Aircraft Engine Emission Reduction Programme Zurich Airport

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[Erfolgskontrolle L2]

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1 Executive Summary (German)

Im Rahmen des Bewilligungsverfahrens für die 5. Baueteappe wurde den Behörden als Teil der UVB-Ergänzung von 1999 der Massnahmenplan Lufthygiene der Flughafendirektion Zürich eingereicht. Eine der Massnahmen richtete sich an den Flugbetrieb im bodennahen Bereich:

L2 –	Optimieren der Flugzeugbewegungen innerhalb des immissionswirksamen Emissionsperimeters.

In diesem Bericht (gilt als Umsetzungsnachweis und Erfolgskontrolle) werden die verschiedenen untersuchten sowie realisierten Einzelmassnahmen erläutert und quantifiziert.

Tabelle 1: Massnahmenübersicht

Massnahme	Beschreibung	Status	Resultat
Standort Dock E	Minimale Rolldistanzen zwischen neuem Dock E und den Start- und Landepisten.	Realisiert (war Teil der 5. Bauetappe)	-15t NOx, -13.5t HC, -11'400t CO_2 (Basis 2004).
Schubreduktion LTO	Für die LTO Phasen wird weniger Schub eingesetzt, als bisher als Grundlage für bisherige Emissionsberechnungen angenommen wurde.	Realisiert. Ist heute Standard bei den Fluggesellschaften.	Effektiv werden rund 30% weniger NOx emittiert als bisher berechnet (-300 t NOx, Basis 2003).
Startsequenz-Optimierung	Mit einem Flugzeug-Führungssystem wird die Startsequenz optimiert und Wartezeiten vermindert.	Mit dem System DARTS realisiert.	-4.2t NOx, -4t HC, -33.7t CO (Basis 2004)
Umkehrschub	Der Einsatz von Umkehrschub wird reduziert.	Die NOx-Emissionen sind mit weniger als 0.1% der gesamten LTO- Emissionen nicht relevant. Der Einsatz ist zudem bereits über das AIP eingeschränkt (nur Leerlauf-Umkehrschub).	
Flugzeugschleppen	Die Flugzeuge werden vom Standplatz zur Startpiste geschleppt, bevor sie die Triebwerke starten.	Eine Studie zeigte bereits 1992, dass am Flughafen Zürich eine Realisierung ökonomisch nur geringe Vorteile bringt, technisch, operationell und rechtlich aber nicht realisierbar ist. Daran hat sich zwischenzeitlich nichts geändert.	
Rollen mit weniger als allen Triebwerken	Im Rollbetrieb werden weniger als alle Triebwerke des Flugzeuges eingesetzt.	Die Geometrien des Flughafens lassen die Massnahme aus Sicherheitsgründen nicht gesamtheitlich zu (rechtwinklige Kurven). Weitere Einschränkungen ergeben sich aus technischen und operationellen Parametern.	
Bevorzugte Standplatzzuweisung	Die Flugzeuge werden so nah als möglich bei den Start- und Landepisten aufgestellt.	Das Benutzerkonzept richtet sich nach dem Tagesgang, den Flugzeugen, den Airlineallianzen und weiteren Parametern, die eine systematische Anwendung nicht zulassen.	

Fazit:

- Die Emissionen, wie sie bisher jeweils berechnet worden sind, sind viel zu konservativ. Die heutigen operationellen Flugverfahren sind ökonomischer und in diesem Fall auch ökologischer als zu Beginn der 80er Jahre. Die Emissionen sind damit um etwa 300 t/a geringer als in früheren Studien modelliert (mit Bezugsjahr 2003). Die daraus resultierenden Veränderungen in der regionalen Immissionsbelastung werden separat modelliert.
- Die effektiv umgesetzten Massnahmen haben gesamthaft zu einer Reduktion der Emissionen von knapp 20 t NOx und 18 t HC aus dem Flugbetrieb geführt.

