Innovative Slot Allocation: an Overview

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### Innovative Slot Allocation: an Overview

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<td>ATFM, CFMU, TACT, CASA, ISA, slot allocation, delay, capacity, cost, equity, bunching</td>
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**Abstract:**

This document is a summary report presenting the Innovative Slot Allocation (ISA) project. This project aims at investigating new slot allocation strategies to improve the performance of the current operational slot allocation system used by CFMU (CASA) so as to better regulate congested European airspace areas and thus to reduce delays experienced by airlines.

Pre-tactical simulations' results show that not only do state-of-the-art techniques applied to slot allocation decrease the overall delay incurred by Aircraft Operators, but they can also overcome some of the other shortcomings of CASA.
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1. INTRODUCTION

This summary report describes a software tool, Innovative Slot Allocation (ISA).

The report demonstrates that ISA can be used as a tool for investigating en-route slot allocation strategies as developments of, or alternatives to, the current CASA ‘First Planned - First Served’ principle.

The report presents the results of investigations that have already been carried out into the use of alternative slot allocation strategies. There is the potential for significant savings in delay and a series of other benefits that would improve ATFM.

The report invites airlines, ATSPs and CFMU to work jointly with EEC to exploit the potential offered by the ISA tool.

2. BACKGROUND

The current system used by the CFMU for Air Traffic Flow Management (ATFM), TACT, is both a philosophy of operation and a software tool. It was designed in the early 90’s and has been used operationally since 1995. Within TACT, the slot allocation software module is called CASA. CASA has been demonstrated to work, as evidenced by the undoubted success of CFMU since its introduction.

ATFM needs to develop to meet the challenges of ever increasing demand and the need to deliver an ever more efficient service. The introduction of the Enhanced Tactical Flow Management System (ETFMS) as a part of that development will require development of the slot allocation software in order to introduce options and operational flexibility into the system.

For the allocation of slots to be equitable between slot users it is necessary to introduce a set of governing rules. Current practice uses the principle known as ‘First Planned - First Served’ (FPFS). This principle requires that a slot be allocated to the first aircraft that plans to arrive at the boundary of a congested sector, which is subject to flow restrictions (Regulations). In practice, the simple application of the FPFS principle would result in excessive delays to an aircraft traversing more than one regulated sector, and a modified version is applied by CFMU. Thus, a slot is allocated to such an aircraft, on the basis of FPFS, in the sector that imposes the worst delay on its entire route. Slots in other regulated sectors that this aircraft passes through are allocated on a priority basis and without further delay. For the purposes of this paper we are referring to this application of the principle as the First Planned Penalising Regulation (FPFR) principle. CASA works on the basis of the FPFR.

There is a high regard amongst airlines\(^1\) for the equity that is achieved through the use of FPFR. CASA is thought to come very close to optimising the system within the limits of the FPFR principle. However, FPFR imposes such constraints on the use of the ATM system that optimum system capacity cannot be achieved. Such constraint was necessary when ATFM was conceived, because of the limits on computing power and the techniques available to resolve the complex interactions occurring within such a widespread system. However, new programming techniques (e.g. constraint programming) have emerged in the last 5-10 years. It is now possible to define more precise and sophisticated rules and to deal with the complexity arising from their use. It is, therefore, appropriate

\(^1\) Study of ATFM Priorities, European Commission & Eurocontrol 1998
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3. ISA – A DESCRIPTION

3.1 WHAT IS ISA?

ISA is the product of a workstream carried out at the EEC since 1995 and documented in Report 322 (Dec. 97) and a further Report to be issued in 2001.

ISA is a generic software tool that can be used to model a wide range of slot allocation strategies using any specific algorithm and a number of different optimisation techniques. Programming techniques include constraint programming and linear programming. This compares to the TACT/CASA tool that is constrained to using the FPPR strategy.

To establish its baseline integrity, ISA was set up to use a CASA algorithm that is identical to the operational version (FPPR). This was demonstrated to give the same results as CASA. On that basis ISA has been developed to investigate different principles of slot allocation and the CASA model is used as the baseline for comparison.

ISA has been parameterised and is supported by a user manual so that it can be used by operational personnel and not only by computing experts.

