



Final Workshop

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Abstract

This deliverable contains the material used for the project final workshops that were held in Maastricht, Brussels and Rome. A brief abstract of each presentation is also enclosed along with the main comments gathered during the workshops.

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Executive summary

This deliverable contains all the material that was presented during the validation workshops held in the final phase of the project. The objective of these workshops was to review with ATM experts and other relevant stakeholders the main project results in order to assess the potential applicability of the proposed solutions to the ATM world. The results were also presented to an academic audience to gather feedback from a research-oriented point of view. The first workshop was held in Maastricht on February 13th 2014 with ATM and safety expert, two workshops were held at EUROCONTROL in Bruxelles on March 18th 2014 with people respectively from CODA and from the EUROCONTROL Safety unit. The last workshop was held in Rome on March 20th 2014 and was more oriented to an academic audience with people invited from Universities and research centres.

In all the occasions the presentations about the ELSA project results were very well received and we gathered positive feedbacks both from the ATM experts, in terms of the possible operative applicability of the proposed solutions, and from the academic researchers in terms of the possible follow-ups of the analyses.

1 Introduction

This document presents the dissemination activities carried out in the last phase of the ELSA project. In order to disseminate the project results and gather useful feedbacks to further validate the proposed solutions (Best analyses and Agent Based Model) three workshops have been organized.

The selection of the audience for the final dissemination activities followed three main criteria:

- Presenting results to external experts that have been collaborating with ELSA, mainly in the validation activities.
- Disseminate the project results to the academic community in a workshop format, in order to get richer feedback than in conferences.
- Assess the potential for exploitation by interacting with potential users of the ELSA analyses.

In total three workshops were organised in the period February-March. The first two workshops were held in Maastricht, with ATC and safety experts attending, and at EUROCONTROL, with people from CODA and the Safety Unit attending (two separate workshops). The EUROCONTROL workshop was also attended by SJU project officer. The last workshop was held in Rome and was targeted to an academic audience.

1.1 Purpose of the document

The purpose of the present document is to collect all the material that was presented during the workshops at the end of the project.

1.2 Intended readership

This document is relevant for the ATM research community at large and more specifically for the WP-E research community.

External experts may also be part of the readership.

1.3 Acronyms and Terminology

Term	Definition
ABM	Agent Based Model
ATM	Air Traffic Management
ATCO	Air Traffic Controller
CODA	Central Office of Delay Analysis
E-ATMS	European Air Traffic Management System
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.

2 Background and motivation for the workshop

The main ELSA results concern a set of best analyses that during the project have been progressively refined with the goal of matching selected ATM target benefits. The final goals of these analyses were defined as:

- analyse changes and variation in predictability during execution phase of the flight,
- analyse the sensitivity of predictability to external disturbances, like weather and traffic load,
- analyse the sensitivity of predictability to change of strategies by users, i.e. NM and Airline Operators.

Another major strand of work is related to the development of multi-layer Agent Based Model, composed by a Strategic and Tactical Layer. The Tactical Layer aims at describing the interactions between flights and controllers in a single sector. This model was calibrated against real data and used to perform current ATM scenario simulations, in order to investigate how the presence of shocks (due to weather or high traffic load) affects the system performance. The strategic Layer instead simulates the submission of flight plans by the air companies to the Network Manager, who is in charge of computing the loads of sectors and reject flight plans if capacity of some sector is exceeded. Some sectors can also be randomly shut down after the first round of submissions, allowing to analyse the system response in case of major disruptions.

These two sets of results present different levels of maturity, with the analyses being more developed and already subject to several rounds of validation activities. However validation was mainly done with the same set of experts throughout the project. Therefore the main goal of these final workshops was to have an external validation of the assumptions, methods and target benefits. For this reason the following experts were involved:

CODA: People from the Central Office of Delay Analysis were involved at the beginning of the project. So they were aware of the project background and objectives and provided valuable feedback for all the best analyses.

EUROCONTROL Safety Unit: They were our target audience for the analysis on correlations between safety occurrences and network metrics. They provided a perspective of EU wide KPI, also in relation to SES target reference period 2.

Maastricht Safety team: They provided the perspective of an ANSP located in a EU core area. Their feedbacks were useful to assess the maturity of the proposed analyses.

During the first two workshops, held in Maastricht and at EUROCONTROL we presented thoroughly the ELSA best analyses with a stronger focus on the analysis of safety occurrences that was of more interest for the safety experts. All the analyses were well received and we collected positive comments and useful suggestion for further developments.

The objective of the last workshop was instead to disseminate the project results to the academic community. We chose the workshop format in order to get richer feedback than the one you can have in a conference. This was allowed by the possibility of focusing the attention on the project results and on other relevant topics strictly related to them. This last workshop was held in Rome and was attended by all the consortium members and the following three invited speakers from the research world:

- [REDACTED]: Researcher at Innaxis Foundation and Research Institute, Madrid. He is involved in other SESAR WP-E project in the field of Complex System Science.
- [REDACTED]: Post-Doc at the Physics Department of “Sapienza” University of Rome. His main research interests are in the field of Complex Systems. He has been involved in studies on dynamical routing networks and he developed specific software for the generation and statistical analysis of complex networks.
- [REDACTED]: Associated Professor at University of Bologna. His main research interests are about intelligent mobility and transport systems in general. He focused on the development of methods and tools for the application of Complex Systems science to the analysis of urban mobility.

The invited speakers were selected because they are all people involved in research projects that address issues in the transport systems by applying Complex System Science. Their expertise and research interests were then coherent with the work carried out in ELSA thus allowing interesting exchanges of suggestions and ideas. In fact, during the workshop, after the invited and the presentation of the structure and the main results of the Strategic and Tactical Layers of the Agent Based Model, there were long and interesting discussion about the findings of the ABM and the possible ways to interpret its results and to improve the model structure.

During the workshop the invited speakers presented the following:

1. **██████████ - Functional and Multi-layer representations of Air Transport networks**

Content: The presentation contains an analysis of delay propagation on a multi-layer network built by considering both functional and physical links between the nodes. The main finding is that a multi-layer structure of the network has to be considered in order to effectively represent the structure and the dynamics of the system.

2. **██████████ - Serious Games for Research Purposes**

Content: This presentation contains an overview of games that were used for research purposes. In particular the author analysed how ATM related games, like the Virtual Air Traffic Simulator Network (VATSIM) can be exploited to test new operation concepts and scenarios. The conclusion is that selected games could be successfully used to do research but the involvement of the gamers and the analyses have to be set up cleverly.

3. **██████████ - Human Mobility: from Individual Behaviour to Network Dynamics**

Content: The objective of the research presented is to understand from empirical data on individual mobility (complex system) the emergence of macroscopic 'universal' statistical laws on human mobility (statistical physics for complex systems), their meaning and their applicability distinguishing between cognitive aspects and physical dynamics.

3 Feedbacks collected

The main feedbacks collected during the workshops were the following:

1. Maastricht – 13 February 2014:

- a. ATC experts were interested in the analysis of the critical airspace fixes. The differentiation between high strength fixes and high betweenness was found to be relevant also to capture relevant dynamics in the MUAC airspace and provide additional insights as compared to currently available metrics.
- b. In particular they asked to re-run the analysis also for the Maastricht airspace to compare which are the most critical points during normal operations and when a white strike occur. This would be useful to highlight how safety critical areas change across the airspace.
- c. The Safety Team was instead more interested in the analysis of the correlations between safety occurrences and network metrics. They saw the potential of the analysis and asked us to try the solution with other datasets in order to assess the validity of the methodology.

2. EUROCONTROL (Brussels) – 18 March 2014:

a. Experts from CODA:

- They were positively impressed by the five best analyses.
- They recognized them as potentially useful monitoring tools.
- They also suggested to improve the analyses by differentiating the outputs by market segments. They think that useful information can emerge if we consider separately low-cost and regular air companies. For example we can expect to see different community structures or ATCO management strategies depending the type of company they are dealing with. In particular for the analysis of ATCO management strategies they suggested to highlight the particular behaviour of selected companies in specific countries (e.g Iberia in Spain) to highlight how controllers deal with them in a different way.

b. SJU attendants

- SJU had several requests of clarification on some details of the best analyses. The major ones are described in the following bullets.
- SJU asked what is the expected benefit for ATM for the analysis of correlation between safety occurrences and network metrics. The reply was that the proposed method could be used as a means to monitor the airspace criticalities, in accordance with the requirement for Safety KPI contained in EU Regulation 390/2013, to identify hotspots and steer improvement actions.
- SJU asked what is the expected benefit for ATM for the community analysis. The analysis proved to be very powerful in detecting variations in the airport communities, detecting which airports are more frequently connected than others, in the different seasons of the year. This information can be used to implement direct communication links (and dedicated coordination procedures) between closely-connected distant airports as they are identified by the community detection algorithm. The implementation of this direct lines can also occur on a seasonal basis to cope with the observed seasonal variations of the airspace configuration. The multi-resolution community analysis could be used to run post-flight analyses and detect alternative configurations that would have been more justified (from a functional point of view). In the long-term, dynamic configurations exploiting this analysis on simulations could also be explored as a possibility. Thanks to the multi-resolution parameter, the analysis can be tuned to detect sectors, FIRs, FABs. For disruptions like the volcanic ash cloud, community

detection could be used to identify which parts of the ATM system to shut down to prevent propagation of problems, or to predict which parts will be shutting down.

- SJU asked what is the expected benefit for ATM for the analysis on ATCOs' management strategies. The analysis is effective in showing in a compact form how controllers manage flights in different traffic conditions, capturing statistical regularities and not individual behaviours. Other analyses would be needed to have a more complete picture of ATCOs' behaviours, but there are not feasible with the current dataset. Another benefit lies in its applicability at various levels, e.g. sectors, FIRs, nations.

c. EUROCONTROL Safety Unit:

- They provided a positive feedback on the analysis of the correlations between safety occurrences and network metrics. They stated that the analysis is mature enough to be proposed as a monitoring tool of safety critical areas and as a way to highlight positive and negative deviations from normal operational situations.
- They stated that a coherent approach was adopted in previous projects, e.g. the Danube FAB safety activities, with different metrics. The goal of this work was to identify safety hotspots, comparing the perception of controllers, with the assessment made by safety experts, and quantitative measurements collected with automatic safety monitoring tools (i.e. ASMT).
- In their opinion the analysis also addresses the new Safety II concept of improving safety through learning from the positive occurrences. The DNM Safety Unit representatives also mentioned the possibility to present the ELSA best analysis "Correlations between STCA events and Complex Network metrics in the Rome FIR" during the EUROCONTROL Safety forum, to be organised in Lisbon in September 2014, with an expected audience of Safety Managers. The Consortium will pursue this opportunity by following up with ENAV on the current results, and by trying to gain access to other datasets, through existing business contacts.

3. **Rome – 20 March 2014:**

- Strategic Layer: the main comment was about the definition of the parameter describing the number of available navpoints paths per each sector. Its definition and the way in which it has been calibrated was not completely clear at the first time. The discussion that followed helped in improving the understanding of the physical meaning of this parameter.
- Tactical Layer:
 - i. there was an interesting discussion on the reason why when we increase the number of small shocked areas in the sector the negative delay increase. The output was that the presence of a shock can be seen as an occasion for optimizing the trajectory, thus bringing to the conclusion that the system has room for optimization.
 - ii. The calibration results were thoroughly discussed. It was pointed out that the correlation between real and simulated data was not always as good as expected. The discussion that followed clarified that the model has a sufficient degree of realism that has been improved during the development process by adding more features (e.g. directs). In the end it matches the real data within acceptable statistical limits.
- Lessons learnt: from all the presentations emerged that network science is very good for deriving general laws. However it needs to follow up with more detailed analyses in order to deliver useful results for practical applications.
- Data access: It emerged that getting data is quite hard. Data may not be fit for purpose due to granularity and low quality, it is hard to integrate different datasets and moreover there are some problems in publishing results based on those data.

4 Workshop presentations - ELSA

The presentations included in this document are the following:

1. The ELSA project and the 5 best analyses

Content: This presentation contains an overview of the ELSA project, from its motivation and objectives to the main results achieved especially in the data analysis work package. The focus of the presentation is on the 5 best analyses that were extracted from the work carried out in WP1. The analyses are presented without details on the mathematical process that led to the results but with a strong attention on the possible benefits and applications that the proposed solutions can bring to the ATM world.

Workshop Site: Maastricht (13/2/14) and Bruxelles (18/3/14)

Audience: ATM and Safety expert (e.g. ECTL Safety Unit, CODA)

2. The interrelations between safety occurrences and network metrics

Content: This presentation contains a detailed overview of the best analysis about the correlations between safety events (Short Term Conflict Alerts – STCA) and some selected network metrics derived from the Complex System Science. The presentation has the objective of showing the potential applications of the proposed tool to assess its maturity to be used as a support for safety teams to monitor the airspace. The analysis has in fact demonstrated the capability to predict a higher probability of occurrence of safety events on the basis of the analysis of the network topology. Moreover the experts recognized as very useful the possibility of highlighting areas which perform better or worse than expected according to the model predictions. The analysis of these outliers could drive the improvement of the procedures in the worst areas or help in learning from the virtuous ones.

Workshop Site: Maastricht (13/2/14) and Bruxelles (18/3/14)

Audience: Safety expert (e.g. ECTL Safety Unit)

3. The ABM tactical layer

Content: This presentation contains an overview of the development of the tactical layer of the Agent Based Model and the main results delivered after the simulation campaign. The different agents and their relations are presented along with the strategies implemented in the model to de-conflict the air traffic and to mimic the real world (weather perturbations, closes areas of the airspace). The results part presents all the comparisons between real data (extracted from WP1 results) and the simulations to assess the adherence of the model to the reality.

Workshop Site: Rome (20/3/14)

Audience: Academic

4. The ABM strategic layer

Content: This presentation contains an overview of the development of the strategic layer of the Agent Based Model and the main results obtained. The different agents and their relations are presented along with the calibration used to replicate in the model real world features. The results show that when we have a mixing of companies that prefer re-routing and of companies that prefer shifting in time, the overall satisfaction can even increase together with the number of flights, which is an effect not observed when one have in the system one type of company only.

Workshop Site: Rome (20/3/14)

Audience: Academic



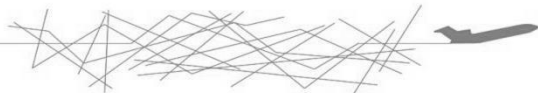
ELSA

Empirically grounded agent based models for the future ATM scenario



ELSA – The Partners

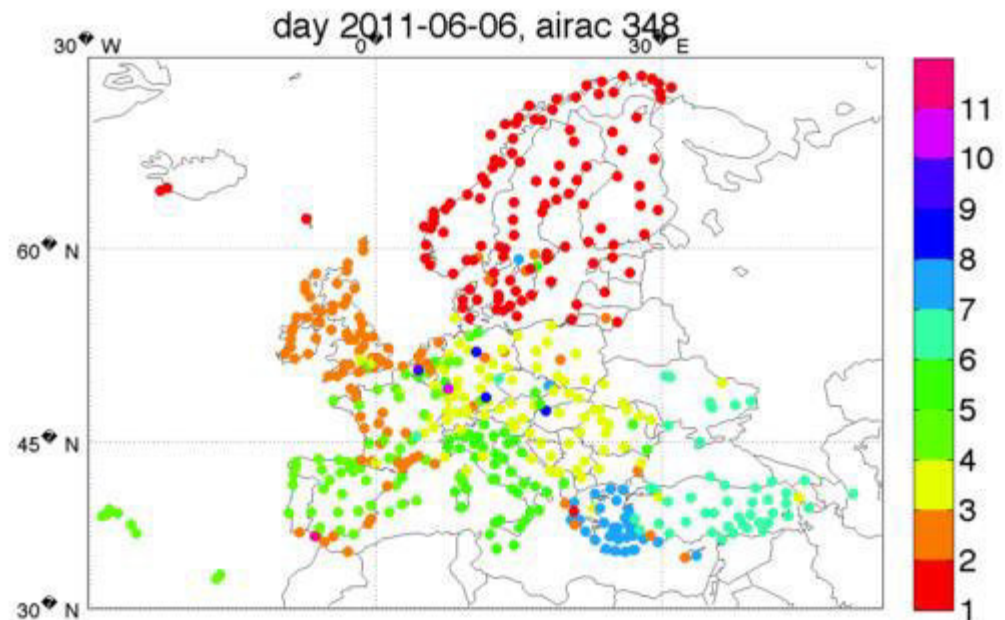
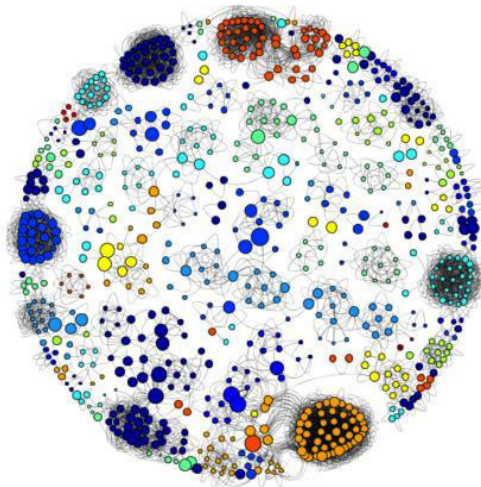
Deep Blue, University of Palermo & Scuola Normale Superiore di Pisa



ELSA Objectives

Motivation

- Lack of suitable means to analyse and monitor the emerging characteristics at the system level, e.g. EU-wide performance scheme [Commission Regulation (EU) No 691/2010]
- Application of methods used for the data analysis in complex system science to ATM

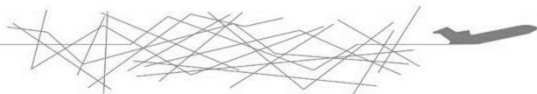




ELSA Objectives

Three main objectives:

- characterisation of statistical regularities in the current scenario
- simulation of the emergent properties of the trajectory-based SESAR scenario
- inform the design of a tool to monitor, predict and intervene on the ATM system

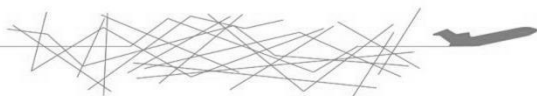




ELSA Objectives

Three main objectives:

- characterization of statistical regularities in the current scenario
 - *an extensive (1 year, ECAC-wide) statistical analysis of data of the ATM system with Complex Systems theory techniques in order to characterize statistical regularities (e.g. propagation of delays and safety events, correlation between different metrics, seasonal fluctuations, etc.)*
- simulation of the emergent properties of the trajectory-based SESAR scenario
- inform the design of a tool to monitor, predict and intervene on the ATM system

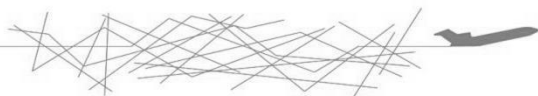




ELSA Objectives

Three main objectives:

- characterisation of statistical regularities in the current scenario
- simulation of the emergent properties of the trajectory-based SESAR scenario
 - *the development of a hierarchy of an Agent Based Model of increasing complexity and degree of realism, to simulate the trajectory-based SESAR scenario*
- inform the design of a tool to monitor, predict and intervene on the ATM system

