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Fluctuation Scaling in the Air Traffic Controller Communication Activities

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☆ EUROCONTROL Experimental Centre

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Outline

1. ATM Complex System Modeling
2. The understanding of ATCO activities
3. Data and Methods
4. Initial Results
5. Validation and Future Work

ATM Complex System Modeling

Goal:

- Exploring a complex systems modeling approach for ATM Model-Based Simulation. [5 years project 2009-2013]

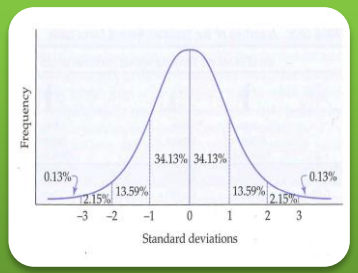
Relation to SESAR:

- Contribution to the identification and development of Model-based Simulation Tools – to be used as a platform for validation of ATM concepts (ATC operating principles, Airspace management organizations, Flight operations, *etc.)* – which can produce both local and holistic behaviours of different configurations of ATM systems in terms of systems KPI such as:
  - Efficiency,
  - Predictability,
  - Reliability,
  - Availability,

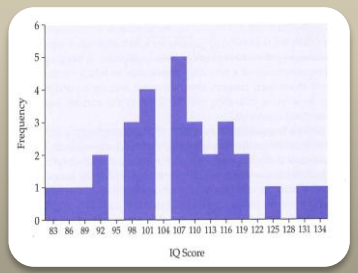
ATM as a Complex System?

	Primary Characteristics of Complex Systems	ATM System
1	Structural Complexity **(combinatorial or detail complexity), i.e. when system consists of a large number of interconnected parts**	✓
2	Behavioural Complexity **(dynamic complexity), i.e. when prediction of system outputs or *emergent* behaviour is difficult.**	✓
3	Nested Complexity **(multi-levels organizational complexity), i.e. complex physical/technical system embedded in a larger system. The two-way interactions between adjacent levels create *nested complexity.***	✓
4	Evaluative Complexity**, e.g. multi-stakeholders environment where good performance to one may not be good to another: difficult decision to make**	✓

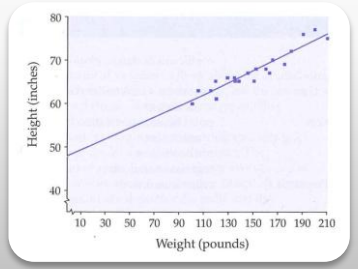
Implications



Can't *readily* predict *emergent behavior* even if we understand the subsystems, e.g. ASAS in Controlled Airspace or Data-Link in ATC.

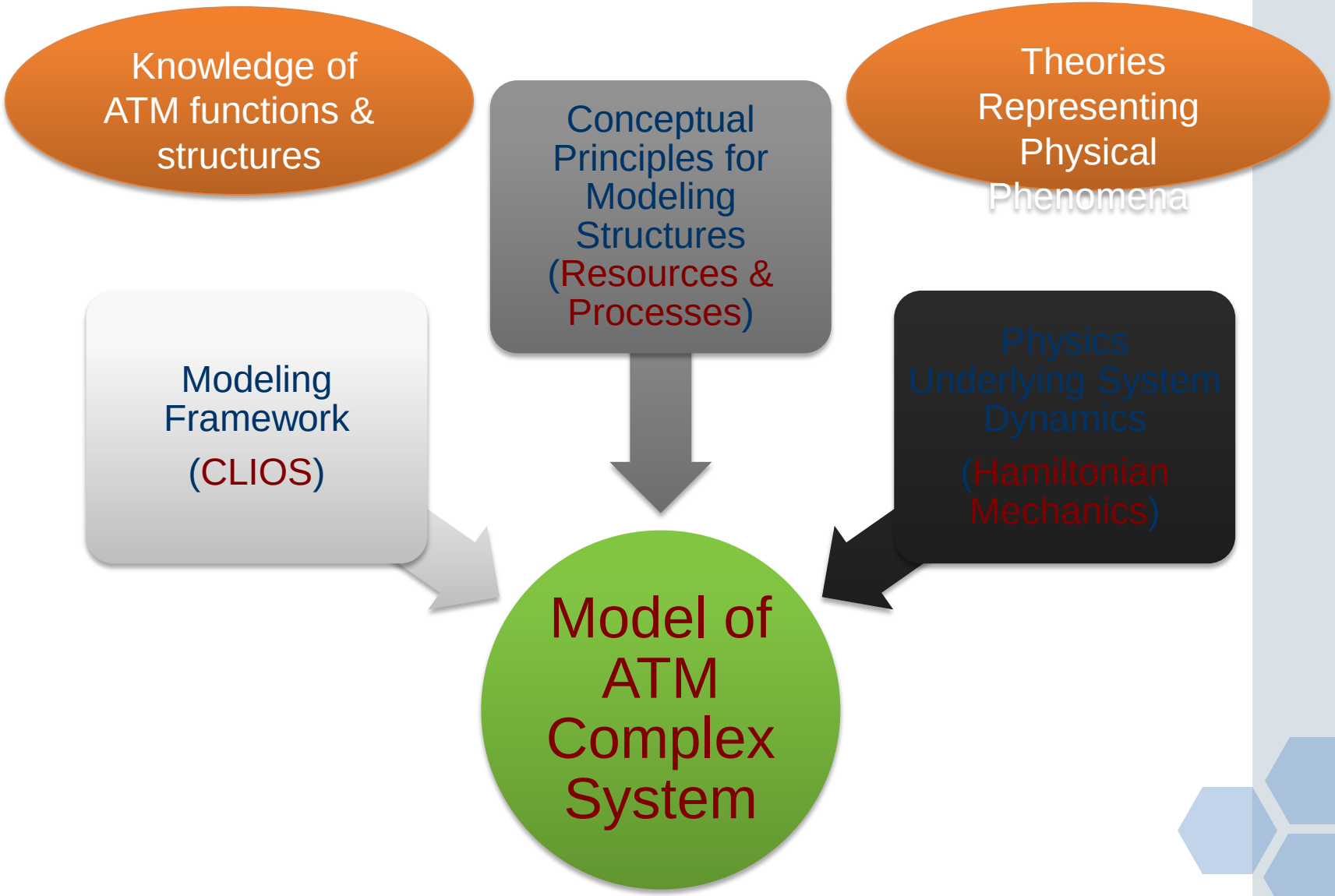


Simplification doesn't work – If focusing on single sectors, the results may be counterproductive, e.g. "Capacity" or working methods in Super Sector Project.



System may be "*policy*" resistant, e.g. harmonization of ATC systems.

Modeling Approach



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ATCO in the continuous environment