2 Background

According to Swiss environmental legislation, the 5th expansion programme required an environmental impact statement that confirmed compliance with environmental standards and suggesting measures to reduce impacts as far as possible. A first assessment carried out in 1997 showed the need for further measures in airport air quality particularly for NOx. Zurich Airport Authority then drafted the 1999 Zurich Airport Air Quality Mitigation Plan, suggesting a number of measures to further reduce emissions from aircraft, handling and airport infrastructure. This plan has been submitted to the authorities who made it a mandatory part of the construction permit in 1999.

One particular measure (L2) addressed the emissions of aircraft within the perimeter relevant for air quality impacts. Previous studies have shown that 35% of NOx emissions from aircraft within the LTO cycle are emitted at ground level (taxiing and take-off) and another 15% up to an altitude of approx. 200 m. This suggested that the operational procedures of an aircraft at ground can have a significant impact on the overall emission load.

The stipulated measure includes assessing all possibilities that reduce emissions of aircraft at ground level.

3 Overview over Measures

3.1 Constructional Measures

Within the 5th expansion programme the new concourse E was one of the key elements of the programme. As such, it was a measure in itself, but leads to a reduction in taxi-times due to the central location between the runways.

Measure	Description	Status
Aircraft stands close to runways	Aircraft stands (pier or remote) are located as close to the runways as possible	Realised concourse E

3.2 Operational Measures

Measure	Description	Status
Derated / reduced thrust in LTO modes	For take-off, climbout, approach and taxi, less thrust is applied than indicated for the ICAO certification LTO cycle	realised
Sequencing improvements	The sequencing of aircraft between stands and runways is improved to minimise queuing	realised
Reverse thrust deployment	The deployment of reverse thrust when landing is reduced	not relevant
Operational Towing	Aircraft are towed to the departure runway threshold	not realised
Taxiing with less than all engines	Aircraft taxi with less than all engines operating for inbound and outbound operations	not realised
Preferential stand allocation	Aircraft are preferentially placed to stands as close to runways as possible	not realised

The emission related landing charges measure is not part of this programme (economic measure). The landing charges have been introduced in September 1997 and are still in effect.

4 Emission Reduction of Realised Measures

4.1 Location of new Concourse E

The new concourse E is located between the two main take-off thresholds (RWY 28 and RWY 16). As a consequence many aircraft operations that have been handled at concourse B and at open stands on the Southern part of the apron are now handled out of concourse E. This leads to a reduction of taxi-time, particularly to RWY 16 which is the main take-off runway for large long-haul aircraft.