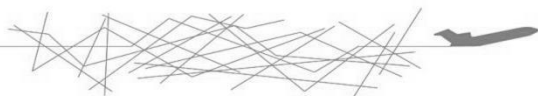




ELSA Objectives

Three main objectives:

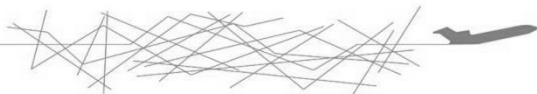
- characterisation of statistical regularities in the current scenario
- simulation of the emergent properties of the trajectory-based SESAR scenario
- inform the design of a tool to monitor, predict and intervene on the ATM system
 - *the design and implementation of a prototype of a decision support tool, to monitor, predict (based on the Agent Based Model) and intervene on the airspace*



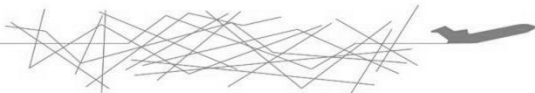
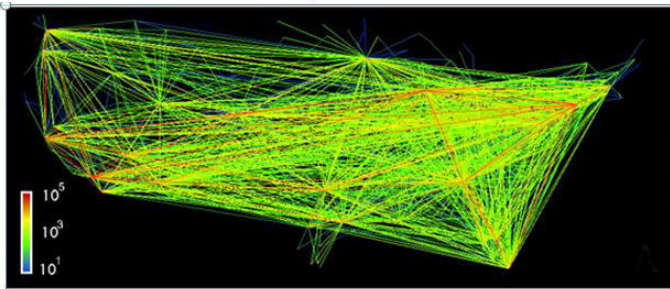
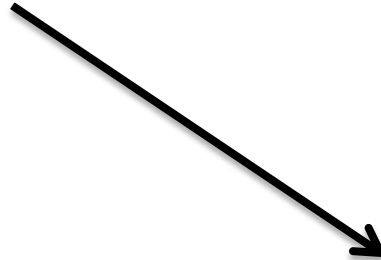
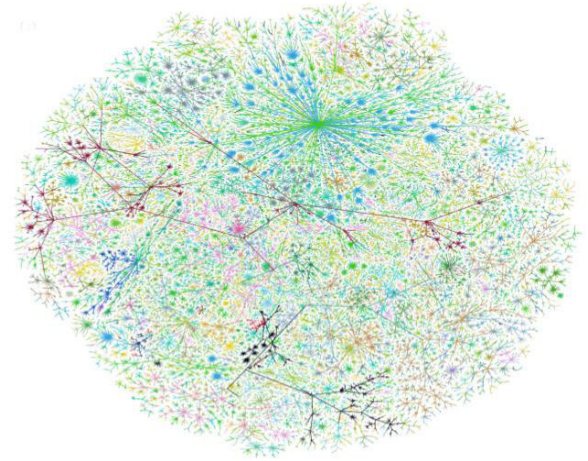
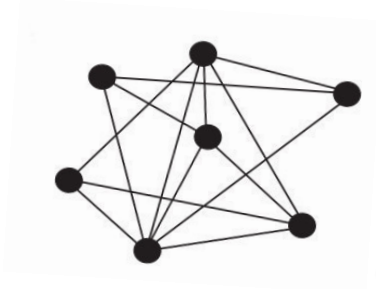


Complex Networks in Techno-Social Systems

- Complex Networks: a new challenging branch of mathematical and physical research
- Complex Networks:
 - Large number of nodes (>100)
 - Irregular, complex, dynamical structure
- Not just a theory:
 - Transportation networks (Air Transport, Railways...)
 - Social Networks (Twitter, Facebook,...)
 - Technological Networks (WWW, Power Grids,...)
 - Biological Networks (Neural Networks..)
- How the structure of a network affects the processes taking place on it?



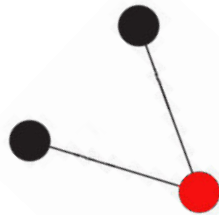
Complex Networks in Techno-Social Systems





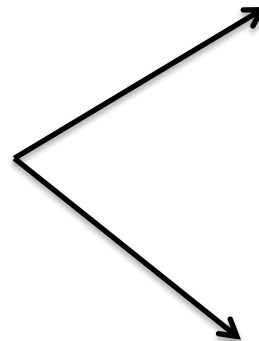
Basic Topology

- Degree k of a node (number of friends in a social network, number of connections in a transportation network..) (immagine di esempio)

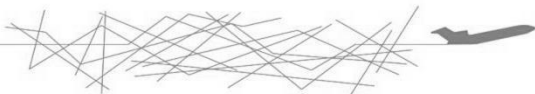


$$K = 2$$

- $P(k)$ the distribution of k

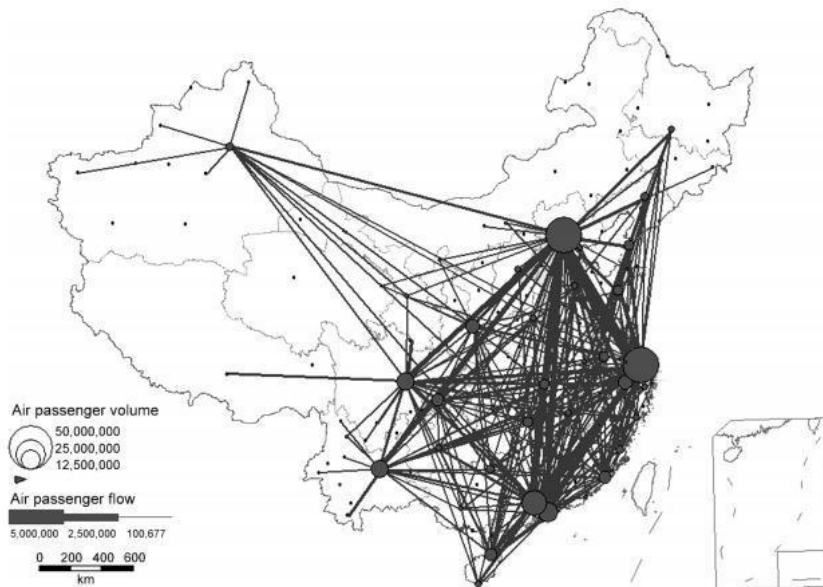


- Exponential (road networks)
- Power-law (hub-n-spoke)

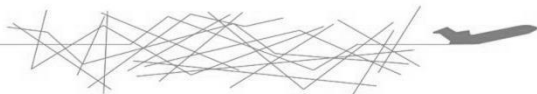




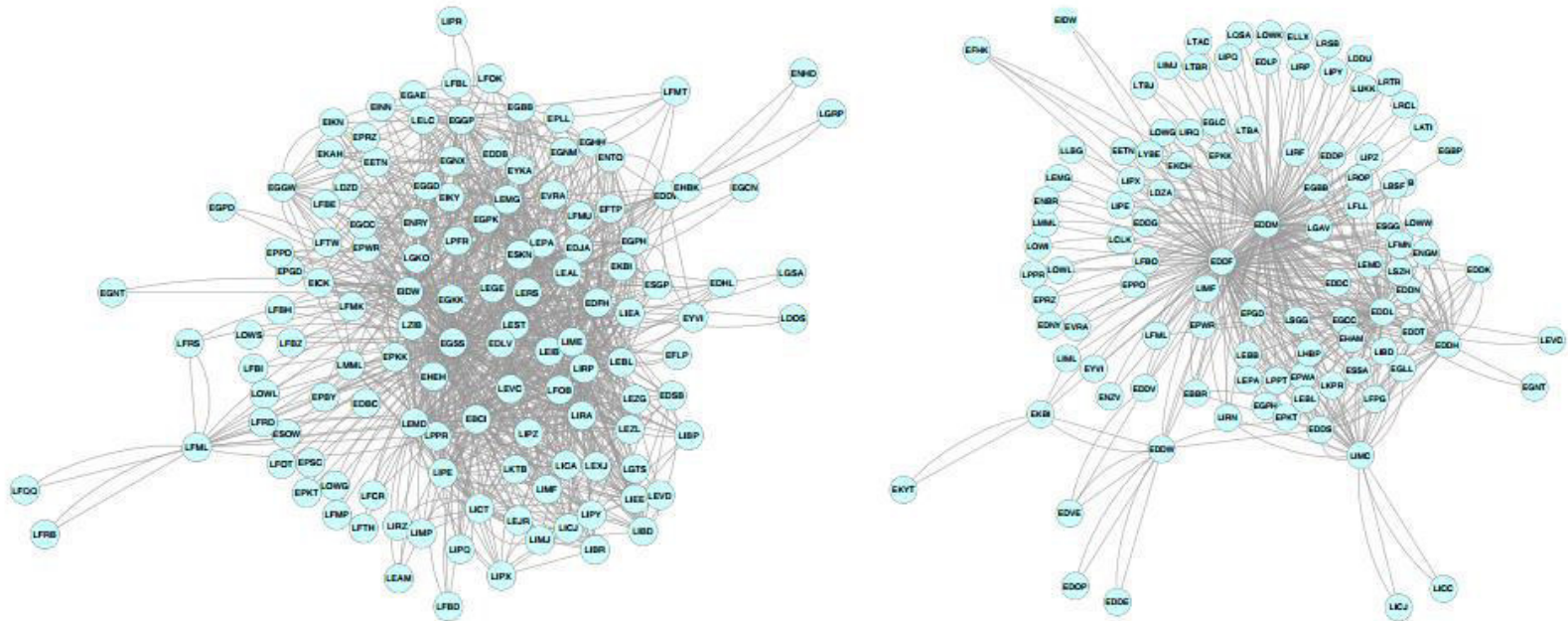
Basic Topology: Companies and Regulations



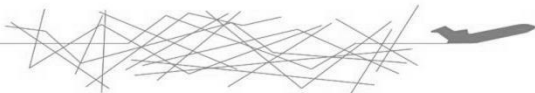
Emergence of Hub-n-Spoke topology in China, Europe, USA after deregulations.



Basic Topology: Companies and Regulations



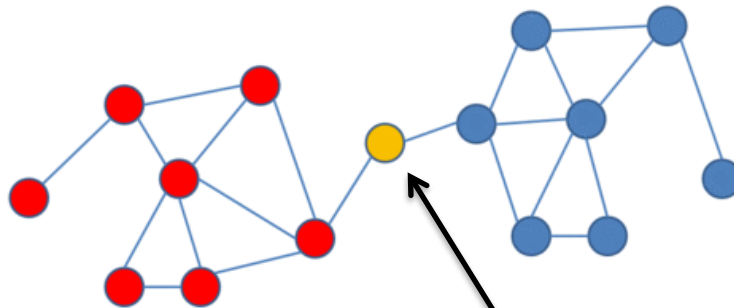
Airport Networks of Ryanair (left) and Lufthansa (right).
Hub-n-spoke dominates in the Lufthansa network.



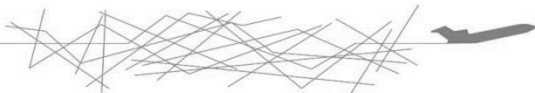


Advanced Topology: Centrality Measures

- Centrality Measures determine the **importance** of a node inside the network
- Most Famous Example: **Betweenness Centrality**

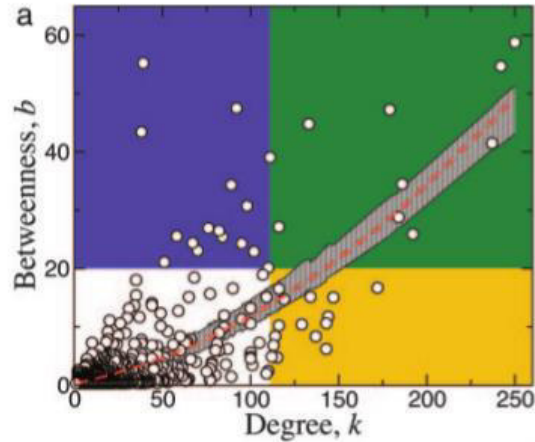


**Most Important
Node!**

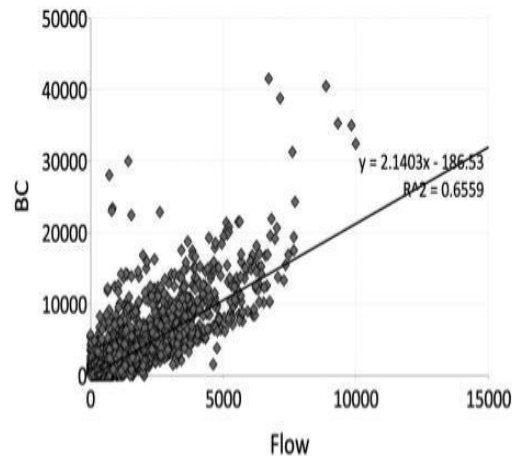




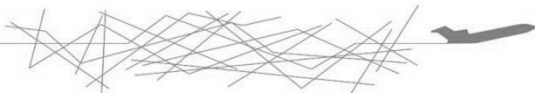
Centrality Measures in Transportation Networks



- World Wide Airport Network: **anomalous centralities** due to community structure



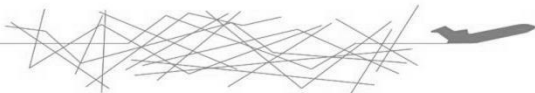
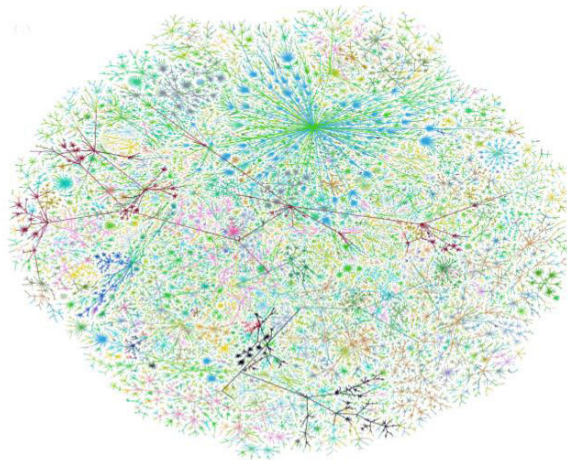
- Road Network: **traffic forecasts** without traffic information



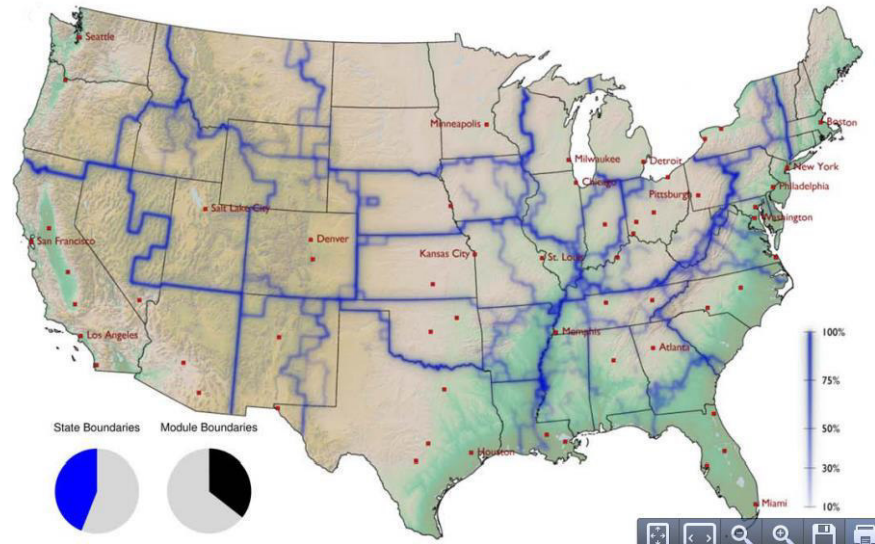


Community Structure

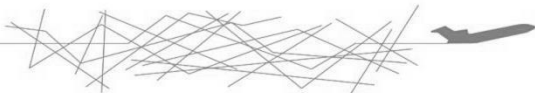
- Networks can usually be divided in **Communities**
- **Communities** are important to identify different group of people in social networks, different units in technological and biological network etc..
- Many different algorithms have been proposed: no unambiguous view about the problem



Community Structure



Community detection on the human proxy network of USA,
built using bank note dispersal



Best analyses



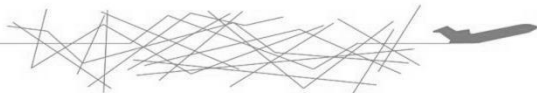
ELSA

Empirically grounded agent based models for the future ATM scenario



Best analyses development process

- The work carried out in WP1 aimed at identifying a set of significant statistical regularities in the ATM data using methods and techniques derived from statistical mechanics and complex network analysis
→ more **than 20 different analyses methods** were identified
- After internal reviews we identified a subset of analyses that were more promising in terms of potential operational impacts
→ **8 analyses** were identified at this stage
- Iterative validation activities helped in further refining the analyses
→ **5 best analyses** identified. The others were dropped after we discovered they were either of limited operational interest (e.g.: Detection of different types of airport networks) or of high computational load with respect to the expected outcomes (e.g Deep comparison of deviations/delays).

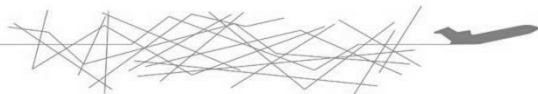




Dataset

We used two types of data:

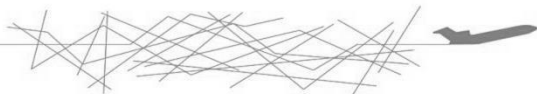
- one concerning the flights (DDR), involving the last filed in flight plan (file type named M1) and the updated one (file type named M3);
- one concerning the structure of the European airspace, involving airports, sectors, airspaces, etc.





1. Community analysis

- We detected sets (**communities**) of nodes (airports, or sectors, or navpoints) clustered together, i.e. that share a common profile with respect to the flights that are connecting them. Communities are generically defined as sets of nodes that are more connected among themselves than with the rest of the network.
- We carried out a qualitative analysis with the objective of highlighting global patterns that can have some operative impacts on the airspace organization.
- We analyzed seasonal variations of the airport community distribution and we determine how they reshape in response to an external event like the ash cloud in 2010





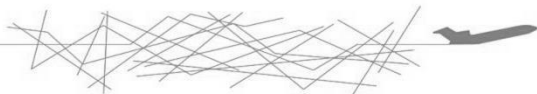
1. Community analysis: Algorithms

- **Infomap**: The idea behind the method is to consider a random walk over the network. The more the nodes are connected one with each other, the more the walker will stay with them and thus form a community. The analysis of the flows over the network gives access to the underlying community structure.

[1] Rosvall M, Bergstrom CT (2008) Maps of information flow reveal community structure in complex networks. PNAS 105: 1118.

- **Blondel**: Based on the minimization of a quantity called modularity Q : The sum of the number of links within each community minus the expected number of links for a given null model (i.e. a certain randomization of the links of the network).

