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A CASE STUDY OF ARRIVAL AND DEPARTURE MANAGERS COOPERATION FOR REDUCING AIRBORNE HOLDING TIMES AT DESTINATION AIRPORTS

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Abstract

Congestion of flights arriving at terminal areas invariably leads to aircraft having to extend their flying time, which often results in the need to orbit at a holding point as aircraft are sequenced to land. This extended flying time can be significantly reduced by the implementation of the delay-on-ground concept, where aircraft flying short sectors are delayed in their departure from the respective airport, thus reducing the amount of congestion at the destination point. This paper analysis the impact, in terms of reduced flying time, fuel burn and carbon emissions, that can be achieved at Oslo-Gardemoen airport if the present flights that have a flying time of 1 hour or less are delayed on the ground at their departure point. The impact such a concept would have if traffic densities of 15% and 30% above current levels were to be experienced is also considered.

1 Introduction

Commercial aviation provides enormous benefits to society in terms of mobility and communication, both for business and other purposes. It also has a major impact on the world economy. Indeed, the direct, indirect and induced aviation contributions to the European GDP in 2004 was in excess of €200 Billion [1]. This activity is expected to grow significantly, with air traffic expected to double in a decade.

In 2005, the European Commission set the political vision and high level goals for the Single European Sky, which, amongst others, focussed on:

- the enabling of a 3-fold increase in capacity with the reduction of delays, both on ground and in the air;
- enabling a 10% reduction of the effects flights have on the environment.

In response to this vision, the definition phase of SESAR has concluded that ATM can significantly contribute to reaching these goals, targeting a 73% increase in capacity and a 10% reduction in environmental impact over the 2004/2005 figures by 2020 [1].

The foundation of the SESAR Concept of Operations (ConOps) is the trajectory-based ATM system, which will replace the 'first-come-first-served' concept that is widely used in ATM practices today. A key enabler will be the Four Dimensional Trajectory (4DT) concept, where aircraft are, on agreement, assigned a small time window within which they will be required to fly over a particular waypoint at a pre-defined altitude.

The 4DT concept will, of course, provide a strong basis for improved efficiency and airfield throughput. This is because it will allow better tactical planning of sequencing of aircraft into and out of airports, providing sufficient lead time and accuracy to enable planning to be effective.

An increase in air traffic will naturally also increase pressures on terminal areas, particularly

those already experiencing medium to high density traffic (in terms of capacity) today. Economic and environmental pressures tend to limit further growth in terms of additional terminals and runways, thus limiting the increase in airfield throughput, requiring airports to operate with higher densities which, in turn, will require smooth coordination in the sequencing of arrivals to be efficient.

In such circumstances, effective Arrival Management (AMAN) is critical, particularly at terminal areas operating at medium and high densities. AMAN essentially involves sequencing arrivals for landing, balancing operational considerations with airfield throughput. Here, keeping aircraft separation, which is primarily classified by aircraft weight and wake vortex category and where grouping traffic of similar categories tends to improve runway throughput, is ideally kept to a minimum. AMAN software tools are used in several airports to facilitate this task.

In the current environment, where aircraft are dispatched without coordination with AMAN tools at the destination airport, it can be expected that aircraft arriving at the terminal area of busy airfields will be required to hold until sequenced to land. Indeed, the concept of holding and the development of a stack at holding points, with aircraft being successively taken out of the bottom of the stack and vectored to the final approach, allowing aircraft at higher levels to descend to lower levels, is common practice in peak hours at busy airfields such as Heathrow Airport, which operates close to 98% of its operational capacity. As an indicative example, the UK NATS is reported in 2011 to have identified that aircraft spend a cumulative 55 hours a day holding at Heathrow, burning 190 tonnes of fuel in the process. Besides the estimated £119,000 wasted in additional fuel burn each day, this also has an effect on the environment, as an additional 600 tonnes of CO_2 are discharged in the skies over London [2].

It is acknowledged that a significant portion of the holding time is fundamentally due to the limited coordination exercised currrently between the arrival of aircraft at the inital approach fix and their sequencing to land.