All ISA simulations to-date have been carried out using static data and the tool has been designed to accept dynamic data and to run in tactical mode at a later stage. A common tool set is available for analysis.

ISA is compatible with CFMU applications and can be used as a plug-in slot allocation module to TACT.

3.2 SOME FEATURES OF ISA

ISA supports the same input data format as TACT, which allows slot allocation tests to use realistic European data samples provided through operational databases. As a consequence the results can be compared with those from other CFMU studies.

ISA can generate the same reports and statistics as TACT/CASA. This makes it easier to evaluate precisely and exhaustively the advantages and shortcomings of new slot allocation strategies and to take account of real operational issues.

ISA is flexible and has the capability to respond to changes in operational systems and rules.

Both its flexibility and its closeness to the operational world account for the increasing use of ISA within the scope of various operational studies such as “Unused Slots”, “ATFM priorities”, “SIT 1” etc.
4. ISA USE AND RESULTS

ISA has been used to investigate a range of slot allocation strategies, which are either developments of FPPR or alternatives. A small selection of these strategies is summarised below:

**Reduce Overall Delay (ROD):** This strategy aims to reduce the total number of minutes of delay incurred by all aircraft. This is achieved by changing the order in which flights enter the regulations if doing so would provide an overall delay benefit.

**Reduce Delay per Seat (RDS):** This strategy aims to minimise the delay per seat flown. Thus it gives priority to aircraft with a greater number of seats.

**Optimise Delay according to Flight Duration (DFD):** This strategy allows investigation of the allocation of delay between short-haul and long-haul flights.

In each case the tool reduces overall delay by using available resources more effectively. All constraints remain, the number of regulated flights remains a constant, and no additional "external" capacity is introduced.

4.1 THE RESULTS - ROD AND RDS

Results for ROD and RDS are set out in Table 1 and Table 2 below. These results refer to 9 and 10 July 1999, which are two of the three days for which the models were run and which represent busy, but not peak, days.

<table>
<thead>
<tr>
<th>Slot Allocation Strategy</th>
<th>Number of Regulated Flights</th>
<th>Total Delay (Minutes)</th>
<th>Mean Delay per Regulated Flight/Seat</th>
<th>ISO</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASA - FPPR</td>
<td>11,605</td>
<td>156,259</td>
<td>13.5</td>
<td>.763</td>
</tr>
<tr>
<td>Reduce Overall Delay Limit Maximum Delay</td>
<td>11,605</td>
<td>131,450</td>
<td>11.3</td>
<td>.774</td>
</tr>
<tr>
<td>Reduce Delay per Seat Limit Maximum Delay</td>
<td>11,605</td>
<td>129,157</td>
<td>9.2</td>
<td>.773</td>
</tr>
</tbody>
</table>

Table 1: Results of alternative slot strategies using 9 July 1999 data

Because ISA allows optimisation, it is possible to adjust the strategy in order to keep performance within reasonable bounds for all output measures. Therefore, in order to be operationally feasible, a limit has been imposed on the maximum delay, which may be experienced by any single aircraft. For 9 July the maximum delay is limited to the CASA level. For 10 July it is allowed to exceed the CASA level (see below for further discussion).

ISO is a partial measure of smoothing, which improves as the value approaches 1. In the examples below the ISO value is kept at about the CASA level so that the delays can be compared. If a system benefit could be identified, such as the release of buffer capacity, it might be beneficial to improve the smoothing (increase the ISO value) (see 5.4 below).
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Table 2: Results of alternative slot strategies using 10 July 1999 data

<table>
<thead>
<tr>
<th>Slot Allocation Strategy</th>
<th>Number of Regulated Flights</th>
<th>Total Delay (Minutes) % change on CASA</th>
<th>Mean Delay per Regulated Flight/Seat % change on CASA</th>
<th>ISO</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASA - FPPR</td>
<td>10,083</td>
<td>212,289</td>
<td>21.1</td>
<td>.757</td>
</tr>
<tr>
<td>Reduce Overall Delay Limit Maximum Delay</td>
<td>10,083</td>
<td>164,981 –22%</td>
<td>16.4 –22%</td>
<td>.746</td>
</tr>
<tr>
<td>Reduce Delay per Seat Limit Maximum Delay</td>
<td>10,083</td>
<td>163,682 –23%</td>
<td>14.5 –31%</td>
<td>.751</td>
</tr>
</tbody>
</table>

