University of Belgrade
Faculty of Transport and Traffic Engineering
Division of Airports and Air Traffic Safety

Influence of Airport Operations Management on Traffic Complexity and Efficiency

Tatjana Krstić Simić, Obrad Babić and Velibor Andrić

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Outline

- Introduction;
- Concept and measure of airport traffic complexity;
- Flight inefficiency metrics;
- Fuel consumption and gas emission;
- Experiment: modelling assumptions, results and discussions;
- Conclusions;
- Further research.
EUROCONTROL’s “most-likely” growth scenario: flight demand in Europe is predicted to be 14.4 million movements in 2035 (1.5 times the 2012 volume).
Positive as well as negative effects on the society and environment.

Concept of sustainability and sustainable development.

Three main categories of sustainable development issues: economic, social and environmental.

In this research, emphasis is on the environmental dimension of the air traffic effects - a very important issue.

Air traffic → 3.5% of European CO₂ emission and still growing (2050 air transport CO₂ emission would grow 3 to 4 times compared to 2000).
Introduction (3)

- Single European Sky ATM Research (SESAR), Clean Sky and US - Next Generation Air Transportation System (NextGen):

  → environmental impact reduction targets regarding noise, air quality and climate change.

- ATM improvement as a very important element in meeting their overall goals.

- Literature: reduction of fuel consumption through improvement in operational performance for up to 10%.
Airports - one of the bottle-necks in the air transport system ⇒
airfield movements and traffic in the airport vicinity were chosen to be analyzed.

Busy airports during peak hours:
runway queuing delays and taxi-out/in times increase ⇒
⇒ additional, unnecessary fuel consumption and gas emission.

By 2035: airport delay from around 1 minute/flight in 2012 increase to 5-6 minutes - major contributor of delay.

Airports have to be enlarged, or to utilize the existing resources as efficiently as possible.
Potential airport delays „generators“ indicator - a measure of airport traffic complexity is proposed.

Research on the relationship between airport traffic complexity and time and environmental airport efficiency under different air traffic control (ATC) tactics.
Large number of studies deal with relationship between complexity and air traffic controller workload.

Concept of complexity as "weight" of the traffic situation, i.e. possible impact of the exact traffic situation on air traffic controller workload.

The concept and measure of airport traffic complexity used in this research were proposed by Krstić Simić and Tošić, 2010 (*2004).

Complexity through traffic characteristics, i.e. as a measure of quantity and quality of traffic interactions on airport airfield and in airport vicinity, under certain circumstances.
The term **Dynamic Complexity - DC** is introduced as a measure of airport traffic complexity and is defined as a linear combination of traffic density and a number of proposed traffic complexity factors:

\[
DC (t) = \alpha TD (t) + \beta_1 N_h (t) + \beta_2 N_{tl} (t) + \beta_3 N_{sv} (t) + \beta_4 N_m (t) + \\
+ \beta_5 N_c (t) + \gamma_1 N_{REND} (t) + \gamma_2 N_{RMID} (t) + \gamma_3 N_{RXR} (t)
\]

\(\alpha, \beta_1 \ldots \beta_5\) and \(\gamma_1 \ldots \gamma_3\) - specific “weights” of traffic density and traffic complexity factors (*could be the subjective judgments by the ATCo - not considered in this paper.*
The system (analyzed in this research) boundaries are:

- **for arriving aircraft** – from FAF, to the moment of arriving on the apron;
- **for departing aircraft** - from the moment of push-back or start-up clearance request, until a given time after departure.

**TD - traffic density** shows the total number of aircraft in the system, either aircraft already “inside” the system or waiting at the system boundary (due to assigned delays), at a certain moment in time.
Traffic complexity factors

- **number of pairs of take-off / landing successive operations**, where operations are overlapping during a time interval they spend in the system – $N_{t/l}$.

- **number of potential separation violation**, i.e. number of aircraft pairs whose minimal separation will be violated without controller intervention, (overreach situations or in intersections), all referred to airfield movings – $N_{sv}$.

- **number of merging**, i.e. number of aircraft pairs which will, during their taxing phase, go through the same point and go on by the same path (they will be merged in the same flow) - $N_{m}$.

- **number of crossing**, i.e. number of aircraft pairs which will, during their taxing phase, go through the same point and go on by different paths – $N_{c}$.

- **number of departing aircraft holding at gate** - $N_{h}$,

- **number of runway crossings, in the middle of RWY** – $N_{RMID}$,

- **number of runway crossings, at the end of RWY** – $N_{REND}$, and

- **number of runway crossings in two runways crossing point** – $N_{RXR}$. 
Time crossings question

- Time $t$ is the moment when any change in the system occurs, which further implicates DC value change, such as:
  - when aircraft appear or leaving the system,
  - the beginning and ending of a potential separation violation, aircraft path merging or crossing situation for the taxing aircraft,
  - when aircraft occupy or release some resource (RWY, intersection).

