Innovative Cooperative Actions of R&D in EUROCONTROL Programme CARE INO III

Dynamic Cost Indexing

Progress Report (Deliverable 1)

Project led by: Transport Studies Group
University of Westminster

In partnership with: Centre for Transport Studies, Imperial College London
Lufthansa Systems Aeronautics

Report prepared: 26 October 2007

Version: 1.0
Please note

As stated in our proposal, this report (Deliverable 1) is designed to illustrate progress to date on the project, also presenting the draft system architecture, the draft interface definition and the draft database design. It will be added to and updated, where necessary, in Deliverable 2: the paper to be presented at the 6th EUROCONTROL Innovative Research Workshops & Exhibition, 4-6 December 2007, EUROCONTROL Experimental Centre (due for submission by 15 November 2007).

Where planned or potential updates due (next month) are known, these are flagged in the text. We respectfully reserve the right to make other changes. A summary of next steps is given in section 3.

Other outputs in Year 1 are listed in Appendix 2.
CONTENTS

1. PROGRESS DURING YEAR 1 ................................................................. 4

1.1 PROJECT MOTIVATION ..................................................................... 4
  1.1.1 Overview ..................................................................................... 4
  1.1.2 Introduction to the Cost Index ..................................................... 4
  1.1.3 Immediate benefits for airlines .................................................. 5
  1.1.4 Environmental benefits ............................................................... 6
  1.1.5 Datalink context ......................................................................... 7

1.2 METHODOLOGY .............................................................................. 8
  1.2.1 Airspace procedures .................................................................... 9
  1.2.2 Aircraft performance ................................................................. 11
  1.2.3 Cost to airline ............................................................................. 12
  1.2.4 Environmental impact ................................................................. 15
  1.2.5 Integrating emissions into flight planning ..................................... 16

2. DISCUSSION ..................................................................................... 19

2.1 SUMMARY OF TWO AIRLINE CASE STUDIES ................................. 19

2.2 DISCUSSION OF WAY FORWARD — PLANS AND CHALLENGES ....... 20

3. NEXT STEPS .................................................................................. 22

REFERENCES ..................................................................................... 23

APPENDIX 1: PROGRESS IN YEAR 1 .................................................. 24

APPENDIX 2: KEY OUTPUTS IN YEAR 1 ............................................ 26
1. Progress during Year 1

1.1 Project motivation

1.1.1 Overview

The research project described in this report develops the concept we describe as ‘dynamic cost indexing’, which encompasses the ability to manage delay costs for any given flight on a dynamic basis, i.e. in an operational context whereby the cost of a delay varies according to the magnitude of the delay and also strongly as a function of other temporal factors such as passenger connectivities.

The project has two parallel objectives. These are to:

- map the types of data which are required to build a generic, ideal dynamic cost indexing (DCI) tool, including the framework for exchanging such data
- start building an operational prototype tool within an advanced, existing flight planning software application

By describing and mapping the general model, the objective is to enable airlines to build their own solutions, or improve existing ones. By building an operational prototype, in parallel, the objective is to establish proof of concept and ensure that a practical focus is maintained. The prototype will be built as a module within Lufthansa Systems Aeronautics “Lido OC” flight planning suite.

The DCI framework developed as part of this research also encompasses environmental costs (such as emissions related charges or permits) and impacts (such as contributions to climate change). This will future-proof the DCI concept by ensuring that evolving charges and/or permit schemes may be integrated seamlessly into the both the general model and the prototype.

1.1.2 Introduction to the Cost Index

Cost Index (CI) settings vary from manufacturer to manufacturer. Common ranges are 0 to 99 (e.g. Smiths), or 0 to 999 (e.g. Honeywell). The lowest value causes the aircraft to minimise fuel consumption and to maximise range. High values cause the FMS to minimise flight time, regardless of fuel cost. In this sense, a low value assumes the cost of time is low and the cost of fuel is high, and vice versa for a high value. The Cost Index is the cost of time divided by the cost of fuel, multiplied by a scalar:

\[
CI = \frac{C_{\text{time}}}{C_{\text{fuel}}} x k
\]

\[
C_{\text{time}} << C_{\text{fuel}} \Rightarrow CI \approx 0
\]

\[
C_{\text{time}} >> C_{\text{fuel}} \Rightarrow CI = [\text{max}]
\]
In the context of delay recovery, the 'cost of time' may more usefully be thought of as the 'cost of delay'. CI units are kg/min or 100 lb/h, but are often omitted due to the scalar issue: it is more useful to refer to the generic values CI₀ and CIₘₐₓ, representing maximum fuel conservation and maximum delay recovery (minimum flight time), respectively. The optimal cost solution, taking into account the trade-off between the cost of delay and the cost of fuel, usually lies somewhere between CI₀ and CIₘₐₓ.

A flight is often delayed before push-back. Pre-departure delay recovery is an important tool for airlines, often referred to as slot management. The most common method is by re-routeing on an alternative route, with the advantage of an earlier slot but usually at the cost of incurring greater fuel burn.

A very similar trade-off exists once the aircraft is airborne. To recover delay, increased fuel burn could be used (employing a higher CI setting in the FMS) and/or a change could be requested of ATC for a more direct route. Corresponding measures could be applied to slow down and conserve fuel. More details on this will be given later.

Despite the similarities in these methods of delay recovery, it is important to note three key aspects regarding airborne recovery:

- the fuelling decision has already been taken
- it must start early in the flight to be effective
- it is usually dependent on ATC acceptance (often a limiting constraint)

### 1.1.3 Immediate benefits for airlines

Whilst fuel prices are accurately known by airlines, the other part of the CI ratio, the true cost of delay, very often is not. CI values used by airlines are, in many cases, based on very limited supporting cost of delay data. Many airlines will readily concede that the way in which delay recovery decisions are made can be fairly arbitrary, or based on crude rules of thumb, such as pursuing all slot delays greater than ‘x’ minutes, or using a fixed CI value for all intra-European flights, with only irregular adjustments for changing fuel prices, or even none at all. This is because airlines very often do not have the tools or resources to accurately calculate these costs. Echoed later by Boeing (2007), much of earlier commentary made by Airbus (1998) is still just as true today:

Much progress could be obtained by having airline accountants look into the other time-related costs also. In practice, however, it has been hard for flight operations departments to persuade their airline financial analysts into assessing marginal operating costs. This is probably because the latter have not yet integrated the importance of the cost index itself, largely an unknown concept to their decision-makers ... A large variation exists in how airlines actually use the cost index : some of this variation is related to specific operator requirements, some of it may reflect difficulties with the concept that may lead to inappropriate application.