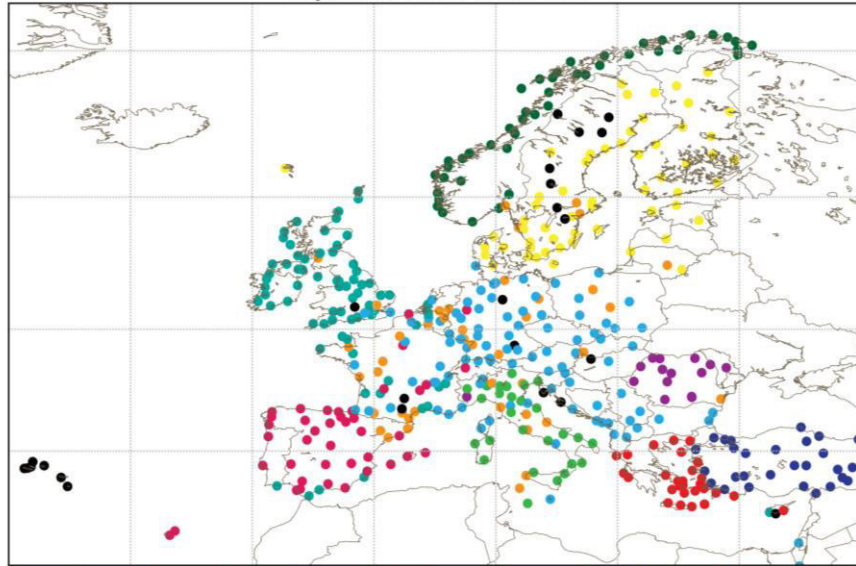
[2] Blondel VB, Guillaume JL, Lambiotte R, Lefebvre E (2008) Fast unfolding of communities in large networks. JSTAT, P10008.



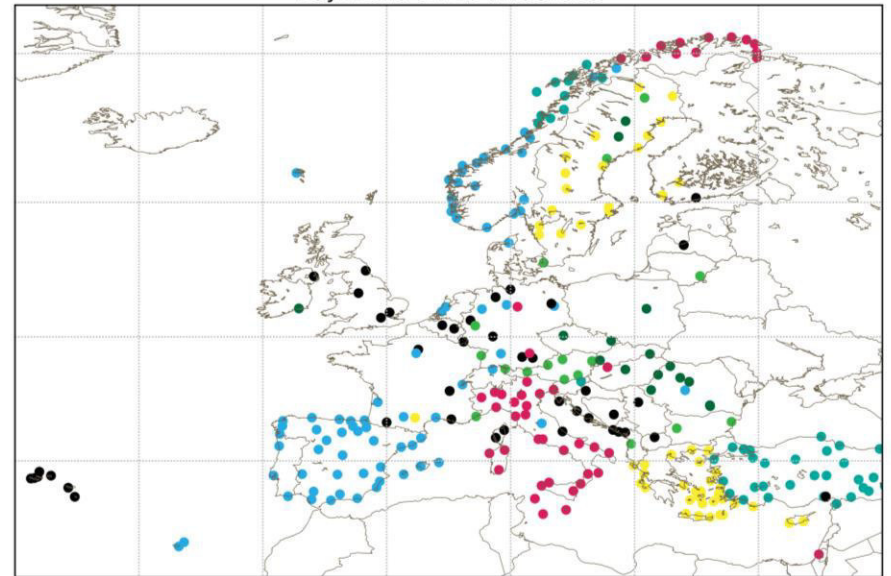


COMMUNITY DETECTION ANALYSIS: ASH CLOUD IMPACT

Day: 2010-04-11 Airac: 333



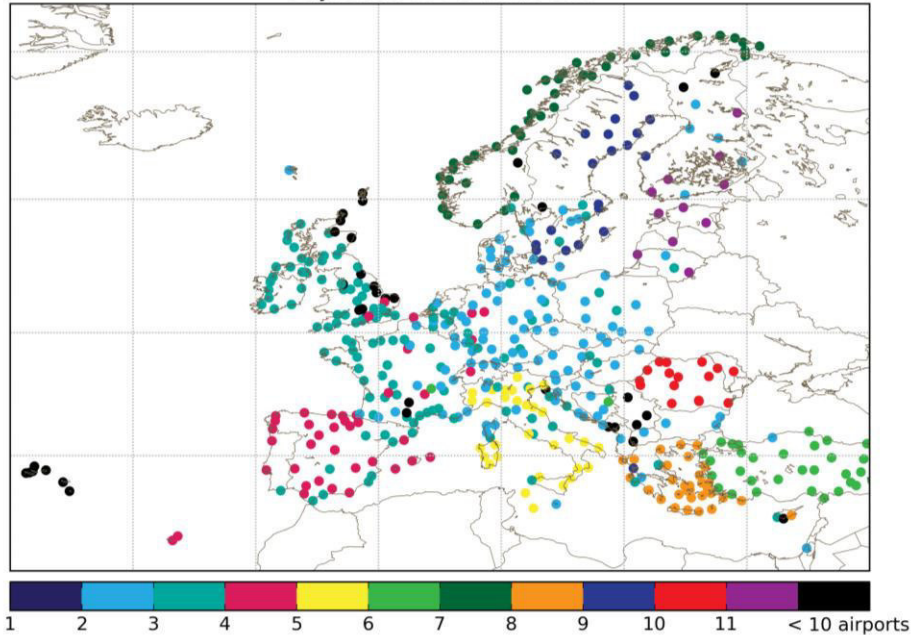
Day: 2010-04-18 Airac: 333



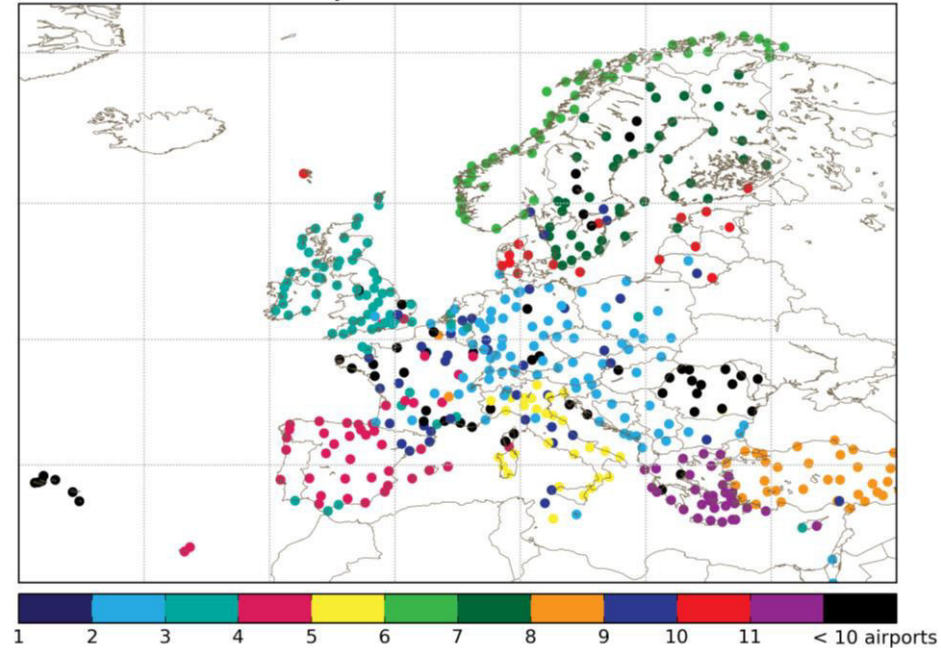


COMMUNITY DETECTION ANALYSIS: SEASONAL VARIATIONS (JULY/NOVEMBER)

Day: 2010-07-15 Airac: 336



Day: 2010-11-11 Airac: 340





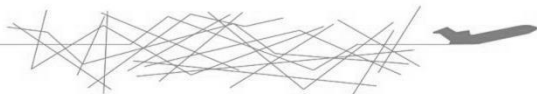
PLOS ONE Journal Paper - Just accepted

Analysis of ATM as a multi-scale network:

- Airports
- Sectors
- Navpoints

“Horse-race” between:

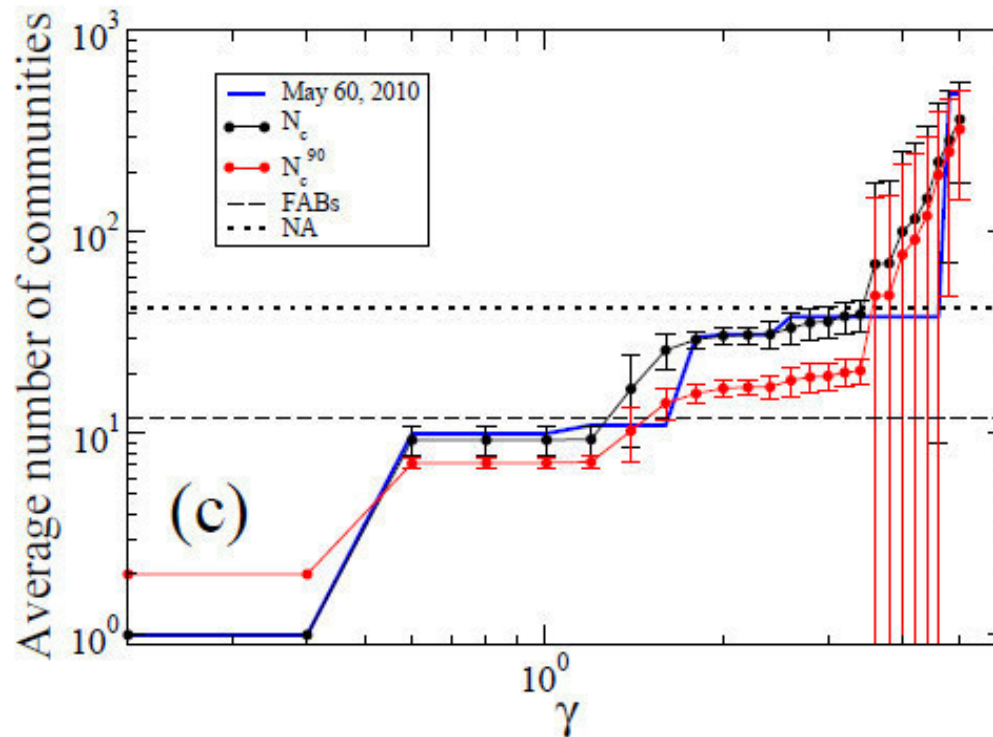
- Infomap
- Maximization of the modularity with the Louvain method
- OSLOM
- Multi-resolution modularity



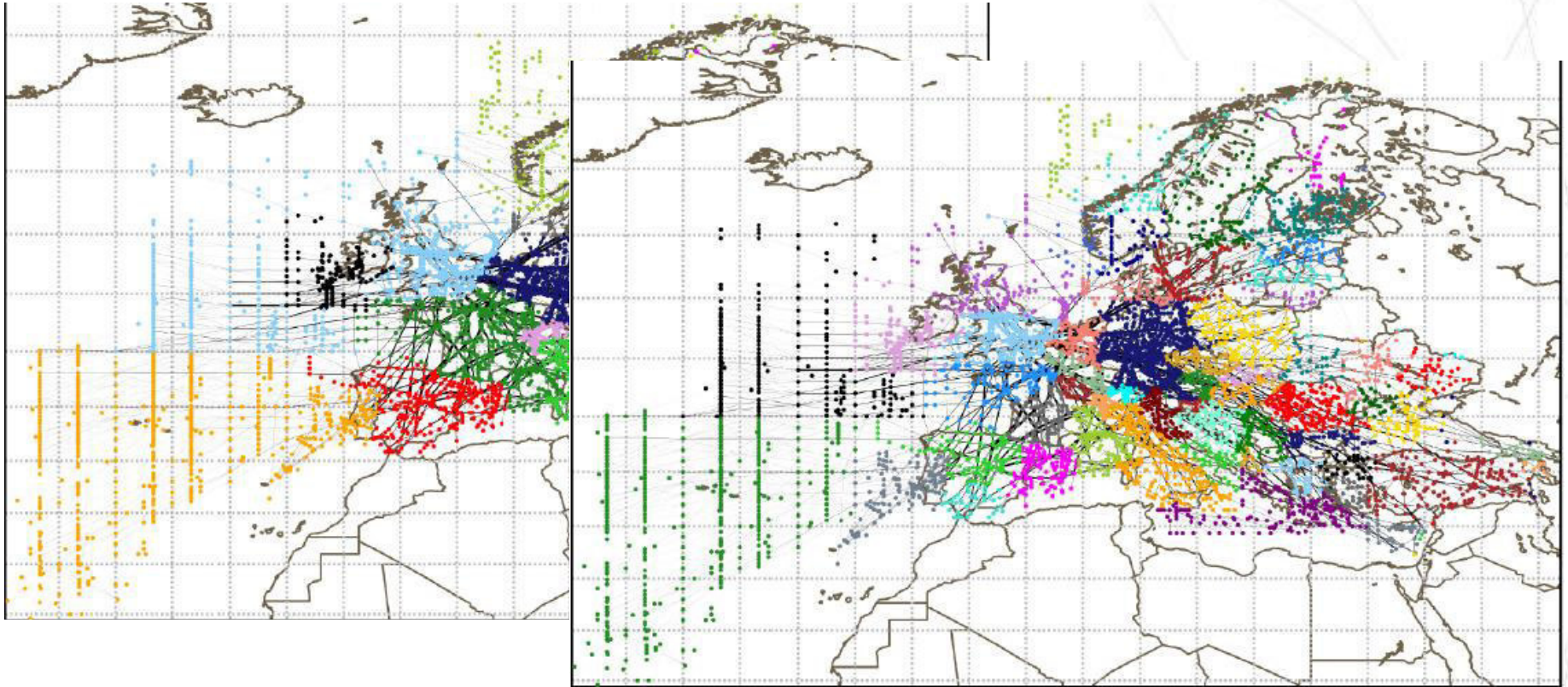
PLOS ONE Journal Paper - Just accepted

Capable of capturing different organisations:

