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Methodologies for Calculating Delays/ Improvement Opportunity Pools By Phase of Flight

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1 Background and Purpose

The document is intended to serve as a guide for calculating ATM improvement opportunity pools by phase of flight. The precise data sources and automation software may vary by ANSP; however the core methods described should be consistent. For CANSO purposes the basic phases of flight are identified as:

- Taxi-out
- Departure to 40nm Ring
- Cruise (en route) from Departure Ring to 100nm Ring around arrival Airport
- Descent from 100nm Ring to Runway
- Taxi-in

Improvement pools are identified by examining the difference between actual travel time, travel distance or fuel burn against an un-impeded or benchmark travel time, travel distance or fuel burn. This difference between actual performance and an ideal or benchmark performance is also referred to as a flight efficiency estimate. The difference between actual travel time and benchmark travel time is also called delay. The terms "opportunity pool", "delay" and "flight efficiency" are used throughout this document to refer to calculated difference between actual values and benchmark values.

Section II of this document describes the recommended data sources and process for calculating opportunity pools by phase of flight. These data sources consist of radar or ADS-B position data for the airborne portions of the flight and several key event times recorded by airlines for surface times. In the US this is done through the Aircraft/ARINC Communications Addressing and Reporting System (ACARS). Software development or automation support may be necessary to partition the position data by phase of flight as well as to process the key event times on the surface.

Section III expands on Section II by providing details on processing specific phase of flight efficiency calculation using the data and benchmark values described in Section II.

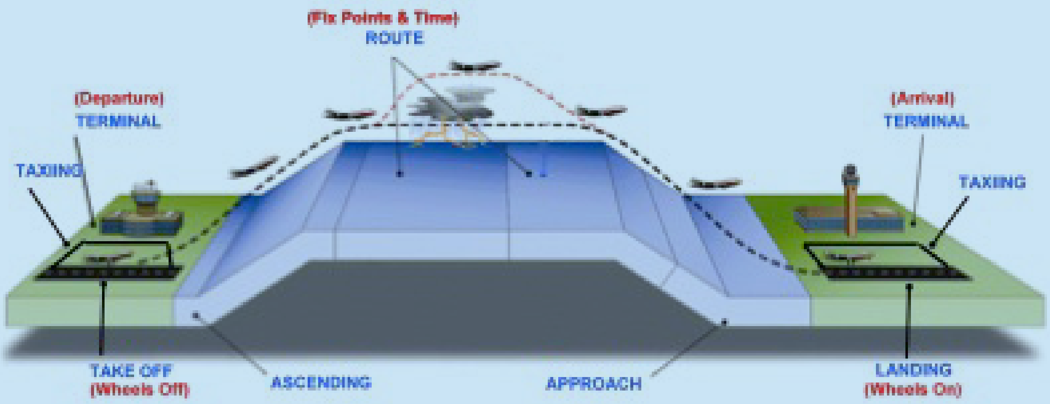


Figure 1 - Phase of Flight

2
Developing a Benchmark Measure for Efficiency

2.1_Recommended Benchmarks by Phase of Flight

Ideally there is one optimal gate-to-gate trajectory for each flight that can be compared to actual times. Historical experience has found that it is instructive to assess the individual components of the overall trajectory. Different data sources often track the trajectory between the surface and airborne phase. It is also often more practical to explore causal reasons for inefficiency when the trajectory is divided into phases. Table 1 describes the phases of flight and the recommended values to be used for a benchmark trajectory. Flight efficiency indicators will measure the difference between actual values and the benchmark values.

The specific processing to develop the benchmark times and distances may require site specific adjustments that make the best use of the performance data available to the ANSP. The CANSO Operations Standing Committee can help address implementation issues through its Environmental and Operational Performance work groups. In general, the following high level principles should be observed:

1. Minimum times and distances should be developed for a common population of flights. This will require some grouping of flights prior to establishing the benchmark time. For example, arrivals over a common fix, to a common runway, using aircraft with common speed characteristics would be part of a common group.
2. The absolute minimum time for a population may be an outlier, perhaps with missing position information. Recommended minimum times may be obtained by using the 5th, 10th, or 15th percentile of the common population. To minimise the effects of data errors, it is recommended that the average times or distances from the 5th-15th percent be used as the benchmark. Alternatively, the process may filter for periods of low congestion and average the flights times or travel distances over the low congestion period. Congestion analysis may require some estimate of capacity.
3. Benchmark distances for the airborne part of flight focus on the horizontal efficiency of the flight. However, the trajectory processing should include some assessment of the vertical component and whether level flight is detected at altitudes different than the ideal. Ideal altitude may be difficult to discern for flight specific reasons such as weight or due to wind or other weather effects. However if level flight appears to cluster rather than be

Table 1- Benchmark Values by Phase of Flight

Phase of Flight	Benchmark Value
Taxi-Out	**Minimum of the Observed Taxi-Out Times. Indicative of periods of low congestion.**
Climb/Ascent	**Minimum of the observed Climb-Out trajectory distances between departure runway and 40nm. Should include no level segments.**
En-Route	**Great Circle Distance between 40nm of departure and 100nm of arrival airport. Should show level flight at ideal cruise altitude.**
Approach/Descent	**Minimum of the observed Descent trajectory distances between 100nm radius of airport and the arrival runway. Should include no level segments.**
Taxi-In	**Minimum of the Observed Taxi-In Times. Indicative of periods of low congestion.**

random, the process may have detected a potential inefficiency in the system.

4. Wind and weather effects can affect the accuracy of horizontal efficiency based on great circle and vertical efficiency based on level flight, particularly over long distances. For longer time frames, an airline may adjust as ideal conditions change.

2.2_Recommended Data and Software for Flight Efficiency Calculations

Table 2 provides a summary of the data sources available to ANSPs for calculating the efficiency pools described in this document.

The core examples in this document are designed for ANSPs that have access to radar information for the airborne portion of the flight and ACARS or ACARS equivalent messages for the surface portion of the flight. ACARS equivalent messages include key event times that may be recorded by a Departure Manager or provided by an airport. Table 3 contains a description of the four key event times provided by ACARS. These times include the Gate-Out, Wheels-Off, Wheel-On and Gate-In messages and are often referred to as the OOOI times for a flight.