However, it should be stressed that a range of airline operational practice does exist, with some airlines notably more advanced than others. A few already have tools for dynamic delay cost estimation, but even these would not claim that there is not room for significant advance in this area. Through previous research undertaken by the University of Westminster, and at a dedicated open-invitation CI technical meeting held in Frankfurt in August 2007 as part of this project, the views of a number of airlines have been considered in this context. There was strong support at this meeting, and at a subsequent Lido OC user
conference in Berlin, in September 2007, for further development: equally to support airlines just starting to use cost indexing, and for those wishing to strengthen existing tools. Many airlines have a significant barrier to identify which costs should be included in 'cost of time' and how to quantify them. In addition, the absence of industry standards for defining and interfacing such tools has been highlighted.

This project is committed to tackling these problems and sharing the results with the airline community, from whom invaluable feedback and support are welcomed and gratefully acknowledged. An overview of two more advanced cases of operational practice is given in section 2.1.

1.1.4 Environmental benefits

As the political position relating to emissions charges remains uncertain, this project aims to deliver a flexible framework in this context, which will serve two main purposes:

- to ensure that both the DCI general model and prototype remain useful and relevant should emissions related charges or permits be introduced
- to allow airlines to consider emissions in their decision-making process in response to delay, allowing them to monitor how this affects such emissions: which may become particularly relevant for airlines wishing to use good environmental practice as a marketable competitive advantage (an aspect of emerging importance to many airlines)

The inclusion of environmental costs has a strong link with the vision for an ultra green air traffic system in 2020, set out by the Advisory Council for Aeronautical Research in Europe (ACARE, 2004). This vision sets out specific targets for improved environmental performance by airports, aircraft, airlines and air traffic management. For ATM, the vision includes the use of 'green routes or areas', to provide an incentive for aircraft to be equipped with improved environmental technologies. The vision also includes the specification of an 'environment signature' for each aircraft to be included in flight plans and regionally, or centrally, environmental impact assessments to compute optimised 4D trajectories. By including emissions, the framework developed in this project will contribute to the realisation of this vision. It offers an environmental decision support tool for airlines, which could be used as a differentiating technology required for access to designated 'green' airspace. The framework combines an 'environment signature' with airline costs, providing valuable support for collaborative decision-making between airlines and air traffic management both pre-tactically and during flight, allowing both environmental and economic impacts to be considered.

The development of these types of decision support tools to enable cost-effective optimisation of environmental performance could also contribute significantly to the SESAR objective of reducing the environmental effects of flights by 10%, specifically by addressing excess fuel consumption (SESAR Consortium, 2006). Such considerations relating to fuel burn could, in particular, be related to:
- assessment of route extension fuel penalties to reduce slot delays

- avoidance of unnecessary (and costly) extra fuel burn to recover delays which are not financially worth recovering (e.g. those with few connecting passengers on the delayed airborne flight and/or where the connecting flights at the destination are already also delayed)

- accelerated fuel burn offsets from the potential for reducing off-stand holding at airports by freeing waiting aircraft from gates, thus improving local air quality

### 1.1.5 Datalink context

This project also assesses how the technology of datalink might be used more in the facilitation of DCI. Datalink is already used by Lido OC to send a variety of messages to the cockpit, including FPLs, NOTAMS, CTOTs and free text. Direct changes cannot be poked to the FMS, i.e. the pilot has to select ‘[ACCEPT]’ to uplinked messages to pass them into the FMS. This would apply to FPLs or proposed CI changes, for example. Due to FMS memory constraints\(^1\) on the number of routes which may be stored, it is often very useful to send a new FPL to the cockpit in this way.

Datalink also plays a central role in Lido OC’s flight-watch tool, ‘AeroView’, for dynamically monitoring the progress of flights. AeroView automatically sends (uplink) messages requesting position, altitude and remaining fuel data which generate automatic (downlink) replies, i.e. without pilot intervention.

Furthermore, datalink is also a key mechanism for airlines to receive information pertaining to aircraft intent, which is an important consideration in the DCI context. If a change to the planned flight profile is instigated by either independent pilot request or by ATC, the airline’s operations control will not ordinarily be aware of this (see section 1.2.1) unless the pilot informs them, usually by a downlink message.

Whilst ACARS is mostly used off-gate, the at-gate analogue, ‘gatelink’, is a two-way ground/ground communication link based on standard IEEE\(^2\) protocols, e.g. over a wireless local area network (WLAN). Once connected at the airport (typically within a range of 100 metres of the gate), the cockpit becomes a node on the airline’s IP-based network, with a high rate of data transfer (often several hundred times faster than ACARS).

Not all airlines are currently exploiting these technologies. In section 2.1, where two airline cases are overviewed, the use of datalink will be looked at in the context of operational practice.

---

\(^1\) Such constraints may currently be overcome by using Electronic Flight Bag applications, some of which may still run on stand-alone devices (such as laptops) in the cockpit.

\(^2\) Institute of Electrical and Electronics Engineers.
1.2 Methodology

Figure 1 illustrates the relationships, in a simplified way, between the various elements of delay management. Cost to the airline is clearly a key element: the more costly a particular delay, the more effort the airline will be willing to expend to resolve it. The ability of given aircraft to recover from delay is based on both the aircraft’s performance characteristics (e.g. how fast it can fly) and the airspace procedures (e.g. what ATC will allow). The darker solid lines represent strong interactions: it is clear, for example, that both aircraft performance characteristics and airspaces procedures affect the environmental impact of the flight.