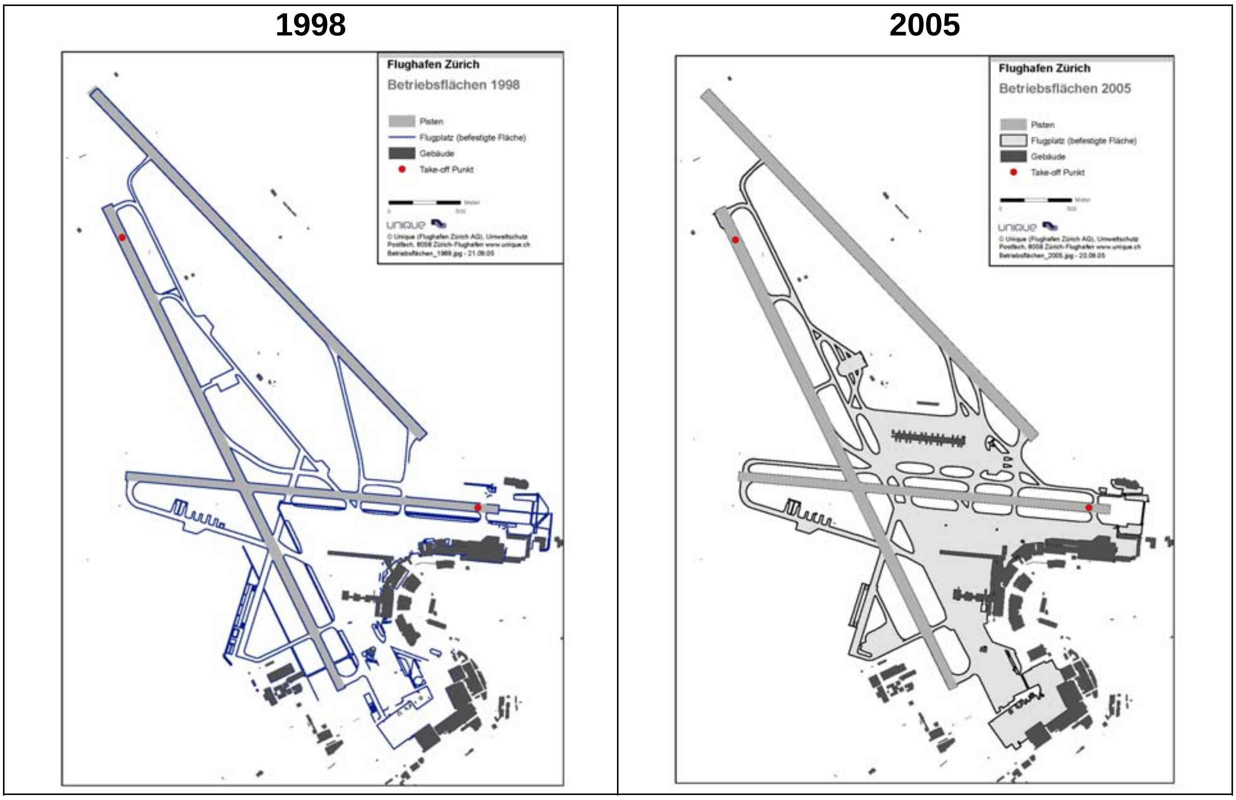


Fig. 4-1: Situation before and after construction of concourse E with respect to main take-off thresholds (RWY 28 and RWY16)

The environmental benefits have been assessed for a scenario 1997 and 2004 with regard to traffic volume, fleet mix, stand and runway allocation (even if some assumptions are rather hypothetical).

Table 4-1: Environmental benefits with shorter taxi-times

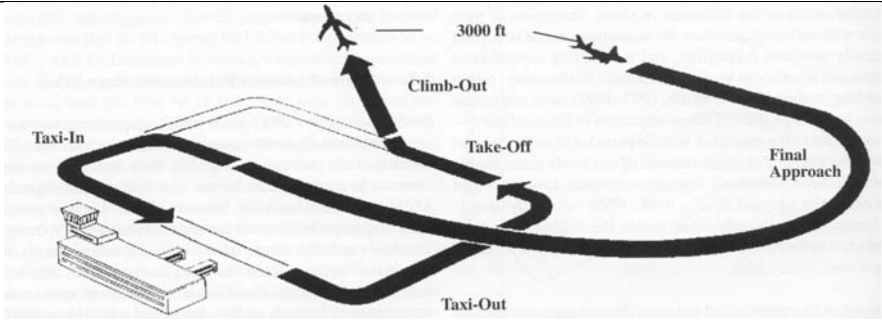
Scenario	**ΔNOx (t/a) taxi operation**	**ΔNOx (%) taxi operation**	**ΔNOx (%) ICAO LTO**
1997 traffic volume and fleet mix (technology); 1997 and 2004 stand and runway allocation	-17.1	-20%	-1.5%
2004 traffic volume and fleet mix (technology); 1997 and 2004 stand and runway allocation	-15.2	-19.3%	-1.5%

This measure has yielded an economic benefit of approximately 15t NOx, 13.5t HC and 11,400t CO_2 per year for the traffic volume of 2004.

4.2 Operational LTO Cycle

Emission inventories of aircraft in the vicinity of airports are traditionally calculated by using ICAO engine exhaust emission data and the ICAO reference LTO cycle, the latter sometimes adapted to airport specific taxi times. Initially intended for certification purposes, the LTO cycle cannot sufficiently take operational issues (de-rated take-off, climb profiles) into account (figure 4-2).