Consequently, application of the 4DT concept is expected to contribute to reducing holding times at destination airports, allowing smoother transitions to sequencing for landing with a reduced Air Traffic Controller (ATCo) intervention both at strategic and tactical level. However, an increased level of automation requires new key enabling technologies to be developed, including new on-board Flight Management Systems (FMS) and ground ATM tools for real-time 4DT negotiation and validation. If one could rely on the continuous and smooth running of operations in accordance with the strategic plan, there would be no need for renegotiation at the tactical level. However, external factors, such as weather and opertional constraints will inevitably affect the system and as a consequence, 4DT negotiation will be required in real-time to allow the continued and safe operation of the ATM system. The greatest impact will, of course, be experienced at busy airports and at peak hours where the airport may be operating close to its practical throughput limit and any delays will translate to a lower throughput. When the actual (achieved) throughput falls below the arrival rate and possibly even as it approaches it, holding will be inevitable short of diverting the flight to other terminal areas.

Given the high demand for operations into aiports such as Heathrow, the lack of additional capacity and bad weather (such as low visibility and thunder storms) that a terminal area can be expected to experience, it is reasonable to expect that the smooth flow for arrivals into an airfield will eventually be disrupted and holding will again be required until the backlog can be cleared.

Situations where backlogs will need to be cleared are not expected to only arise at hubs such as Heathrow, but also at other airports of medium densities where throughput demand at peak hours is high. Futhermore, as demand for operational densities is expected to rise, this can be expected to have a significant impact on airfields that currently already have a medium density of operations, as this will push levels towards high density, introducing new challenges that are experienced by only a few major hubs today.

2 The Delay-on-Ground Concept

A strong candidate mechanism for avoiding excessive holding at the destination airfields whilst accumulated backlogs are cleared is the spreading of the incoming flow of traffic. In other words, if flights could be delayed on ground prior to departure, backlogs at the destination airport can be reduced and even eliminated, thereby reducing (or eliminating) airborne holding. Of course, this concept depends significantly on the availability of short haul flights, typically those with flight times of 1 hour or less, which are often referred to as pop-up flights. Even today, with traditional air navigation practices (that is, not operating on 4DT contracts), once an aircraft becomes airborne, a short or medium haul flight will probability arrive at the destination within a few minutes of its expected arrival time. Consequently, once all aircraft planned to arrive at the destination airport depart, the flexibility that enables the diffusing of arrivals to facilitate sequencing to land is limited. The key opportunity, therefore, lies in exploiting the short-haul sector where, through advanced communication methods, aircraft can be advised to take a delay on ground prior to departure.

2.1 AMAN-DMAN Cooperation

Airport throughput and efficiency do not only depend on maximising the number of inbound movements, but also in getting as many aircraft out of the airport as possible. As for the case of arrival, departure scheduling is key to the efficient operation of busy airfields. Consequently, Departure Management (DMAN) software tools are likewise available at airfields to facilitate the expeditious departure of aircraft.

As a result, there is value in cooperation between AMAN and DMAN tools at the respective airports in order to automate the delay-on-ground concept without compromising departure and arrival throughput at the airports.

The concept of AMAN-DMAN cooperation is not new. Indeed, the CASSIS and CASSIS2 projects proposed and evaluated the possibility of operating a delay-on-ground concept in which pop-up flights are entered into the destination airport's AMAN sequence before take-off [3, 4].

The work in this paper is aimed at assessing the potential benefits of introducing the delay-on-ground concept in selected airport pairs in terms of reduction of airborne holding time (or, alternatively airborne delays through vectoring or similar ATCo interventions), fuel burn and carbon emissions.

3 The Case Study

3.1 Methodology

The methodology adopted in the case study was as follows: an appropriate destination airport was selected to provide the case study. The airport selected was required to have a medium density, typically between 400 and 800 movements per day with clear peak hours of operation and be AMAN equipped. Furthermore, the airport was required to have a significant proportion of its movements comprising of pop-up flights involving aircraft that are RTA-equipped in order to facilitate the coordination of the delay-on-ground concept, provide the ability for the aircraft to arrive at the destination within a predescribed time window and enable the achievement of the desired holding times in the air. The selection of the airport was made after using data extracted from Flightstats.com [5] and the AMAN Status Review 2009 [6]. Next, real flight schedules of arbitrarily chosen days were extracted and used as a baseline. Two fictitious timetables were then created to represent a 15% and 30% increase in traffic respectively over this baseline. Although it is expected that the number of pop-up flights will increase with increased traffic densities, the number of pop-up flights in the increased traffic scenarios was not increased, but instead was intentionally kept at the same levels as that of the baseline (current traffic level) scenario. This was done in order to enable the assessment of the impact higher traffic densities and higher proportions of flights that are not involved in AMAN-DMAN cooperation would have on the delays and the performance of the sequencing of pop-up