Figure 1. The wider context of delay management

Currently, the interaction between airline costs and environmental impacts are weak (represented by the lighter, dashed line), but this situation is likely to change. Exogenous factors such as technology and policy affect the upper three elements. Policies such as military access to airspace, and indeed, environmental considerations, determine airspace procedures to a considerable degree. External policies such as EU compensation regulations for delayed passengers, along with internal airline policies on crew remuneration, determine the actual cost of a delay to the airline. Acting as a ‘cement’ between these elements is data exchange.

In specific terms of DCI, three primary aspects may be considered:

- **aircraft performance**
  - communications with the aircraft, e.g. ACARS message to speed up / slow down
  - operational capability of the aircraft to adapt speed

- **cost to airline**
  - internal data management, e.g. on predicted passenger missed connections

- **airspace procedures**
  - ATC/ATM communication, e.g. to facilitate delay recovery
Whilst Figure 1 is primarily illustrative in nature, it serves to show the important elements of DCI which need to be considered as a whole. The desire to avoid incurring costs is a primary driver of AO behaviour. Actions taken to recover such costs are constrained by both aircraft performance and airspace procedures. Data exchange is a primary enabler of delay recovery, without it, neither the true costs of delay can be computed, nor is there any means to manage the delay. As a consequence of the way the delay is managed, different environmental impacts result. The coupling between this impact and the associated cost to the airline is set to become stronger.

A DCI tool which does not fully consider the wider operational constraints, and which is not in an adequately integrated data environment, will not work. These four elements are discussed in turn, in the following sections.

1.2.1 Airspace procedures

Dynamic cost indexing relies on being able to vary aircraft speeds to arrive at the destination at economically optimised times. To understand two constraints on this process, it is necessary to establish the context of both airspace procedures (current practice and restrictions) and aircraft performance (the capability of speeding up or slowing down, for example).

Whilst arrival management in TMAs is frequently achieved through the use of speed control, usually in combination with heading and altitude constraints, en-route separation is normally managed in European airspace through these latter two alone (be that through the airways structure or controller instruction). The focus of attention in the context of delay recovery is on the en-route phase, for two reasons. Firstly, this is the longer phase in the vast majority of cases; it is difficult to achieve large alterations to the arrival time during the more limited time the aircraft is in the TMA. Secondly, other pressures – not least separation and runway management – are more severe in the TMA.

In the en-route phase, speed control is less favoured probably because it requires higher controller monitoring. As EUROCONTROL’s Performance Review Unit (2005) point out, whilst en-route sequencing is common practice in the US\(^3\), it is hardly ever used in Europe. Where it does exist, this is on the basis of bilateral agreements between neighbouring ACCs. Ehrmanntraut and Jelinek (2005) report that the effect of speed control to resolve aircraft conflicts has not been well described in the literature, and although speed control may be used in conflict resolution, only very rarely do clearances in Europe involve speed in upper en-route sectors. Their paper further states, however, that “speed manoeuvres have a very high potential for [multi-sector planning] ... by applying very low speed adjustments”. From RAMS (Reorganized ATC Mathematical Simulator) computations, it goes on to conclude: “Best results are achieved when ... one [controller] applies speed and the other one a horizontal manoeuvre”.

In terms of speeds adopted by aircraft, an analysis by Lenka (2005) shows considerable homogeneity of ranges:

---

\(^3\) Known as ‘Miles in Trail’ – the distance required between consecutive aircraft on a given flow, usually to the same destination.
... 89.8% of the CEATS [Central European Air Traffic Services] traffic prefers 10 different speed ranges out of proposed 36. The most preferred speed range 446-450 NM/h is used by 1500 aircraft representing 29% of the traffic, followed by 857 aircraft (16.5%) with the speed between 456-460 NM/h and 685 aircraft (13.2%) with the speed between 426-430 NM/h. These three speed ranges show high potential to be assigned to the inbound traffic for synchronization purposes.

In terms of operational variances for given aircraft, Averty et al. (2007) suggest that controllers are typically exposed to such variances of +3% to –6% (more usually only ±3%, in fact) and that such orders of change impose no significant increase in perceived controller workloads and remain largely unnoticed in normal conditions, citing Ehrmanntraut and Jelinek (2005a), these authors go on to comment that:

... between FL320 and FL400, speeds are very homogeneous: all aircraft flying within this altitude range have a cruise speed between 430 and 470 kts

Evidence therefore suggests that the typical speed variances to which controllers are exposed are relatively low. Indeed, Averty et al. (2007) further comment that:

... ATCOs are not expected to monitor accurately/specifically speed changes, as these rarely vary as long as aircraft maintain their cruising altitude (en-route airspace). Such changes occur in relation with a few specific events (head or tail winds, turbulence, etc.)

Controllers can call up flight plan data with the planned speeds of aircraft entering their sector and check by RT if the (ground) speed appears to be inappropriate. However, the controller’s focus of attention will be on separation, such that whilst this looks secure, speed variations of the order referred to above are unlikely to be noticed. As mentioned, this is made less of a critical issue by the fact that aircraft on the same cruising altitudes tend to be operating at rather similar speeds.

In terms of en-route aircraft actively wishing to change speed, regulations (ICAO, 1990) specify that if the average TAS⁴ at cruising level between reporting points varies, or is expected to vary, by ±5% or more of the speed declared in the flight plan, this should be notified to ATC. (Such regulations refer to “inadvertent changes”, which has caused some confusion, as discussed in section 2.2). In such cases either a manual adjustment would then be made by ATC in the Flight Data Processor, or, for more advanced systems, this would be automatically detected by the system which would also recalculate the internal flight profile.

For long-haul flights from the IFPS Zone, for example to the US⁵, FPLs are normally filed well in advance of the Scheduled Time of Departure (STD), to avoid ‘late-filer’ status, such that by the time the aircraft is airborne, en-route conditions may well suggest a better routeing (in addition to, or instead of, a speed change). In this case, the airline may request ATC to file an air-filed flight plan (AFIL⁶) on their behalf. Usually, however, the intent to change a flight plan en-route is driven by ATC itself. Instruction is passed by ATC to the aircraft by RT, or, increasingly via ACARS, then it sends an AFIL to IFPS⁷.