Airborne surveillance position data, ground position data from an Advanced Surface Movement Guidance and Control System (A-SMGCS) and/or airline data (ACARS) can provide the potential for assessing a large volume of flights in a consistent and automated way. Benchmark values are improved by additional flight information such as aircraft type and runway used which allow for more specific grouping of flights. For example, flights arriving east landing east will have a lower travel time or distance than flights arriving east and landing west. Table 4 (page 6) lists recommended values for grouping flights into a common population and developing benchmark times.

Table 2 - Data Sources Available for Performance Measurement

Data Source	Description
radar/ADS-B	Aircraft position data that is processed and distributed to ATC via a central system. Use for Airborne Benchmark Values
ACARS or Equivalent	A digital data link system for transmission of small messages between aircraft and ground stations via radio or satellite. Used for Surface Benchmark Values.
A-SMGCS or Multi-Lateration Surface Data	System that provides surveillance tracking information for aircraft and vehicles on and near the surface of the airport. Used for Surface Benchmark Values.
Statistically derived Surface Messages	Data derived to account for airport operations detected by radar/ADS-B but not accounted for in the surface ACARS or A-SMGCS systems.

Table 3 - Key Event Times from ACARS or Equivalent System

ACARS Event	Action	Condition
Gate Out	Aircraft leaves gate/ parking position	Parking brake is released
Wheels Off	Aircraft takes off	Air/ground sensor on landing gear set to “airborne” state
Wheels On	Aircraft touches down	Air/ground sensor on landing gear set to “ground” state
Gate In	Aircraft arrives at gate/parking position	Parking brake is applied

Table 4 - Recommended Data for Computing Benchmark Times

Field	Last 100 NM	Taxi out	Description
DEP AIRPORT		X	Departure airport
ARR AIRPORT	X		Arrival airport
DEP RUNWAY		X	Departure runway
ARR RUNWAY	X		Arrival runway
AIRCRAFT CLASS	X	X	Physical class: jet, turboprop, piston
BEARING CROSS 100 nm	X		The bearing from the airport (0 is due North, 90 is due East) of the 100 NMI crossing point (if crossed)
TIME CROSS 100nm	X		Time at the 100 NMI crossing (if crossed)
BEARING CROSS 40nm	X		The bearing from the airport of the 40 NMI crossing point
TIME CROSS 40nm	X		Time at the 40 NMI crossing
Actual Landing Time	X		ACARS Wheels On or Similar
AOBT		X	Actual Off-block Time
DEPARTURE GATE		X	Departure gate/ stand
Actual Take-off time		X	ACARS Wheels Off or Similar

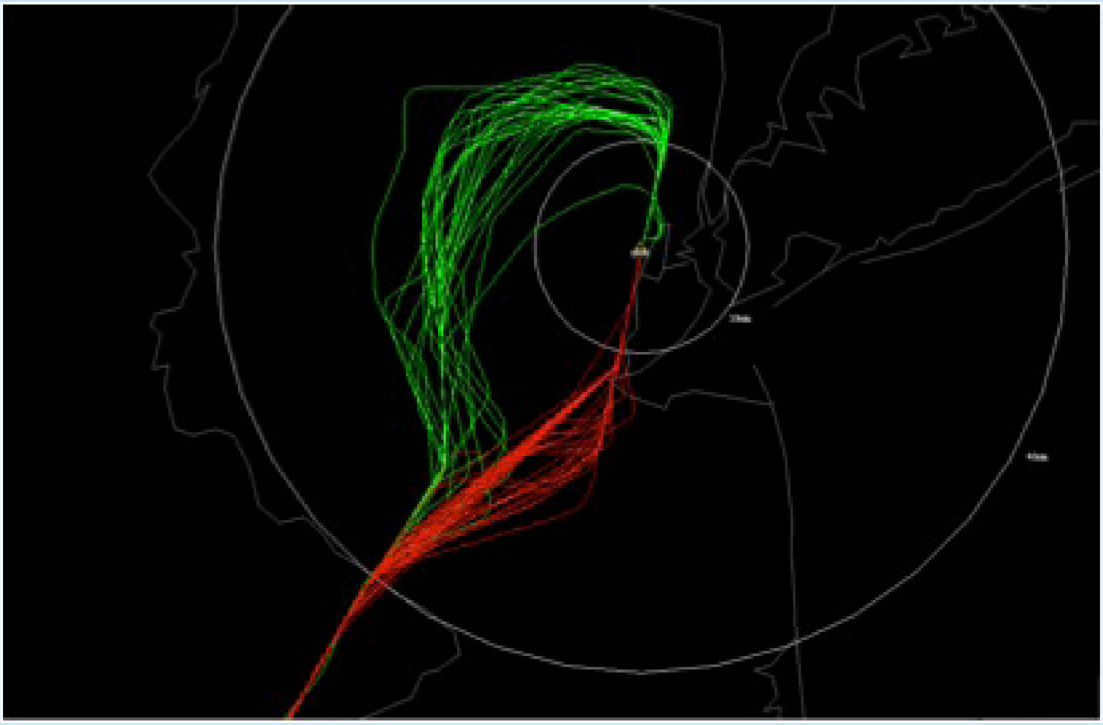
2.3_Development of a Benchmark Value

This section provides an overview of the process used to develop a benchmark value using the data sources above. The process involves the following 3 steps 1) grouping flight by similar category 2) filtering flights for bad values or congested periods and 3) selecting a benchmark value from the grouped/filtered data.

2.3.1_Grouping Flights

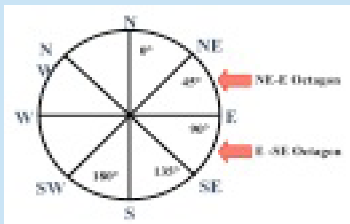
Figure 2 (page 7) shows an example of approaches from a common fix but landing in two different runway configurations. Ideally, each approach-landing configuration should have its own benchmark distance and time. Jet, turboprop and piston aircraft may have different distributions due to their performance characteristics. The degree to which flights are grouped determined the granularity of the benchmark values.

Figure 2 - Approaches over a Common Fix



For surface operations flights will be clustered by Gate-Runway-End Combinations. This may be further sub-divided depending on other traffic patterns such as whether the path requires crossing an active runway. However all levels of specificity may not be practical or necessary. Table 5 contains groupings recommended for creating benchmark values.