The message from the ROD and RDS strategies is clear:

*The use of alternative slot allocation strategies can reduce delay by between 16% and 32% compared to the CASA - FPPR strategy.*

The actual improvement over CASA - FPPR will depend on the parameters chosen for optimisation and the trade-offs accepted. In the cases presented the trade-off between the total (and mean) delay and limiting the maximum delay experienced by any aircraft has already been incurred.

Figure 1 shows the distribution of delay for 9 July. It demonstrates how small delays are distributed more evenly between all aircraft and how the number of delays above a 9 minute threshold, which would probably cause operational impact, is reduced. The number of delays greater than 130 minutes is the same for each strategy.
ISA is a flexible tool. It is a feature of slot allocation models that they are extremely sensitive to single additional flights in certain locations. By using the concept of the Flight Marginal Cost (the impact that a single flight has on the overall performance of the system) ISA can help identify those flights that are causing the most disruption and therefore, if appropriate, can help in identifying alternative flight options.

Studies based on linear programming techniques have already demonstrated that the ISA results presented in this paper could further be improved.

The improvements quoted are the direct CFMU delay and take no account of the reactionary delay\(^2\). Reactionary delay is thought to nearly double the total delay experienced by aircraft\(^3\).

### 4.2 The Results - DFD

One result for the Optimise Delay according to Flight Duration (DFD) strategy is shown in Figure 2.

**Figure 2**

Mean delay plotted against the flight duration.

**Figure 2** demonstrates that ISA can reduce delays for short-haul flights by up to 57% and for long-haul by 12%.

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\(^2\) Reactionary delay is the consequential delay experienced by later flights as a result of delays to an earlier flight. Thus, delay to the first flight of the day can cause a series of missed slots later in the day and an accumulation of delay to the point at which the final flight of the day can be lost altogether.

\(^3\) [PRC report PRR3 May 2000]
In this case the trade-off is that maximum delays for long-haul flights are increased. This strategy may or may not be acceptable, the point is that it can be modelled and quantified for consideration.

5. OTHER BENEFITS OF ISA

The overall benefit in terms of being able to investigate slot allocation strategies that reduce delay is stated above. The following paragraphs set out other benefits of the ISA investigation of alternative slot allocation strategies as they relate to some of the stakeholders.

5.1 GENERAL

ISA generated slot allocations can provide a much more stable output than CASA FPPR, so that ISA slot allocation results in dynamic mode are likely to be more independent of the order in which events occur and more focussed on the potential for optimisation.

A particular feature of CASA is that it allocates a time-window for a flight to arrive at the boundary of a regulated sector. One consequence of this is that aircraft can arrive in groups, thus creating bunching and sector overloads. Such bunching causes considerable concern. As traffic becomes more dense and complex and the system works closer to its ultimate capacity, it is expected that bunching will become a more and more critical issue. Thus, techniques to reduce bunching will become essential.

ISA does not need to allocate time-windows and therefore bunching from this cause can be reduced. Other causes of bunching, such as poorly sequenced runway departures, will not be improved. The Figure 3 presented below illustrates the bunching reduction brought by ISA. Let us note that the term “slice” designates a 20 minutes time period and is typically used to get a more accurate insight into traffic distribution.

![Analysis of most overloaded slices](image)

**Figure 3 : Overload percentage for the 20 most overloaded slices**

In addition, it is possible for CASA to produce plans, which include sector overloads. Integrated monitoring tools within TACT would produce a warning if planning included such overloads, therefore this is not currently a problem. It does, however, result in a number of manual operations, which would increase dramatically with more traffic. ISA will not exceed sector capacity constraints.
5.2 CFMU

ATFM is a live operation and will continue to respond to changes in the wider ATM system to provide more and more stable capacity. CFMU system development has provided an impressive armoury of applications and tools to assist that response. ISA is now available as a further tool to support a step change in the development of the CASA module of TACT.