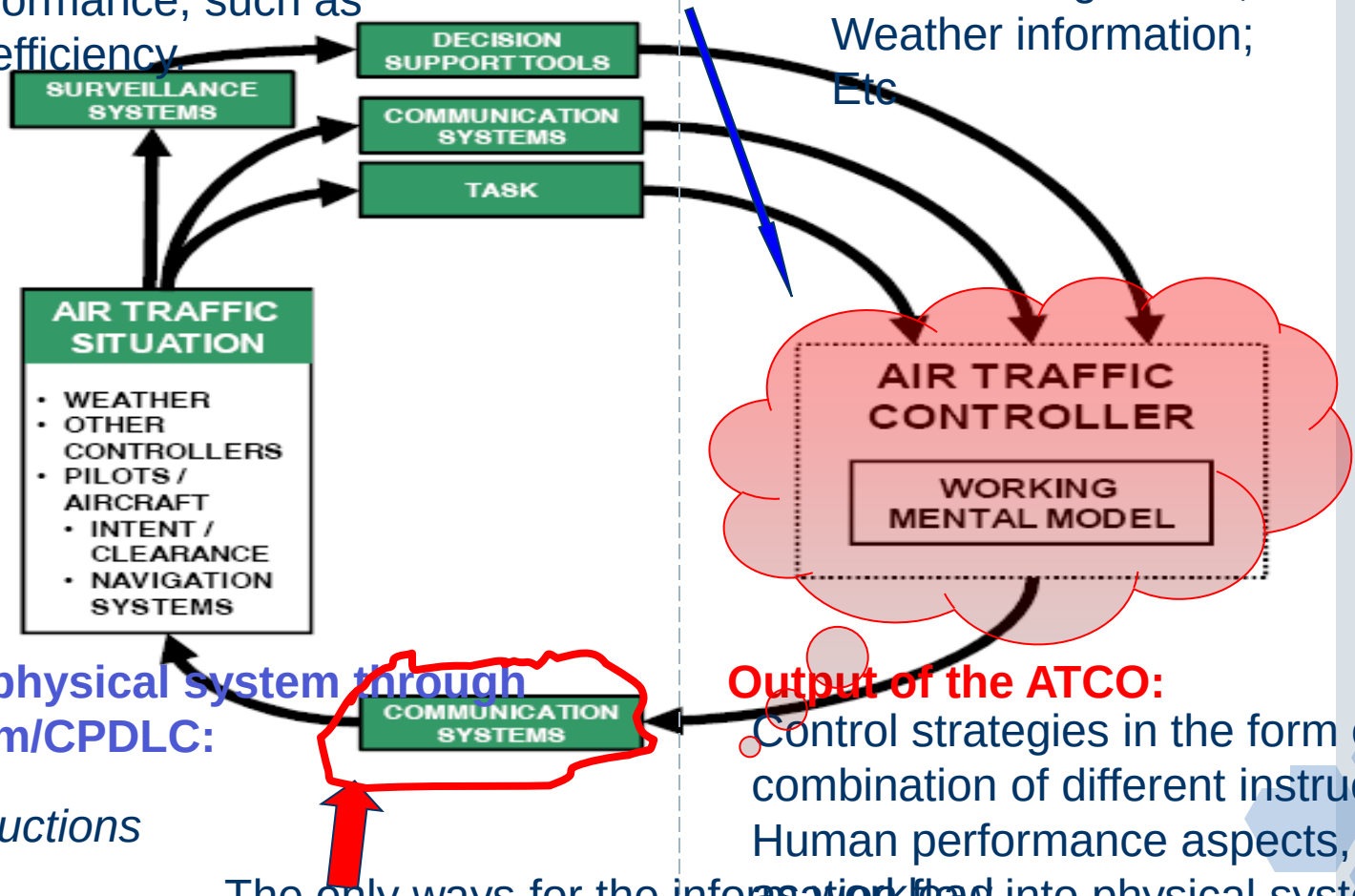
Output of the physical system:

Rapid changed traffic situation which may result in various system performance, such as safety and efficiency.

How does the ATCO manage all the resources?

Input into ATCO:

Flight plans;
Current traffic Situation;
Sector configuration;
Weather information;
Etc



Input into physical system through voice comm/CPDLC:

ATC instructions

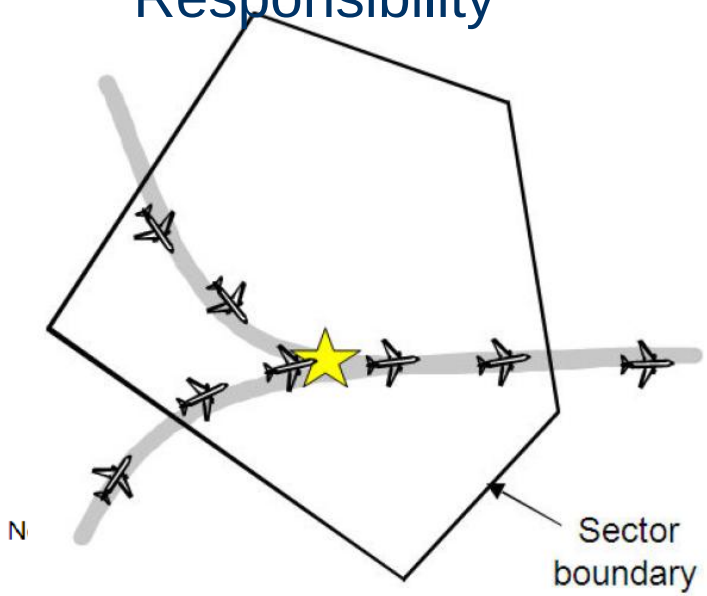
Output of the ATCO:

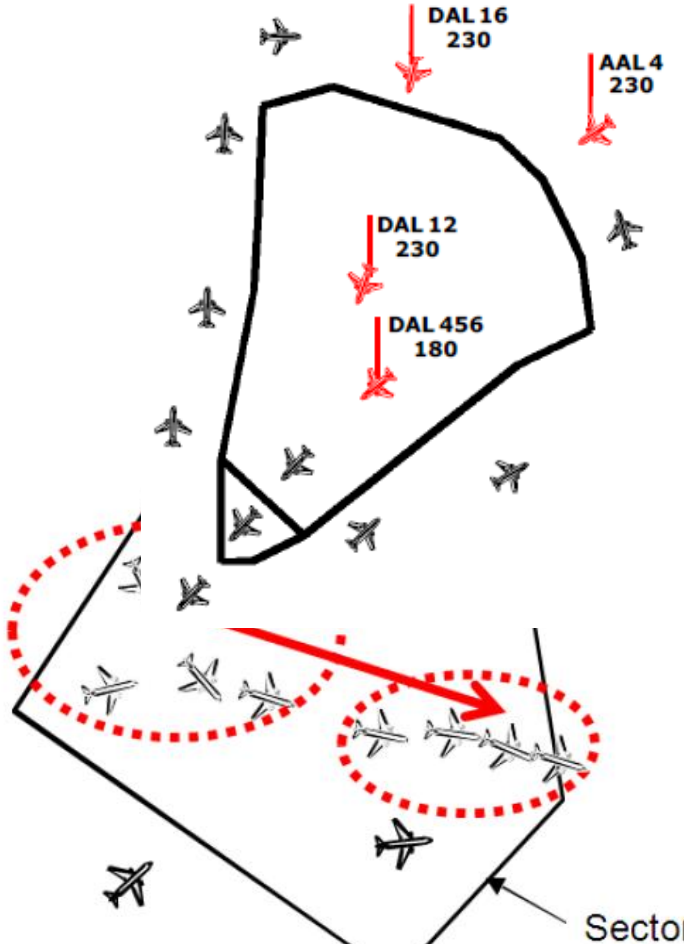
Control strategies in the form of combination of different instructions
Human performance aspects, such as workload

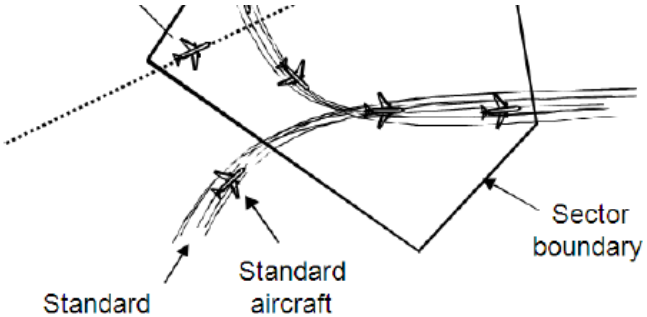
The only ways for the information into physical system

The understanding of ATCO

- **Structure-based abstraction employed by the ATCO to simply mental load (Histion & Hansman, 2008):**
  - Standard flow, Critical point, Grouping, and Responsibility