---

⁴ True Air Speed.
⁵ Eastbound transatlantic flights are not subject to ATFM regulations, since the departure airports are outside the IFPS Zone, although some flights from outside this Zone may still be subject to ATFM slot allocation.
⁶ AFIL: a flight plan submitted to IFPS on behalf of an airborne aircraft by an ATS unit (controlling the aircraft at that time, or into which airspace the aircraft wishes to fly). If instigated by the airline, it first sends this normal-format flight plan message to ATC (e.g. from Lido OC). The departure aerodrome text is replaced by “AFIL”.
⁷ In fact, only to IFPS, such that the airline is often unaware of this, which can be problematic. These changes are often driven by CFMU requests, for ATFM purposes.
1.2.2 Aircraft performance

As already discussed, the minimum cost solution for a given flight lies somewhere between CI\(_0\) and CI\(_{\max}\). The question then arises as to the relationship between CI\(_0\) and CI\(_{\max}\) and the minimum and maximum speeds of the aircraft. In other words, how tightly does the CI\(_0\) – CI\(_{\max}\) envelope sit within the performance envelope of the aircraft? This envelope is defined by V\(_{MU}\) and V\(_{MO}\) which are, respectively, the minimum and maximum operating speeds of the aircraft, signifying limits which should never be disregarded\(^8\).

Figure 2. The wider context of delay management

Furthermore, in order to set DCI into its en-route context, it is necessary to quantify the performance envelope itself in terms of the speed changes available to aircraft at typical cruise levels. Reference to Jenkinson et al. (1999) suggests values in the range of 5 - 7\%. Based on EUROCONTROL’s ‘Base of Aircraft Data’ (‘BADA’), Ehrmanntraut and Jelinek (2005) used speed variances of up ±7.5\% in their RAMS simulations. Our calculations, also based on a range of BADA aircraft, gave very similar results at cruise levels, with much higher envelopes at lower altitude, as indeed also shown by Ehrmanntraut (ibid.).

In terms of the ‘inner’ Cost Index envelope, Airbus technical documentation (Airbus, 1998) shows that CI\(_0\) and CI\(_{\max}\) correspond pretty closely to V\(_{MU}\) and V\(_{MO}\), respectively. In practice, the speed used for flight planning with CI\(_0\) is usually a little above V\(_{MU}\) (because V\(_{MU}\) is too unstable to operate at, e.g. in turbulence) and CI\(_{\max}\) is a little below V\(_{MO}\) (because V\(_{MO}\) actually results in a very high rate of fuel burn with approximately no gain in speed, relative to a value just below it). Boeing (2007) uses very similar settings.

CI values not only affect speed, but other performance characteristics, such as turning and climbing. Higher CI values (assuming time is more important than fuel burn) produce higher speeds during climb, with a shallower climb path resulting in Top of Climb being further out, although it is reached slightly sooner. Conversely, Top of Descent occurs later.

It is important to note, however, that airlines do not usually use the full CI envelope, as touched upon above. This is due to a steeply diminishing return on fuel burn with respect to time saved at high CI values, plus the negative effects of increased cockpit and cabin noise at such higher speeds, which reduces both passenger and crew comfort. For these reasons, airlines usually define a limiting CI value for their operations, which will vary by aircraft type. In practice, very low values of CI are also normally avoided, due to negligible

\(^{8}\) All four of these parameters are also a function of weight, altitude, temperature and wind.
differences in fuel consumption for non-negligible flight time reductions. CI₀ is normally only selected if there is an abnormal fuel concern.

At optimum flight levels, Airbus data (ibid.) suggest working speed envelopes of 4-6%, making the following useful summary points regarding altitude and weight (author’s emphases):

... ECON speed is very sensitive to the cost index when flying below optimum altitude especially for low cost indices, a sensitivity effect which is rather reduced around and above optimum flight level.

... ECON cruise Mach stays fairly constant throughout the flight for representative cost indices ... as well as for representative weights and flight levels.

Having established the operational context of the Cost Index within aircraft performance parameters, the main driver of delay costs – delayed passengers – is assessed in the next section. Other airline costs will be addressed within the scope of this project, but passenger costs are the Year 1 focus in this respect.

1.2.3 Cost to airline

Passenger costs resulting from air transport delays fall broadly into three categories:

- ‘hard’ costs borne by the airline (such as rebooking and compensation costs)
- ‘soft’ costs borne by the airline (such as loss of market share due to passenger dissatisfaction)
- costs borne by the passenger, not passed on to the airline (e.g. potential loss of business due to late arrival at a meeting; partial loss of social activity)

The latter category is not of direct concern to this research, since it is internalised by the passenger. The objectives of this study are only to quantify those passenger costs which directly impact the airline. Indeed, the inclusion of these costs is at best rather arbitrary and can lead to highly inflated generalised cost estimates if not treated with caution.

Of the two categories borne by the airline, both are difficult to assess. The ‘hard’ costs are difficult to compute due to the problems involved in integrating the necessary data. It is an objective of this research to resolve this as far as possible.

‘Soft’ costs are problematic to quantify because of the number of complex assumptions which must be made when modelling them, plus their strong dependence on market conditions (such as service availability and price structures). By the end of this study, a crude methodology will be suggested to enable airlines to estimate and adjust these costs according to different operational assumptions.

Returning to the ‘hard’ passenger delay costs, these refer to actual, measurable, bottom-line costs incurred by an airline as a result of delayed passengers, such as those due to: right of care (under Regulation (EC) 261/2004), re-booking / re-routeing costs, and compensation.
Figure 3. Example of dynamic pax data required by flight

Notes
Example data only. All costs in Euros. All times local.
MCT = Minimum Connect Time
FFP = Frequent Flyer Programme (Regulation 261/2004 applies to 'free' tickets issued under such schemes - see Article 3)
Lufthansa Miles & More levels: Member (MMM), Frequent Traveller (MMFT), Senator (MMS), HON Circle (MMHC)

Figure 4. Delay cost scenario decision tree: example of static pax data required
In order to assess these costs fully it is necessary to have access to both the data in Figure 3 for any given flight, on a dynamic basis, and also, for the same passengers, to be able to populate the (mostly) static decision tree in Figure 4, which is both a function of airline policy and EU law (Regulation (EC) 261/2004). Figure 4 is structurally based on the Regulation, which came into force on 17 February 2005: it only relates to departure delay (nothing is legally due to the passenger for any type of arrival delay *per se*), denied boarding, and cancellation. It confers passengers with rights only at the point of departure.