flights. Previous work by the National Aerospace Laboratory of the Netherlands (NLR) [7], in line with predictions by the Eurocontrol Air Traffic Statistics and Forecast Service (STATFOR), was used to obtain realistic estimates for the generated time-tables, particularly in terms of how the traffic would increase at each hour of the day.

The actual departure and arrival times of flights recorded over several days were also retrieved from Flightstats.com and these were then compared to identify the average and variance of the observed delays. Taxi times were also observed and the relevant statistical parameters collected. This was required because eventually, demand runway times at both the departure and destination airports were required to be generated. Movements were grouped by sector length, namely short, medium and long-haul, as these were suspected to exhibit different delay patterns and characteristics. The statistical data was next used to generate data (actual departure and arrival times, rather than scheduled times, and then the actual times of runway occupation were derived from these) for a large number of simulated operational days with the same timetable. In this way, typical variations from the scheduled times that can be expected in actual departure and arrival times were introduced in the simulations. These departure and arrival times were then used to carry out the Monte Carlo simulations of expected operations, based on the selected timetable (that is, with present-day traffic levels) as well as on the derived 15% and 30% increases in traffic volume scenarios respectively. 180 simulated days were generated and thus 180 Monte Carlo simulations were run in total, 60 for each traffic density scenario.

The sequencer elements of an AMAN and a DMAN were modelled by using the Sequencing and Scheduling model developed in the Environmentally Friendly Airport ATM Systems (EFAS) project. A cooperation between the AMAN and DMAN sequencers were then simulated in the Matlab/Simulink® environment so that departure times could be correctly re-scheduled. BADA models of the aircraft involved were used to determine the flight times, thus generating, through the Monte Carlo simulations, the expected residual airborne hold times (at the destination airport) and the delay-on-ground (at the departure airport) resulting from AMAN-DMAN cooperation. These results were then compared with results (airborne holding times) obtained without AMAN-DMAN cooperation.

3.2 The Case Airports and Data

The destination airport chosen was Oslo-Gardermoen. Arrivals of RTA-equipped aircraft into Oslo-Gardermoen are typically Boeing 737 / Airbus A320 category aircraft, departing from 10 departure airports. These airports, together with their respective traffic densities (which affect DMAN coordination), are listed in Table 1.

The first five departure airports, all with less than 100 movements a day, will probably be able to accommodate the AMAN sequence without DMAN cooperation, but the lower five, and in particular the last two (ARN and CPH) will require AMAN-DMAN cooperation to provide effective support of the delay-on-ground concept.

The scheduled distribution of traffic densities throughout the day for the baseline (current traffic densities), as well as the 15% and 30% increased traffic level scenarios for Oslo-Gardermoen is shown in Figures 1 and 2.

#	Departure Airport	Typical number of daily movements
1	Kristiansund (KSU)	18
2	Molde (MOL)	18
3	Haugesund (HAU)	24
4	Aalesund (AES)	36
5	Kristiansand (KRS)	46
6	Trondheim (TRD)	147
7	Stavanger (SVG)	174
8	Bergen (BGO)	244
9	Stockholm-Arlanda (ARN)	602
10	Copenhagen-Kastrup (CPH)	647

