On the Operational Feasibility of Traffic Synchronisation – preliminary results

Lenka DRAVECKÁ
EUROCONTROL CRDS (Budapest)
University of Zilina (Slovakia)

Supervisors: Vu DUONG and Tomas DENDIS
lenka.dravecka@eurocontrol.int
Future vision of Synchronised ATM system

- Proposed organizational changes
  - Shift
- The potential of flow synchronisation
  - Future ATFM measures
  - En-route Miles-In-Trail Spacing

Difference: en-route techniques

US controllers more productive than European in terms of aircraft handled in an hour!
Why traffic synchronisation?

- Robust traffic growth is expected in the coming years.

- Unbalanced speed distribution on FL’s is affecting controller’s workload (required communication).

- Regulation of traffic in a flow is much needed.

- Synchronisation might be the solution for increasing the airspace throughput.
What is Synchronisation?

- **Operational feasibility**
  Is the solution solving the problem?
  Technological & economical issues to be investigated later.

- **But for whom?**
  Airspace users-airlines, providers
  Controllers, pilots
  Better utilization of existing route network

- **Want to achieve**
  Objective results of traffic flow synchronisation through traffic flow capacity increase (?) and potential conflict situations decrease (?) and hence improvements of safety to support the operational feasibility applied in case of Central European Upper Airspace

The new speed fixes the speed of the flight.

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4/19
Synchronisation model – simplified
(goal, criteria, indicators)

\[ S = R; W; C \]

**Level 1**
Goal

**Level 2**
Criteria

- **R** – REGULARITY
- **W** – WORKLOAD
- **C** – COSTS

**Level 3**
Indicators

**Input:**
- Flight Plan
- Aircraft performance

**Output:**
- Rule-based Algorithm
- Modified Model indicators

- **Model indicators**
  - Variance of speed distribution over 1FL
  - Bunching index
  - Standard deviation of aircraft between FLs
  - Moment of spread of aircraft count on 1FL

- **Model indicators**
  - Number of horizontal conflicts
  - Number of vertical conflicts
  - Number of conflicts within a flow

- **Modified Model indicators**
  - Over-flown time

- **Output:**
  - Modified Trajectories
  - Synchronised traffic flow
The Target Flow is defined by:

- $A_T$ – the Assigned Flight Level
- $V_T$ – the Target Speed (desired speed of the flow)

Each aircraft $i$ is defined by:

- $V_i(t)$ – Actual Speed
- $A_i(t)$ – Actual Flight Level

The goal:

- $V_i(t) \rightarrow V_T$
- $A_i(t) \rightarrow A_T$

Does the transit phase encompass ONE sector (?)
Parameters: limitations for changes in speed and altitude

Threshold values:
- Share of the aircraft on the FLs ($m_{FL}$)
- Share of speed on target FLs ($m_V$)

1. Speed adjustment on FL +/-0.02M;
2. Speed adjustment on FL +/-0.01M;
3. Speed adjustment on FL +/-0.02M, change FL of aircraft falling into predefined speed range in neighbouring FL into FL selected for synchronisation.

Diagram:
- Select FL
- Select speed
- Speed adjustable?
- Change FL
- Yes: Adjust speed
- No

Flowchart:
CEATS—Central European Air Traffic Services

- High traffic growth
- Large area of operation
- Better inter-sector coordination

Czech, Slovakia, Austria, Hungary, Slovenia, Croatia, Bosnia & Herzegovina, Italy (ACC Padua)

There are some notable increases in delay in Paris, France West and “CEATS” =124%.
Traffic analysis of selected segments

CEATS is not under the operation yet, the last model simulation is taken as a basis

Assumptions:

- 2 routes through the CEATS airspace
  - Routes with the highest traffic load
  - Parallel, no crossings

- CHIEM – OBEDI – (%LO19 – KFT – PODET) – ZAG – JULIE (348) (6.64%)
- TONDO – BEGLA – GISPO – %LO11 – PASAU (184) (3.51%)

- These routes are uni-directional
- Results of the calculation of the criteria indicators

  - CHIEM-OBEDI-ZAG (cruising and descending traffic) (302 aircraft)
  - TONDO-BEGLA (cruising and descending traffic) (184 aircraft)
Preliminary results CHIEM - ZAG

**CHIEM-ZAG FL290-unlimited (302 aircraft)**
- FL370: 40.40% (122 aircraft)
- FL350: 22.52% (68 aircraft)
- FL370 most preferred speed 0.8M: 50.82% (62)
- FL350 most preferred speed 0.78M: 70.59% (48)

- FL330: 18.54% (56)
- FL390: 7.28% (22)

**Speed adjustment on FL +/-0.02M:**

**CHIEM-ZAG**
- FL370: 37.09% (112 aircraft)
- FL350: 19.87% (60)
- FL370 most preferred speed 0.8M: 100%
- FL350 most preferred speed 0.78M: 100%