From the perspective of Regulation (EC) 261/2004, nothing is due to a passenger as a result of a missed connection *per se*. Therefore, with a Lufthansa conjunction ticket JFK-FRA-CDG, nothing would be due as the result of a late arrival at FRA, even if the connection is missed, except:

**Table 1. Example of passenger rights according to Regulation (EC) 261/2004**

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>In which case the passenger would not even be on the JFK-FRA segment</th>
<th>In which case the cost would be attributable to the FRA – CDG segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>If the JFK – FRA flight is delayed by five hours or more and the passenger decided not to fly on it (in which case a reimbursement would be due, and a flight back to the point of origin – i.e. the passenger was connecting at JFK)</td>
<td>In which case the passenger would not even be on the JFK-FRA segment</td>
<td>In which case the cost would be attributable to the FRA – CDG segment</td>
</tr>
<tr>
<td>Case 2</td>
<td>‘Right of care’ (e.g. a meal) at FRA, if the CDG flight itself was delayed by two or more hours (i.e. nothing is due to the passenger specifically on account of arriving late in FRA)</td>
<td>In which case the passenger would not even be on the JFK-FRA segment</td>
<td>In which case the cost would be attributable to the FRA – CDG segment</td>
</tr>
<tr>
<td>Case 3</td>
<td>If the FRA – CDG flight was delayed by five hours or more and the passenger decided not to fly on it (in which case a reimbursement would be due, and a flight back to JFK)</td>
<td>In which case the passenger would not even be on the JFK-FRA segment</td>
<td>In which case the cost would be attributable to the FRA – CDG segment</td>
</tr>
</tbody>
</table>

Figure 4 can also be used to understand departure delay without any connecting flight, by following the left-hand side of the figure. Grey text (centre) means that a right is not afforded by Regulation (EC) 261/2004 as a result of delay. It is to be noted that no additional compensation *per se* (i.e. above reimbursement) or re-routing is required by the Regulation as a result of any amount of delay. This again emphasises the need to integrate ‘company’ policy into this scheme, in particular:

- compensation policies
- re-booking policies and, taking Lufthansa as an example, how these vary:
  - internally (whether allocated at zero cost for LH – LH re-booking)
  - within STAR alliance (e.g. special arrangements with SAS)
  - with other carriers (typical costs; any special arrangements by route / ticket class)

Such static data could be integrated with the dynamic data of Figure 3 to build a continuously updated estimate of the current cost of the unrecovered delay. Figure 3 shows that with the current arrival delay of 90 minutes, an estimated total of € 12 077 passenger delay costs would be incurred. Data flagged red in the ‘MCT’ and ‘connex flight DLY’ columns indicate a missed connection. It is noteworthy that this design allows the airline to set different policies for different passengers, for example by giving special care to the high-yield and/or higher status frequent flyer programme members. This does indeed happen in practice; several airlines have the capacity to differentially and dynamically track a problem with a delayed high-status passenger – some can even determine if the same passenger has recently suffered a delay on one of its services.
Further practicalities of this approach will be explored later in this report. For now, it is important to identify the importance that: proper consideration is given to the decision windows involved in delay recovery (it is obviously too late to recover a delay in the final stages of a flight); data on connecting flight status may not be available; the database(s) must protect confidential airline data such as fuel prices and special compensation policies. It is also important to note that there will very often be no economic advantage to recovering the entire delay: allowing say five minutes to persist will often not incur any (significant) airline costs but will save unnecessary fuel burn.

1.2.4 Environmental impact

Carbon dioxide

Once emitted, carbon dioxide remains in the atmosphere for hundreds of years and becomes uniformly mixed by atmospheric motion. As a result, the climate impact of 1 kg of emitted CO$_2$ does not depend on the altitude or location of emission. The amount of carbon dioxide emitted by combustion of fuel depends only on two factors, the carbon content of the fuel, which for kerosene is typically 71 500 kg/TJ (IPCC, 2006), and the amount of fuel burned. This allows fuel consumption to be used as a direct indicator of carbon dioxide emissions. The main institutional mechanisms for regulating carbon dioxide emissions from aviation are the Kyoto Protocol and the proposed extension of the EU Emissions Trading Scheme to include air transport.

The Kyoto Protocol requires that domestic aviation be included in national carbon dioxide emission inventories and in emission reduction targets for Annex 1 signatory countries. Emissions associated with fuel sales for international flights are reported separately. These emissions are excluded from national reduction targets under the terms of the Protocol, which instead called for action to be pursued through the mechanisms of the International Civil Aviation Organization (United Nations, 1998).

In December 2006, the European Commission issued a proposal for legislation to bring aviation into the European Emissions Trading Scheme (European Commission, 2006). The proposed design would impose a cap on maximum CO$_2$ emissions from aviation, with aircraft operators required to undertake monitoring and reporting, and to surrender permits covering their emissions. The negotiation process is ongoing and the scheme design is not yet finalised. ICAO have produced draft guidelines for the participation of aviation in emissions trading schemes, with a preference for open schemes: allowing aviation to be a net purchaser of emissions permits from other industries (ICAO, 2007).