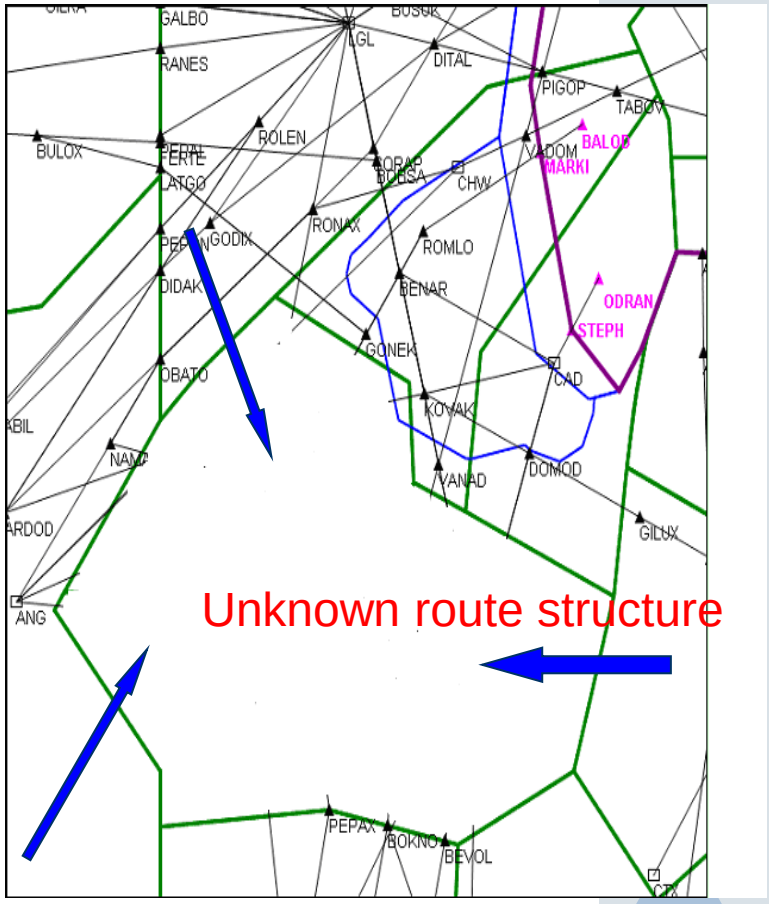
Universal laws govern human activities

- **Since 2005, there have been more than 50 papers on human dynamics published in the renowned journals, such as** *Nature, Science, PNAS, Physical Review Letters*, **etc.**

- **Investigations on the large empirical data sets show that**
  - The timing of many human activities can be characterized by the *heavy tailed feature* with bursts of rapidly occurring events separated by the long periods of inactivity.
  - There exist *similarities* between activities patterns among human beings, which *are irrelevant to the context of the activities.*

How about ATCO?

- 1. Temporal behavior of communication
- 2. Spatial behavior
- 3. Relationships between the aggregate communication activities and traffic amount



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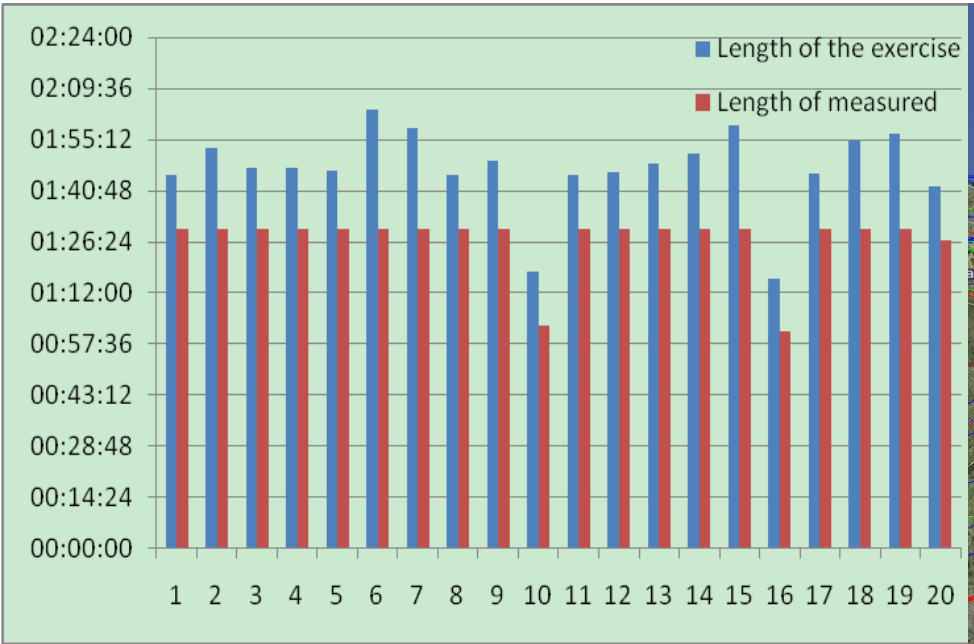
Data 1: ATCOSIM

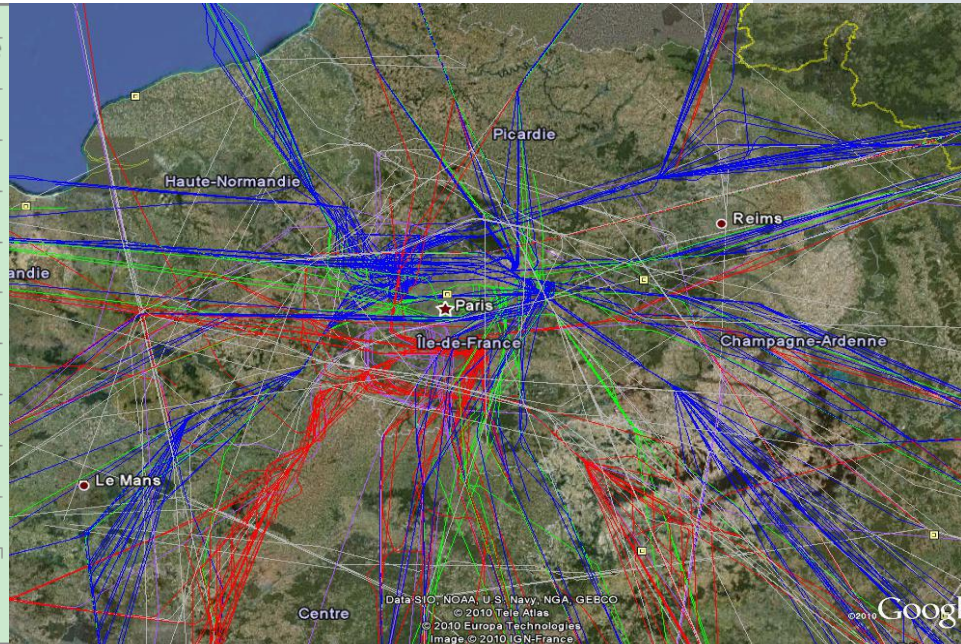
- The data we analyzed is the ATCOSIM Air Traffic Control Simulation Speech corpus of EUROCONTROL Experimental Centre.
- ATCOSIM consists of ten hours communication data, which were recorded during ATC real-time simulations conducted between 20/01/1997 and 14/02/1997.
- During the simulations, only the voices of controllers, not of pilots, were recorded.