- In the paper “Airfield traffic complexity” (Krстиć Simić and Tošić), it was shown that:

  „The proposed measure - DC is a good indicator of the system situation changes (traffic structure and volume changes) and the measure “reacts” in the expected way in different airport configurations, under certain circumstances.“
Flight inefficiency metrics

- Ideal air transportation system: all aircraft fly their optimal 4D trajectories between airports and taxi on the optimal airfield routes:
  - lowest fuel burn and gas emissions,
  - lowest noise level and
  - lowest overall effects upon air quality.

- Real world constraints (such as required minimum aircraft separation):
  - less efficient aircraft flying and taxiing trajectories
  - greater environmental negative effects than ideal.

- ATM - a significant role in reducing the environmental impacts.

- Quantify ATM performance and identify the levels and sources of inefficiency: using relevant performance measure.
“Inefficiency Metric” provides information about the difference between actual and optimal values of the analyzed parameters (Reynolds, 2009):

\[
\text{Inefficiency Metric (\%)} = \left(\frac{\text{Actual} - \text{Optimal}}{\text{Optimal}}\right) \times 100
\]

In this research - relative measure of:

- time which aircraft spent in the system – Time Inefficiency,
- fuel consumed - Fuel Inefficiency and
- corresponding gas emission - Emission Inefficiency,

were analyzed (within defined system boundaries).

* Optimal values: values which aircraft would obtain in case of unimpeded flight, taxiing on the shortest route with no holds (as if it were alone in the system).
Fuel consumption and gas emission depend on:

- aircraft type (engine type),
- flight phase(s),
- engine power regimes,
- meteorological conditions and on
- time spent in considered flight phase(s).

Literature review: different values of engine thrust suggested for different taxiing phases.

In this research: Values for fuel consumption and corresponding emission data (CO$_2$, H$_2$O, CO, HC, NO$_x$, benzene and SO$_x$) in different flight phases, taken from the data base of model AEM3 – Advanced Emission Model (EUROCONTROL) and from ICAO Aircraft Engine Emissions Databank.
Fuel consumption and gas emission (2)

Total fuel burned of the flight $i$ for the observed flight phases $j$ is:

$$TF_i = \sum_i FB_{ij} = \sum_i (T_{ij} \times N_i \times FBI_{ij})$$

- $FB_{ij}$ - fuel consumption during phase $j$ of the flight $i$,
- $T_{ij}$ - time which the given flight spends in the phase $j$ of the flight $i$,
- $N_i$ - number of engines of the aircraft on the flight $i$ and
- $FBI_{ij}$ - single engine fuel consumption index in the phase $j$ for the engine type of the flight $i$ (in kg/s).

Total fuel burned $TF_a$ of all observed flights $i$ (for the observed flight phases $j$) is:

$$TF_a = \sum_i TF_i \quad i = 1, \ldots, n$$

- $n$ - total number of flights in the analyzed system during the observed time period.
Fuel consumption and gas emission (3)

Total gas emission of all observed pollutants $k$ during flight phases $j$ for the flight $i$ - $TE_i$ is:

$$TE_i = \sum_j \sum_k E_{ijk} = \sum_j \sum_k (T_{ij} \times N_i \times EI_{ijk})$$

- $E_{ijk}$ - emission of the pollutant $k$ during phase $j$ on the flight $i$,
- $EI_{ijk}$ - single engine emission of the pollutant $k$ during phase $j$ for the certain engine type of the aircraft on the flight $i$ (in kg/s).

Total gas emission $TE_a$ of all observed flights $i$ (for the observed system) is:

$$TE_a = \sum_i TE_i \quad i = 1, \ldots, n$$

- $n$ - total number of flights in the analyzed system during the observed time period.
ATC tactics

- ATC management actions could significantly influence system performances.

- Different runway sequencing tactics (for arriving and departing aircraft) could be used.

- During taxiing aircraft could be assigned to different taxiing routes.

- Different constraints: departures and arrivals slots, some airlines’ priority over others, connecting flights, etc.

- Chosen and applied ATC tactics for airport infrastructure utilization influence both the complexity and inefficiency values.
Two ATC tactics were analyzed:

- **Arrivals priority sequencing tactic (AP).** Departure could get the take-off clearance only if there is enough time (separation) to be inserted between two arrivals.

- **Arrival-departure sequencing tactic (A/D).** Arrivals were additionally separated in order to insert departure between each two arrivals.