Table 5 - Recommended Groupings for Benchmark Values

Flight Grouping	Description
Core Recommended Groupings	
Runway/Runway Configuration: Provides Start/End point for surface and airborne performance analyses. This data may be available by specific runway or by landing configuration.	
ASMA entry sector: The ASMA (circle around airport with a radius of 100Nm) may be divided into 8 sectors of 45° in order to capture the direction from which the flight entered into the ASMA. An alternative approach may search a configuration for “clusters” of flights and dynamically partition the sectors based on a density of flights.	
Physical/Weight class: grouping of aircraft type to account for speed differences.	
Airline/Gate/or Movement Area Entry Point.	
Secondary Grouping	
Meteorological Condition	**At the time of arrival. May be IMC/VMC or grouped by ceiling/visibility values.**

2.3.2_Grouping and Filtering Flights for Benchmark Times

Flight grouping determines the number of unique benchmark values in the data. Care should be taken in filtering data for flights that will skew the calculation of the ideal time. These values are usually the result of errors in processed radar data and can be detected statistically as outliers. Other processes may simply truncate distributions and only process flights within the 5th-95th percentile. Another method for accounting for outliers or congested periods is to simply average the travel times or distances of the most ideal observed flights. For a common group, flights are sorted by time or distance from shortest time or distance to longest time or distance. The flights in the first 5th percentile are considered as outliers. Flights between the 5th and 15th percentile are then averaged to determine an idealized time. Flights with times or distances longer than this average (roughly 85-90%) are considered less than ideal. Populations with low variation will score as near efficient while populations with larger variability will score lower in efficiency.

Care should also be taken to review if the idealized trajectory identified by averaging the 5th to 15th percentile is truly indicative of the best trajectory that can be achieved. More complex processing will consider other factors such as the effect of congestion. The next section presents a method that considers congestion and requires some estimate of capacity of the facility for determining a congestion level.

CONGESTION FILTERING

Congestion may also skew the processing of a benchmark time. A Congestion Level may be defined as the number of other aircraft ahead of the categorized flight. For surface this may be the number of other departing flights active between off-block and take-off time for taxi-out of a given flight. For airborne approaches this may be the number of other landings between 40NM crossing and runway touchdown. In general, screening based on congestion relates the number of "active" aircraft at a facility to the capacity of the facility.

In order to take the difference in airport throughput into account, the threshold for the congestion index (CI) to be used for the calculation of the unimpeded time is defined as 50% (or alternatively 25%) of the maximum airport throughput using the formula further down the page.

Given a 20th percentile estimated unimpeded transit time of 12 minutes and an airport with maximum throughput of 40, the congestion index = .50*40*(12/60) = 4. Only flights with a congestion index of 4 or less would be included in the final calculation of the unimpeded transit time.

CI = 50% * Max Throughput * (Unimpeded Estimate/60)		
Where:		
Max Throughput	=	Maximum Hourly Throughput
Unimpeded Estimate	=	20th percentile of the distribution

2.3.3_Selecting a Benchmark Value

Once the data has been grouped and filtered, an appropriate benchmark time may be chosen based on the actual observations. If congestion filtering is not applied, it is recommended that that the average times or distances for the upper 5th to 15th percentile of the distribution are averaged to determine an ideal time. This procedure removes outliers at the top of the distribution. The 5th-15th percentile should represent the best observed trajectories or taxi-times within a particular group. Alternatively, a specific taxi time or trajectory such as the 5th or 10th percentile may be chosen as the benchmark for the group. The average may prove more stable especially when comparing over different time periods.

If congestion filtering is used, this smaller population may be considered representative of idealized flights. For this smaller sample, it is recommended that the average of the 10th to 90th percentile be used to determine the benchmark times or distances.

2.3.4_En-Route Calculations

The above sections that determine a benchmark from observed actuals are recommended for the taxi-out, departure, descent and taxi-in phases of flights. For the en-route phase of flight, there is a precedent in many CANSO Members' States for assessing en-route efficiency against a great circle calculation. There are of course, several considerations that limit the use of the great circle distance as a surrogate for an ideal flight (especially for longer flights) which are described in section 3.3.

Figure 3 shows a depiction for the airborne phases of flight. The terminal environments are approximated by a 40nm circle around the departing airport and a 100nm circle around the arrival airport. Two great circle distances between the entry and exit points (D) and the two reference circles (G) provide lower and upper benchmark trajectories for the en route environment. Differences between the actual trajectory (A) and the benchmarks (D&G) provide indicators of en route inefficiency.

The schematic is only applicable when both the arrival airport and departure airport are located within the controlled airspace of the ANSP. For flights that cross ANSP control areas, the first entry point into the airspace and/or the last exit point from the airspace can take the place of the entry circle point and exit circle point.

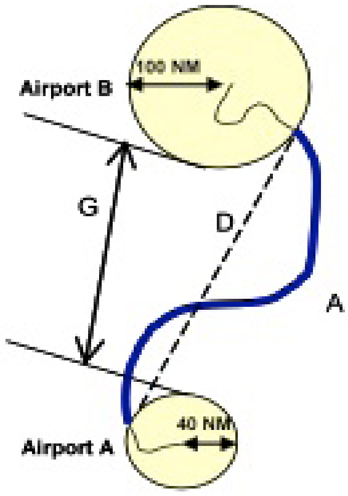


Figure 3 - Airborne Phase of Flight

Inefficiencies within the circles are detected by a separate process that examines minimal travel times and distances between wheels off and terminal exit (departure) and terminal entry at 100nm and wheels on (arrival).

To fully implement these algorithms, the ANSP will need software that can process airborne position data (radar/ADS-B) and perform the following tasks:

1. Calculate the great circle distance between radar points
2. Detect the time and location when a radar track crosses a 40nm circle (departure) and 100nm circle (arrival)
3. Calculate the great circle distance between the reference circles of 40nm and 100nm.