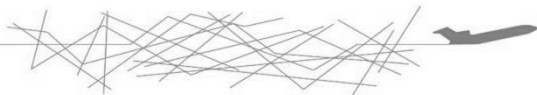
- ACCs
- National Airspaces
- FABs



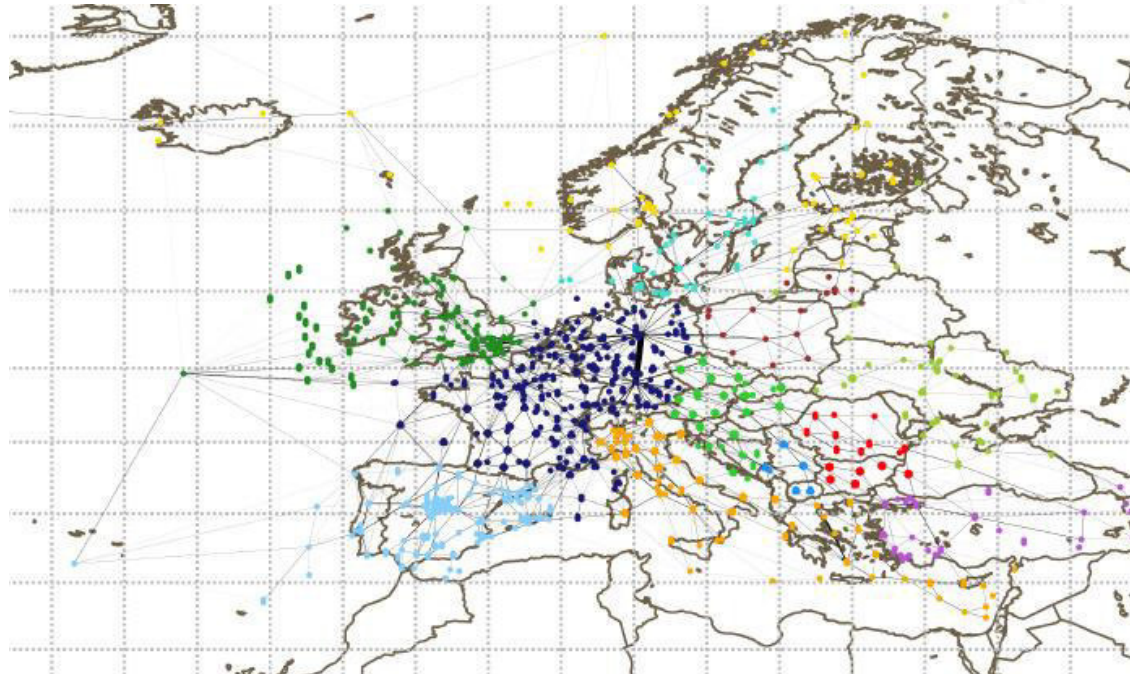
PLOS ONE Journal Paper - Just accepted



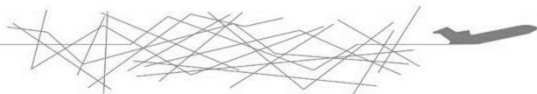
Navpoint network: Nations and ACCs



PLOS ONE Journal Paper - Just accepted

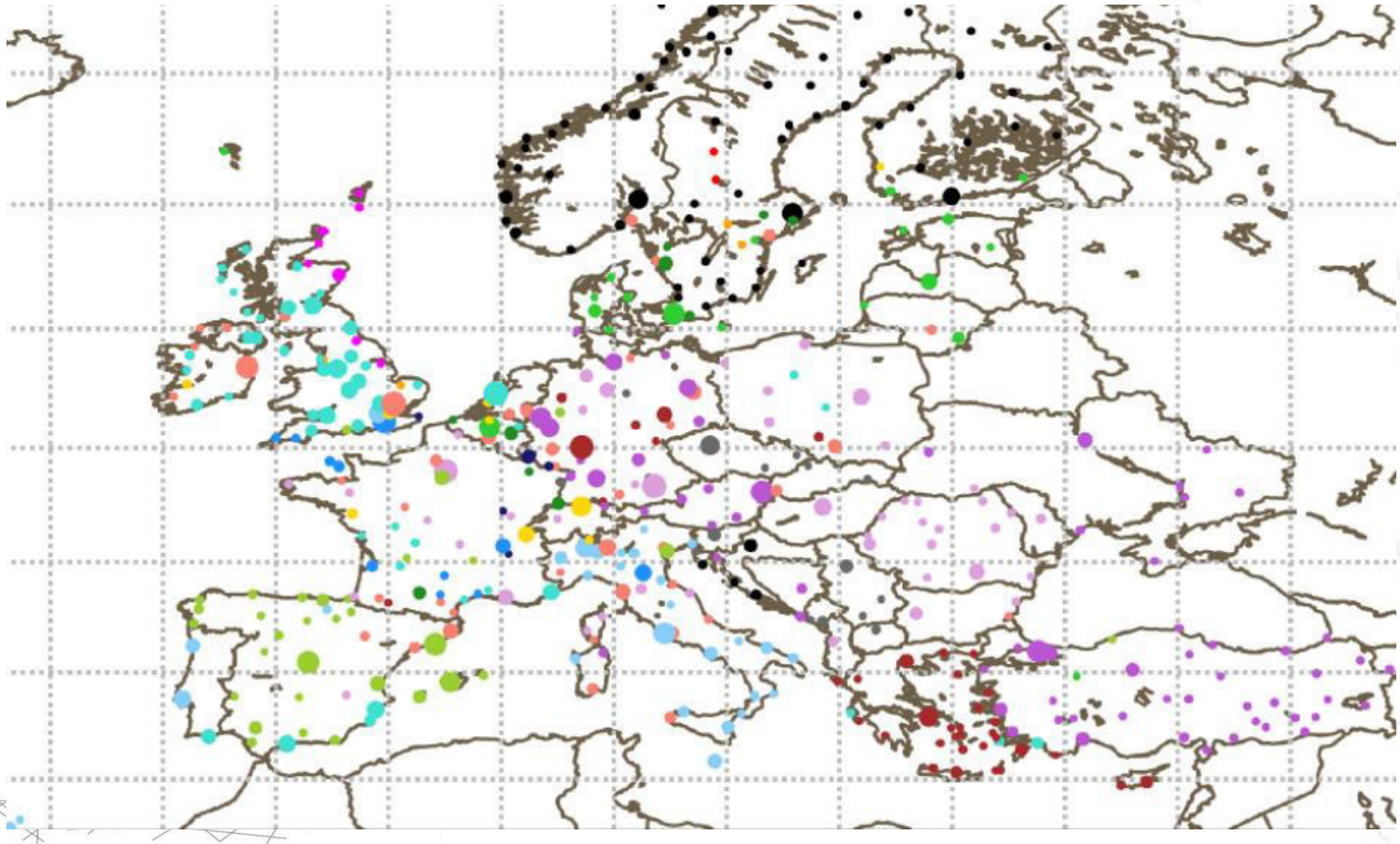


Sector network: FABs



PLOS ONE Journal Paper - Just accepted

- Airport networks: spatial null model

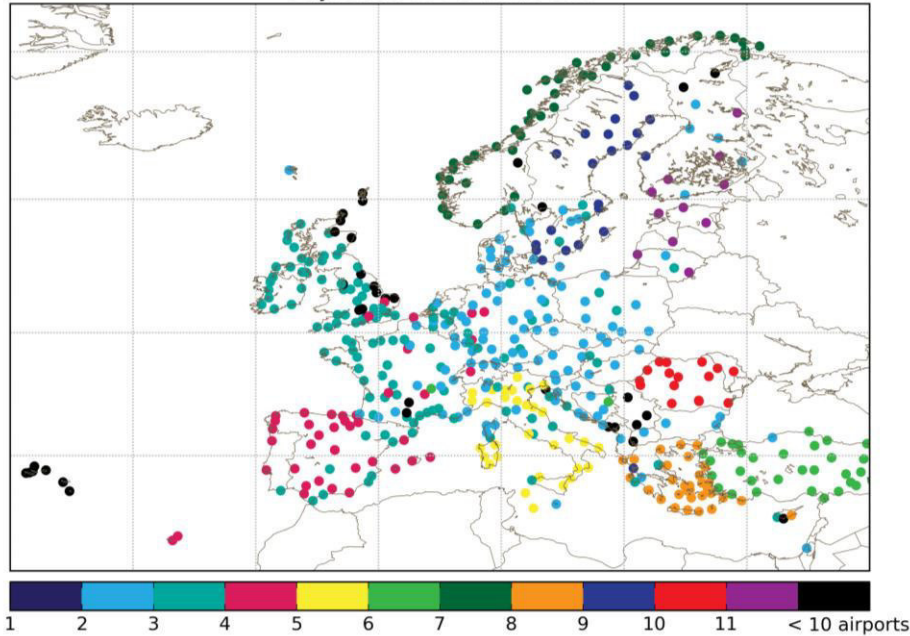




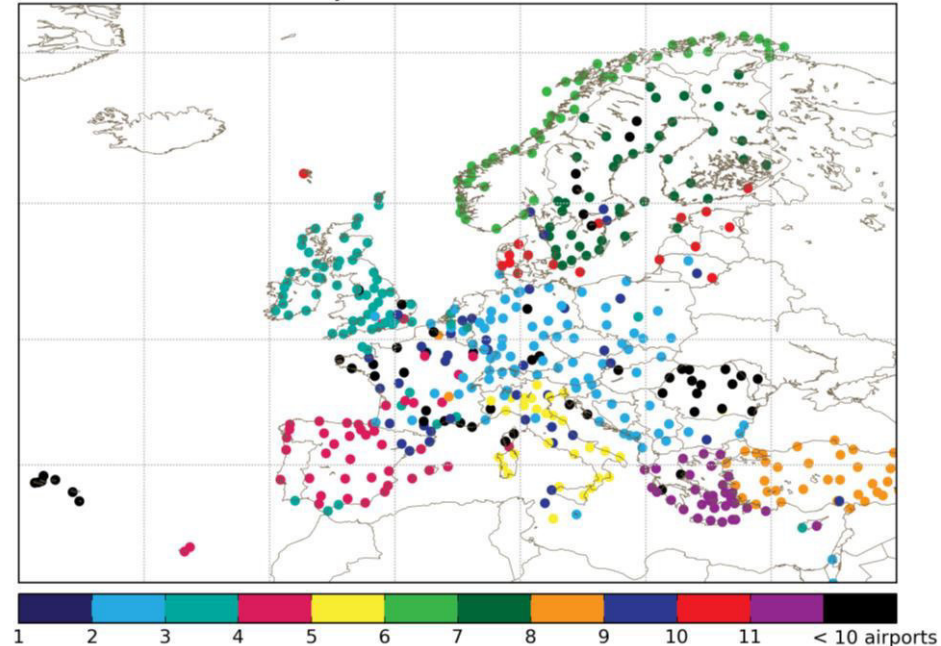
PLOS ONE Journal Paper - Just accepted

Potential benefit: functional partitioning which is really “functional”

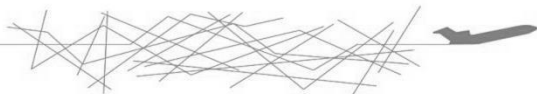
Day: 2010-07-15 Airac: 336



Day: 2010-11-11 Airac: 340



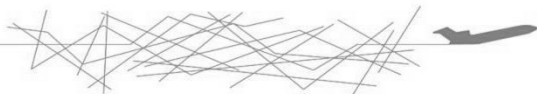
Seasonal variations





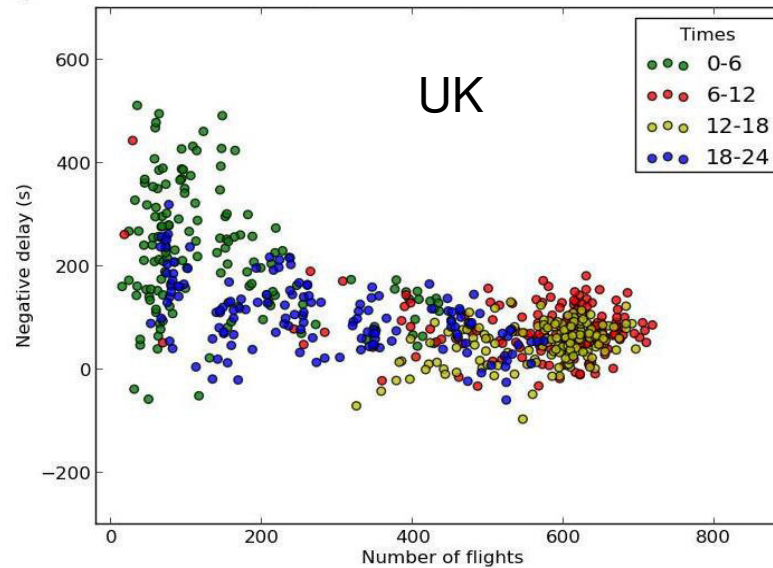
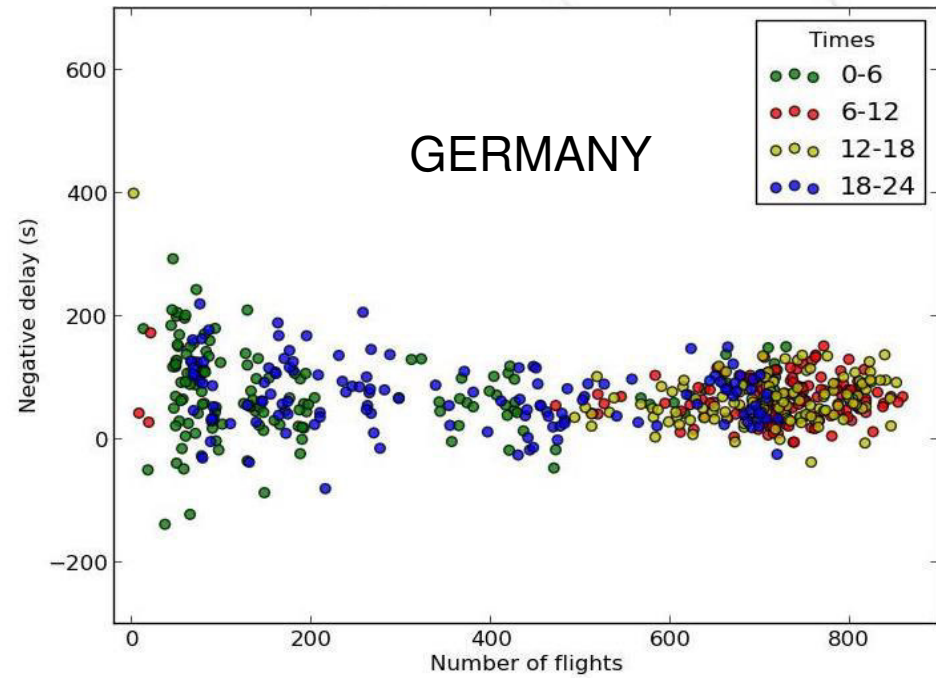
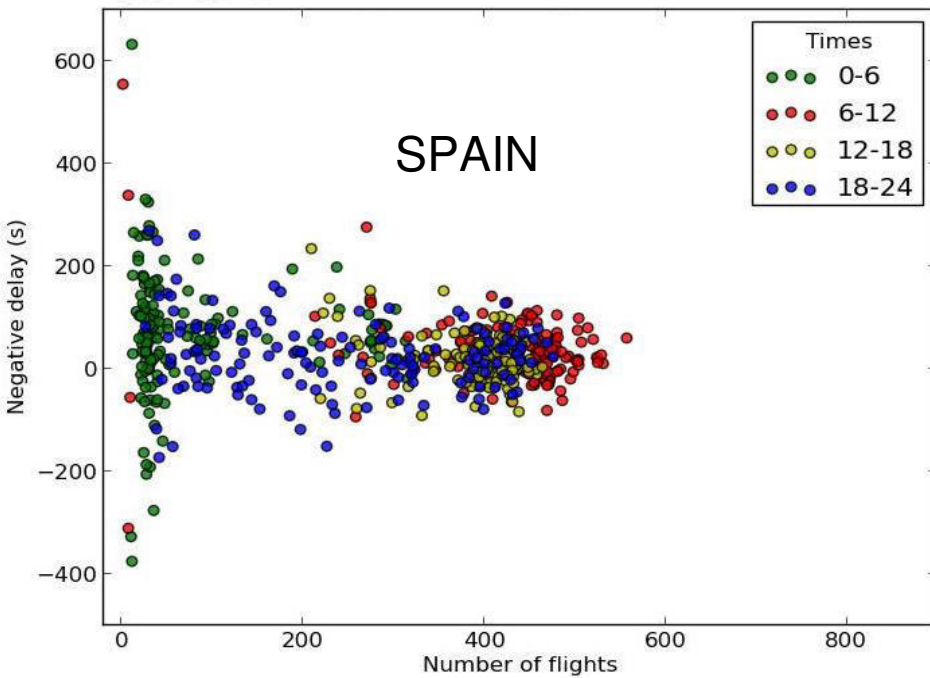
2. ATCO management strategies

- We correlated the spatially averaged negative delay and the number of flights for different countries or single sectors. This measure allows to highlight different ATC management strategies among the different countries or sectors.
- We considered the following countries: Italy (LI), Spain (LE), United Kingdom (EG), France (LF), Germany (ED). Moreover we did the same analysis on the sectors LIRROV and LIRRMW of Rome FIR.
- The analysis was carried out in May and September 2010.



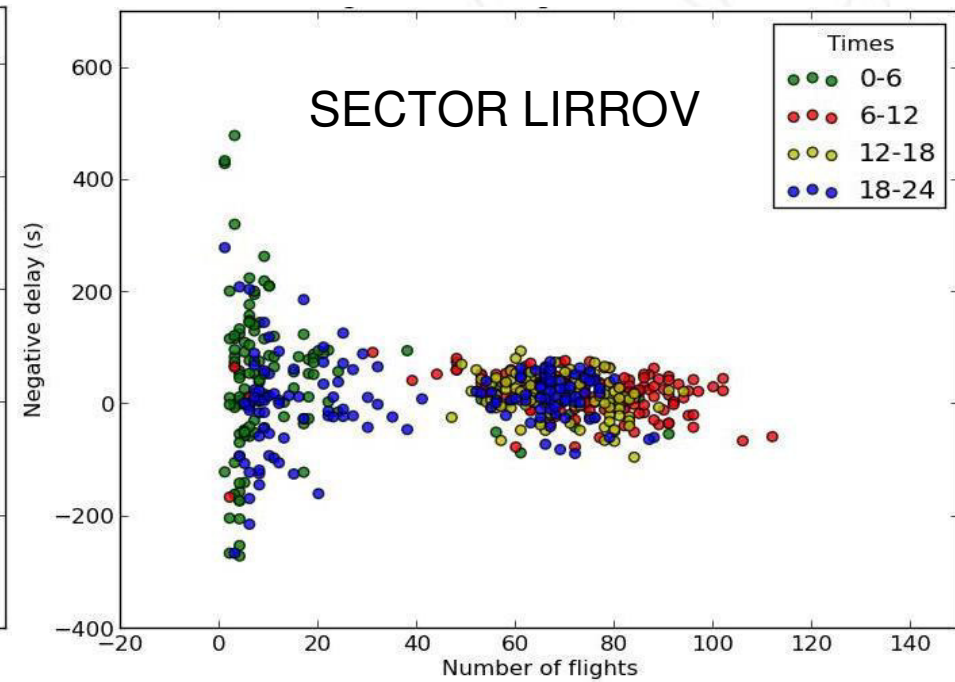
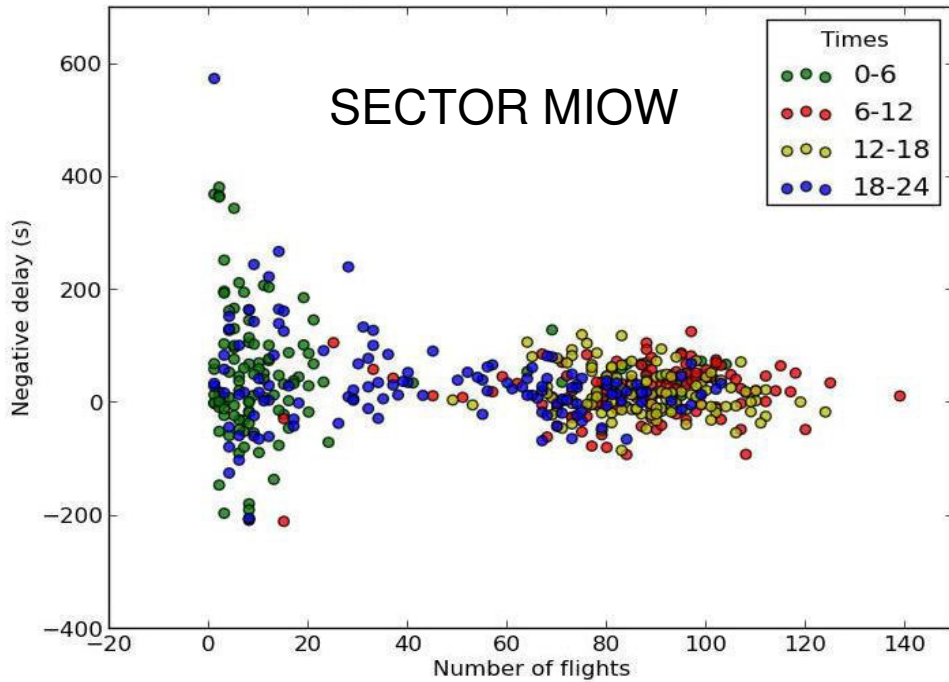


ATCO MANAGEMENT STRATEGIES - MAY 2010





ATCO MANAGEMENT STRATEGIES – SEPTEMBER 2010



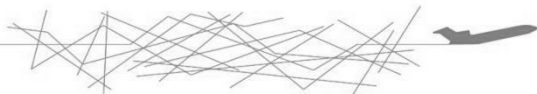
3. Analysis of the most critical navpoints

We computed relevant network metrics for the Italian navpoints network and for the Maastricht navpoints network.

In both cases the network resulted to be composed by several nodes (including airports) and the corresponding edges. Each edge represents a link between two navpoints that was actually travelled by one or more aircraft in the timeframe analyzed.

