of this model is influenced by, for example, the amount of traffic presented to a controller, it's path through the airspace, the intentions of the traffic, aircraft performance capabilities of traffic, just to name a few factors. This indicates that the predicted workload to air traffic controllers in en-route ANSP's should be considered when considering a tactical re-route. This is something that should be researched when further assessing the implications of TDT.

Furthermore, the instruction of a re-route should be discussed on time with the cockpit of the flight in question. The pilots should be allowed time to adjust their procedures. For example, information that was filed in the flight plan of the flight would change when a re-route is instructed. For example, not only the flown route and waypoints passed would change. A new first and second alternate landing airport would have to be identified. This indicates that an in-flight re-route could increase workload inside the cockpit considerably. This aspect of TDT should also be considered if the application is to be developed operationally. This increase in workload could potentially be mitigated in a multiple ways. An obvious method of restricting the increase in workload would be to inform the pilots of their change in route well before the point of diversion. This would allow the flight crew time to work out their new route and the possible complications that this re-clearance might come with. Another method of mitigating this challenge would be to pre-emptively select routes suited for TDT and informing flight crew that they might receive a re-route before they depart. The flight crew would then know that the route they are operating is susceptible for a re-route and they could plan accordingly. This concept could even be taken so far that the information on the secondary route could be included into the filed flight plan. This flight plan could then include, for example, the point of diversion, the new route to be taken and alternative landing airports.

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