	TOTAL (50)	AVERAGE
Length of the exercises (hh:mm:ss)	**11:18:37**	**1:11:10**
Number of the flights (complete flights*) identified in the exercise	**3121 (1966)**	**63 (40)**
Number of the communication events (Unidentified) in the exercise	**10078 (1276)**	**202(26)**

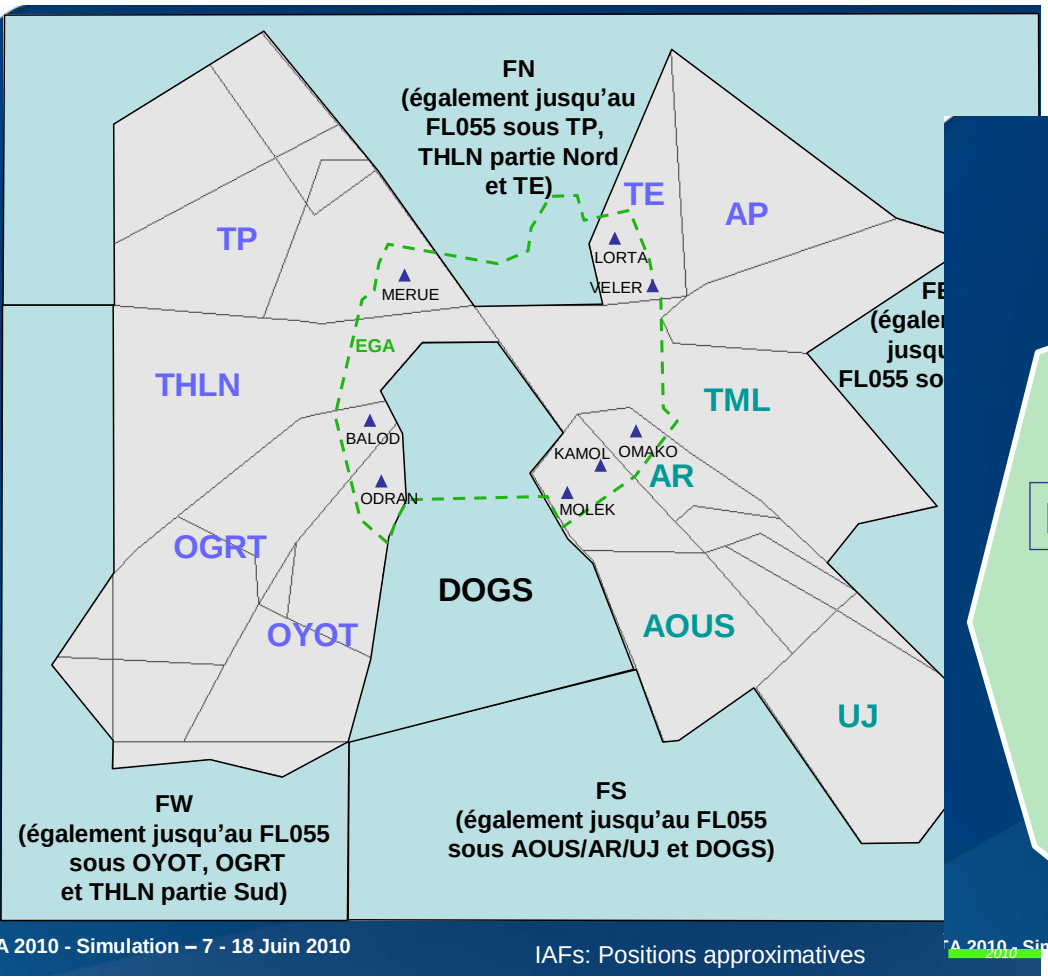
Data 2: TMA Paris

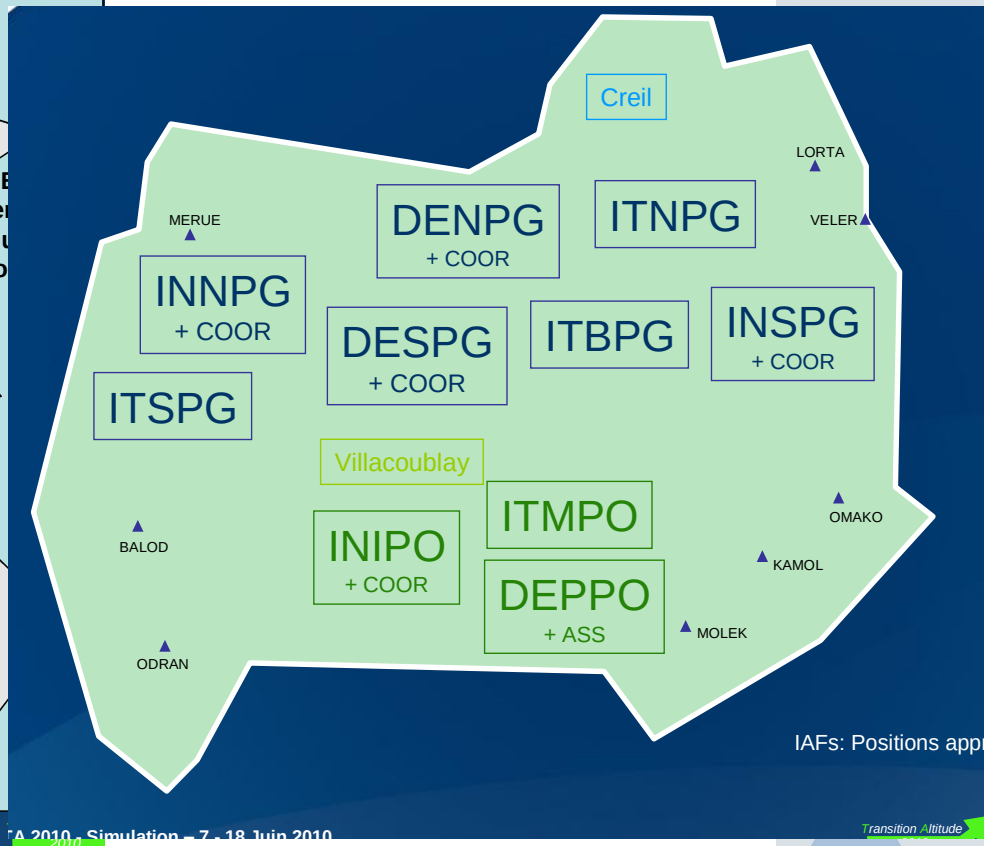
- EUROCONTROL has launched on 7 June a two weeks real-time simulation to test the viability of improvements proposed by the French DSNA to the air traffic system serving Paris-Charles De Gaulle, Paris-Orly and Paris-Le Bourget airports.
- There are 20 simulation exercises, and each exercise includes more than 22 sectors.





Sectors simulated





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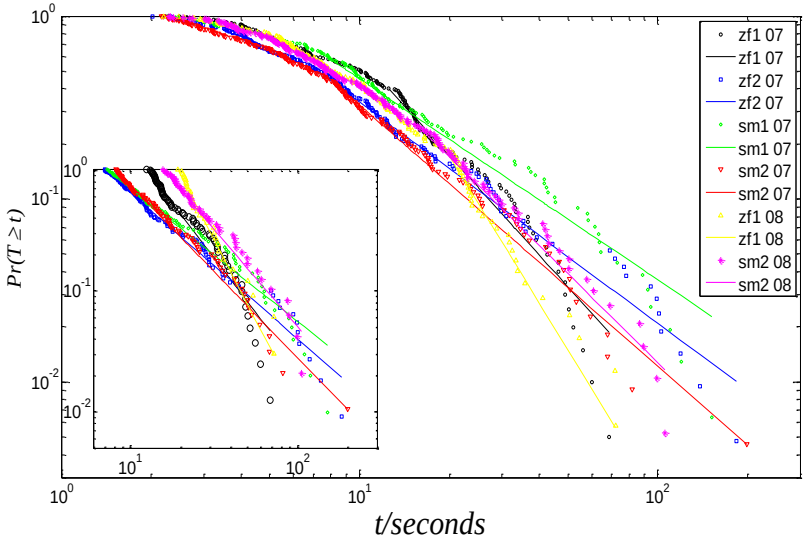
Initial Results

- Temporal behavior: heavy tailed feature of
- Fluctuation Scaling: *Taylor's law*

Temporal behavior (ICRAT 2010)