We computed the following metrics:

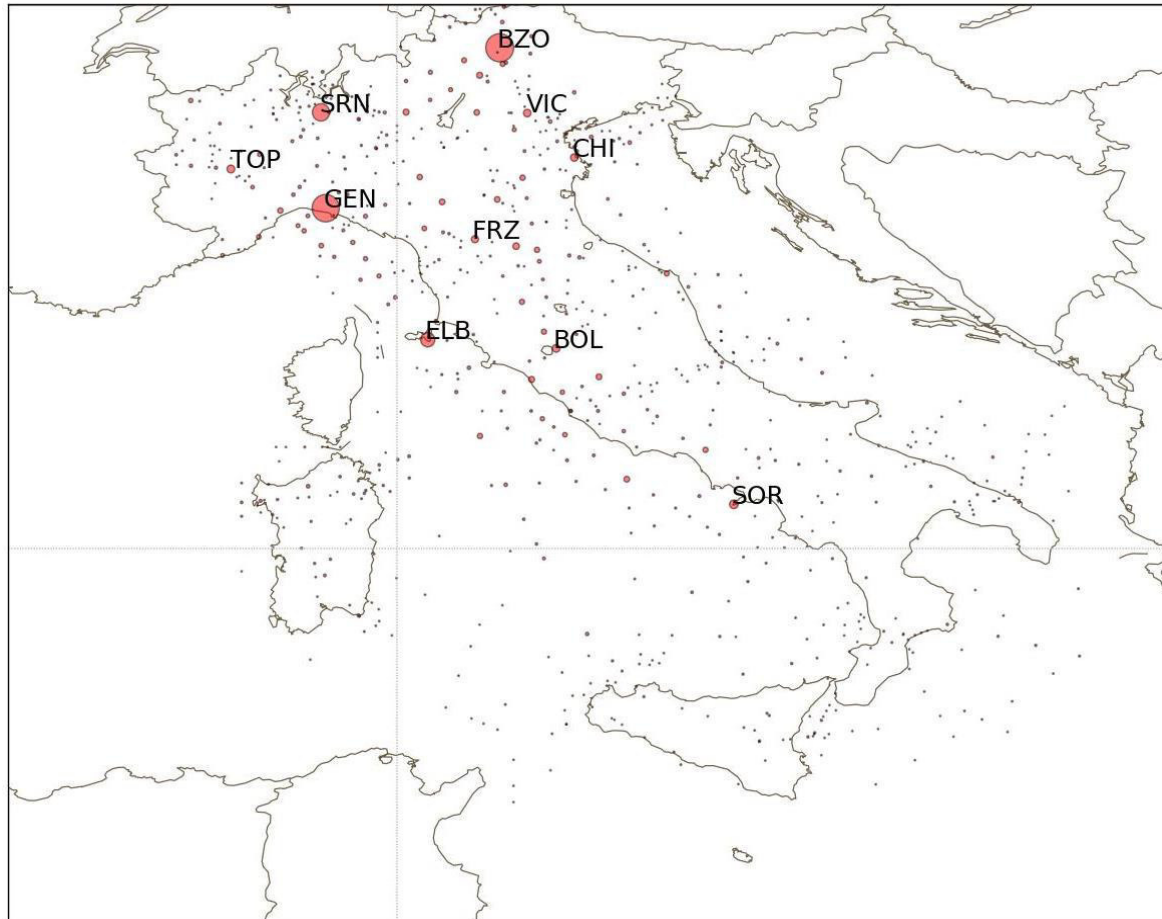
- **Strength**: The strength of a node is essentially a measure of the traffic load on its adjacent links. It is the most direct measure of the traffic load on the node. Nodes with high strength are also the most busy.
- **Betweenness**: It is a measure of a node's centrality in a network. It is related to the number of shortest paths from all vertices to all others that pass through that node. A node with a high value of betweenness means that there are a lot of airways passing through it. There are other definitions of betweenness, the most useful for our case are:
 - **Origin-Destination Betweenness**: for its computation only the nodes that are points of entry and exit from the national airspace are considered
 - **Random walk Betweenness**: It is based on the traffic flows on the network. Imagine to travel on the network numerous times going from a navpoint to another on the most trafficked airways; a node will have a high value of Random-Walk many more times you go over it





THE MOST CRITICAL NAVPOINTS OF THE ITALIAN AIRSPACE

STRENGHT

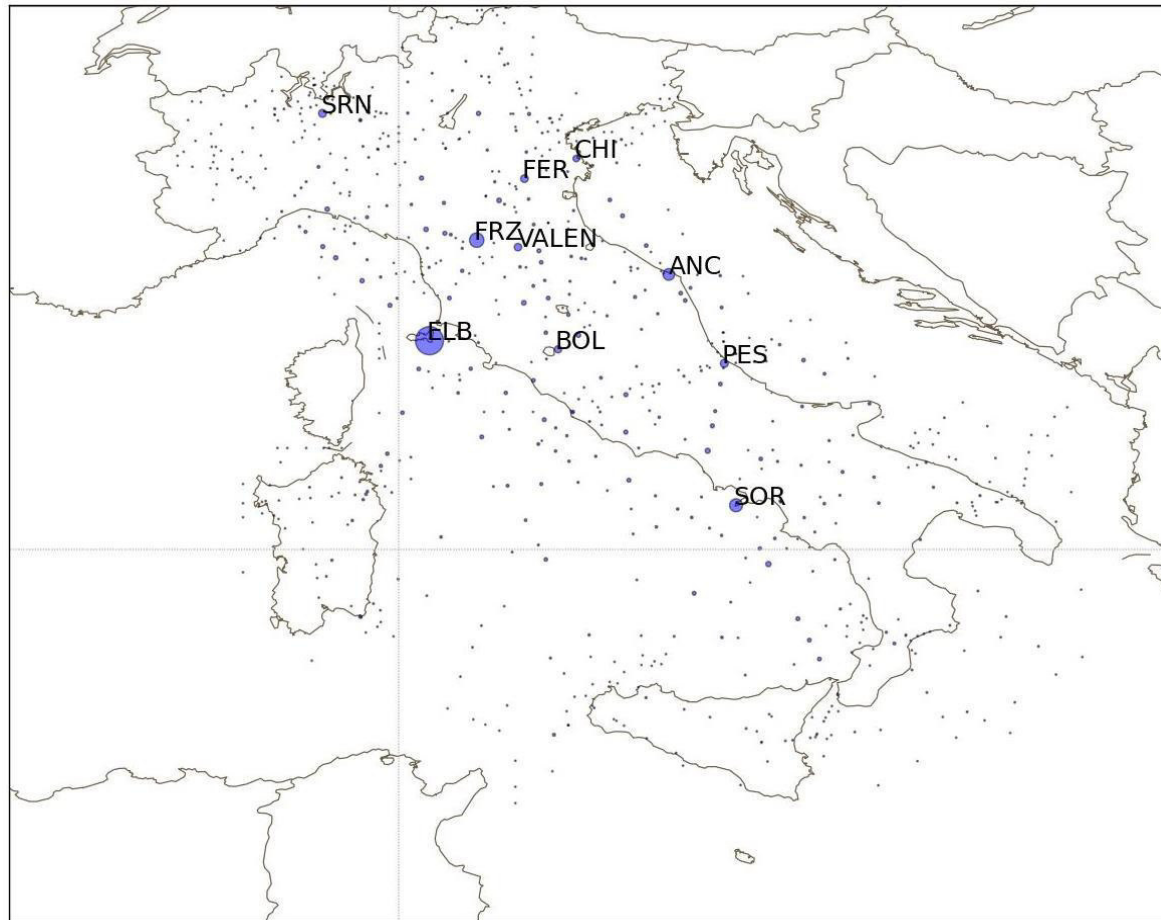


Rank	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
Navpoint	BZO	GEN	SRN	ELB	SOR	TOP	BOL	VIC	CHI	FRZ



THE MOST CRITICAL NAVPOINTS OF THE ITALIAN AIRSPACE

BETWEENNESS

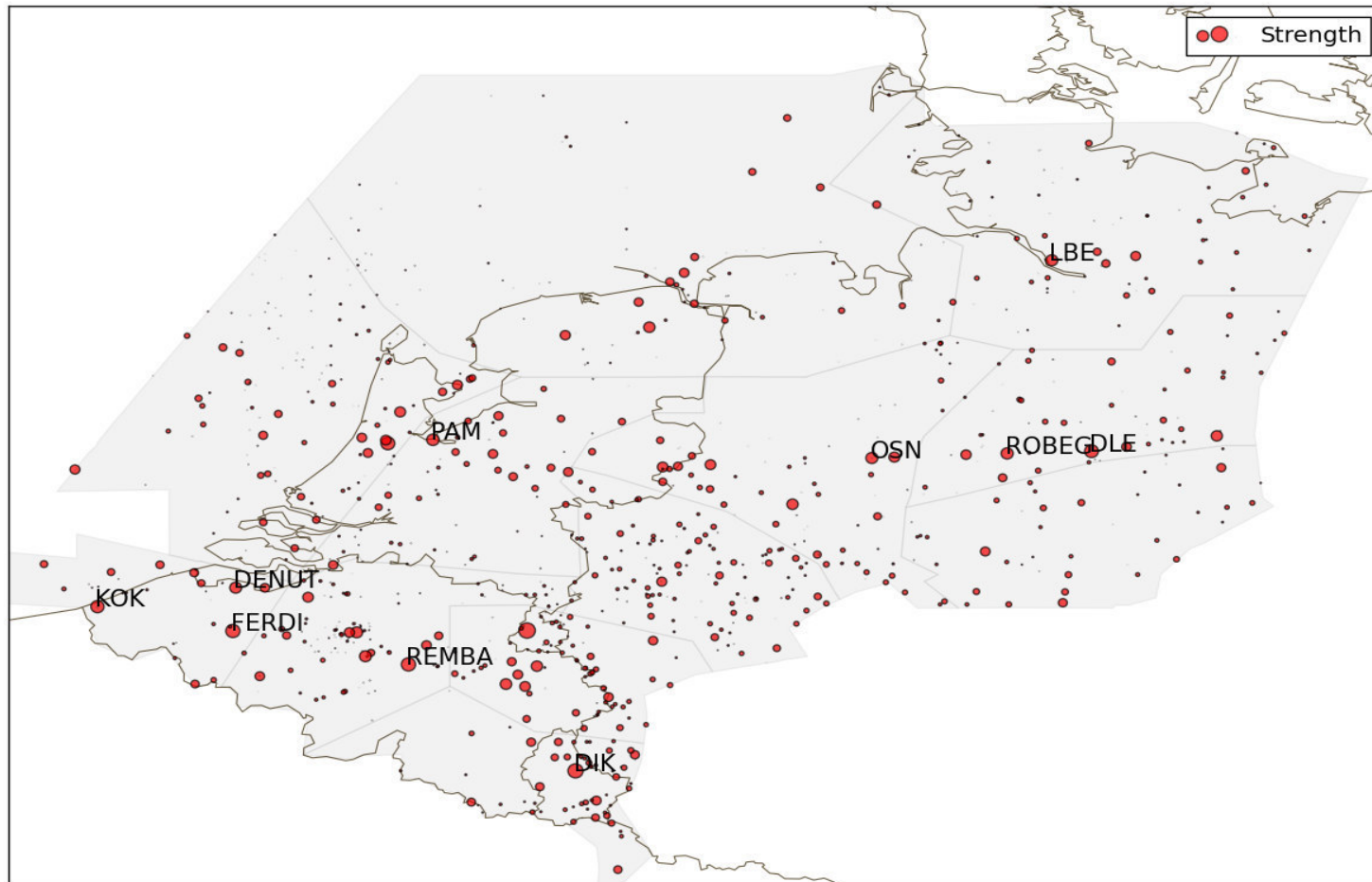


Rank	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
Navpoint	ELB	FRZ	SOR	ANC	PES	CHI	BOL	TEA	PEMAR	TINTO



THE MOST CRITICAL NAVPOINTS OF MAASTRICHT AIRSPACE

STRENGTH

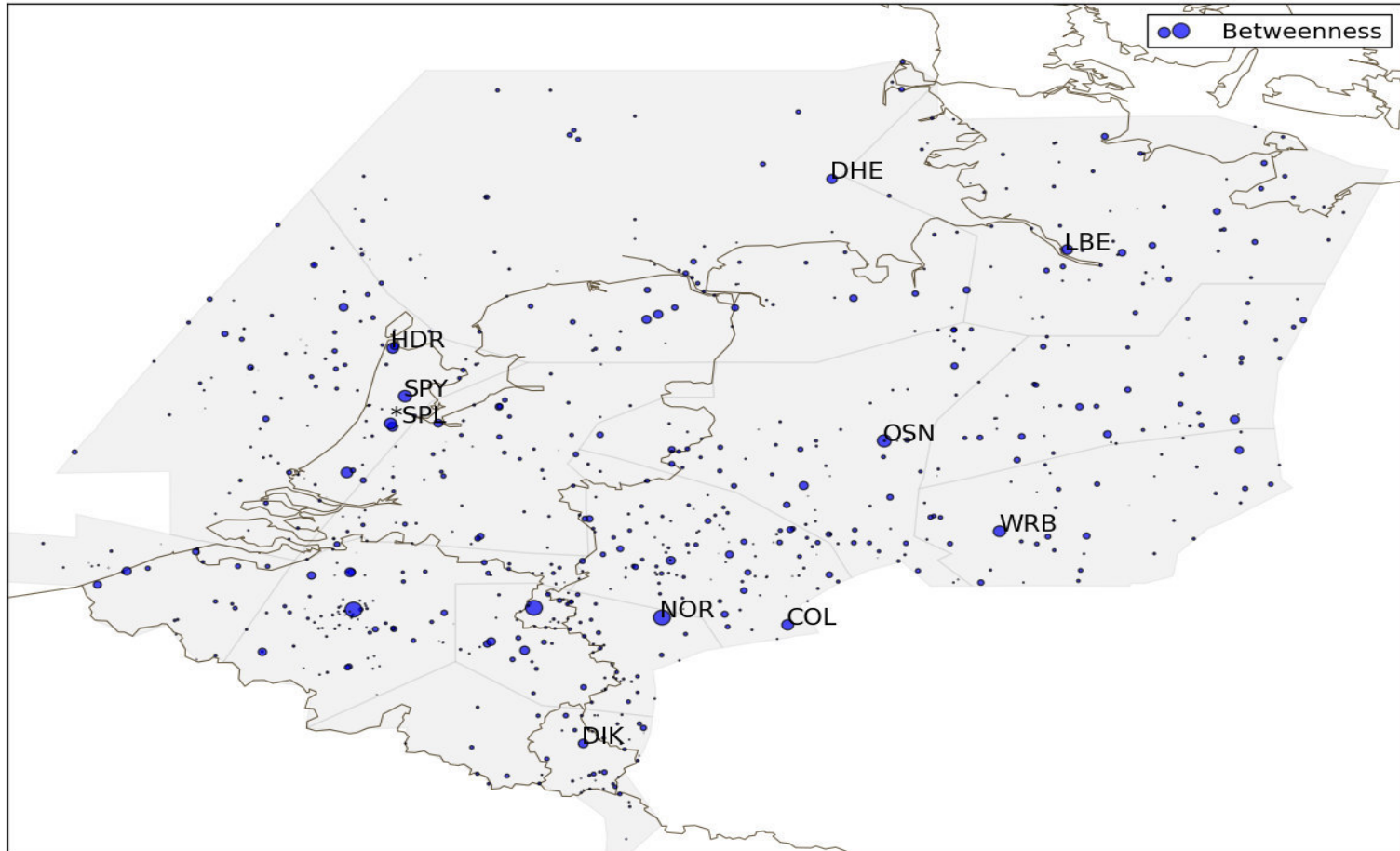


Rank	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
Navpoint	DIK	REMBA	FERDI	DLE	KOK	PAM	ROBEG	LBE	OSN	DENUT



THE MOST CRITICAL NAVPOINTS OF MAASTRICHT AIRSPACE

BETWEENNESS

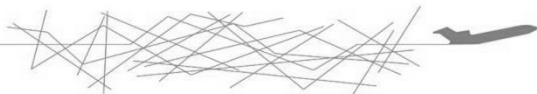


Rank	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
Navpoint	NOR	OSN	SPY	WRB	SPL	COL	HDR	LBE	DHE	DIK



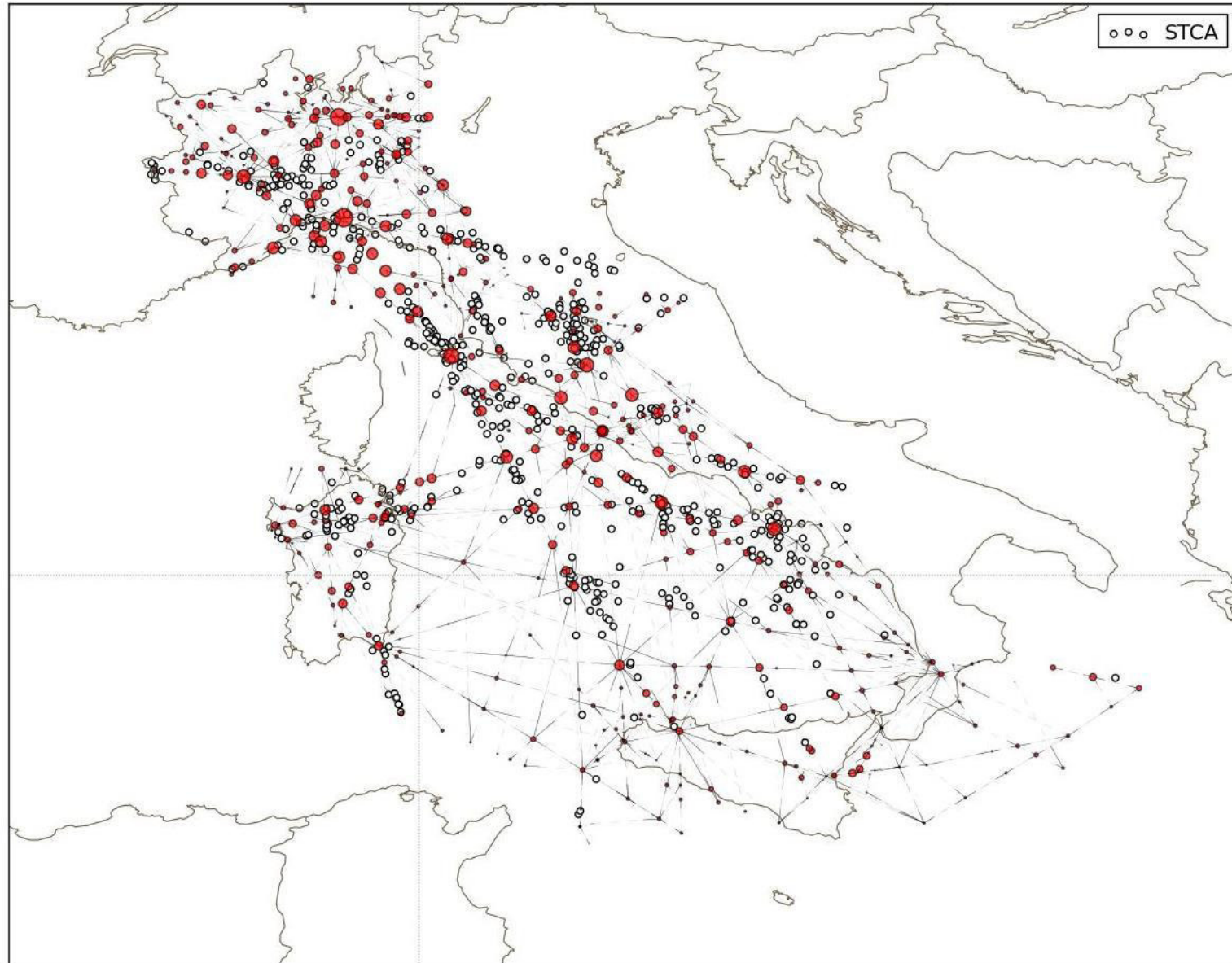
4. Correlation between STCA events and Complex Networks Metrics

- We look for correlations between the occurrence of Short-Term Conflicts Alerts and Loss of Separation events, gathered with ASMT, and complex network metrics measured over the navpoint network.
- All the events are gathered over the Rome ACC and covers a limited period of time, thus the navpoint network has been built using traffic data of the same part of the Italian Airspace and in the corresponding days.