Table 1. The main departure airports for RTA-equipped pop-up flights flying into Oslo-Gardermoen.
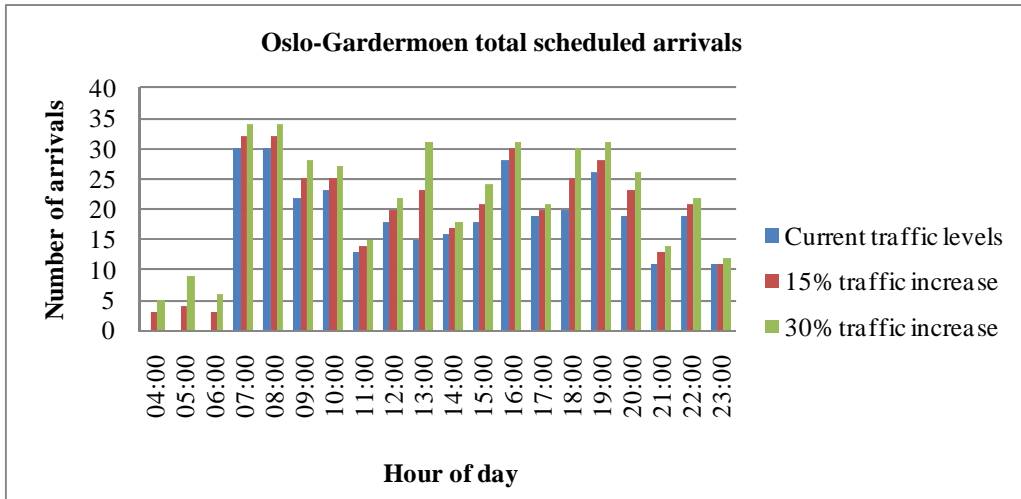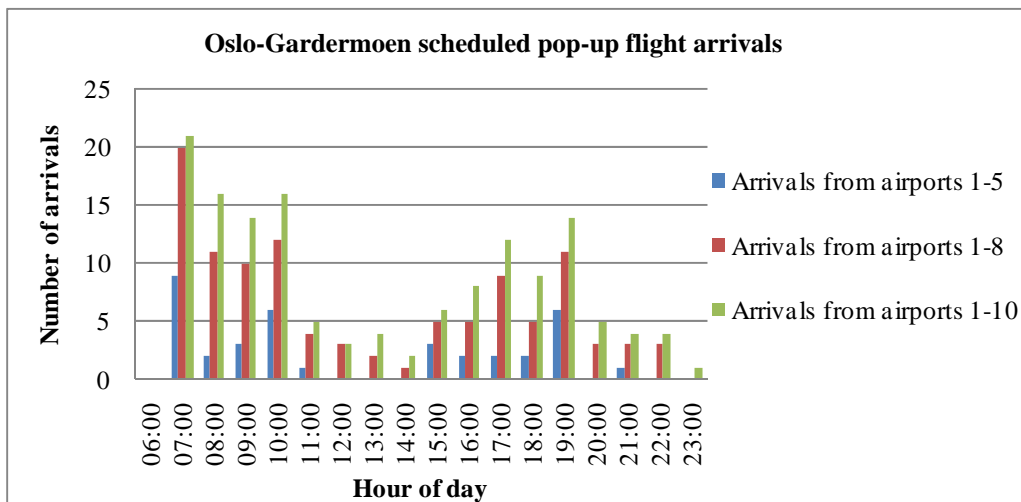
Fig. 1. The distribution of the total scheduled flight arrivals at Oslo-Gardermoen.

Note: the numbering of the airports corresponds to the numbering used in Table 1.

Fig. 2. The distribution of the scheduled pop-up flight arrivals at Oslo-Gardermoen.

3.3 Assumptions and Limitations

The major assumptions taken in the modeling were:

- No weather was modeled, thus no weather affected any of the flights and simulations. All flights were conducted in still air, in a standard atmosphere (ISA).

- Whilst factors such as wake vortex and SID separation requirements have been taken into account, other factors such as runway occupancy time and ATC strategies have not been considered.

4 Results

The maximum, average and total expected reduction in airborne holding time of the pop-up flights afforded by the introduction of adequate delay-on-ground through AMAN-DMAN cooperation on the flights at Oslo-Gardermoen, as per schedules of Figure 2 are presented in Figures 3-6.