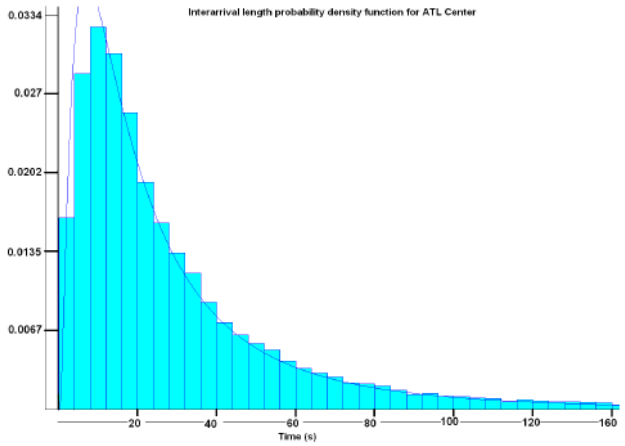
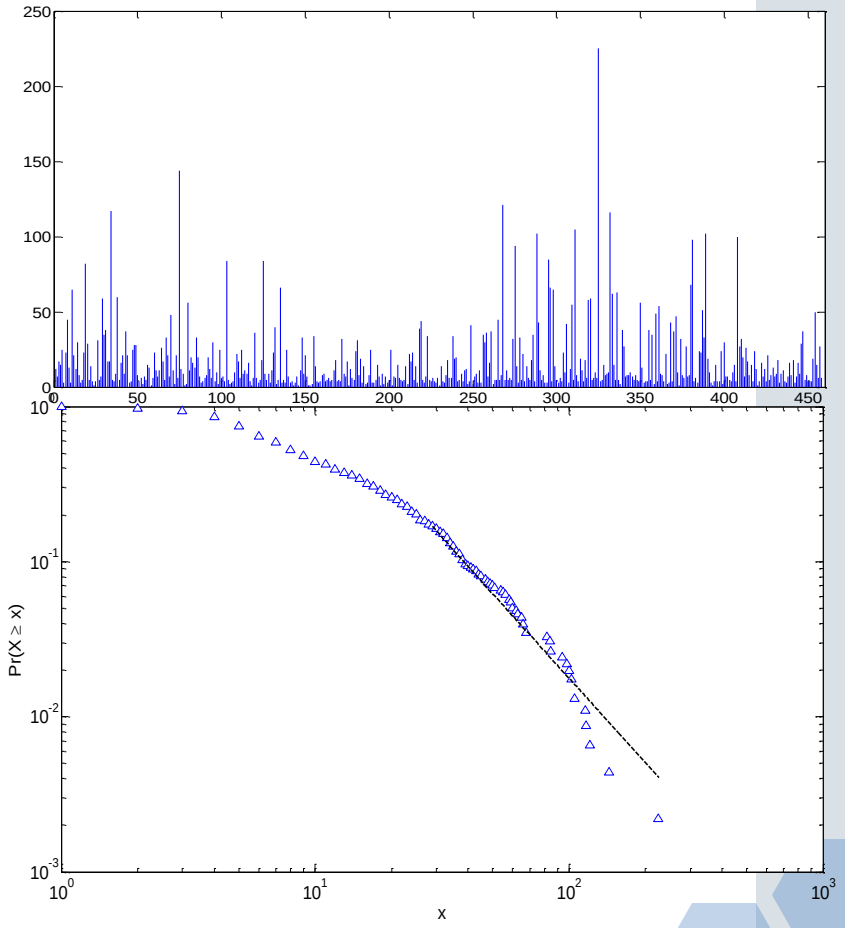
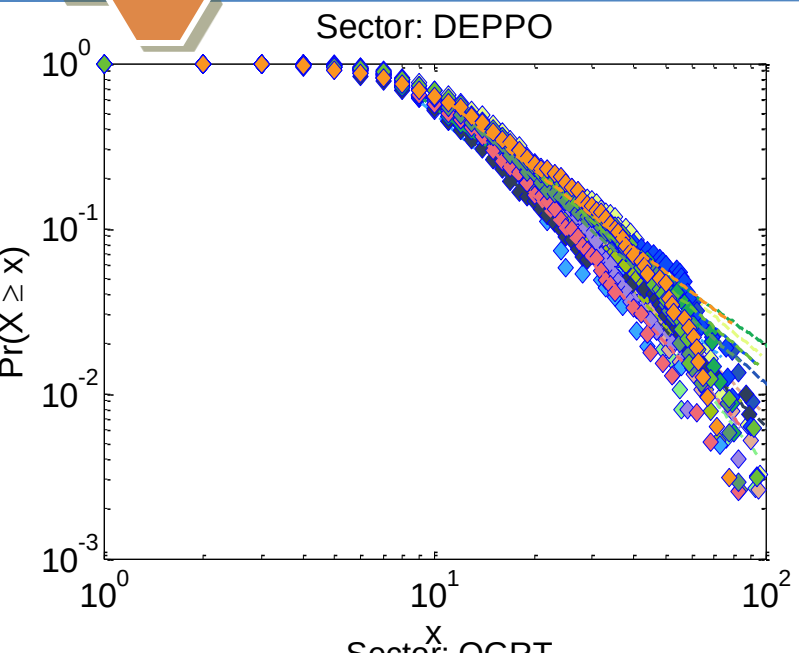
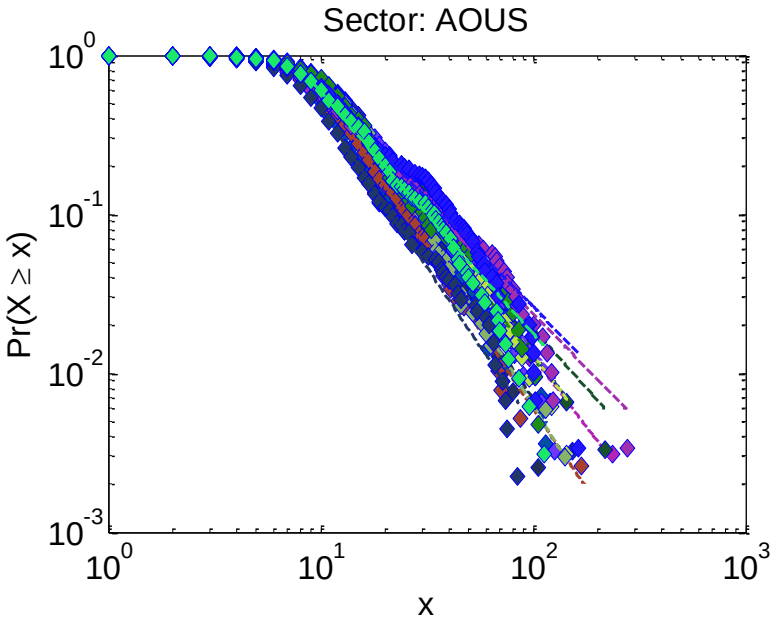
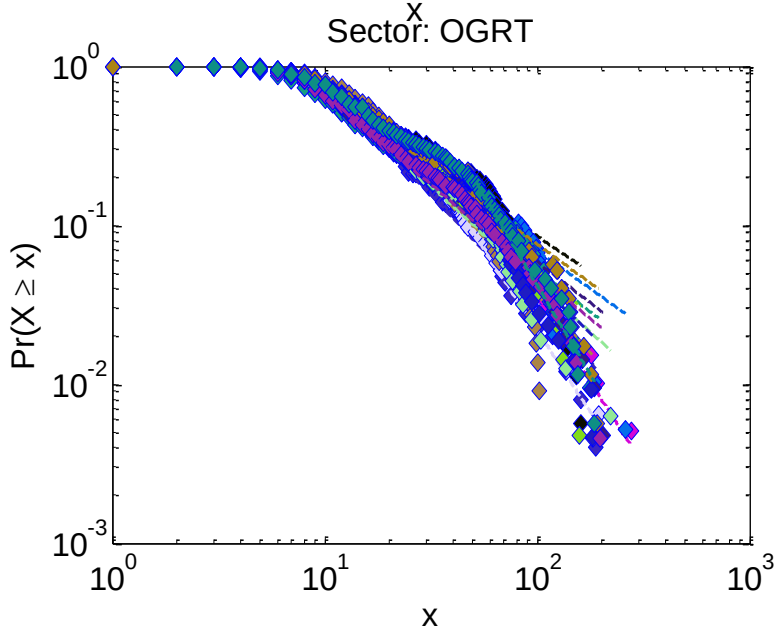