ICAO reference LTO cycle for engine certification: 4 phases with defined thrust and time in mode



Operational LTO cycle, reflecting today's operations with derated or reduced take-off

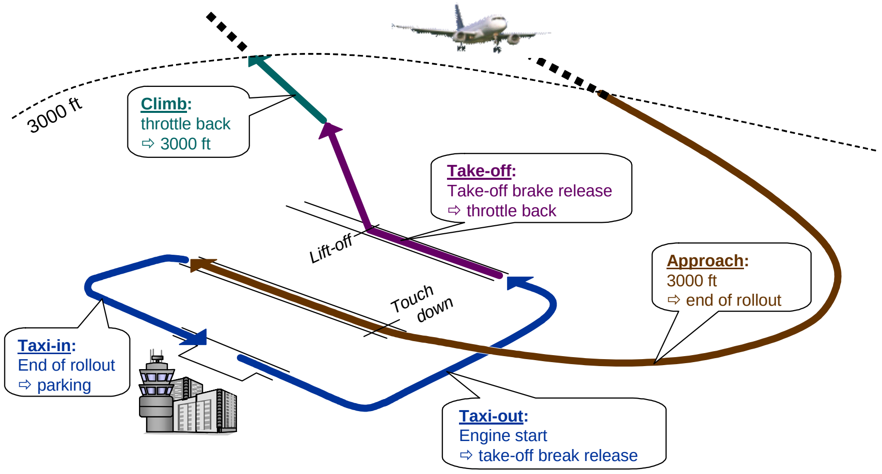


Fig. 4-2: ICAO reference and operational LTO Cycle

Using actual flight data information from 9 aircraft-engine combinations with thousands of movements operating at Zurich airport by several Swiss airlines and the ICAO guidance material to calculate fuel flow and emission factors at other then the four standard reference points in the LTO cycle, the operational effects have been assessed in a study in 2004. As illustrated in table 4-2, there are considerable differences that also include the more specific definition of the LTO modes (e.g. take-off is from brake release up to main engine throttle back at approx. 1,500 ft).

Table 4-2: Operational vs LTO cycle

Element	Take-Off	Climbout	Approach	Idle/Taxi	LTO-Cycle
Time in Mode	+130%	-77%	+10%	-43%	--
Fuel	+101%	-81%	-34%	-53%	-38%
NOx	+76%	-83%	-54%	-53%	-31%

(values: percentage in relation to ICAO LTO values)

The generic information obtained has been applied to all aircraft operations at Zurich airport.