3

PHASE OF FLIGHT EFFICIENCY CALCULATIONS:

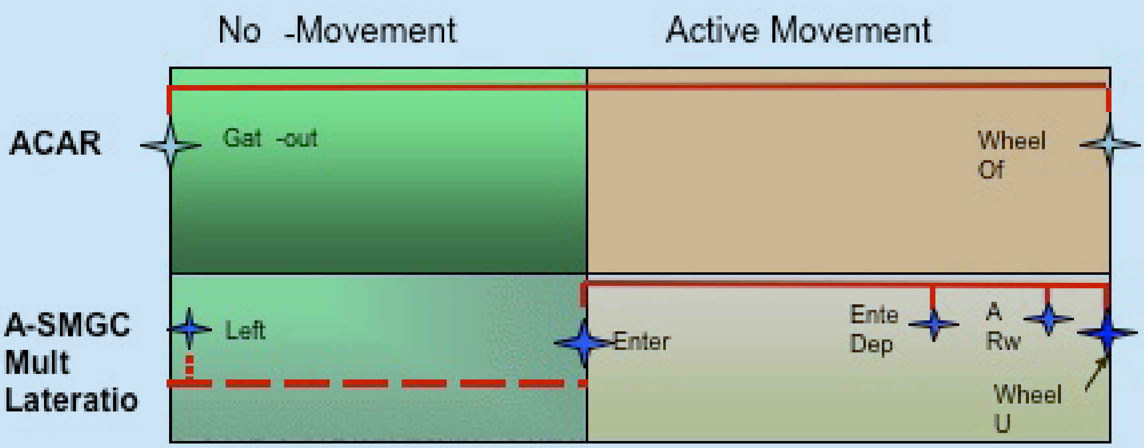
Section 2 established a method for calculating a benchmark time to measure against actual operations. These benchmarks are provided by phase of flight. The difference between actual travel times to these benchmark values provides a measure of efficiency that can be tracked over time.

3.1_Taxi out/Taxi in

For Taxi out/Taxi in, the nominal time is conceptually the un-impeded time required to traverse the surface from entry into the movement area until the runway position prior to take off (taxi-out) or from runway exit until exiting the movement area for (taxi-in). In theory, there may be hundreds of un-impeded times based on these combinations. In practice, ANSPs have developed approximations for these times using the data available in existing performance databases and the fidelity of the benchmark time will be dependent on the breadth and accuracy of this data. The methodology described below is based on an ANSP having ACARS messages which detect key times on the surface. ASDE-X data or actual field operations may be used as a substitute. However field operations will be labor intensive. Figure 4 shows key event times available from either an ACARS or ASDE-X source for a Taxi-Out operation.

ATM performance on the surface may be separated into the Active Movement Area, where ATM exercises control and the Non-Movement Area which may be controlled by another entity such as the operator of the RAMP tower. For an ACARS system, two event times are recorded; 1) A Gate-Out message which signals the start of taxi-time and 2) the wheels off message signaling the end of surface movement and the start of the airborne phase of flight. A-SMGCS data or even Departure Manager systems offer the potential for a more refined calculation of surface performance and may be able to distinguish between the movement area and non-movement area. In the case of Multi-Lateration, this data needs to be coupled with sophisticated algorithms that use the geometry of the airport surface to detect key event times. If coverage back to the gate exists, a left-gate message can be inferred. However it may not be clear from A-SMGCS data if aircraft are holding at the gate and some airport systems begin detection near entry into the movement area.

Figure 4 - Key Event Times in Taxi-Out Calculation



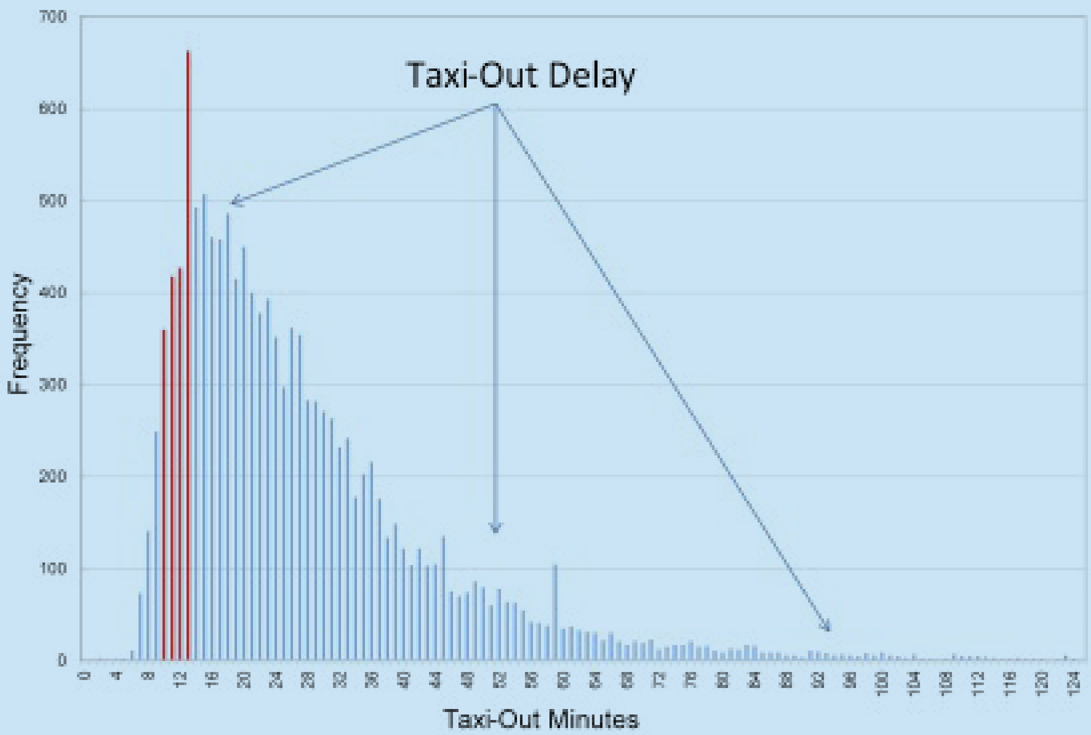
The data above can be used to create a distribution of ground taxi-travel times. For the ACARS sources, taxi-out is defined as the time from Gate-Out to Wheels-Off. Figure 5 below shows a distribution of actual out times representative of a congested airport. The 5th-15th percentile taxi-out times are represented in red and range from 10 to 13 minutes (13 minutes is the mode of the distribution). The average taxi-out time over the 5th-15th percentile region is 11.6 minutes. With delay or inefficiency taken as the difference between actual taxi-out time and 11.6 minutes, total delay for this distribution is 16.9 minutes per flight on average.

In addition to the total taxi-out time, this process may be used to detect the number of aircraft active on the ground in either a taxi-out state or taxi-in state. For the congestion filtering process, the number of aircraft on the ground is a surrogate for congestion and from these values; taxi-out time can be related to congestion on the ground. Periods of no congestion can be considered indicative of the ideal benchmark time.