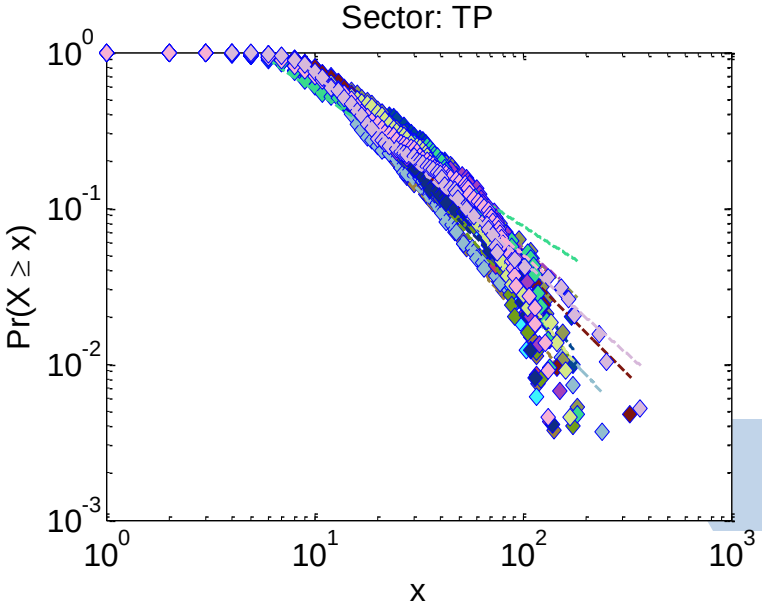
Fig. 4. ATL center interarrival log-normal probability fit



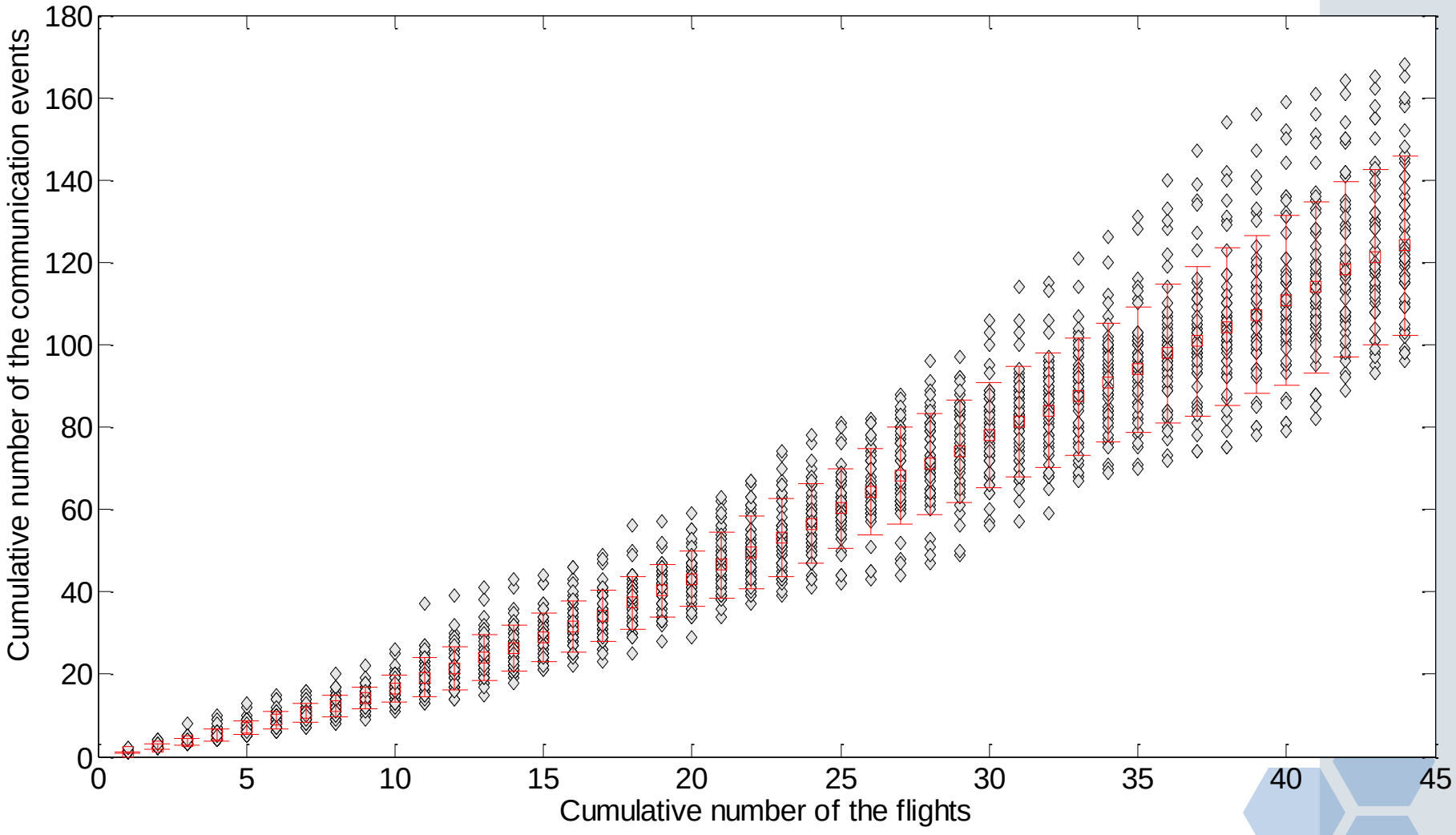

Sector: DEPPO
Pr(X ≥ x)
x


Sector: AOUS
Pr(X ≥ x)
x


Sector: OGRT
Pr(X ≥ x)
x


Sector: TP
Pr(X ≥ x)
x

EFS (Data 1)

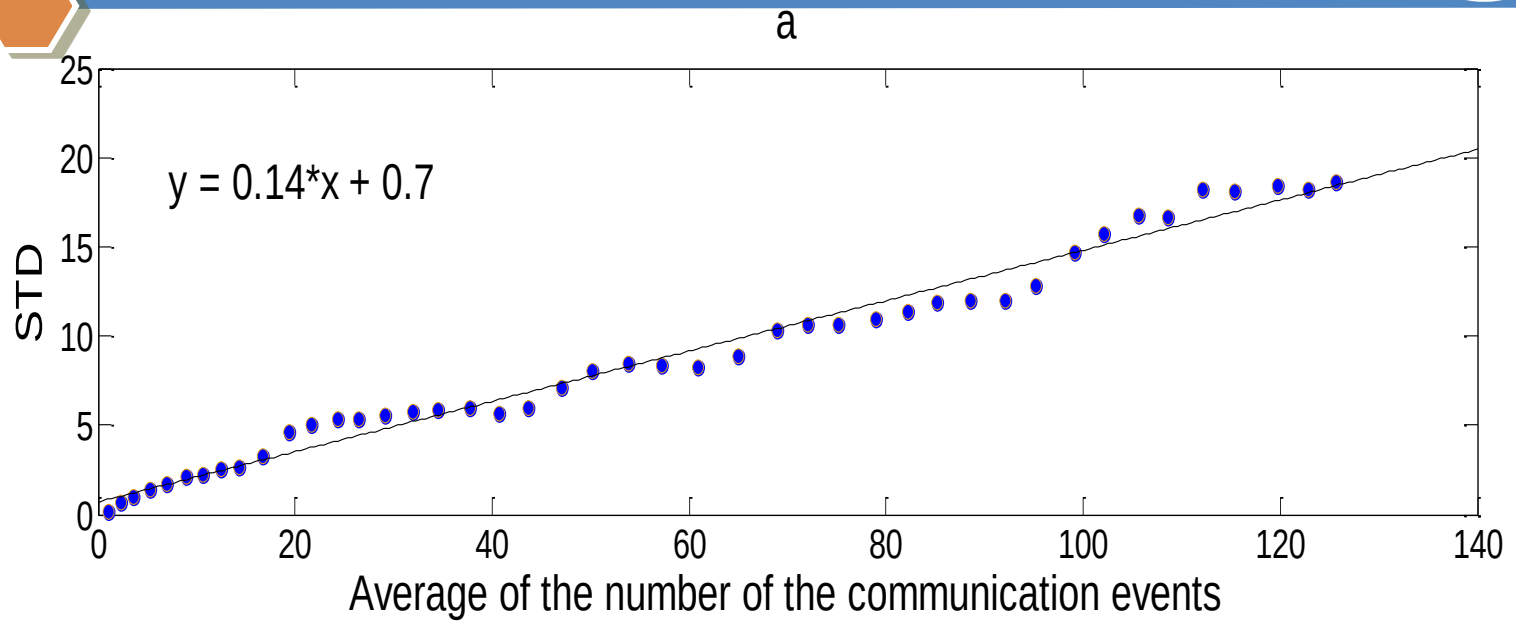

Cumulative number of the communication events
Cumulative number of the flights
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
40
45