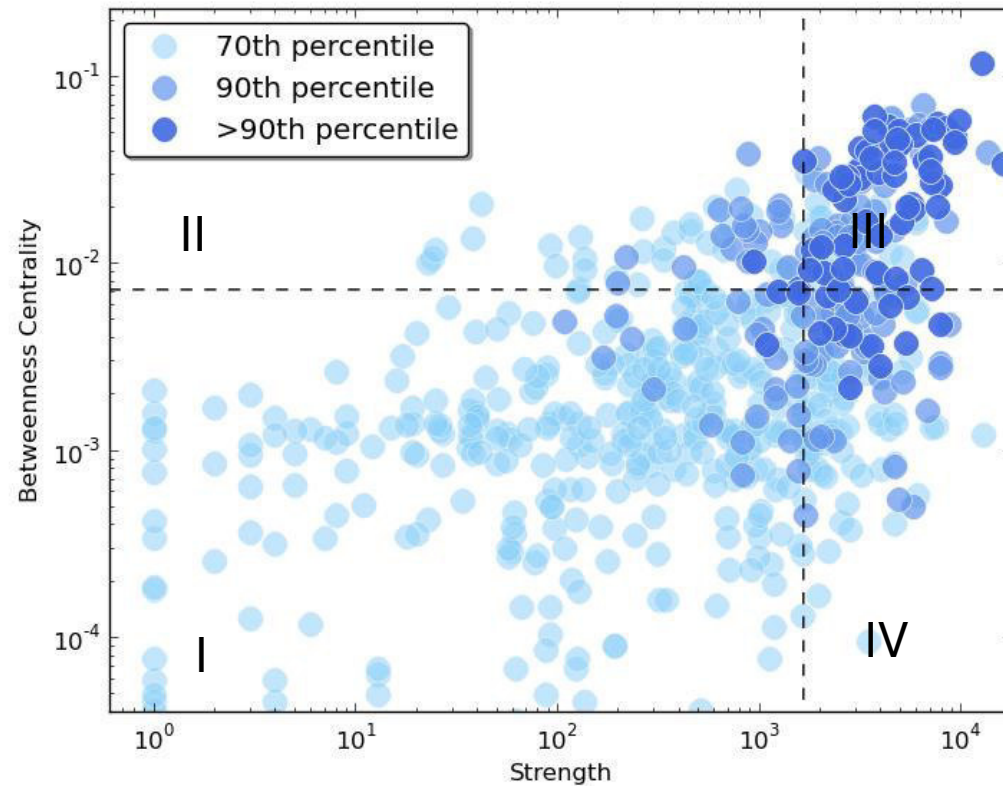


CORRELATION BETWEEN STCA EVENTS AND COMPLEX NETWORKS METRICS (STRENGHT)



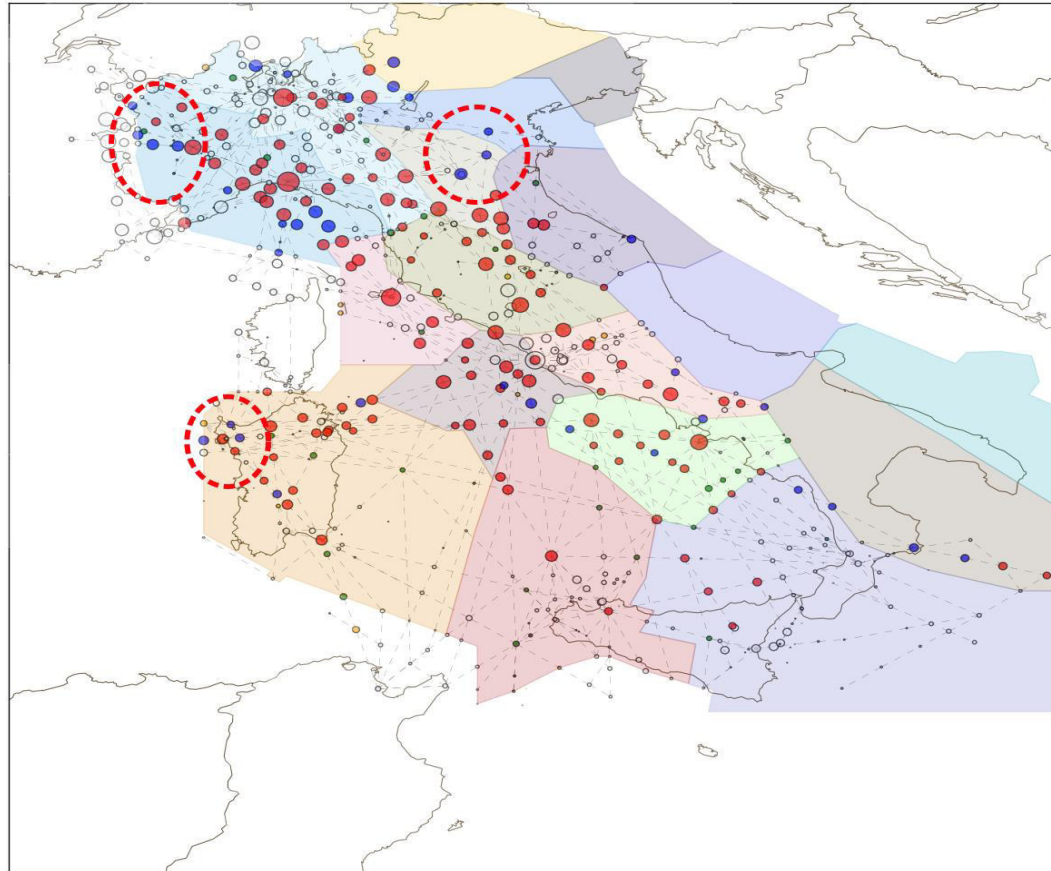


CORRELATION BETWEEN STCA EVENTS AND COMPLEX NETWORKS METRICS



70 th percentile	90 th percentile	> 90 th percentile
No events associated	1-7 events associated	More than 7 events associated

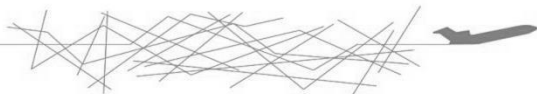
OUTLIERS





Positive feedbacks collected

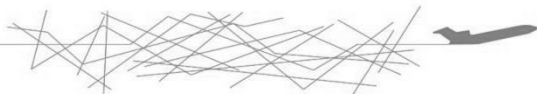
- **Network analysis is a powerful and innovative tool** that may have several applications in the ATM world.
- Some ATM experts recognized some of the proposed analyses as **promising tools for monitoring the airspace structure especially in the future SESAR scenario**. Community analysis could help in efficiently driving the allocation of resources and improving the coordination between different entities. The analysis of safety occurrences and of the most critical navpoints are instead useful for monitoring the airspace allocation and the associated criticalities.
- The analysis of the ATCO strategies is useful in underlying commonalities in the management. Moreover this analysis can be effective in showing different controlling strategies within the same ANSP (younger vs older controllers) to monitor the application of new procedures put in place.
- Some networks metrics (e.g. betweenness) can give useful information for designing the airspace because they are able to predict the location of the most congested areas without basing the assessment on a huge amount of historical flight data, but only on the intrinsic characteristics of the airspace structure.





Negative feedbacks collected

- The practical applicability of the proposed concepts is difficult.
- According to the ENAV supervisor it is unlikely that a major redesign of the airspace will happen in the future. Therefore the impact of the analysis on safety occurrences and critical navpoints may be limited.
- Some of the network metrics are not easy to understand intuitively.
- The analysis of safety occurrences need to be further explored by enlarging the dataset and by linking the events to different metrics more related to the phase of flight they belong to (descent, ascent, cruise).



Concluding remarks



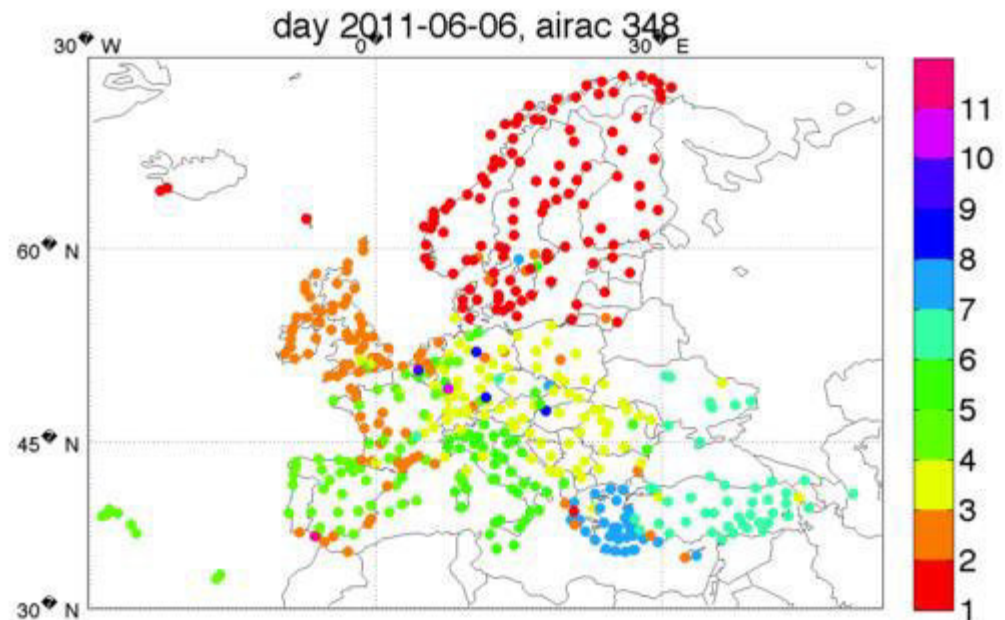
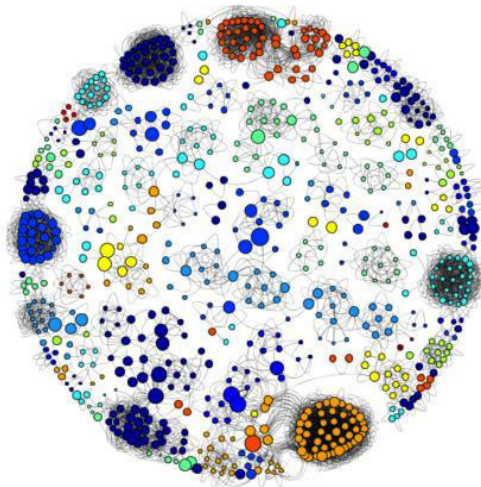
ELSA

Empirically grounded agent based models for the future ATM scenario

ELSA Objectives

Motivation

- Lack of suitable means to analyse and monitor the emerging characteristics at the system level, e.g. EU-wide performance scheme [Commission Regulation (EU) No 691/2010]
- Application of methods used for the data analysis in complex system science to ATM



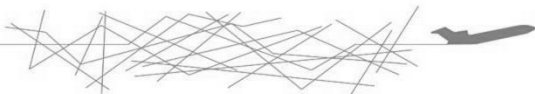
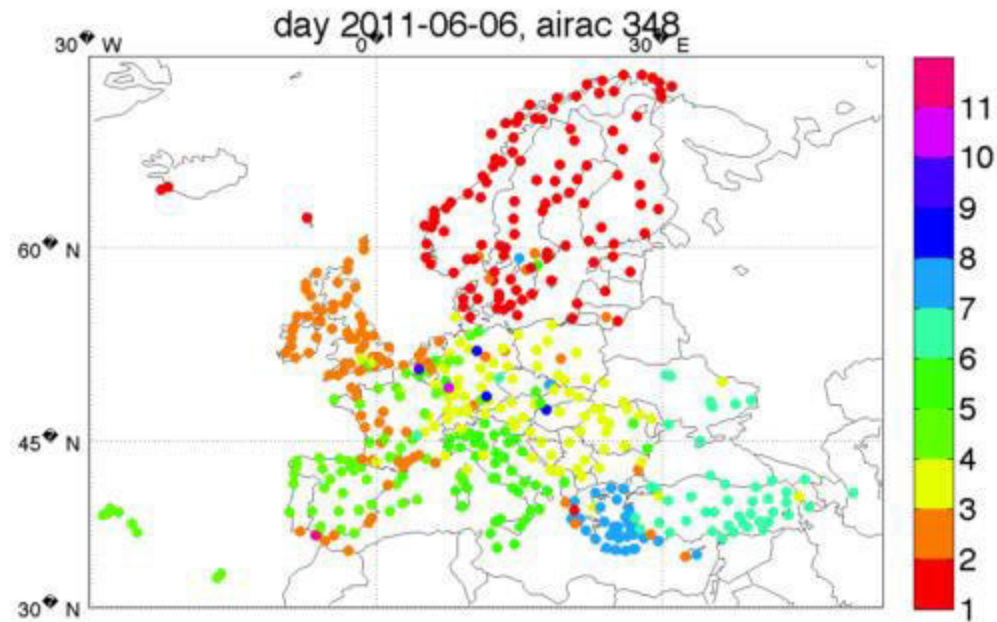
Complex system science and ATM

Good for:

- Capturing ECAC-wide system dynamics and phenomena
- Focus on relations and interactions: space-time correlations (btw geo areas, fluctuations...)

To be continued:

- From general behavior to case-study analysis (e.g. outliers)
- Until operational benefits are clarified





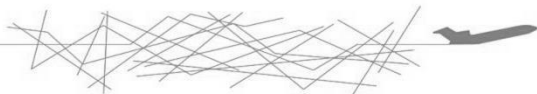
Complex system science and ATM

What could be improved:

- Data availability: format, infrastructure

E.g. final dataset after 11 months, effort to self-develop database and research infrastructure (re-use?)

- Support from experts: rare breed of research & operations
- Clarification of benefits: requires better access to “customers”



Thanks for your attention!



ELSA

– DBL

– UniPa

- SNS



ELSA

Empirically grounded agent based models for the future ATM scenario

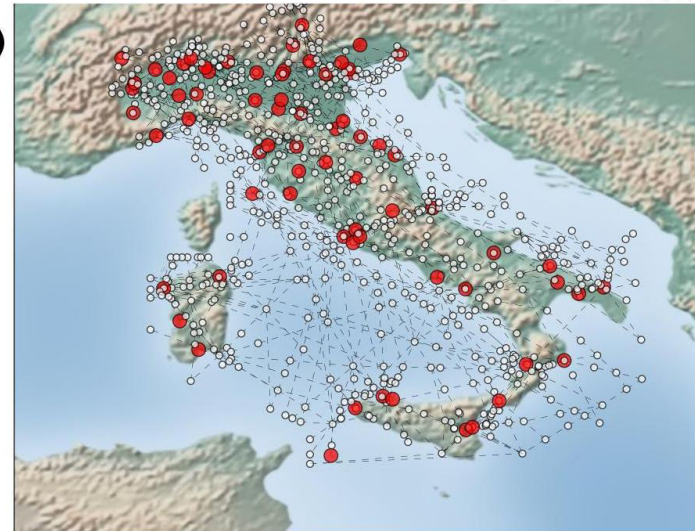
The Italian Navigation Point Network

Using data about flight plans in a certain airspace it is possible to build a Navigation Point Network:

- Nodes: Fixes crossed by the aircraft
- Links: Two nodes are connected if at least an aircraft has flown from one to the other in the considered period.

Navigation point networks are suited to reproduce the structure of the airways in an airspace. Such structure can be studied in the framework of “complex networks”.

A)



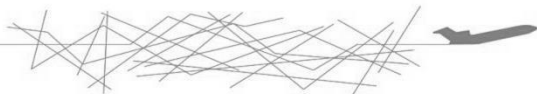


Network metrics of the Italian airspace

In order to compute network metrics on the Italian navpoints network we analyzed it in the timeframe spanning from May to December 2011. The network resulted to be composed by 792 nodes (including airports) and 2242 edges. Each edge represents a link between two navpoints that was actually travelled by one or more aircraft in the timeframe analyzed.

We computed the following metrics:

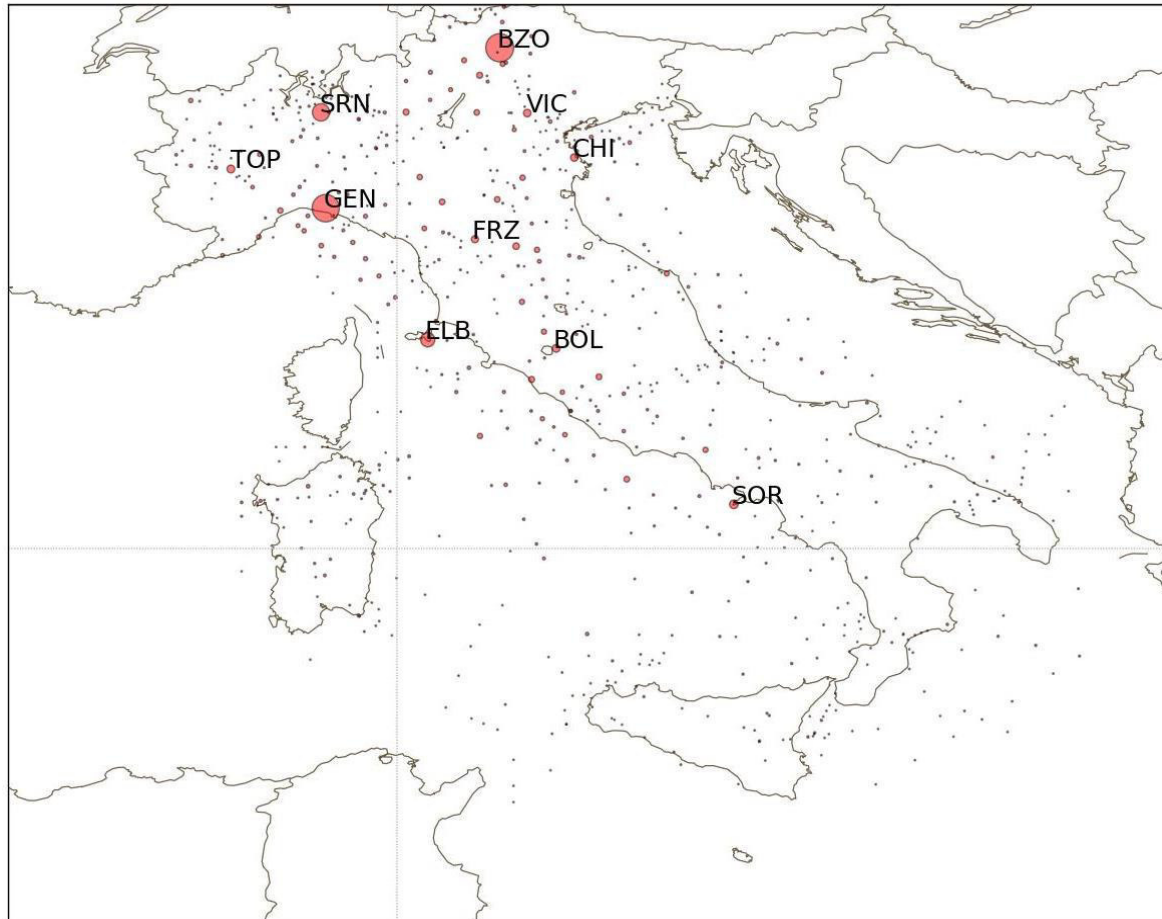
- **Strength**: The strength of a node is essentially a measure of the traffic load on its adjacent links. It is the most direct measure of the traffic load on the node. Nodes with high strength are also the most busy.
- **Betweenness**: It is a measure of a node's centrality in a network. It is related to the number of shortest paths from all vertices to all others that pass through that node. A node with a high value of betweenness means that there are a lot of airways passing through it.