- FL330: 15.89% (48)
- FL390: 18.87% (57)
Preliminary results
Scenario 1 compared with non-synchronized scenario

**Speed distribution comparison**

- 46.36%
- 41.06%
- 26.16%
- 24.44%
- 2.65%
- 0.66%
- 0.99%
- 2.65%
- 0.00%
- 0.00%
- 5.30%
- 5.30%
- 0.66%
- 2.32%
- 1.36%

**Traffic distribution on FLs**

- Before
- Scenario 1

<table>
<thead>
<tr>
<th>Flight Level</th>
<th>290</th>
<th>310</th>
<th>330</th>
<th>350</th>
<th>370</th>
<th>390</th>
<th>410</th>
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<tbody>
<tr>
<td>Before</td>
<td>8</td>
<td>20</td>
<td>70</td>
<td>56</td>
<td>68</td>
<td>112</td>
<td>26</td>
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<tr>
<td>Scenario 1</td>
<td>22</td>
<td>26</td>
<td>122</td>
<td>112</td>
<td>122</td>
<td>26</td>
<td>6</td>
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</table>
Regularity values for CHIEM-ZAG (2)

Comparison of Bunching index
CHIEM-OBEDI

Comparison of Variance of speed on the FLs
CHIEM-OBEDI

Comparison of Moments of Spread
CHIEM-OBEDI
<table>
<thead>
<tr>
<th>Vertical movements</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL change +/- 2</td>
<td>0/6</td>
<td>0/6</td>
<td>0/6</td>
</tr>
<tr>
<td>FL change +/- 1</td>
<td>5/48</td>
<td>10/56</td>
<td>33/59</td>
</tr>
<tr>
<td>Total</td>
<td>59</td>
<td>72</td>
<td>98</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CHIEM - JULIE</th>
<th>initial TAS [M]</th>
<th>initial TAS [kt]</th>
<th>sync. TAS [M]</th>
<th>sync. TAS [kt]</th>
<th>initial flight time</th>
<th>sync. flight time</th>
<th>time difference</th>
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<tbody>
<tr>
<td>FL</td>
<td>390</td>
<td>0.78</td>
<td>446,350</td>
<td>0.8</td>
<td>457,795</td>
<td>0:52:39</td>
<td>0:51:20</td>
</tr>
</tbody>
</table>

Reference flight: CHIEM - LTF

<table>
<thead>
<tr>
<th>CHIEM - JULIE</th>
<th>initial TAS [M]</th>
<th>initial TAS [kt]</th>
<th>sync. TAS [M]</th>
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<td>390</td>
<td>0.78</td>
<td>446,350</td>
<td>0.8</td>
<td>457,795</td>
<td>2:08:14</td>
<td>2:05:02</td>
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</table>

<table>
<thead>
<tr>
<th>Change of the degree of synchronisation [%]</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHIEM - JULIE</td>
<td>20.27</td>
<td>20.01</td>
<td>27.74</td>
<td>20.8</td>
<td>-7.49</td>
</tr>
<tr>
<td>TONDO – BEGLA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Scenarios assessment

- Prioritizing the criterion Workload scenario 1 could be used for synchronising the traffic in real time.
- Through the moderate speed adjustment allowed, over maximum +/- 0.02 M, little changes in flight times are caused.
- In all three scenarios a reduction of potential conflict situations by the complete synchronisation is achieved.
- The synchronisation without additional shift of aircraft into the target FLs improved approximately of 20%.
- The traffic load on the route could be balanced; except in scenario 3 (CHIEM-JULIE). The best balance is achieved in scenario 2.
- The synchronisation smoothen the traffic load between the FLs. Aircraft are shifted from the high loaded synchronization FLs into the neighbouring FLs with a lower traffic load.
- The value of the standard deviation in all scenarios improved; except scenario 3 of the route CHIEM – JULIE.
- The degree of synchronisation improved in all scenarios in about the same value; except scenario 2 for the route TONDO – PASAU.
The synchronised traffic flow is characterized by a unified flight speed. Thus constant distance separation is achieved.

Costs are spared when a constant speed is flown and thus predictability of the over-flown time increases.

The comparison of the predefined indicators and the costs (over-flown time) suggests selecting scenario 1 for both routes.

It is shown that synchronisation is a good approach to reorganize the traffic on speed levels in order to cope with future demands.
Traffic synchronisation in en-route environment

RAMS PLUS™ Reorganized ATC Mathematical Simulator (developed by the ISA Software)
- fast-time simulation model available for airspace structure, capacity and workload analysis

Objective is to verify (through measurements)

**Reduction of controllers’ workload** – important factor of sector capacity limit at the moment
**Minimum over-flown time** – the study will focus on the potential impact that a model may have on minimum over-flown time
**Route density** – synchronisation of traffic on selected FL’s may cause several bottlenecks at congested areas
**Conflicts variations** – important factor for controllers’ workload reduction
**Task sharing** – different task sharing may have impact on level of synchronisation
Conclusions

Increasing the airspace throughput and remove potential conflict situations are the main elements of synchronised ATM concept.