3.2_Descent Phase (100nm Ring to Runway)

Benchmark trajectories for the approach phase are developed using concepts similar to the surface. Operations are grouped using the procedures described in Section 2 above. Figure 6 (page 12) shows an example of a set of flights that have been partitioned into a unique group by approach fix, runway configuration and aircraft performance class (note this is a subset of the full annual population of arrivals in this group).

Figure 5 - Distribution of Taxi-Out Times



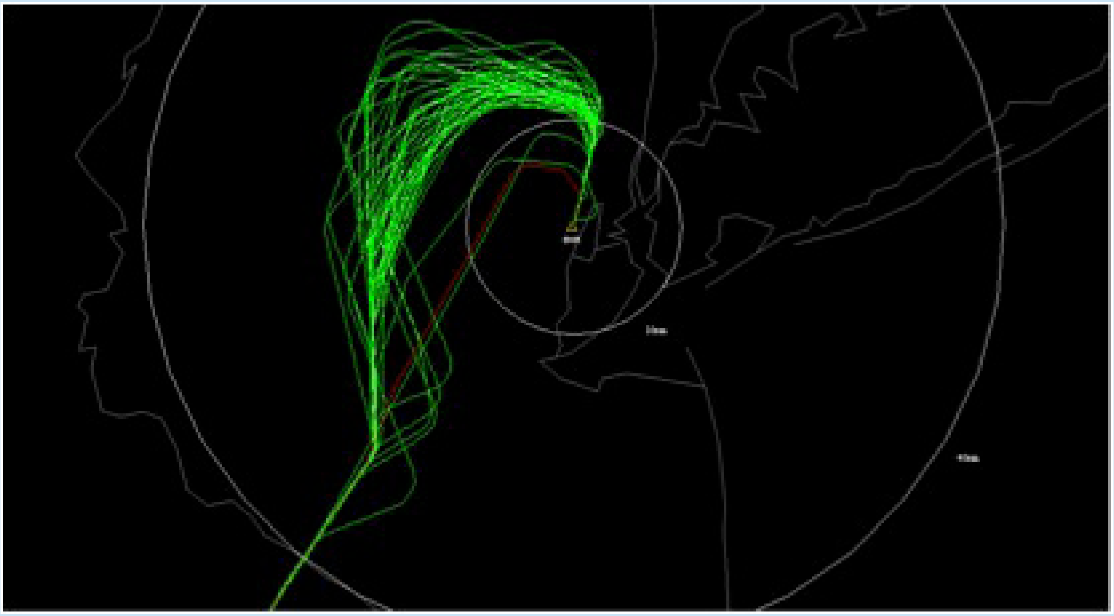


Figure 6 - Example of Descent Phase Efficiency

The flight track in red represents the ideal trajectory representative of the top 5th-15th percentile of shortest travel distances and times within this group. There are several variations that may be used in processing the upper grouping of idealised trajectories. The example below is based on the flight travel distance from the 100nm circle and is documented in other publically available documents on performance benchmarking.

After partitioning flights into a common group, trajectories are sorted by track distance from shortest to longest. This is actual track distance from the 100nm range ring to the last radar point or wheels-on location if this can be determined. Figure 7 (page 13) shows an example of this 100nm distance distribution for the fix-runway combination shown above. The distribution in Figure 7 is for a full year of flights. Short flight distances of 100 or 102 are not possible and are probably indicative of missing radar data for the flight. The 5th-15th percentile distribution spans from 114nm to 128nm. It is recommended that this population of flights be used for determining the idealized flight time or distance. If simply considering overall flight distance, the average over this range is determined to be 120nm. All flights in excess of this value would be considered to have an excess distance.

This process can also be repeated to identify a benchmark time either using the same flights sorted by distance or by sorting on time separately.

The ANSP may make adjustments to the above process to best fit the data requirements and operational characteristics of the facility. The important point is that the process identifies a trajectory that stakeholders agree is a reasonable benchmark for assessing flight efficiency. Popular adjustments include those that refine the clustering flight grouping algorithm, address approach dispersion from 100nm to 40nm, or perform congestion filtering as described in Section 2.