THE MOST CRITICAL NAVPOINTS OF THE ITALIAN AIRSPACE

STRENGHT

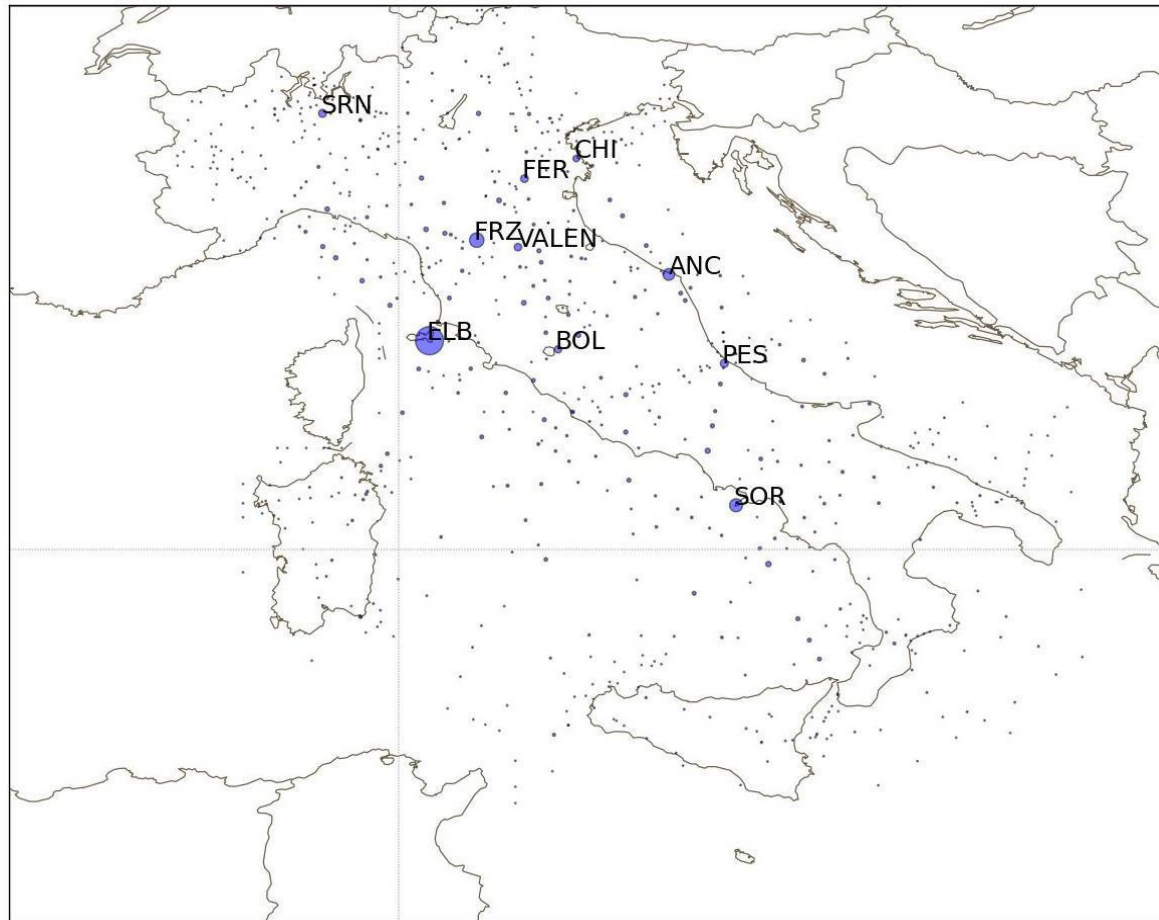


Rank	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
Navpoint	BZO	GEN	SRN	ELB	SOR	TOP	BOL	VIC	CHI	FRZ



THE MOST CRITICAL NAVPOINTS OF THE ITALIAN AIRSPACE

BETWEENNESS

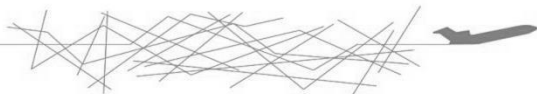


Rank	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
Navpoint	ELB	FRZ	SOR	ANC	PES	CHI	BOL	TEA	PEMAR	TINTO



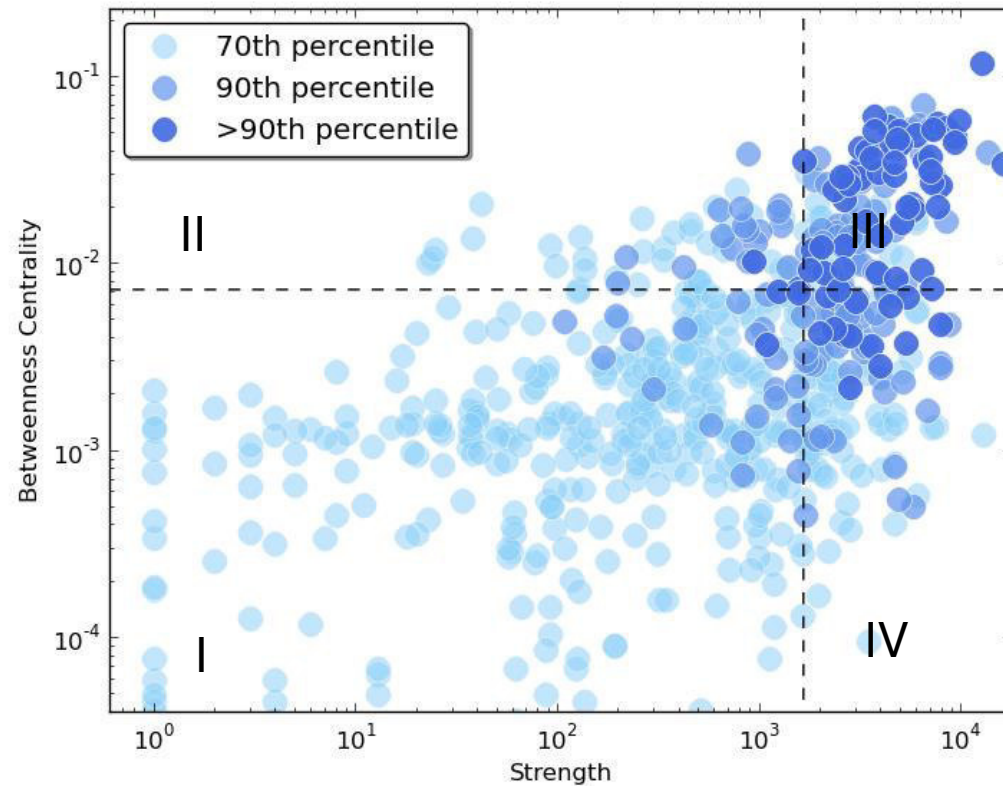
Correlation between STCA events and Complex Networks Metrics

- We look for correlations between the occurrence of Short-Term Conflicts Alerts and Loss of Separation events, gathered with ASMT, and complex network metrics measured over the navpoint network.
- All the events are gathered over the Rome ACC and covers a limited period of time, thus the navpoint network has been built using traffic data of the same part of the Italian Airspace and in the corresponding days.
- Other node metrics regarding dynamical aspects of the airspace have been investigated: vertical movements, redirections, generated delay over the node.





CORRELATION BETWEEN STCA EVENTS AND COMPLEX NETWORKS METRICS

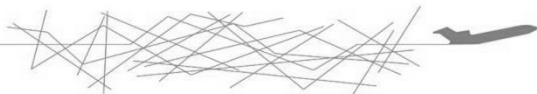


70 th percentile	90 th percentile	> 90 th percentile
No events associated	1-7 events associated	More than 7 events associated



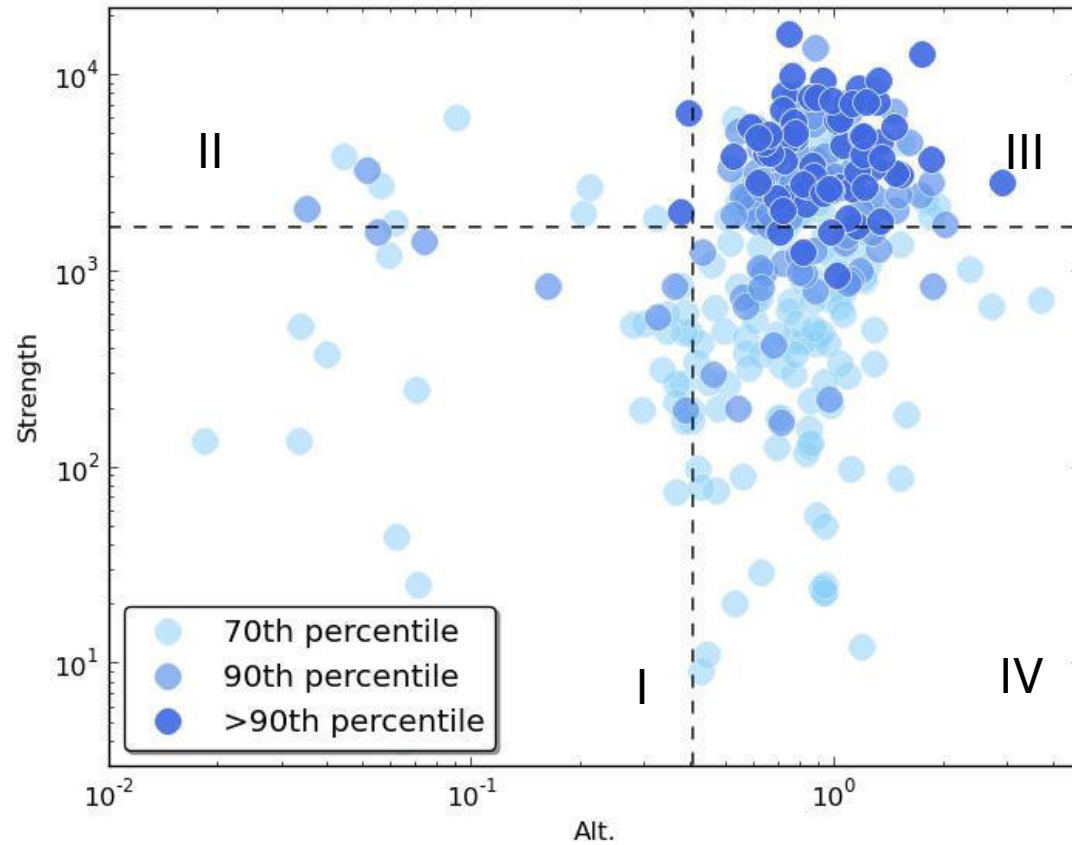
Correlation between STCA events and Complex Networks Metrics

- I: nodes with low metrics, small number of events associated (about 50% of nodes)
- II: nodes with high betweenness and low strength (18% of nodes)
- III: nodes with high betweenness and high strength, nodes in the 90th percentile are usually here (25% of nodes)
- IV: nodes with low betweenness and high strength (12% of nodes)





DYNAMICAL METRICS



70 th percentile	90 th percentile	> 90 th percentile
No events associated	1-7 events associated	More than 7 events associated

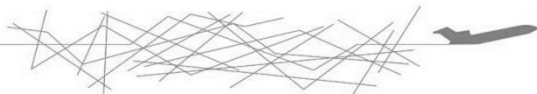


Outliers

The study of nodes out of trend, the outliers, could give information about the structure of the airspace:

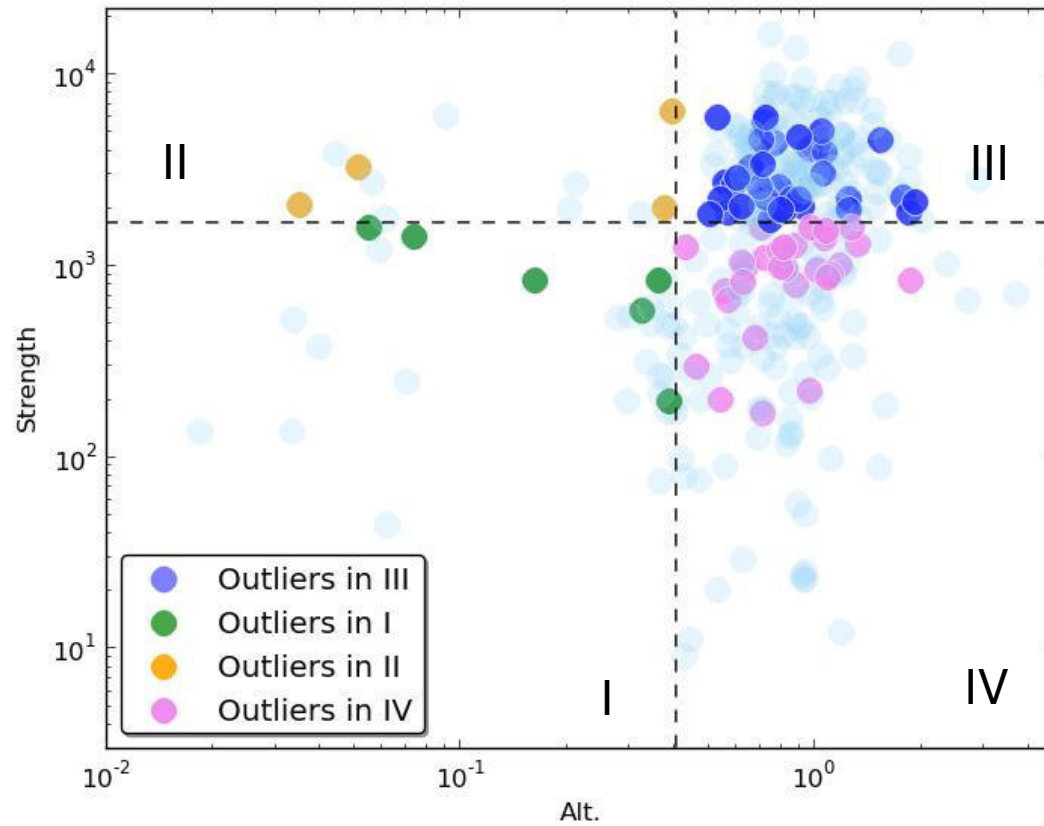
1. Nodes in III below the 70° percentile
2. Nodes in I over the 70° percentile
3. Nodes in II over the 70° percentile
4. Nodes in IV over the 70° percentile

We can indicate them on a map with **blue(1)**, **green(2)**, **orange(3)** and **violet(4)** nodes. **Red** nodes are those correctly identified as critical in III.