Tables 2 and 3 present the total flight (holding) time expected to be reduced for pop-up flights if the delay-on-ground concept were to be employed throughout the day and at peak hours (07:00hrs – 11:00hrs and 16:00hrs – 20:00hrs) only respectively.
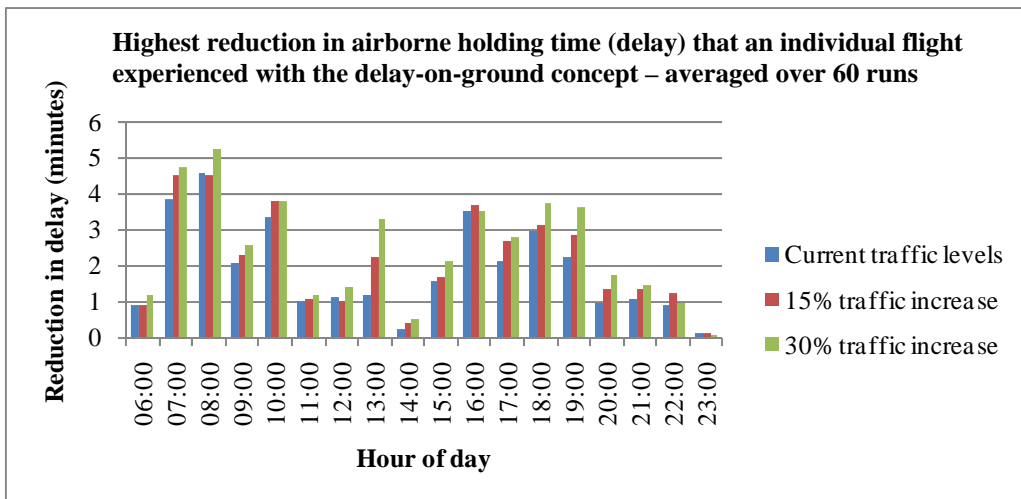
Fig. 3. The highest expected reduction in airborne holding time at Oslo-Gardermoen.
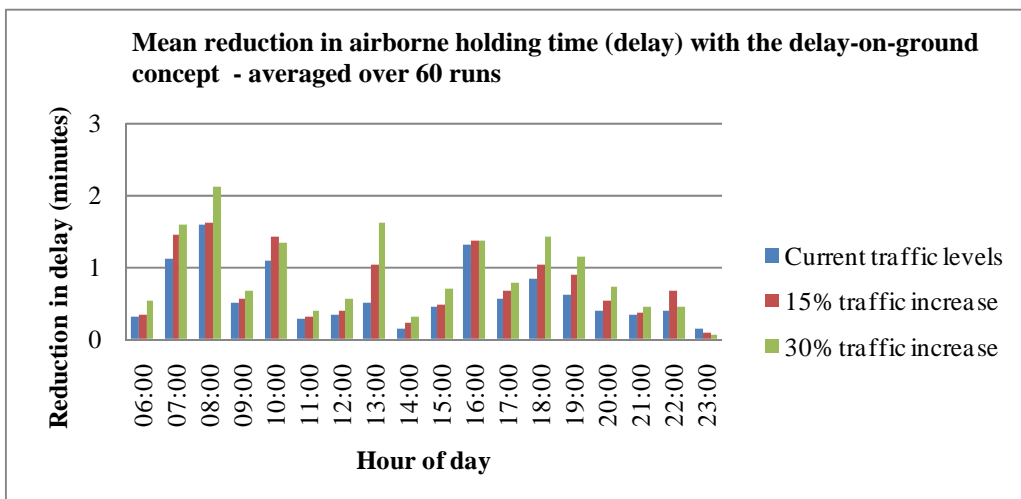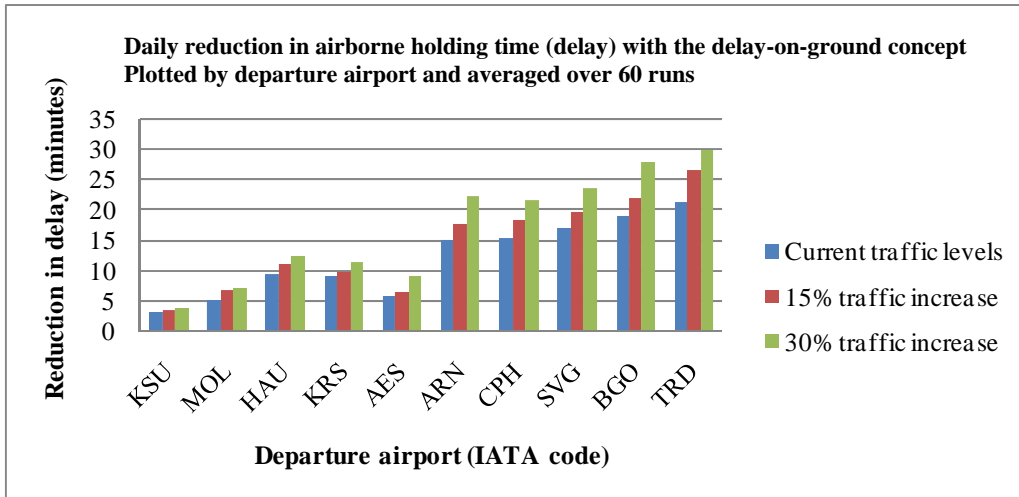