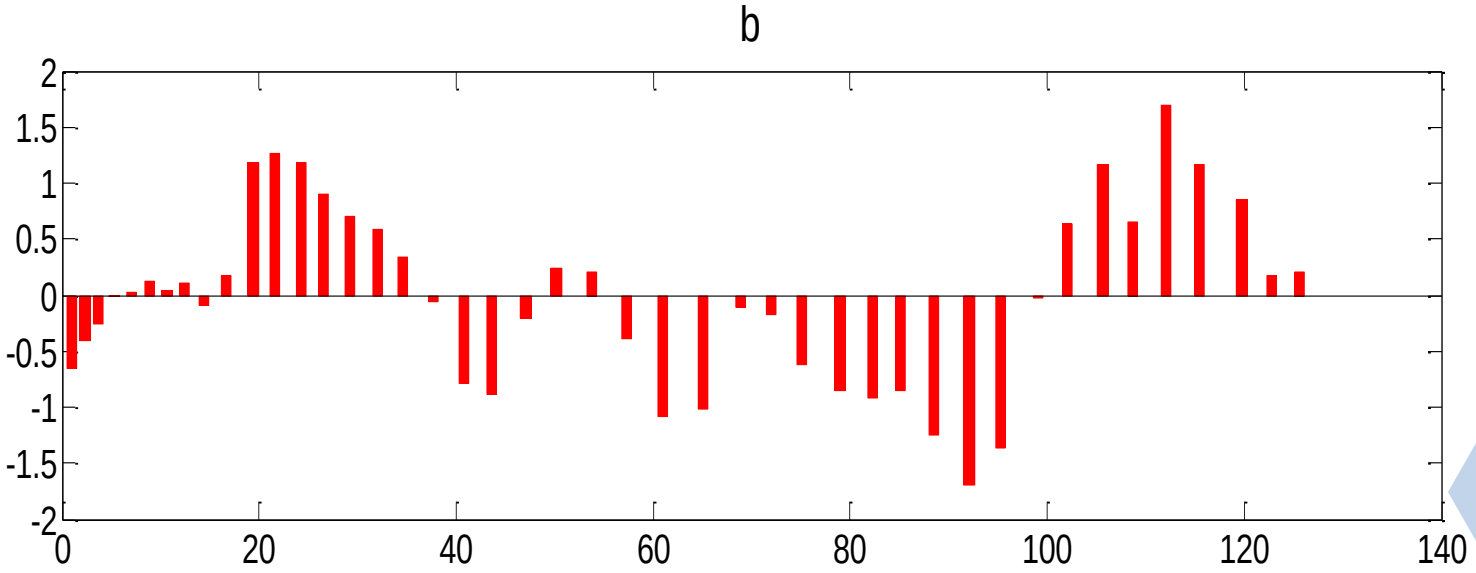
Taylor's Power Law

- The Taylor's power law is named after L. R. Taylor in recognition of his paper in 1961.
- Taylor's law can be applied to describe many complex systems in characterizing the relationship between the fluctuation in the activity of an element and the average activity.

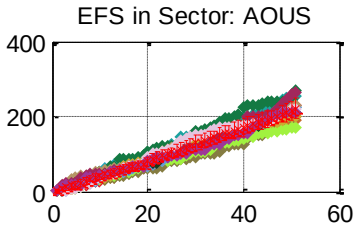
- The relationship is usually in the following from:

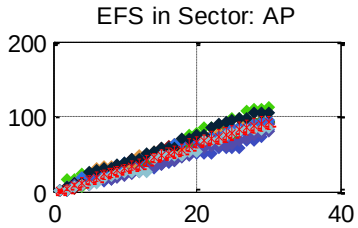
$$fluctuation \approx const. \times average^{\alpha}, \text{ where } \alpha \in [1/2, 1]$$

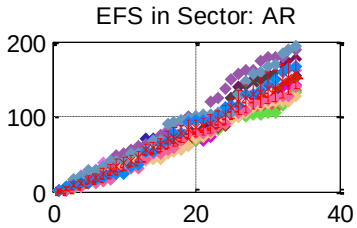

a
y = 0.14*x + 0.7
STD
Average of the number of the communication events
0
5
10
15
20
25
0
20
40
60
80
100
120
140

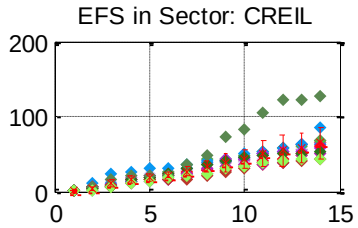

b
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
20
40
60
80
100
120
140

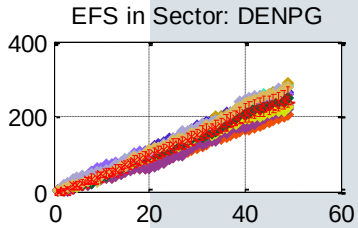
EFS (Data 2)