The Intergovernmental Panel on Climate Change recommends three methods for calculating emissions from aviation for reporting purposes. Tier 1 is based only on fuel sales, while Tier 2 uses fuel sales in conjunction with standard data for Landing-Take Off (LTO) procedures. Tier 3 is the most detailed approach and is based on flight movement data. Tiers 2 and 3 are more accurate at differentiating between international and domestic emissions. Tier 3 offers the best disaggregation of emissions by individual flights (IPCC, 2006).
**Nitrogen Oxides**

The European Commission has pledged to develop a proposal to address nitrogen oxide emissions from aviation by the end of 2008 (European Commission, 2006). The form this proposal will take is uncertain, but includes a number of options for corresponding measures to operate alongside emissions trading for CO$_2$ (Wit et al., 2005). There are existing restrictions on NO$_x$ emissions in the LTO cycle administered through ICAO’s Committee on Aviation Environmental Protection. The effectiveness of extending these limits to control NO$_x$ emissions at cruise altitudes is not clear. The limits apply to the certification of new aircraft engines, so there would be a significant delay before new emissions restrictions would apply across the full aircraft fleet. Other options include modifying airport landing charges according to certified LTO NO$_x$ emissions. This is in use at some airports as an air quality measure, but again it is uncertain whether providing incentives to reduce low altitude NO$_x$ emissions would be an effective way to reduce emissions at cruise. The option that would most accurately address cruise altitude NO$_x$ emissions would be an en-route charge based on emissions calculated from the fuel flow rate and applying an emission index based on aircraft type and adjusting for temperature and humidity (Wit et al., 2005).

In addition to the uncertainty surrounding proposed legislation, several factors complicate the inclusion of nitrogen oxides (NO$_x$) in the DCI framework. While carbon dioxide emissions are proportional to fuel burn, NO$_x$ emissions depend on the background atmospheric conditions. The climate impact of such emissions depends on their altitude and location; reducing cruise altitude can increase NO$_x$ emissions but reduce the climate impact. NO$_x$ emissions at typical cruise altitudes have two competing climate effects. Methane concentrations are reduced which has a cooling effect; the ozone concentration increases, contributing to warming. These two effects do not simply offset each other. Methane has a longer lifetime than ozone, and the spatial patterns of the two effects are very different. At cruise altitudes in the stratosphere, NO$_x$ emissions can reduce, rather than increase, ozone. Our approach to NO$_x$ emissions will be discussed further in Deliverable 2.

1.2.5 Integrating emissions into flight planning

For integrating CO$_2$ emissions into the DCI framework, Tier 1 and Tier 2 approaches would be too coarse to allow any fine level resolution to be made regarding delay management decision-making. We propose an approach which is consistent with the most detailed option (Tier 3b, in fact) which is based on flight trajectory as well as aircraft and engine data, and by calculating CO$_2$ emissions on a flight-leg basis. This methodology will integrate with existing functionalities of Lido OC, which is capable of outputting fuel burn at the flight-leg level (although users rarely require such data).

Looking ahead to Year 2, it has been commented above that the option that would most accurately address cruise altitude NO$_x$ emissions would be an en-route charge, based on emissions calculated from the fuel flow rate, applying an emission index based on aircraft type, and adjusting for atmospheric conditions. This would also be highly suited to the flight-leg model, and suggests an additional functionality of identifying emissions within national boundaries, following the way en-route ATC charges are currently calculated in Europe.

By considering potential CO$_2$ and NO$_x$ calculational requirements together, and taking the common approach of a flight-leg model which is able to respect international boundaries, allows a flexible and future-proofed solution to be constructed. Figure 5 shows an example flight plan with corresponding flight-leg data in Table 2.
Table 2. LHR – FRA flight plan: planned route and timing, with restrictions

<table>
<thead>
<tr>
<th>Phase</th>
<th>State</th>
<th>From</th>
<th>To</th>
<th>Elapsed time (@ 'To')</th>
<th>On</th>
<th>Permitted planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climb</td>
<td>EG-EG</td>
<td>EGLL/09R</td>
<td>DET</td>
<td>0009</td>
<td>DVR6J</td>
<td>SID</td>
</tr>
<tr>
<td></td>
<td>EG-EG</td>
<td>DET</td>
<td>DVR</td>
<td>0012</td>
<td>DVR6J</td>
<td>SID</td>
</tr>
<tr>
<td>Cruise</td>
<td>EG-EB</td>
<td>DVR</td>
<td>KONAN</td>
<td>0015</td>
<td>UL9</td>
<td>airway FL 250 – FL 660</td>
</tr>
<tr>
<td></td>
<td>EB-EB</td>
<td>KONAN</td>
<td>KOK</td>
<td>0018</td>
<td>UL607</td>
<td>airway FL 195 – FL 660</td>
</tr>
<tr>
<td></td>
<td>EB-EB</td>
<td>KOK</td>
<td>FERDI</td>
<td>0023</td>
<td>UL607</td>
<td>airway FL 195 – FL 660</td>
</tr>
<tr>
<td></td>
<td>EB-EB</td>
<td>FERDI</td>
<td>BUPAL</td>
<td>0028</td>
<td>UL607</td>
<td>airway FL 195 – FL 660</td>
</tr>
<tr>
<td></td>
<td>EB-EB</td>
<td>BUPAL</td>
<td>REMBA</td>
<td>0029</td>
<td>UL607</td>
<td>airway FL 195 – FL 660</td>
</tr>
<tr>
<td></td>
<td>EB-EB</td>
<td>REMBA</td>
<td>SPI</td>
<td>0033</td>
<td>UL607</td>
<td>airway FL 195 – FL 660</td>
</tr>
<tr>
<td></td>
<td>EB-ED</td>
<td>SPI</td>
<td>DITEL</td>
<td>0037</td>
<td>UT180</td>
<td>airway FL 195 – FL 660</td>
</tr>
<tr>
<td></td>
<td>ED-ED</td>
<td>DITEL</td>
<td>BENAK</td>
<td>0037</td>
<td>T180</td>
<td>airway 6000 – FL 660</td>
</tr>
<tr>
<td></td>
<td>ED-ED</td>
<td>BENAK</td>
<td>POBIX</td>
<td>0039</td>
<td>T180</td>
<td>airway 6000 – FL 660</td>
</tr>
<tr>
<td>Descent</td>
<td>ED-ED</td>
<td>POBIX</td>
<td>AKIGO</td>
<td>0040</td>
<td>T180</td>
<td>airway 6000 – FL 240</td>
</tr>
<tr>
<td></td>
<td>ED-ED</td>
<td>AKIGO</td>
<td>OSMAX</td>
<td>0041</td>
<td>T180</td>
<td>airway 6000 – FL 240</td>
</tr>
<tr>
<td></td>
<td>ED-ED</td>
<td>OSMAX</td>
<td>EDDF/07L</td>
<td>0103</td>
<td>OSMAX3E</td>
<td>STAR</td>
</tr>
</tbody>
</table>

Notes
* KONAN-MATUG not FL 270
Nav aids at: DETLING (DET), DOVER (DVR), KOKSY (KOK) & SPRIMONT (SPI) (other points are waypoints only)
After take-off, the aircraft is subject to a series of AIP-published instructions for the DVR6J SID, notably not to exceed 250 knots below FL 100 (unless instructed otherwise), not to climb above 6000 feet (until instructed), that the en-route cruising level will be issued by ATC after take-off, and that the aircraft should be levelled off at 6000 feet as it approaches DET. In practice, the aircraft is normally at FL 250 by DET (which is 50NM from EGLL/09R: ATC usually takes the aircraft off the SID as soon as possible). As shown in the flight plan, it is desired that the aircraft be established on FL 330 at 444 knots from top of climb.