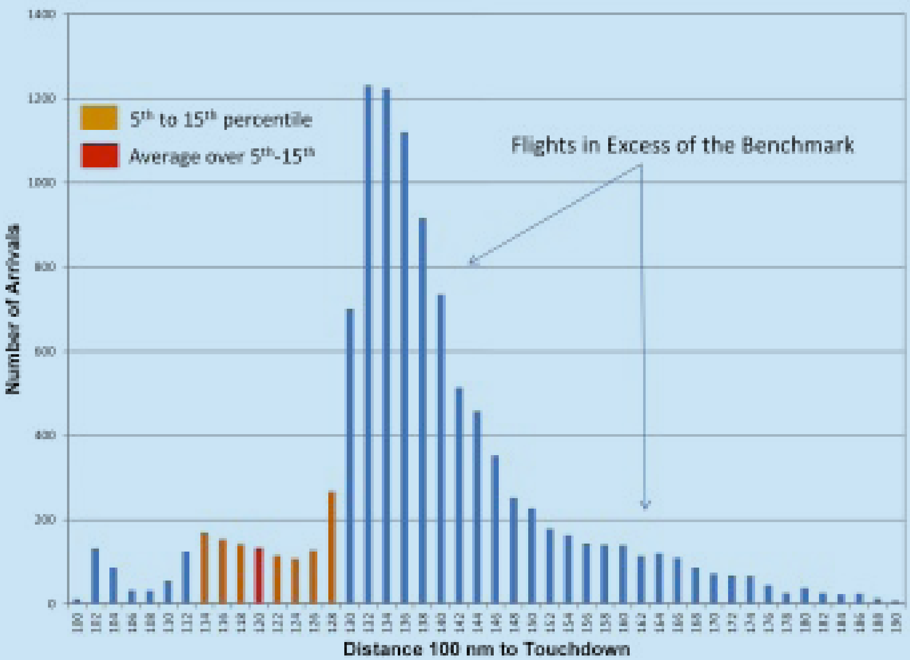


Figure 7 -100nm to Touchdown Distance Distribution

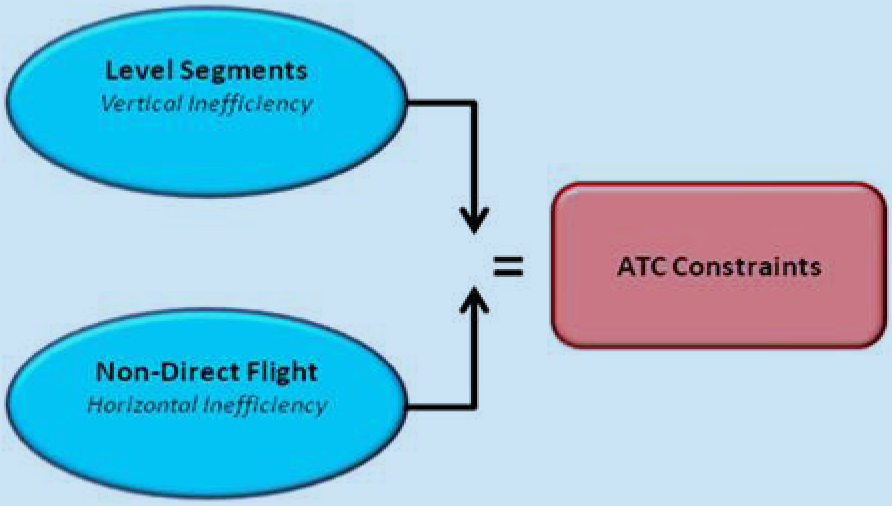


Figure 8 - Inefficiencies Detected from Position Data

SPECIAL PROCESSING TO CONSIDER LEVEL FLIGHT AND FUEL BURN

The process described above may be enhanced to explicitly account for level flight during descent. This direct accounting of level flight was developed to allow for an improved link to publically available fuel burn data which provides fuel burn rates for different aircraft states and flight levels.

Figure 8 (page 13) shows two types of inefficiencies detected from the position data a) level flight and b) non-direct flight (extended path).

In this approach excess distance and level vertical segments are translated into time and fuel. The BADA (base of aircraft data from EUROCONTROL) provides fuel burn rates for a broad spectrum of aircraft and has been used extensively to estimate excess fuel from the vertical and horizontal inefficiencies.

The unconstrained benefit pool actionable by ATM in the descent phase of flight is represented by the difference between an unimpeded trajectory and the actual trajectory flown. The total benefit pool represents the amount of time and fuel that could be saved with unlimited capacity and optimal trajectories.

The first part is the vertical component. It is the additional fuel to fly the same distance compared to an optimal vertical trajectory. The second part is the horizontal component. It is the additional fuel to fly the distance (x-x0) assuming both have an optimum vertical profile.

In the vertical phase, efficiency is calculated by comparing the fuel flown on the observed level segment to fuel burn under a scenario where the level segments that occur under climb or as part of descent are removed. This does not necessarily require calculating the fuel over the entire flight domain.

The second step assesses the horizontal component. At this stage the profile is a theoretical profile. All level segments have been removed and excess distance, if it exists, is presumed to occur at cruise altitude. The time and fuel are not exactly what occur at altitude in the true profile. However, this two-step process provides a means that eliminates double counting of vertical and horizontal inefficiency and is believed to be mathematically equivalent to the true benefit pool.

In the horizontal phase, efficiency is calculated by comparing the actual distance flown with ideal benchmark distance using the process described above. The excess distance is then translated into excess fuel burn at cruise level. Details related to the specific calculations for horizontal and vertical inefficiency on descent are presented in the following steps:

An aircraft performance database is a key component to many of the equations below. In general it is difficult to obtain velocity information from airborne position information. This is due to the influence of winds and the quality of the radar/ ADS-B processing. Fuel calculations must also be supplemented by an aircraft performance database. For these types of metrics, the BADA aircraft performance database provided by EUROCONTROL provides fuel burn rates at each flight level for cruise, climb, and descent. BADA contains a nominal cruise speed and nominal cruise fuel burn at each flight level. From BADA tables, fuel burn at higher altitude is in general lower, but nominal cruise speed is higher. To conclude, distance traveled is inferred from airborne position data. However velocity information is assumed to be the modeled nominal values from BADA or other suitable aircraft performance database. This assumes that BADA speed works better for benefits analysis that what could be inferred from radar data (if available). In addition, there is evidence that BADA has inherent inaccuracies (in particular for descents and arrivals) that need to be improved in future versions.

Step 1: Remove Vertical Inefficiency

The main driver for vertical inefficiency is assumed to be level flight segments flown at lower altitude. To increase efficiency and reduce fuel burn, level flight segments at lower altitude are assumed to be flown at cruise altitude. By moving level flight segment from lower altitude to a higher altitude, this method assumes the distance covered for each segment will be identical; however, speed and fuel burn will be different.

To cover the same distance at higher altitude, less time is needed and less fuel is used overall. Figure 9, shows the distance and time perspective of shifting level segments to higher cruise altitudes.

By extending the cruise phase (higher speed) and removing the level segment, the overall time is shortened. As illustrated in the graph, this method assumes flying distance will be kept the same before and after moving level flight segments. It also assumes that flying time is unconstrained and the flight can arrive before its actual arrival time conflict free.

The relevant equations for this section are:

$$\Delta T = \sum_{i=0}^{N} d_i \bullet (1/v(h_i^c) - 1/v(h_i) \qquad (1)$$

$$\Delta F = \sum_{i=0}^{N} d_i \bullet (f(h_i^c)/v(h_i^c) - f(h_i)/v(h_i)) \qquad (2)$$

where,

ΔT is the change in duration as a result of moving level segments from lower altitude to cruise level,

ΔF is the change in fuel consumption as a result of moving level segments from lower altitude to cruise level,

d_i is the length of level segment i,

h_i is the original altitude of level segment i,

h_i^c is the new altitude of level segment i (cruise level),

$v(h)$ is the nominal cruise speed associated with altitude h from BADA table,

$f(h)$ is the nominal fuel burn rate associated with altitude h in cruise configuration from BADA table.