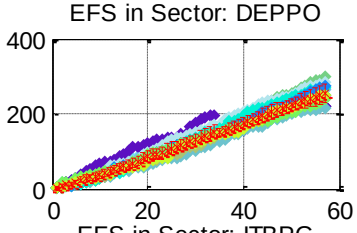

EFS in Sector: AOUS

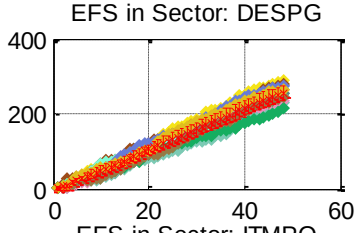

EFS in Sector: AP

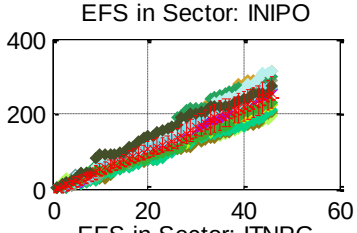

EFS in Sector: AR

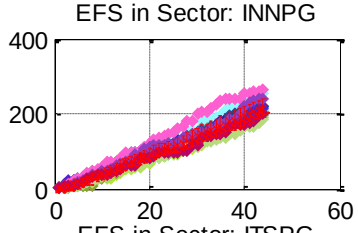

EFS in Sector: CREIL

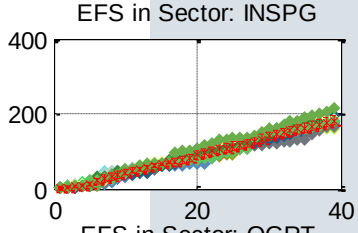

EFS in Sector: DENPG

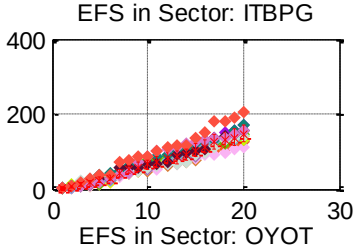

EFS in Sector: DEPPO


EFS in Sector: DESPG


EFS in Sector: INIPO


EFS in Sector: INNPG


EFS in Sector: INSPG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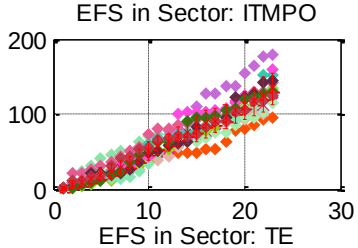
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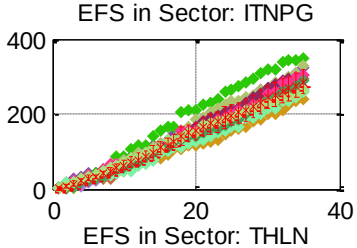
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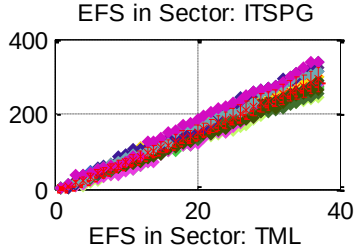
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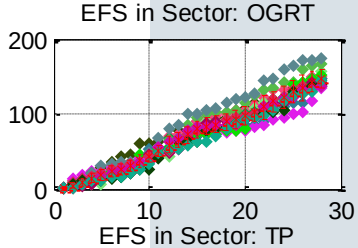
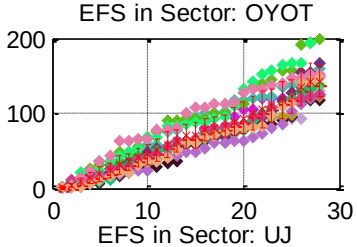
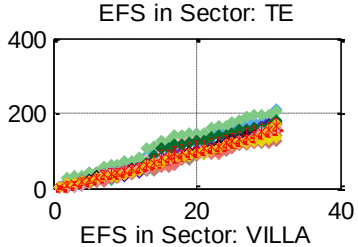

EFS in Sector: OGRT


EFS in Sector: OYOT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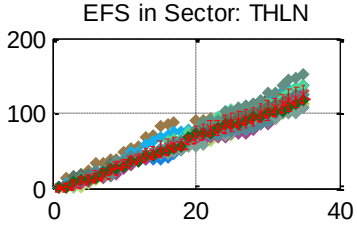
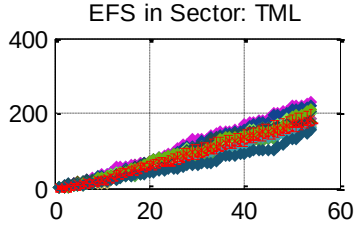
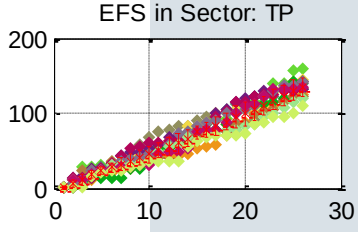
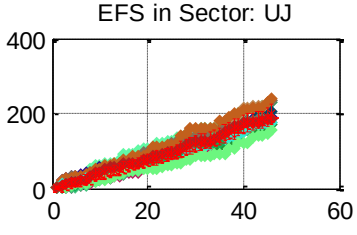
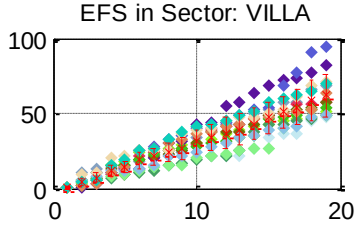
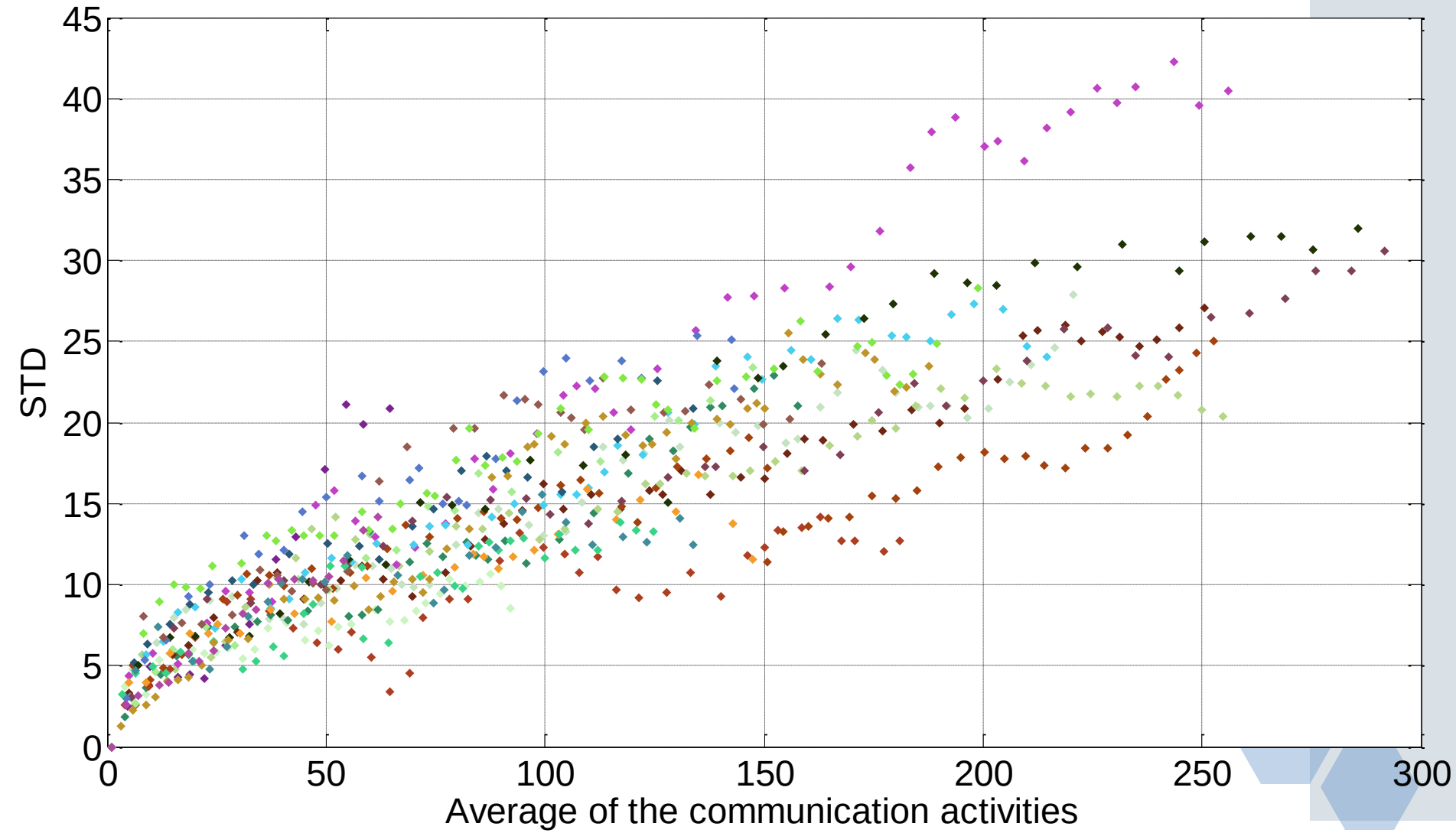

EFS in Sector: THLN


EFS in Sector: TML


EFS in Sector: TP


EFS in Sector: UJ


EFS in Sector: VILLA


45
40
35
30
25
20
15
10
5
0
STD
0
50
100
150
200
250
300
Average of the communication activities

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Future work

- 1. Further analysis of the TMA Paris simulation data.
- 2. Investigate the “spatial behavior” of the ATCO activities.
- 3. Modeling the temporal and spatial phenomena of the ATCO activities.

Acknowledgement

- We would like to thank EUROCONTROL for the support of this study.

Thank you for your attention!