Similarly, the AIP arrival instructions for the OSMAX3E STAR detail that once cleared from the OSMAX holding pattern, the aircraft follows a series of waypoints, not descending below 5000 feet. Once the REDLI waypoint has been reached, the aircraft is not to exceed 250 knots; beyond REDLI, the aircraft is not to descend below 4000 feet until instructed by ATC.

By using a real flight plan as a test case, i.e. planning with permitted routeings and altitude restrictions, with knowledge of national boundaries, it will be possible to populate each flight leg with planned fuel burns based on historical data for a given aircraft (i.e. with actual knowledge by tail-number) for typical meteorological conditions and ATC practice.

These results will be presented in Deliverable 2. After further exploration of typical CI values used by airlines (probably using a longer–haul route example than LHR-FRA), Figure 2 will also be refined.

Forming a key part of our Year 1 results, and using the detailed rationale given in Technical Discussion Document 3.0 (see Appendix 2), a set of at least twenty routes, of varying lengths of haul, will be explored for variations in flight time and fuel burn, based on realistic CI value changes.
2. Discussion

Having discussed the key challenges which AOs face in the context of effectively implementing DCI solutions, it is instructive to briefly overview, as illustrative examples, the cases of two airlines which are particularly advanced in their use of this method: SAS and Air Canada. We will then discuss the broader context of our results.

2.1 Summary of two airline case studies

SAS have two basic approaches to time-managed arrivals. For long-haul, although repeated position update reports are made through ACARS, the flight crew will inform operations control if they judge that the Cost Index needs to be adjusted to recover anticipated arrival delay, awaiting a response on whether to do this or not. This dialogue also occurs through ACARS.

SAS wishes to move more towards firmer rules for decision-making, for example deciding when there is no net financial benefit of recovering a specific aircraft’s delay, or of holding a connecting flight. The carrier plans to incorporate the full use of the DCI concept by 2009, thus moving away from the current practice of recovering all delays on short-haul.

Short-haul experience has shown that when two ETAs are produced, one based on the wheels-off time (ETA_1) and a subsequent estimate based on a position report some 10 or 15 minutes later (ETA_2), then by integrating these with the flight plan and meteorological data, both ETA_1 and ETA_2 produce close, and robust, estimates of the actual arrival time (i.e. continuous position reporting is not usually required on short-haul). Furthermore, for these flights, SAS is able to integrate these data in real-time with connecting aircraft and crew rotation data, although currently (only) to define, as a first step towards full DCI, the latest arrival time that has zero delay cost. Approximately 10 minutes after the wheels-off message is processed by operations control, an ACARS message is sent to the aircraft with this latest, zero delay cost arrival time. As a second step towards soon realising its DCI concept, incremental fuel burn will be balanced with costs per minute of arrival delay.

Air Canada used to carry additional fuel on those flights where the potential missed connection cost was above a common, fixed-dollar threshold, but recently decided not to uplift extra fuel solely for the eventuality that a delay might arise en route, due to sharp increases in fuel prices. Attempts are still made to recover time solely using the fuel on board whenever it is practical (i.e. using additional fuel which was planned for other reasons, such as potential airborne holding or weather), although sophisticated decision-making is still undertaken prior to push-back.

Flights are operated using city-pair defined Cost Index values and utilize the VSOPS\(^9\) feature within Lido OC to determine when a flight may be planned at this (lower) Cost Index value, or the default (higher) value at which the flight was originally planned. This method sometimes allows operations at lower speeds, thus conserving fuel, but operating at higher Cost Index values when required, i.e. in order to maintain schedule.

Other manipulations of Cost Index values are based on whether the dispatcher proposes specific settings when the airline’s custom-built software tool computes this to be cost

---

\(^9\) Variable Speed Operations
beneficial. This tool computes the costs of delays of predetermined values (e.g. STA + 10 mins, STA + 20 mins) which are then traded-off against increased fuel burn. These costs include passenger and crew costs; both of these are based on historical data. The passenger costs notably not only include hard costs (such as hotel accommodation) but also estimates of passenger loss of future value ('goodwill'). Marginal maintenance costs, based on the powerplant element of ‘A’ Checks (which are determined by flight hours) are also factored in. Air Canada wishes to devolve more decision-making to the pilot (c.f. the SAS long-haul model), but currently faces the task both of integrating their in-house system with Lido OC, of sharing this information with the cockpit (especially with respect to dynamically computing the implications of using various Cost Index values), and obtaining reliable data on in-bound delays to build a better network picture. The latter may be realised through Lido’s flight-watch tool, ‘AeroView’.

2.2 Discussion of way forward – plans and challenges

The foregoing discussion can now be synthesised into a draft data architecture for DCI, describing which tasks are to performed where, as shown in Figure 6. Notable in the cockpit context is the role the pilot may play in future decision-making, enabled by improved CI and (dynamic) ACARS data, as also suggested by the SAS and Air Canada case studies.

Figure 6. Draft data architecture for DCI

Although Passenger Transfer Messages (PTMs; see top-right of figure) were investigated as an earlier part of our methodological investigations, it seems that these standard-format, passenger-connectivity messages are usually sent too late for the purposes of DCI. In Year 2, therefore, a high priority will be set for further exploring better dynamic passenger data in the Lufthansa case study context, despite the discontinuation of Lufthansa Systems’ FACE (Future Airline Core Environment) passenger management platform (see Appendix 1).