The positive results depends on appropriate synchronisation model with respect to aircraft performance envelopes.

Traffic flow synchronisation can be used to smoothen the traffic operations in high density areas with mainly long-hauls flights.

The synchronised traffic structure involves a part of standardization in the crowded areas where the control system applies the same rules to each aircraft flying in a flow. This structure is the first layer of safety where potential conflicts are removed.

Synchronisation is partial solution to increase the airspace throughput to solve capacity problems starting in the en-route environment.
Impact of Synchronisation on air traffic

Microscopic level – impact on 1 sector, 1 route

European level – network effect

Better distribution of traffic demand
Improved traffic throughput
Reduced controllers’ workload; required communication with the aircraft
Reduced number of potential conflict situations
Reduced speed diversity on Flight Levels
Improved predictability of the flight time
THANK YOU FOR YOUR ATTENTION!
SFTS4- preliminary scenarios

static

B1
no synchronisation
situation 1, FL +/- 0.02M
situation 2, FL +/- 0.01M
situation 3, modification of 1
new task-list

B2
B3
B4
C

dynamic

A1
Up-to-date (36% traffic increase)
A2
Future (100% traffic increase)
A3
Future (200% traffic increase)

10 SCENARIOS (?)

1  B1 A1 compared to  B2 A1  4  B1 A2 compared to  B2 A2  7  B1 A3 compared to  B2 A3
2  B1 A1  ...  B3 A1  5  B1 A2  ...  B3 A2  8  B1 A3  ...  B3 A3
3  B1 A1  ...  B4 A1  6  B1 A2  ...  B4 A2  9  B1 A3  ...  B4 A3
10  B1 A1 C  ...  B2 A1 C

basic scenario
**Scenario 1**

**Scenario 2**

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### CHIEM - JULIE

<table>
<thead>
<tr>
<th>Sum of change of fuel burned in CEATS [kg]</th>
<th>CHIEM - JULIE</th>
<th>TONDO - PASAU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>-125.84</td>
<td>1387.1</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>2769.641</td>
<td>1297.135</td>
</tr>
</tbody>
</table>

*Only aircraft affected by synchronisation have been counted*

- **Degree of synchronisation:**
  
  \[ \Delta G_s = \frac{MQW_S}{MQW_0} \]

- **Mean square deviation within FLs:**

  \[ MQW = \frac{\sum_{i=1}^{p} \sum_{j=1}^{n} (x_{ij} - x_{m,i})^2}{(n - p)} \]

**CHIEM-JULIE:**

- Scenario 1: Many accelerations + 0.02 Mach; gain on time predominates increased consumption
- Scenario 2: increased consumption due to lower FLs, no speed changes

**TONDO-PASAU:**

- Scenario 1: Large amount of decelerations
- Scenario 2: Large amount of changes to lower FLs
Formulas:

- **Variance of speed distribution over 1FL:**
  \[ \sigma_x^2 := \frac{\sum_{i=1}^{n} x_i^2 - n \cdot x_m^2}{n} \]

- **Coefficient of variance:**
  \[ V_x := \frac{\sigma_x}{x_m} \]

- **Standard deviation of speed over 1FL:**
  \[ \sigma_x := \sqrt{\sigma_x^2} \]

- **Moment of spread of traffic distribution over 1FL:**
  \[ S_{xx} := \sum_{i=1}^{n} x_i^2 - n \cdot x_m^2 \]

- **Bunching index:**
  \[ b := \frac{1}{n} \sum_{j=1}^{n} (c_j - l_j)^2 \]

References:
- Karl Nachtigall, 2001, *Verkehrssystemtheorie*, Manuskript zur Vorlesung im WS und SS 2001/02, Technische Universität Dresden, Dresden, Germany
Horizontal & vertical conflicts

I. Average number of potential conflicts per hour

II. Index of conflict density
   - Describes the crossing without influence of the traffic flow

III. Capacity of crossing
   - Capacity of given average number of potential conflicts per hour
Costs arising due to over-flown time:

Due to the fact, that after the synchronization only one speed per flight one flight level will be used, the over-flown time can be defined precisely. It can be accurately calculated by using the formula:

\[ t := \frac{S}{v_{TAS}} \]

This can be appreciated by the airlines since they will be eventually able to optimize (modify) strategically integrated times in the flight planes when crossing given airspace.

References:

• Eurocontrol, April 2004, *Performance Review Report*
• Eurocontrol, *Evaluating the true Cost to Airlines of one minute of Airborne or ground delay*