- Arrival and departure initial sequences were determined separately, like FCFS sequence.

- Taxiing routes to/from gates were partly assigned to aircraft at random and partly were defined.
Experiments

- In order to obtain the range of values for Dynamic Complexity, Time, Fuel and Emission Inefficiency, for the given traffic scenario and different airfield utilization strategies (ATC tactics), some stochastic experiments were performed.

- Airport with one runway and taxiway parallel to runway was modeled using SIMMOD simulation model (Version 8.1).

- Configuration which enables “high” traffic throughput and for which ATCo has possibilities to organize traffic in different ways on tactical level.
Modeling assumptions were numerous, the most important being:

- **Aircraft appear in the system randomly, by uniform distribution:** aircraft inter-arrival time is 1 to 3 minutes for arrivals, as well as for departures ⇒ arrival : departure = ~ 50 : 50%

- **Type of aircraft (heavy or large):** randomly assigned to aircraft (heavy : large = ~ 25 : 75%).

- **Aircraft occupy taxiways and taxiway intersection points, using the FCFS principle;**

- **Traffic density and all traffic complexity factors have even importance (equal to 1):**

\[
\text{DC} (t) = \text{TD} (t) + \text{N}_{t/l} (t) + \text{N}_{sv} (t) + \text{N}_{m} (t) + \text{N}_{c} (t)
\]
Regarding fuel consumption and gas emission: two types of aircraft for heavy aircraft: B747 and A310 and two types for large aircraft: B737-700 and F100 – randomly assigned: ~ 50 : 50%.

Considered flight phases: aircraft holding in the air, approach, landing, take-off, climb-out, taxi-in/out and holding on the airfields.

Simulation iterations: randomly assigned delays to the aircraft by uniform distribution from 0 to 3 minutes, compared to initial traffic sample.

Calculations were done for aircraft which enter the system in one hour time interval, with assumptions that:

- system is empty at the beginning and
- aircraft continue to appear in the system by the same distribution until all observed aircraft are served.
Results and discussions

- Aircraft delays for different ATC tactics-

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Total</th>
<th>Average number of a/c served in 1. hour</th>
<th>Average total delay for a/c served in 1. hour</th>
<th>Average delay by a/c served in 1. hour</th>
<th>Average total delay for a/c enter the system in 1. hour</th>
<th>Average delay by a/c enter the system in 1. hour</th>
<th>Average delay by a/c enter the system in 1. hour</th>
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<tbody>
<tr>
<td>AP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>56.33</td>
<td>551 min</td>
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<td></td>
<td>Arrivals</td>
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<td>28.17</td>
<td>17 min</td>
<td>0.60 min</td>
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<td>Departures</td>
<td>14.83</td>
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<td>10.64 min</td>
<td>28.17</td>
<td>534 min</td>
<td>18.96 min</td>
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<tr>
<td>A/D</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Total</td>
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<td></td>
<td>Arrivals</td>
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Results and discussions (2)

- Dynamic Complexity for different ATC tactics -
Results and discussions (3)

- Inefficiency values for different ATC tactics-
Total (average) fuel consumption and emission for different ATC tactics

The chart shows the total (average) fuel consumption and emission for different ATC tactics. It indicates that there is a decrease in fuel consumption and emission by approximately 40% for different tactics.

Total (average) emission for different ATC tactics

The second chart displays the total (average) emission for different ATC tactics. It shows a decrease in emission by approximately 70% for different tactics.
The concept and a measure of airport traffic complexity - Dynamic Complexity is proposed.

Flight inefficiency metrics are defined and analyzed - Time, Fuel and Emission Inefficiency.

Some experiments are performed: for the given airport configuration and given traffic scenario.

Values for Dynamic Complexity, Time, Fuel and Emission Inefficiency, for different airfield utilization strategy (ATC tactics), were determined.
“Logical” relationship between Dynamic Complexity and Time, Fuel and Emission Inefficiency is observed.

It was shown how some improvements of the system efficiency could be achieved by ATC tactics changes, while in some cases strategic measures are necessary.

Conducted and future research could enable development of a decision support tool for the airport planners – to evaluate effects of:

- traffic volume and/or structure changes,
- implementation of some ATC tactical and/or strategic measures,

from the efficiency and environmental point of view.
Further research ...

- Traffic complexity measure: include human factor in complexity determination - by interviewing ATCOs.

- New ATM operations and new technologies (aircraft and engine design, energy) influence.

- Analysis for more complex airport configurations (with larger number of runways and taxiways) and higher traffic intensity, where larger number of different aircraft interactions is quite possible.
Thank you for your attention

Questions?
Comments?

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Division of Airports and Air Traffic Safety
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