5.3 AIRLINES

Airlines are always concerned with flight safety and the cost and the level of delay and disruption experienced by flights. CASA and ISA are not expected to have significantly different effects on safety. However, as far as cost and capacity are concerned, we might expect airlines to welcome strategies that would offer sustainable improvement to capacity and delay.

Airlines are also most concerned that there should be equity in the allocation of en-route slots so that no airline suffers a competitive disadvantage compared to any other. The concept of equity is one of fairness, not equality. There is no fairness in an approach that imposes an unnecessary delay across the system to the disadvantage of all.

It is a fact that non-FPPR strategies will change the effect of regulations on flights and, therefore, will move delay around between flights. However, ISA can ensure and demonstrate that no particular traffic flow or airline is disadvantaged overall. In the extreme it would be possible to incorporate special cases to stop extreme examples of poor allocation and to introduce a set of priorities if required.

5.4 ATSPs

To compensate for uncertainty, ACCs build a buffer into their declaration of slot capacity so that they have the local spare capacity to handle overloads. It is thought that in some places this buffer is as large as 30%. If adjacent sectors also hold back on their declaration of available capacity there is a wider system effect that results in an even more significant overall reduction in exploitable capacity.

This means that local actors are actively intervening in the system in order to make their part of it work rather than allowing the centre to optimise the system overall. Alternatively, it could equally well be considered that the ATSPs are performing their primary duty of providing a safe environment in a real operational situation.

The overall effect is the inefficient use of capacity and the need for ACCs to invest in other means to provide additional capacity. Given an increase in traffic of, say, 5% per annum, a 30% buffer represents some 6 years growth and its loss is a serious burden on the system.

However, with respect to delays arising directly from the slot allocation strategy, it should be recognised that, overall, an increase in delays of 25% results from a shortage of capacity of some 5%, which represents about one year’s traffic growth. The opportunity, therefore, is to defer investment rather than to avoid it altogether.

5.5 MILITARY

Military aircraft flying under GAT rules are subject to delays in the same way that civil traffic is. The difference is that there is less pre-planned military traffic and a likelihood that flight plans are filed closer to the desired departure time and possibly after the slot allocation has taken place. Thus, by definition and all other things being equal, a greater proportion of military flights is likely to suffer delays and, consequently, benefit from improvements.
5.6 **States**

From the point of view of States an improvement to ATFM represents a cost-effective means of improving capacity usage and with a short lead-time. In most cases the State provides capital for any ATC improvements, and most States will welcome improvements that do not require a capital investment.

5.7 **Overall Effect**

The overall effect of the current slot allocation strategy is set out in Table 3 in the form of a cause and effect logic. It demonstrates both the benefits of improving en-route slot allocations and also the consequential benefits of reducing the undeclared capacity of ACCs.

<table>
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<tr>
<th>SOURCE OF LOSS</th>
<th>EFFECT OF LOSS</th>
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<tr>
<td>Inefficient en-route slot allocations</td>
<td>Up to 30% increase in delays, which represents a cost of some Euro 1,100,000 on a busy day.(^4)</td>
</tr>
<tr>
<td>Loss of flow integrity, poor smoothing, ATFM bunching and external causes of bunching</td>
<td>Local action taken by ACCs to protect the safety of the system by building in a buffer and anticipating peak situations.</td>
</tr>
<tr>
<td>Buffer retained by ACC</td>
<td>Up to 30% of potential capacity not available for central allocation. Actual capacity losses not known but could be greater.</td>
</tr>
<tr>
<td>Unknown loss of capacity</td>
<td>Further increase in delays of 5 times % loss of capacity.(^5)</td>
</tr>
</tbody>
</table>

Table 3: Overall Effect

6. **Equity and the FPFS Principle**

6.1 **The Equity Viewpoint**

It is not the purpose of this summary paper to argue the case for or against the FPFS principle, only to put it in context.

The CFMU handbook provides the following definition of 'First Planned - First Served'.

"The principle 'First Planned - First Served', which presumes that flights should arrive over a restricted location in the same order in which they would have arrived had there been no ATFM Measures, is applied throughout the CASA process".