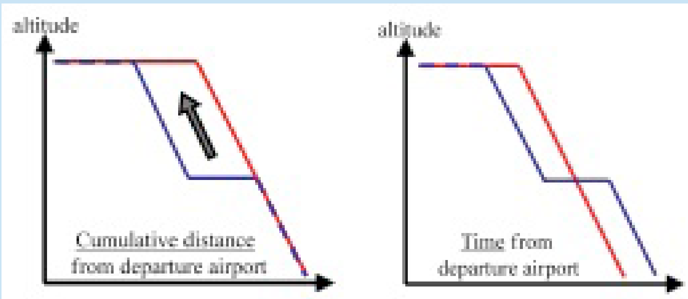


Figure 9 - Shifting Level Segment to Cruise -Distance/Time Perspective

The determination of level segment will require the knowledge of altitude at each track point, usually expressed in hundreds' of feet. Within the descent phase, level flight is detected by comparing the altitude of each point to that of next point. If the two points are within 200 feet of each other over 1 minute of travel time, it is determined these two points are a part of level flight segment.

Step 2: Remove Horizontal Inefficiency

After step one the vertical trajectory is optimized and the excess distance associated with vectors or holding remains. The main driver for horizontal inefficiency is assumed to be excess distance, compared to a benchmark distance (obtained using techniques described above. The difference between actual flown distance and benchmark distance is considered excess. This excess distance can then be converted to fuel burn based on values obtained from BADA tables at cruise altitude for each flight. Figure 10 illustrates excess distance in the descent phase.

From the horizontal efficiency perspective, the black trajectory is the actual trajectory and the red trajectory is a nominal (unimpeded trajectory). In cases of holding or extended downwind legs the difference between the two horizontal trajectories may be much greater. The difference between the red trajectory and the black trajectory is the equivalent excess distance in the cruise phase. The overall distance and time is shortened with the unimpeded trajectory. This excess distance can then be converted to fuel burn using values obtained from BADA tables at cruise altitude for each flight.

The relevant equations for this section are listed here:

$$\Delta D = D_{actual} - D_{benchmark} \quad (3)$$

$$\Delta T = \Delta D / v(h_c) \quad (4)$$

$$\Delta F = \Delta T \bullet f(h_c) \quad (5)$$

where,

ΔD is the change in distance as a result of removing horizontal excess distance,

D_{actual} is the actual distance flown,

$D_{benchmark}$ is the benchmark distance for similar flights,

ΔT is the change in duration as a result of removing horizontal excess distance,

ΔF is the change in fuel consumption as a result of removing horizontal excess distance,

h_c is the cruise altitude

$v(h_c)$ is the nominal speed associated with cruise altititude h_c from BADA table,

$f(h_c)$ is the nominal fuel burn rate associated with cruise altitude h_c from BADA table.

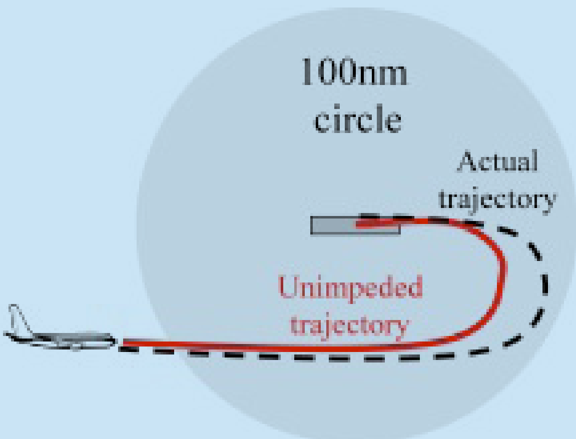


Figure 10 - Nominal Depiction of Excess Distance During Descent

Step 3: Integration of Horizontal Phase and Vertical Phase

For the unconstrained scenario, the benefit pool is simply the sum of benefit pools from the vertical (equations 1-2) and the horizontal (equations 3-5) phases.

3.3_En-Route (Cruise) – Direct Flight En-Route Indicator

To measure horizontal en-route efficiency, the Key Performance Indicator (KPI) chosen is direct en-route extension which is described in 2.3.4 above. Figure 11 below shows an example of this using 1-minute radar trajectory data. For this city pair, the idealized trajectories in red are indicative of the shortest distance path between 40nm and 100 nm of the origin and destination airport and the collected actual trajectories are shown in green. The difference in travel distance between the actual (green) and the direct flight (red) is the measure used for efficiency estimates. In the methodology described in Section 2, each flight track has its own unique benchmark distance depending on its exit from the 40nm circle or the entry into the destination 100nm circle. The graphic below uses representative direct paths for illustration.

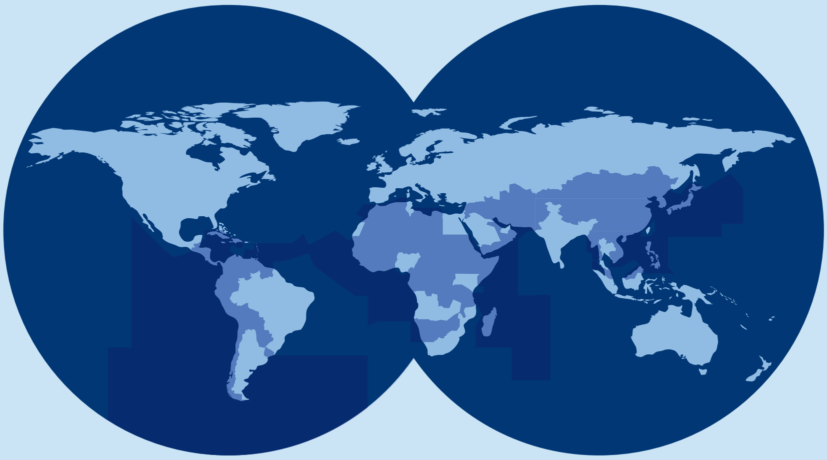
Although these examples use 40nm and 100nm range rings in the terminal area, CANSO ANSPs employ variations including 40nm and 40nm range rings. In either case the ANSP uses this domain as a reasonable benchmark or objective for direct flight. There are two main caveats to this indicator. Firstly, there may be very legitimate reasons why direct flight is not used. Aircraft will be separated for safety reasons or may fly farther distances to avoid severe weather or active Special Use Airspace. Secondly, direct flight becomes a less useful indicator over longer distances where airlines will prefer wind optimal routes. For these cases, a more sophisticated approach based on wind optimal routes or wind optimal times or other considerations such as operator business priorities would be required.