Fig. 4. The average expected reduction in airborne holding time per flight at Oslo-Gardermoen.
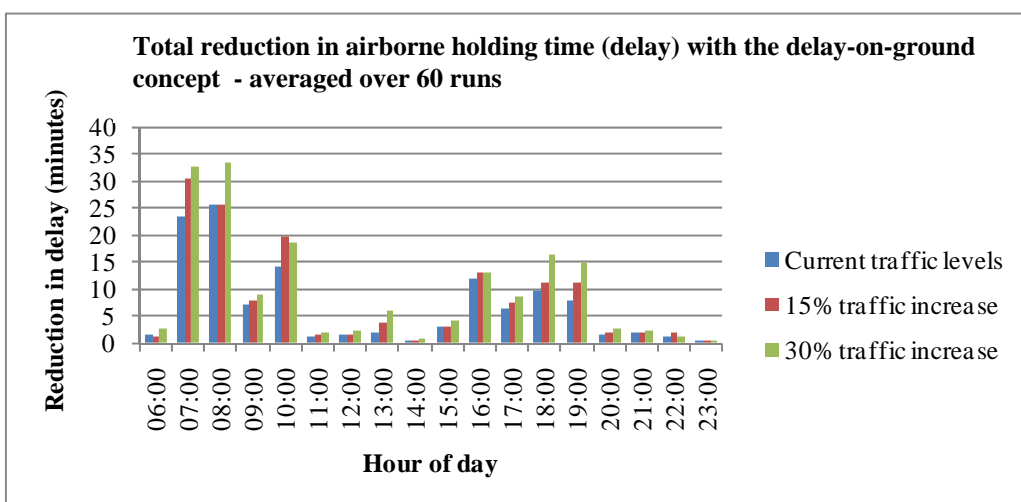
Fig. 5. The total (overall) expected reduction in airborne holding time at Oslo-Gardermoen.

Fig. 6. The daily expected reduction in airborne holding time of flights into Oslo-Gardermoen, grouped by departure airport.

	Current traffic levels (HH:MM:SS)	15% traffic increase (HH:MM:SS)	30% traffic increase (HH:MM:SS)
Airports 1-5	00:32:32	00:37:56	00:44:11
Airports 1-10	02:00:22	02:24:07	02:50:30

Note: the numbering of the airports corresponds to the numbering used in Table 1.

Table 2. The total daily reduction in airborne holding time at Oslo-Gardermoen with the delay-on-ground concept – averaged over 60 runs, if the concept were in use all day.

	Current traffic levels (HH:MM:SS)	15% traffic increase (HH:MM:SS)	30% traffic increase (HH:MM:SS)
Airports 1-5	00:30:29	00:36:07	00:41:13
Airports 1-10	01:46:43	02:07:05	02:26:41

Note: the numbering of the airports corresponds to the numbering used in Table 1.

Table 3. The total daily reduction in airborne holding time at Oslo-Gardermoen with the delay-on-ground concept – averaged over 60 runs, if the concept were in use only during peak hours.