10 Scheduled Time of Arrival
The benefit of drawing on historical passenger data has been clearly highlighted during our discussions with airlines, as a necessary and invaluable complement to the dynamic data. This is an important finding. In essence, historical data can play an important role in helping to estimate dynamic delay costs due to passenger missed connections. This is partly due to the fact that repeated evolutions of delay situations in the past can often be a better cost predictor than partial dynamic data: the true connectivity picture is rarely complete in the complex tactical context of an airline network. Furthermore, static data are also required for estimation of compensation costs, for example, as discussed in section 1.2.3, which must be based on AO-specific rule bases. Thus, reflecting the practice of several airlines, it is envisaged that our passenger statistical (‘pax stat’) tool will incorporate static data as well as interfacing with dynamic (GDS) data.

As represented by the revolving-arrow motif above the ‘pax stat’ box, this tool would use data such as that held in the database of Figure 3, to iterate the best DCI solution for a given flight. As mentioned earlier, this often would not be expected to resolve an optimised solution at zero delay, thus possibly saving unnecessary fuel burn in many cases. Pre-departure fuel uplift and other decision windows must clearly be respected. As with the passenger statistical (‘pax stat’) tool, whilst our emissions (‘ENV’) tool would actually be part of the DCI module within the flight planning suite, it is elaborated in Figure 6 outside of this box to show its particular additional data connectivities, in this case with meteorological and operational (e.g. aircraft specification) data.
3. Next steps

Deliverable 2 is due to be produced by 15 November 2007. As commented, this will update this report, primarily by:

- presenting the fuel burn and CO₂ results for Table 2 (the flight-leg framework example based on a real LHR-FRA flight plan)
- further exploring typical CI values used by airlines (probably using a longer-haul route example than LHR-FRA)
- computing a set of at least twenty routes, of varying lengths of haul, examining variations in flight time and fuel burn, based on realistic CI value changes
- elaborating our approach to NOₓ emissions
- carrying out any necessary updates to the draft architecture of Figure 6
- offering further updates on future research plans
- producing a summary (or abstract) of key Year 1 findings
References


Ehrmanntraut R and Jelinek F (2005), Performance Parameters of Speed Control, 4th INO Workshop 2005, EUROCONTROL Experimental Centre, Brétigny sur Orge, France, December 2005


SESAR Consortium (2006), Air Transport Framework: The Performance Target, SESAR Definition Phase - Milestone Deliverable 2


Appendix 1: Progress in Year 1

Whilst we have been able to make good progress defining our methodology and system architecture, in addition to significant development of the passenger database requirements, maturing the passenger interface has been slow due to the unforeseen discontinuation of Lufthansa Systems’ FACE (Future Airline Core Environment) passenger management platform, on which we had planned to develop our functionality:

---

Lufthansa Systems ceases development on FACE passenger management platform

Lufthansa Systems said it is dropping all further development of its Future Airline Core Environment passenger management platform

By Michele McDonald
Travel Technology Update, September 2007

The company cited "commercial reasons" for the decision. FACE was intended to support the core processes of passenger airlines, such as schedule distribution, reservations, inventory, ticketing and departure control. The next-generation system was touted as more flexible and more cost-efficient than traditional reservations systems. Lufthansa Systems did not elaborate on the commercial reasons for its decision, but the move came on the heels of Cathay Pacific Airways' announcement that it planned to migrate to the Amadeus Altea passenger services platform.

Amadeus also won the contract to build the Star Alliance's common reservations platform, which will be based on Altea. Lufthansa Airlines, the sister company of Lufthansa Systems, is a Star Alliance member.

Lufthansa Systems said the three airlines that had signed on to be FACE customers -- Qatar Airways, BMI and Garuda Indonesia Airline -- still have valid contracts for its existing MultiHost system that can be expanded with Revenue Integrity, Self Service Devices, e-ticketing Hub and other modules.

"We had planned to offer FACE to airlines as a passenger system that is based on new technology. In the development of this highly complex product, we had to rely to a large extent on products and services of different suppliers," the company said in a statement e-mailed to TTU.

"Since the project's launch more than two years ago, progress of the development work has been monitored constantly. After the latest review of the project's progress, and the quality of components delivered by external suppliers in particular, we could no longer assume that we would be able to provide our customers with a product that would meet their requirements within a reasonable time frame and at reasonable costs."

Among FACE's "external suppliers" was Unisys, whose AirCore product was slated to be "the heart" of FACE. AirCore, built on Unisys' "3D Visible Enterprise" technology, provides transactional history and preferences from which future transactions can benefit.

AirCore produces a passenger name record, but the file also includes a full view of the customer relationship, not just a specific transaction. Earlier this year, Lufthansa Systems said it was investing €40 million in FACE.

http://www.atwonline.com/magazine/article.html?articleID=2079

Nevertheless, as mentioned, a high priority will be set for further exploring better dynamic passenger data in the Lufthansa case study context. The extension of the project at this early stage to include a number of other airlines has been seen as a particularly progressive
step. Work on the NO\textsubscript{x} framework, scheduled for Year 2, has been more advanced than anticipated.
Appendix 2: Key outputs in Year 1


Technical Meeting 1, Lufthansa Systems Aeronautics, Frankfurt 12-13 March 2007

Technical Meeting 2, University of Westminster, London 30 April 2007

Presentation of DCI concept at UK ATM Knowledge Network Meeting, London 04 June 2007

Technical Discussion Document 2.0, *Summary of emissions schemes* 15 June 2007


Airline Dynamic Cost Indexing Workshop, Hotel NH Frankfurt Rhein–Main, Frankfurt (Attended by: EUROCONTROL; Air Canada, CSA, Emirates, Finnair, Lufthansa, Qantas, Qatar and SAS) 28 August 2007

Paper to be presented at the 6th EUROCONTROL Innovative Research Workshops & Exhibition, 4-6 December 2007, EUROCONTROL Experimental Centre (Deliverable 2) Due for submission by 15 November 2007