\(^4\) Based on the IATA figure of Euro 22 per minute of delay on the ground

\(^5\) CFMU 2000
As discussed earlier, the practical application of FPFS is to apply it to the most penalising regulation, which we have referred to as FPPR.

FPPR is not the only principle that is important to airlines. They are also concerned that flights with the same departure and arrival airports should take off and land in the same order as defined in their flight plans. In this respect ISA results are similar to those generated by CASA.

The current approach is, therefore, a means of achieving a level of equity that seems to have the confidence of users. However:

*The principle of equity is one of fairness, not of equality. The current approach cannot be said to be fair if it is imposing an overall penalty on all users.*

It is a fact that slot allocation will be most effective if it uses a strategy that is different from FPPR. The extent to which the principle is allowed to be different will ultimately depend on:

- ISA’s ability to demonstrate equity safeguards and
- User’s desire to trade-off a reduction in delay against an amended slot allocation rule.

### 6.2 AN ECONOMIC VIEWPOINT

The current allocation of ATFM delay is based only on the delay that is imposed by the most penalising regulation i.e. the regulation that imposes more delay on a flight than any other it wishes to traverse. An aircraft could travel through any additional number of regulations and therefore increase the peak load on the route without experiencing any additional adverse effect.

Thus, once an aircraft has to fly through the most penalising regulation, there is no incentive for it to try to reduce the load on other, less penalising, regulations by adopting a different flight level or rerouting (if practicable). As a consequence, there is only a limited natural tendency for the system to spread the load, either vertically or horizontally, so as to make maximum use of any capacity available in adjacent airspace.

The extent of the problem is illustrated by Figure 4, which shows the number of regulations traversed by flights. It demonstrates that 50% of the total regulated flights passed through more than one regulation.

![Figure 4: The Number of Regulations Traversed by each Aircraft on 9 July 1999](image-url)
The overall effect is inefficiency in the use of the scarce resource (airspace) and a failure to allocate the cost of use, to all users, of all airspace that is subject to a regulation. It could therefore be argued that some users are being subsidised by others, an inequitable situation.

A comparison can be made to an autostrade with three sections of equal length. Traffic is only allowed into each section when the road is clear. Waiting times for the first two sections are each 10 minutes long and that for the third section is 20 minutes long. According to FPPR, traffic using all three sections is allowed to bypass the queue for the first two sections, but has to wait at the third section for 20 minutes with the rest of the traffic. Traffic using only one of either of the first two sections has to wait 10 minutes in the queue to enter it. Most drivers would not consider that to be an equitable solution.

7. OPTIONS

There are 2 options:

1. Do nothing and lose the potential benefit of an improved slot allocation strategy.
2. Use ISA to investigate alternative slot allocation strategies. This would mean taking ISA to the next stage of practical development by using dynamic data and running it as a simulation in shadow mode in TACT.

*It is not necessary at this stage to take any decisions on the principles of slot allocation strategies or whether to change from the strategy of FPPR.*

If ISA can demonstrate the benefits expected from alternative slot allocation strategies, users will have some basis on which to consider

- whether they wish to change,
- which strategies are most attractive, and
- whether they wish to apply any limits or constraints on a new strategy.

A test using dynamic data will be able to measure a wide range of performance criteria including traffic smoothing, bunching, over delivery, average delay and maximum delay. It will be possible to define a range of measures of equity. Investigation can be carried out to determine the extent to which the allocations are equitable and whether special parameters are required to ensure that individual traffic flows or airlines are not discriminated against.

Under any option ISA, will remain a valuable analytical tool for investigating capacity and slot allocations. In the long run, if a decision is made to change slot allocation strategies, a separate decision will be made on how to develop the slot allocation module within TACT in order to provide the required operational support.
8. **RECOMMENDATIONS**

It is recommended that:

1. A trial should be carried out jointly by EEC and CFMU, with the co-operation of the airlines and ATSPs, using ISA to investigate the potential benefits of alternative slot allocation strategies.

2. The trial should be run as a shadow application to CASA using dynamic data.

3. The results of the trial should be published and used as the basis for discussion about whether changes to the current strategy for slot allocation would be appropriate.