The potential fuel saving that the average daily reduction in airborne holding time corresponds to is presented in Table 4. In current arrival operations at Oslo-Gardermoen airport, an arrival sequencing delay of up to 2 minutes is absorbed in a sequencing leg at FL100-FL120. If a flight has more delay than this, 2 minutes are absorbed at FL100-FL120 in a sequencing leg and the remainder is absorbed at FL240-FL300 in a circular holding pattern[1]. A fuel

consumption of 31.9 kilograms per minute has been used to calculate the potential fuel saving. This is the fuel consumption of a Boeing 737-800 during cruise at FL120 with a low mass level according to the BADA Performance Table File (PTF) for the aircraft type. Using the fuel consumption for a Boeing 737-800 was considered a good estimate, as all pop-up flights are flown either by a Boeing 737 or Airbus 320 aircraft type which have similar aircraft

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[1] The information on how arrival sequencing delay is absorbed at Oslo airport has been obtained from Kristian

Pjaaten, AMAN project leader at Oslo ATCC (June 2011).

performance characteristics. According to BADA data, the fuel consumption at FL240-300 is slightly higher than the consumption at FL100-FL120. It is, however, seen as a good estimate to use the BADA fuel consumption at FL120 for all the delay (holding time) minutes, particularly as the majority of the flights have a delay below 2 minutes. It was also considered reasonable to use the fuel consumption for a low

mass level (BADA specifies fuel consumption for low, nominal and high mass level), as the aircraft is at the end of its flight and is likely to have used most of its fuel [8].

The corresponding potential reduction in carbon emissions (CO_2) is presented in Table 5.

Daily Fuel Savings at Oslo-Gardermoen		
	Current traffic levels (kg)	15% traffic increase (kg)	30% traffic increase (kg)
Airports 1-5	972	1,152	1,315
Airports 1-10	3,404	4,078	4,679

Note: the numbering of the airports corresponds to the numbering used in Table 1.

Table 4. The potential daily fuel savings at Oslo-Gardermoen with the delay-on-ground concept – averaged over 60 runs, if the concept were in use only in peak hours.

Daily Reduction in CO_2 Emissions at Oslo-Gardermoen		
	Current traffic levels (kg)	15% traffic increase (kg)	30% traffic increase (kg)
Airports 1-5	3,062	3,629	4,142
Airports 1-10	10,723	12,846	14,739

Note: the numbering of the airports corresponds to the numbering used in Table 1.

Table 5. The potential daily reduction in CO_2 emissions at Oslo-Gardermoen with the delay-on-ground concept – averaged over 60 runs, if the concept were in use only in peak hours.

5 Discussion

The results show that a substantial amount of airborne holding time (or airborne delay), fuel burn and carbon emissions can be effectively avoided with the introduction of the delay-on-ground concept through AMAN-DMAN cooperation. Also interesting is the impact of the control of the arrival time of the same number of pop-up flights with increased traffic densities. Indeed, from Table 4, it can be seen that with 15% and 30% increases in traffic density, the same pop-up flights will experience a reduction of airborne time by more than 15% and 30% respectively. This highlights the fact that increases in traffic can be expected to increase holding times of individual flights, and this can be effectively eliminated on pop-up

flights with the delay-on-ground concept. Consequently, as traffic densities rise, the reduction of inbound traffic densities through the operation of the delay-on-ground concept will be highly beneficial in such circumstances. This may, of course, result in slightly greater (lengthier) delays in departure times having to be absorbed by the pop-up flights concerned, but this delay should not be significant.

The results are, of course, conservative, as they are based on the assumption that the number of pop-up flights will remain the same, whilst it is expected that these will increase in line with increased traffic densities. Consequently, greater reductions in flying times and associated fuel burn and emissions than observed can be expected in practice.

The peaks in arrival sequencing delay that pop-up flights normally experience occur in the

peak hours and this is where the highest gains are achieved with the delay-on-ground concept. This is as expected, with the effect evident in Figures 3-5.

Figure 6 shows the general trend that the higher the number of daily pop-up flight arrivals per departure airport, the higher is the daily reduction in airborne delay. The only exceptions to this are Kristiansand (KRS) and Aalesund (AES). This is probably due to the distribution of flights from these airports, as the amount of reduction in airborne delay does not only depend on the total number of pop-up flight arrivals but also on the hours in which the flights arrive. For example, Haugesund (HAU) has all of its pop-up flights arriving into Oslo-Gardermoen at peak hours, whereas Kristiansand (KRS) has one flight arriving outside of peak hours and Aalesund (AES) has three flights arriving outside of peak hours.