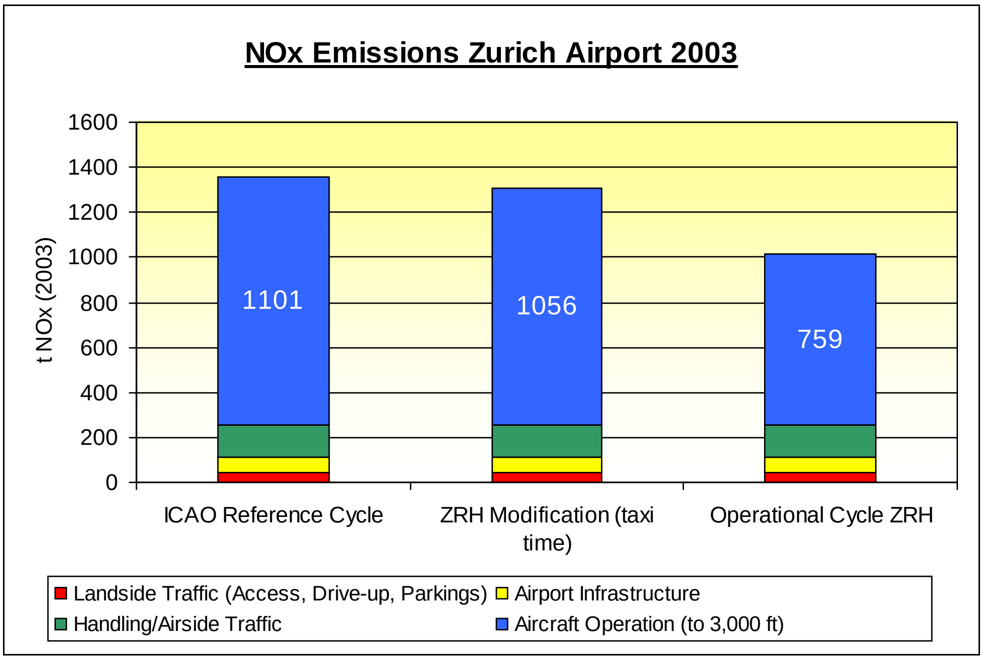


Fig. 4-2: NOx-Emissions Zurich Airport 2003 (134,650 aircraft cycles)

Operational NOx-emissions are significantly lower than the according reference cycle emissions and amount to 300 t in 2003. Further consequences will be seen when using the operational emission inventory as input into a dispersion model (with LASPORT being the standard for Zurich airport).

4.3 Improvement of Departure Sequencing (darts)

In order to optimize all operations at an airport, the organizations (air traffic control, airlines, handling agents) involved in the process have to be integrated in an overall operations planning system. Collaborative Decision Making (CDM) is the key to harmonise the aircraft turnaround process, to align all individual processes to a common target and therefore to improve the overall result. This is the goal of Delair's *darts* system, the Departure and Arrival Traffic Management System.

darts harmonizes air traffic operations at airports by implementing the following measures:

- Planning an optimum overall sequence of arrivals and departures early and in advance, so that better use of the runway system is achieved.
- Constantly comparing planned operations to current operations and initiating updates to the plan in the event of deviations, in order to present a realizable, optimal schedule at all times.
- Supplying relevant information for the respective work stations in due time for all organizations involved.

At Zurich, the system *darts* is operational in use since March 2003 and presently realised as a purely departure management system (DMAN). Based on the flight plan, the airport slot, the RWY concept, the restrictions and limitations of the airspace, the wake turbulence category, the a/c speed class and the departure fix, the system calculates the best possible take off time. According to the start up and/or pushback times, the taxi times from the stand to the RWY, the system calculates the adequate off block time. With this method a continuous flow of traffic on the taxiways is granted. The queuing of a/c on the taxiways waiting for departure is downsized to the minimum. *darts*' planning results are suggestions which the controllers can accept or modify by means of corresponding input devices. Changes to planned operations automatically result in the plan being updated and new data being transmitted to every connected system.

The system *darts* is designed as a cooperative arrival and departure planning system (AMAN / DMAN) for calculating the ideal arrival and departure sequence, and the resulting optimum landing and take-off times. This will be the future of *darts* here at Zurich Airport.

The environmental benefit of darts has been evaluated by assessing the "artificial" delay caused by the system, i.e. the time that aircraft have been kept waiting with their engines turned off rather than have them waiting queued with engines at idle. Given the different operating regimes (summer, winter, snow/ice operations, limited visibility and strong Eastwinds), the total darts attributable delay time is estimated to about 1,740 hours for 2004. Reflecting the current fleet mix and technology, a total of 1,150 t of fuel, 4.2 t NOx, 4.0 t HC and 33.7 t CO has been saved on emissions.

5 Discussion of not Relevant or Realised Measures

5.1 Reduction of Reverse Thrust Deployment

Reverse thrust is often used after touch-down while rolling out on the runway. The reverse thrust level and the reverse thrust duration is determined by factors such as aircraft weight, touchdown speed, wind and braking coefficient. Unique, the operator of Zurich airport, has issued regulations pertaining to the use of thrust reverser:

> **Operating Manual**
>
> **Art. 35**
> When using engine reverse, idle thrust may only be exceeded if this is unavoidable for operational or safety reasons.