Figure 11 - Example of En-Route Indicator for Flight Efficiency

CANSO Members

CANSO – The Civil Air Navigation Services Organisation – is the global voice of the companies that provide air traffic control, and represents the interests of Air Navigation Services Providers worldwide.

CANSO members are responsible for supporting over 85% of world air traffic, and through our Workgroups, members share information and develop new policies, with the ultimate aim of improving air navigation services on the ground and in the air. CANSO also represents its members' views in major regulatory and industry forums, including at ICAO, where we have official Observer status. For more information on joining CANSO, visit www.canso.org/joiningcanso.



Lighter areas represent airspace covered by CANSO Members

Full Members - 78

- Aeronautical Radio of Thailand (AEROTHAI)
- Aeroportos de Moçambique
- Air Navigation and Weather Services, CAA (ANWS)
- Air Navigation Services of the Czech Republic (ANS Czech Republic)
- Air Traffic & Navigation Services (ATNS)
- Airports and Aviation Services Limited (AASL)
- Airports Authority of India (AAI)
- Airports Fiji Limited
- Airservices Australia
- Airways New Zealand
- Angkasa Pura I
- Austro Control
- Avinor AS
- AZANS Azerbaijan
- Belgocontrol
- Bulgarian Air Traffic Services Authority (BULATSA)
- CAA Uganda
- Civil Aviation Authority of Bangladesh (CAAB)
- Civil Aviation Authority of Botswana
- Civil Aviation Authority of Singapore (CAAS)
- Civil Aviation Regulatory Commission (CARC)
- Department of Airspace Control (DECEA)
- Department of Civil Aviation, Republic of Cyprus
- DFS Deutsche Flugsicherung GmbH (DFS)
- Dirección General de Control de Tránsito Aéreo (DGCTA)
- DSNA France
- Dutch Caribbean Air Navigation Service Provider (DC-ANSP)
- ENANA-EP ANGOLA
- ENAV S.p.A: Società Nazionale per l'Assistenza al Volo
- Entidad Pública Aeropuertos Españoles y Navegación Aérea (Aena)
- Estonian Air Navigation Services (EANS)
- Federal Aviation Administration (FAA)
- Finavia Corporation
- GCAA United Arab Emirates
- General Authority of Civil Aviation (GACA)
- Hellenic Civil Aviation Authority (HCAA)
- HungaroControl Pte. Ltd. Co.
- Israel Airports Authority (IAA)
- Iran Airports Co
- Irish Aviation Authority (IAA)
- ISAVIA Ltd
- Japan Civil Aviation Bureau (JCAB)
- Kazaeronavigatsia
- Kenya Civil Aviation Authority (KCAA)
- Latvijas Gaisa Satiksme (LGS)
- Letové prevádzkové Služby Slovenskej Republiky, Štátny Podnik
- Luchtverkeersleiding Nederland (LVNL)
- Luxembourg ANA
- Maldives Airports Company Limited (MACL)
- Malta Air Traffic Services (MATS)
- NATA Albania
- National Airports Corporation Ltd.
- National Air Navigation Services Company (NANSC)
- NATS UK
- NAV CANADA
- NAV Portugal
- Naviair
- Nigerian Airspace Management Agency (NAMA)
- Office de l'Aviation Civile et des Aeroports (OACA)
- ORO NAVIGACIJA, Lithuania
- PNG Air Services Limited (PNGASL)
- Polish Air Navigation Services Agency (PANSA)
- PIA "Adem Jashari" - Air Control J.S.C.
- PT Angkasa Pura II (Persero)
- ROMATSA
- Sakaeronavigatsia Ltd
- S.E. MoldATSA
- SENEAM
- Serbia and Montenegro Air Traffic Services Agency (SMATSA)
- Serco
- skyguide
- Slovenia Control
- State Airports Authority & ANSP (DHMI)
- State ATM Corporation
- Tanzania Civil Aviation Authority
- The LFV Group
- Ukrainian Air Traffic Service Enterprise (UkSATSE)
- U.S. DoD Policy Board on Federal Aviation

Gold Associate Members - 14

- Abu Dhabi Airports Company
- Airbus ProSky
- Boeing
- BT Plc
- FREQUENTIS AG
- GE Air Traffic Optimization Services
- GroupEAD Europe S.L.
- ITT Exelis
- Lockheed Martin
- Metron Aviation
- Raytheon
- SELEX Sistemi Integrati S.p.A.
- Telephonics Corporation, ESD
- Thales

Silver Associate Members - 63

- Adacel Inc.
- Aeronav Inc.
- ARINC
- ATCA – Japan
- ATECH Negócios em Tecnologia S/A
- Aviation Advocacy Sarl
- Avibit Data Processing GmbH
- Avitech AG
- AZIMUT JSC
- Barco Orthogon GmbH
- Booz Allen Hamilton, Inc.
- Brüel & Kjaer EMS
- Comsoft GmbH
- CGH Technologies, Inc
- Abu Dhabi Department of Transport
- Dubai Airports
- EADS Cassidian
- EIZO Technologies GmbH
- European Satellite Services Provider (ESSP SAS)
- Emirates
- Entry Point North
- Era Corporation
- Etihad Airways
- Guntermann & Drunck GmbH
- Harris Corporation
- Helios
- Honeywell International Inc. / Aerospace
- IDS – Ingegneria Dei Sistemi S.p.A.
- Indra Navia AS
- Indra Sistemas
- INECO
- Inmarsat Global Limited
- Integra A/S
- Intelcan Technosystems Inc.
- International Aero Navigation Systems Concern, JSC
- Iridium Communications Inc.
- Jeppesen
- JMA Solutions
- LAIC Aktiengesellschaft
- LEMZ R&P Corporation
- LFV Aviation Consulting AB
- Micro Nav Ltd
- The MITRE Corporation – CAASD
- MovingDot
- New Mexico State University Physical Science Lab
- NLR
- Northrop Grumman
- NTT Data Corporation
- Project Boost
- Quintiq
- Rockwell Collins, Inc.
- Rohde & Schwarz GmbH & Co. KG
- RTCA, Inc.
- Saab AB
- Saab Sensis Corporation
- Saudi Arabian Airlines
- SENASA
- SITA
- STR-SpeechTech Ltd.
- TASC, Inc.
- Tetra Tech AMT
- Washington Consulting Group
- WIDE

Correct as of 7 May 2013. For the most up-to-date list and organisation profiles go to www.canso.org/cansomembers