From Table 3 it can be seen that if the delay-on-ground concept were to be used only in peak hours and airports 1-10 were included in the concept, a total of almost 2 hours (01:46:43) could be saved in airborne delay for the current traffic levels. This can be compared to the average daily overall arrival sequencing delay experienced at Oslo-Gardermoen airport, which was slightly over 4 hours (04:18:41, results not presented herein). This implies that 41% of the airborne arrival sequencing delay that is typically experienced currently at Oslo-Gardermoen on days similar to that simulated could be saved by using the delay-on-ground concept if AMAN-DMAN cooperation were to be available and all of the ten airports from which RTA-equipped traffic departs were included in the concept. This corresponds to an average daily potential saving of 3.4 tonnes of fuel and 10.7 tonnes of carbon emissions, as can be seen in Tables 4 and 5. With 15% and 30% traffic increase, the average daily potential gains are fuel saving increases to 4.1 and 4.7 tonnes respectively for fuel and 12.8 and 14.7 tonnes respectively for carbon dioxide. This gives an indication of the magnitude the impact the concept can have on future air transport operations.

The results in Tables 2 and 3 suggest that the vast majority of the gains of the delay-on-

ground concept are achieved during peak hours. Consequently this suggests the recommendation of the use of such a concept to be limited to these hours at Oslo-Gardermoen. This is because it is expected that the delay-on-ground concept would require an increase in workload for the air traffic controller managing the AMAN (due to the increased coordination with departure towers and pilots) and pilots (communication before departure to get an RTA, ensure that the flight departs at/during the RTA takeoff time/window) [3,4]. It is interesting to note that the deployment of the delay-on-ground concept during peak hours only may actually reduce air traffic controller workload, as the additional effort required to handle the AMAN-DMAN cooperation may very well be more than offset by the reduction in workload brought about by the reduction in the complexity associated with the handling traffic conditions that require less airborne holding times. Less airborne congestion in terminal areas will also contribute to improving operational safety and reducing pilot/ATCo workload.

6   Conclusion

The simulations performed in this work have shown that there is potential for a significant reduction in airborne delay times, fuel burn and carbon emissions if the delay-on-ground concept were to be implemented at the case study airport Oslo-Gardermoen. It has been shown that, if AMAN-DMAN cooperation were to be available and all of the ten airports from which RTA-equipped traffic departs were to be included in the concept during peak hours, 41% (and close to 2 hours daily) of the airborne arrival sequencing delay that is currently typically experienced at the case study airport could be avoided with the delay-on-ground concept. This corresponds to a potential average daily reduction of 3.4 tonnes of fuel burn and 10.7 tonnes of greenhouse emissions. With an increase in traffic densities, at least proportionately greater returns can be expected.

References

[1] Anonymous. *European Air Traffic Management Master Plan. Edition 1 – 30 March 2009.* The European Commission, 2009.

[2] *http://www.telegraph.co.uk/travel/travelnews/8602211/Heathrow-data-shows-capacity-crisis-costing-thousands.html*, as accessed on 28/6/2012.

[3] Anonymous. *Cassis Flight Trials Report.* The Cassis Consortium, 2009. Available on-line: http://www.eurocontrol.int/tma2010/gallery/content/public/image/Docs/Cassis%20Flight%20Trials%20Report%20v1.0.pdf, as accessed on 28/6/2012.

[4] Anonymous. *Cassis 2 Flight Trials Report.* The Cassis 2 Consortium, 2010. Available on-line: http://www.eurocontrol.int/tma2010/gallery/content/public/image/Docs/Flight%20Trials%20Report%201%200.pdf, as accessed on 28/6/2012.

[5] *http://www.flightstats.com/go/Home/home.do*, as accessed on 28/6/2012.

[6] Hasevoets N. *AMAN Status Review2009.* Eurocontrol, 2010. Available on-line: http://www.eurocontrol.int/sites/default/files/content/documents/nm/fasti-aman-status-review-2009.pdf, as accessed on 28/6/2012.

[7] De Jonge H W G, van Dronkelaar J H and Beers J N P. *The Simulation Report for Fast-Time Simulations at Airport Level for Gate-to-Gate.* Report no. NLR-CR-2006-796, National Aerospace Laboratory of the Netherlands (NLR), 2006.

[8] Mouillet V. *Aircraft Performance Summary tables for the Base of Aircraft Data (BADA) – Revision 3.7.* Report no. 2009-05, Eurocontrol, 2009.

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