The decision however, how to apply reverse thrust, remains with the pilot in command. A study done in 2005 at Zurich airport showed reverse thrust deployment at idle for durations of between 60%-75% of the time from touch-down to end of roll-out. Using the initial maximum engine power for changing to reverse thrust for calculation suggests NOx emissions of about 1% or approximately 4 t NOx/a. Given, however, that only idle thrust is permitted which equals regular taxi thrust and emissions, the actual NOx emissions are only approximately 0.1% of the LTO emissions (< 1t/a).

5.2 Operational Aircraft Towing

Operational towing is the procedure when aircraft ready for departure are not only pushed back from their parking position to a taxiway, but are actually towed all the way to the departing runway threshold where they would start-up the main engines. A feasibility study done at Zurich airport in 1992 concluded that with some minimal environmental benefits, technical, legal and operational aspects prevent operational towing on a regular basis.

- <u>Environmental benefits</u>: A benefit of 1%-2% less NOx (8-15 t/a) has been calculated for the traffic volume in 1990. For HC, the benefits are quite significant but have been reduced since 1990 by continuously improved engine technology that yields considerably less HC and also CO emissions.
- <u>Technical Aspects</u>: Aircraft noise gear structures are designed for full load push-back or maintenance towing with low aircraft weights. Operational towing would include modifications in the noise gear and require the manufacturer's certification.
- <u>Legal Aspects</u>: An aircraft tug together with an aircraft forms a convoy that is lead by the tug driver with or without additional guidance by apron control. Responsibilities and liabilities have to be redesigned for these convoy operations.

- Operational Aspects: The longer towing operations require more aircraft tugs, improved mission control and additional service roads to bring the tugs back to the gates.

In the meantime, the average taxi-out times have decreased as well with concourse E and the darts system now in operation. Thus the benefits are even smaller and don't justify the necessary investments.

5.3 Taxiing with fewer than all Engines Operating

Aircraft usually taxi self powered with their main engines on low thrust levels. Taxiing with fewer than all engines operating suggests that one ore more engines are being shut down either during taxi-out (gate to runway threshold) or taxi-in (runway to gate).

A survey by IATA conducted in 2005 showed that the majority of the responding airlines had a reduced engine taxi procedure in place, but that it was operationally restricted or did not apply to the entire fleet. Whether or not this operational measure is applied depends on airline and aircraft operating procedures and on the captain's discretion.

Some of the reasons indicated also apply in particular for Zurich airport:

- Engine Cool-Down Requirements: Several aircraft types require a 5 minute warm up and a 3 minute cool down. With taxi times now being shorter, it becomes operationally impractical to reduce the number of operating engines (e.g. RWY 14 to concourse E or concourse E to RWY 28).
- Limiting Turning Radius on Taxiways: Some taxiway routes have sharp turns and for aircraft with wing-mounted engines, in particular, it becomes difficult to turn an aircraft without excessive thrust on the operating engine(s) (fig. 5-1).
- Weather: In heavy snow or freezing rain, all engines may need to be operational to keep the engines free of ice.
- Manufacturer Limitations: Large aircraft, like the B777, cannot use single engine taxi operations under normal conditions according to the manufacturer recommendations.

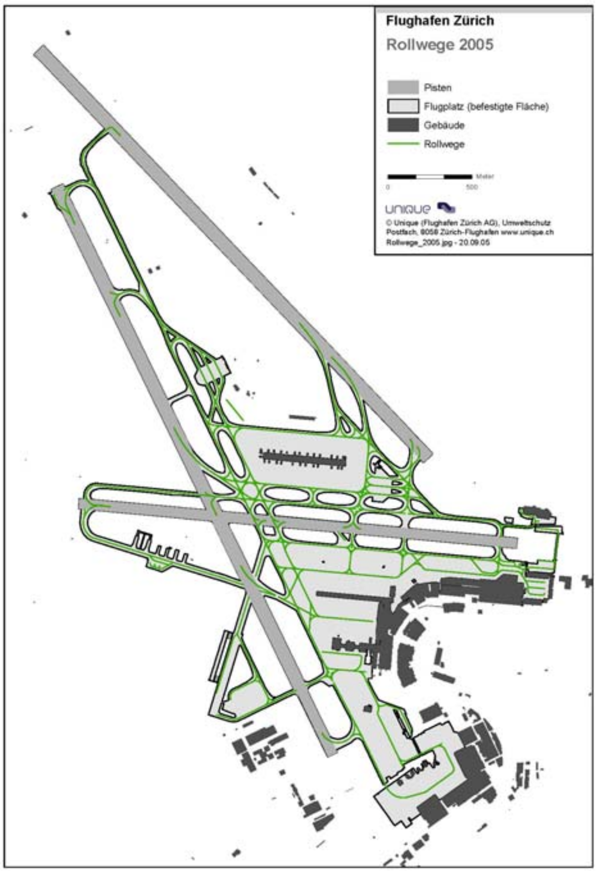


Fig. 5-1: Layout of taxiways in 2005

Nevertheless a reasonable model calculation was performed for 2004. It was assumed that all aircraft equipped with four engines would turn two engines off during taxi-in from the runway to the assigned gate (B-747, A340, B146/RJ). This would have saved approximately 0.7 t of NOx in 2004.

5.4 Preferential Stand Allocation

A potential measure could be to always park aircraft at positions that are as close to the departing runway as possible to minimize taxi-times. Consequently, this should also be applied to incoming aircraft that would be led to a parking position close the runway after the end of rollout. For a number of reasons, the optimized stand allocation cannot be implemented to a degree that would yield significant environmental benefits.

- Different RWY use: The assigned landing runway and the later assigned departure runway not always provide an optimum for both arrival and departure operations. Example: Landing RWY 14 can be optimised with gate at concourse E (North side) but this position then not with e.g. departure RWY 34.
- User concepts: Airlines today operate in alliances where different airlines work together for improved passenger services. This can result in aircraft being parked at adjacent parking positions or at the same stand group even if some of the operations require longer taxi routes.
- Handling efficiency: Handling agents can increase their handling efficiency by having their necessary handling equipment close to the aircraft parking positions in use. Moving the equipment across the aircraft operating area for only few individual operations could lead to a trade-off with increased handling emissions.

- Aircraft type: Certain aircraft types, due to their size, cannot be parked at pier gates even if they were available and preferential for taxiing reasons. They may be parked at more remote positions.

However, the preferential stand allocation is frequently done outside peak hours (e.g. in the evenings, when the aircraft is parked over night) to speed up the handling process and avoid long taxi-times. The aircraft would then be towed to the departing stand later (maintenance towing). The environmental benefits overall marginal with approximately 0.2t NOx/a (assumption of four small jets daily with 1.5 minutes less taxi-in time).

6 Conclusions

Detailed analysis shows that there is a certain potential at airports to reduce emissions from aircraft engines at ground. This potential, however, cannot always be fully exhausted. Some measures can be realised, leading to environmental benefits.

It has to be recognised that the evaluation of not implemented measures are based on the specific situation at Zurich airport. The airport layout with runways, taxiways and terminals might prevent measures that else are technically feasible and ecologically beneficial. This implies that some of the discussed measures could well (and successfully) be implemented at other airports.

The total emission reductions from actual and implemented operational measures for aircraft at ground are estimated at 20 t NOx per year (2 % of the total aircraft emissions in the LTO cycle in 2004).

7 Annex

7.1 Abbreviations

AIP	Aeronautical Information Publication
CO	Carbon Monoxide
DARTS	Departure and Arrival Traffic Management System
FOCA	Federal Office for Civil Aviation, Bern, Switzerland
HC	Hydrocarbons
IATA	International Air Transport Association, Generva
ICAO	International Civil Aviation Organisation, Montreal
LTO	Landing and Take-off Cycle
NOx	Oxides of Nitrogen
PM	Particulate Matter
RWY	Runway
TWY	Taxiway

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