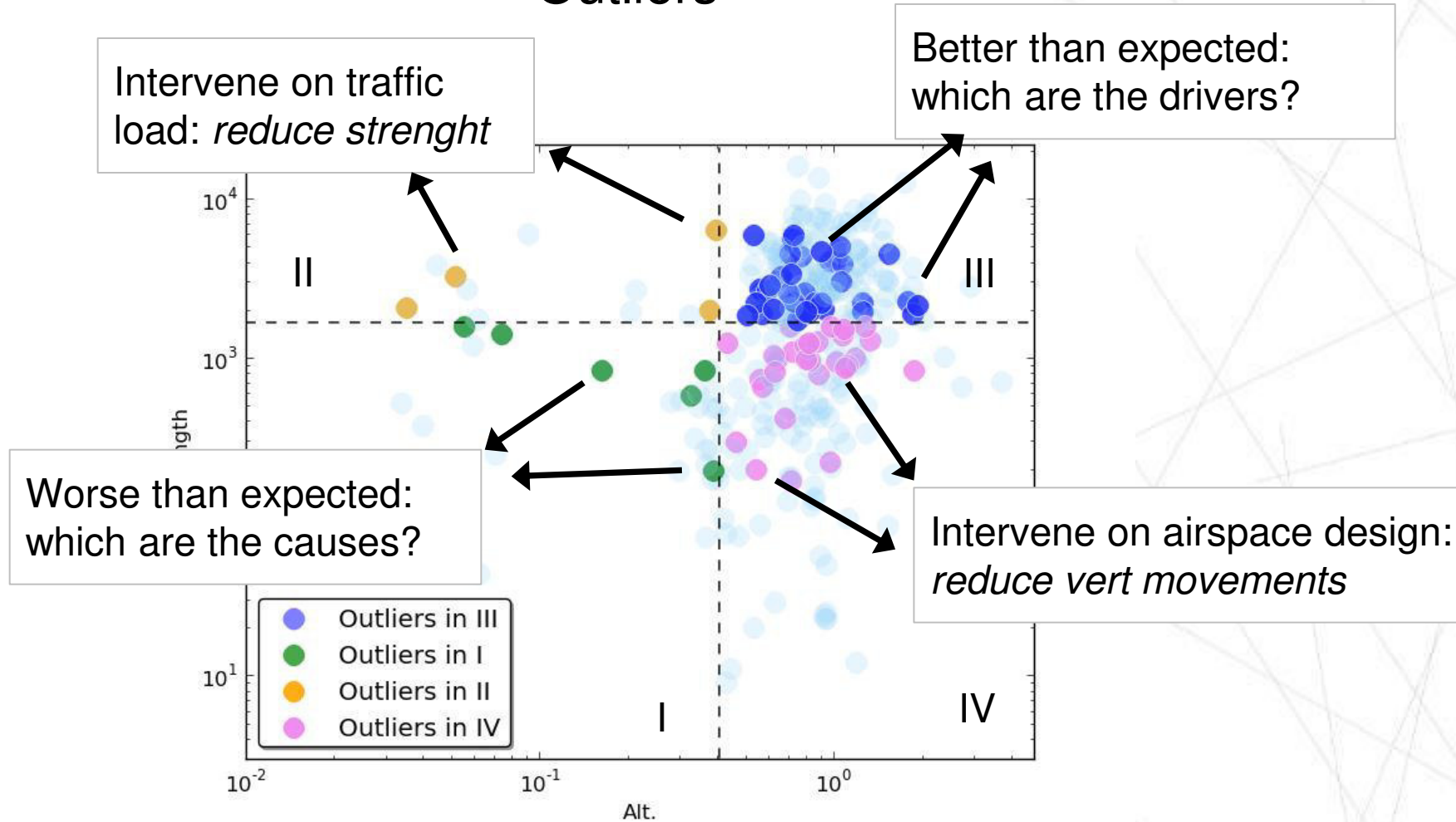


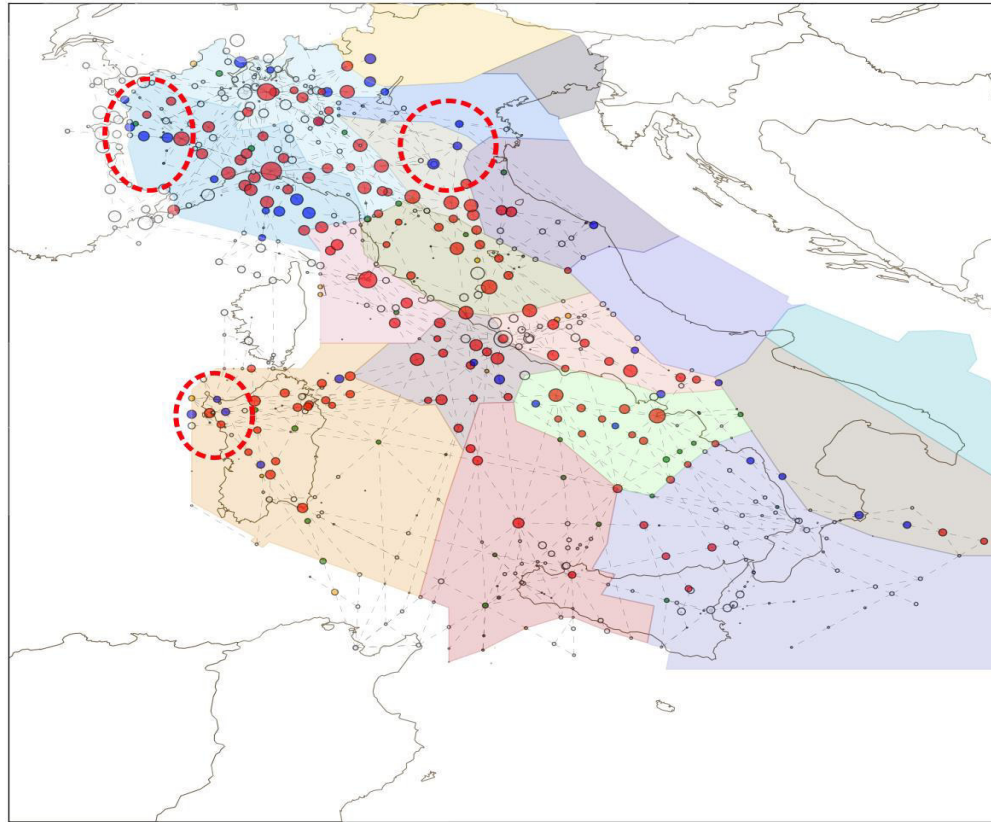


Outliers

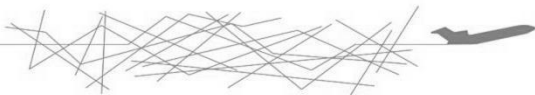


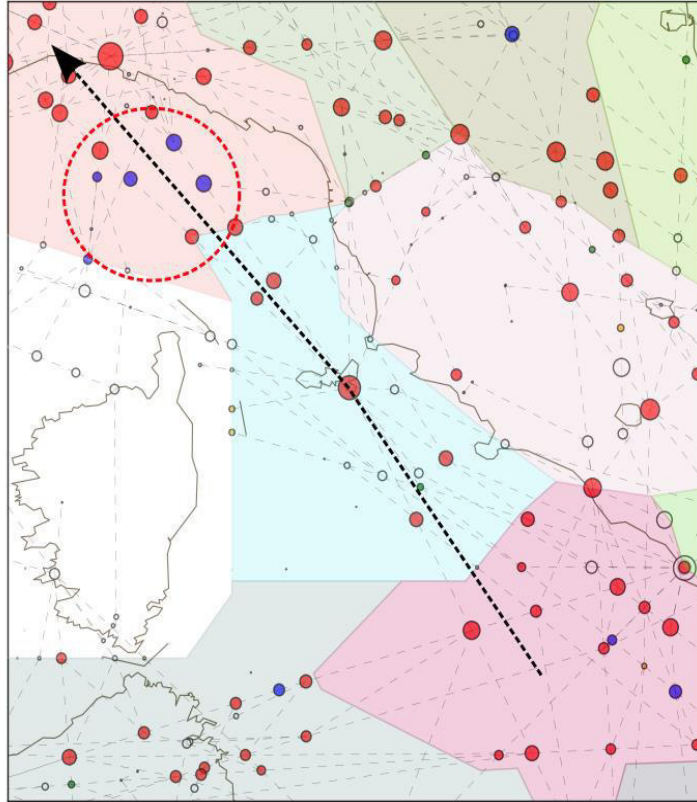
Outliers

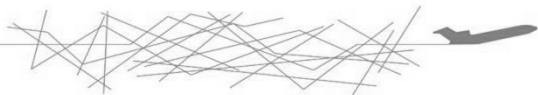
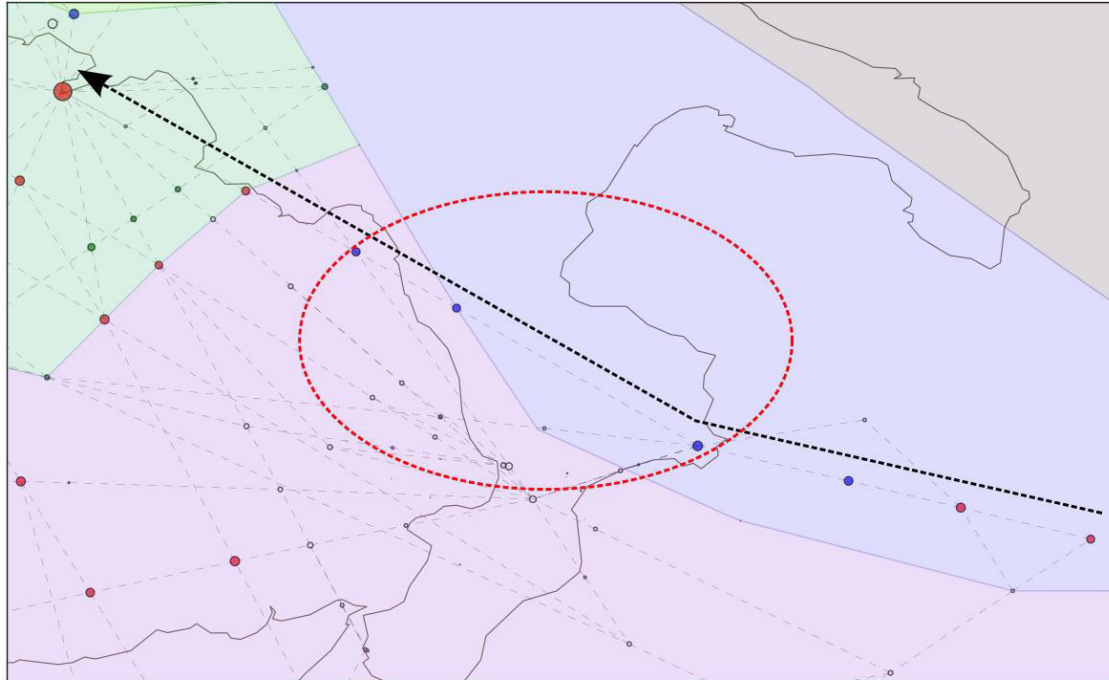




Map of strength vs vertical movements, green and orange outliers almost not present



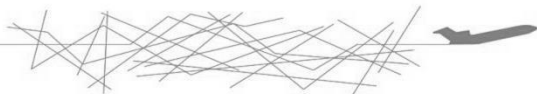






Outliers

- Outliers with high metrics and small number of conflicts can be usually found at the borders of the airspace
- Otherwise they can be found along arieways, when they cross to sectors
- This could indicate the presence of particular procedures taken in order to avoid conflicts in these transition areas
- No particular pattern emerged for the other types of outliers.
- This indications are **stable** in the sense that the same patterns can be found with different couples of metrics





From analysis to application

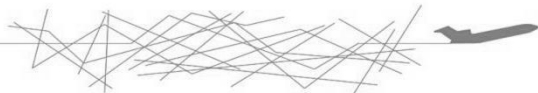
- Outliers can trigger corrective actions: e.g. *reduce strenght*
- They can also require more in-depth analysis to identify desirable ingredients (to be reinforced and reproduced)

Three steps:

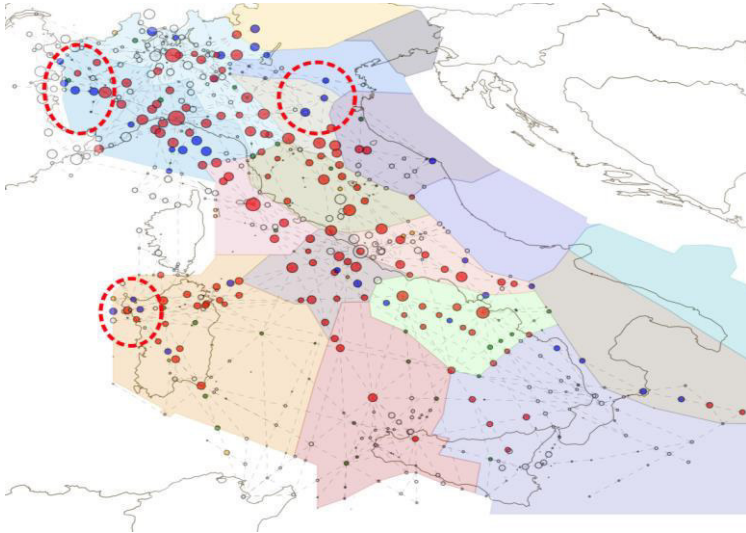
- Use of complex network metrics to monitor the airspace
- Identify areas of attention (i.e. sampling)

Negative dynamics:
improvement actions

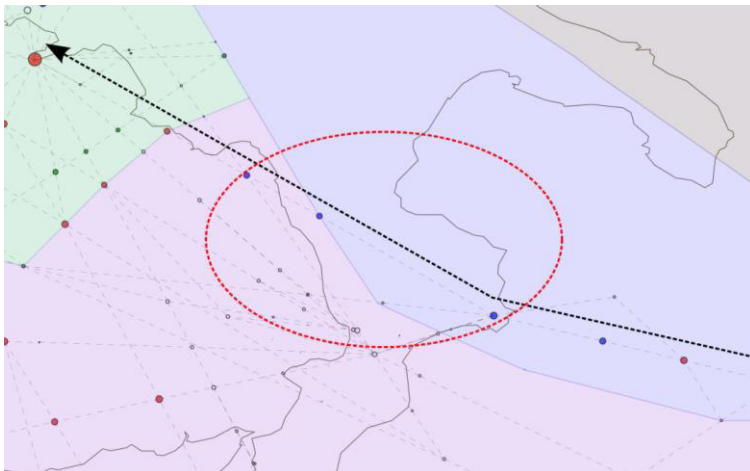
Positive behaviours:
find ingredients to reproduce



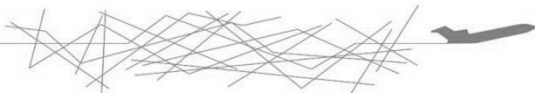
From analysis to application



Level of emergent phenomena
monitoring of high level behaviours to identify areas of interest (geographical functional) -> KPI



Level of micro-behaviours
drill down to understand causes and drivers in order to reproduce or reinforce them



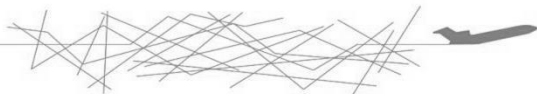


Conflict Probability

- Were the observed correlations just a consequence of the traffic load?

High traffic $\longrightarrow$ Many Conflicts

- To answer this question we defined a new metric for each node n :
 $P_n(\text{conflict})$
- Independent from traffic load
- Not enough data: probability estimators need a large amount of occurrences in order to have small errors (relative errors are $> 50\%$ in many cases)
- Although the previous patterns and correlations are still observed with this metric.



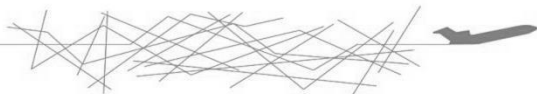


Conflict Probablitiy

	Strenght	Betweenness	Alt	Fork	Pos. Delay
Correlation with $n_{conflict}$	0.59	0.63	0.43	0.04	0.23

	Strenght	Betweenness	Alt	Fork	Pos. Delay
Weighted Correlation with $P_n(conflict)$	0.10	0.43	0.40	0.03	0.32

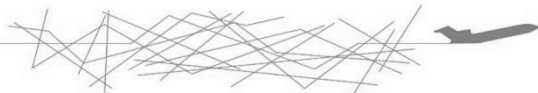
- Effects due to large errors can be absorbed weighting the correlation coefficient: the most trafficked nodes weight more!
- Similarly they can be observed aggregating the nodes according to their traffic load.





Conclusion and Perspective

- Complex Network analysis seems capable of spot most of the critical points in the structure of the airways
- Many of the metrics investigated seem to be correlated with the occurrence of safety events
- Out-of-trend nodes could indicate the presence of procedures introduce to manage particular areas
- Relatively small amount of safety data in a restricted area: better statistics could lead to more precise results (which metric is the best to predict criticalities?)
- A better knowledge of the topology of the current airspace could inform the design of a safer one.



Thanks for your attention!



ELSA

– DBL

– UniPa

- SNS



Agent Based Model of the ATM system: Tactical layer

UNIPA: _____

ELSA

Empirically grounded agent based models for the future ATM scenario



Outline

- Tactical Model – Research Questions
- Current implementation of Model A
- Implementation of Model F



Research Questions

- **M1** is the best prevision of what the flight will be, taking into account
 - the other flights,
 - the airport and sector conditions
 - foreseen external events up to a few hours before departure.
- **M3** reflects the actual trajectory followed by the airplane
it incorporates all possible deviations not foreseen in M1 and occurred during the flight



A comparison between M1 and M3 gives us a **proxy of the efficiency** of the ATM system in managing the interactions between flight trajectories.

Research Questions

- We **model** and **simulate** the events that make M1 transform into M3
- The specific scientific questions will be:
 1. What are **the issues that affect the predictability** of the last filed flight-plan within the ATM system?
 2. Does the EU Air Traffic **predictability improve by moving from today to a trajectory-based SESAR scenario?**

- Two step Model

scenario

actual ATM

- In **Model F** we will consider a transition to the **future SESAR scenario** and try to see whether predictability improves moving to a business-trajectory regulation scheme.



Agents of Model A

- One type of agents in the model is given by **AIRCRAFT/PILOTS**
 - **At this stage**, flights cross the selected sector within a certain time-span as recorded in our database reporting DDR and NEVAC real data
 - Flights can overlap in different segments, can enter the sector in any part of its boundaries and can cross to each other
- For the sake of simplicity, we do not model the take-off and the landing phases of the flight-plans. Our focus is on the “en-route” flights trajectories.
- **CONTROLLERS**
Controllers give instructions to flights whenever a problem occurs.
- **In the present version of Model A:**
 - *Aircrafts/Pilots can not reply to controllers*
 - *Aircrafts/Pilots do not directly interact with each other.*

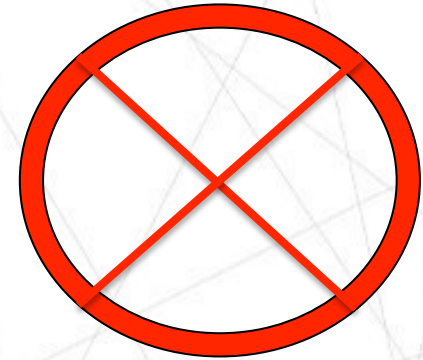


Aim of the model

We check whether there are critical regions:

**Either because flights are crossing a “shocked” area
EXTENDED CRITICAL REGION**

**Either because flights are colliding
POINT-like CRITICAL REGION**



We then apply a 3-step algorithm to avoid the critical region:

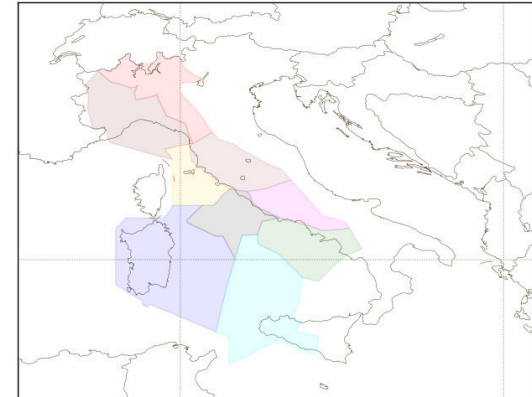
VELOCITY CHANGE

in order to solve the conflicts



NAVIGATION-POINT MODULE

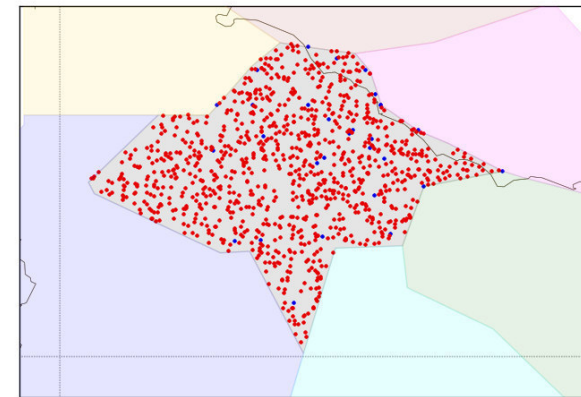
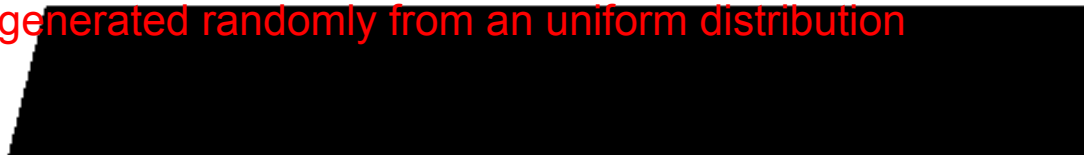
SINGLE SECTOR



NAVIGATION POINTS

real ones

generated randomly from a uniform distribution

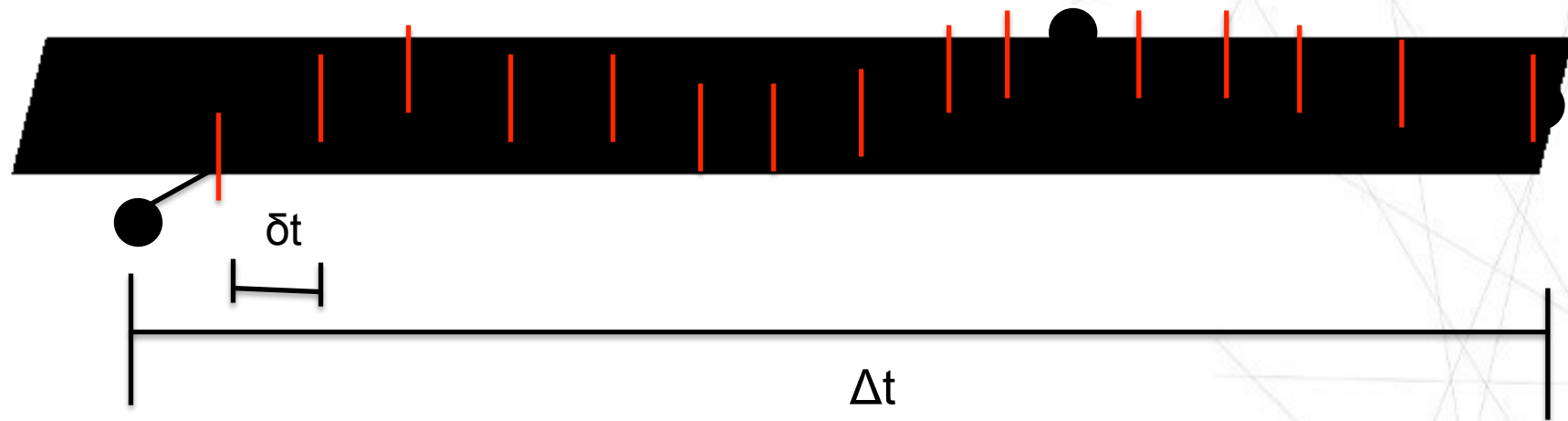


A future step will be to **simulate sectors and navigation points**, in order to model different levels of complexity in the controllers activity, see SNS.



FLIGHT-LIST MODULE

- **At this stage** flight trajectories M1 have been taken from the DB.
We are working on an interaction with SNS that will provide us flight plans resolved at the level of navigation points.
 - The management of the trajectory is done within a $\Delta t = 600$ secs time horizon
 - The Aircraft positions are sampled every $\delta t = 2$ secs (by linearly interpolating if necessary)





FLIGHT-LIST MODULE

At each time-step Δt we create a list of flights.

The list is re-shuffled at each time-step Δt in order to change to order by which the Aircraft is looked after by the controller.

In
th
that are NOT WILLING to change trajectory/velocity.



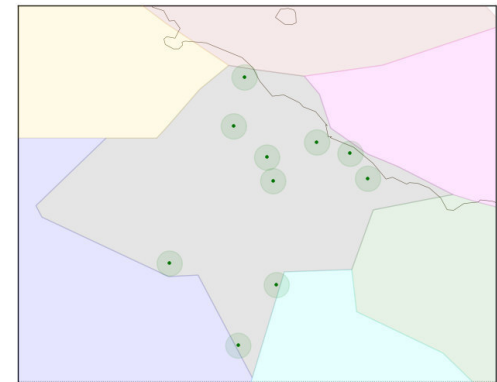
SHOCKS MODULE

model exogenous shocks INSIDE the sector

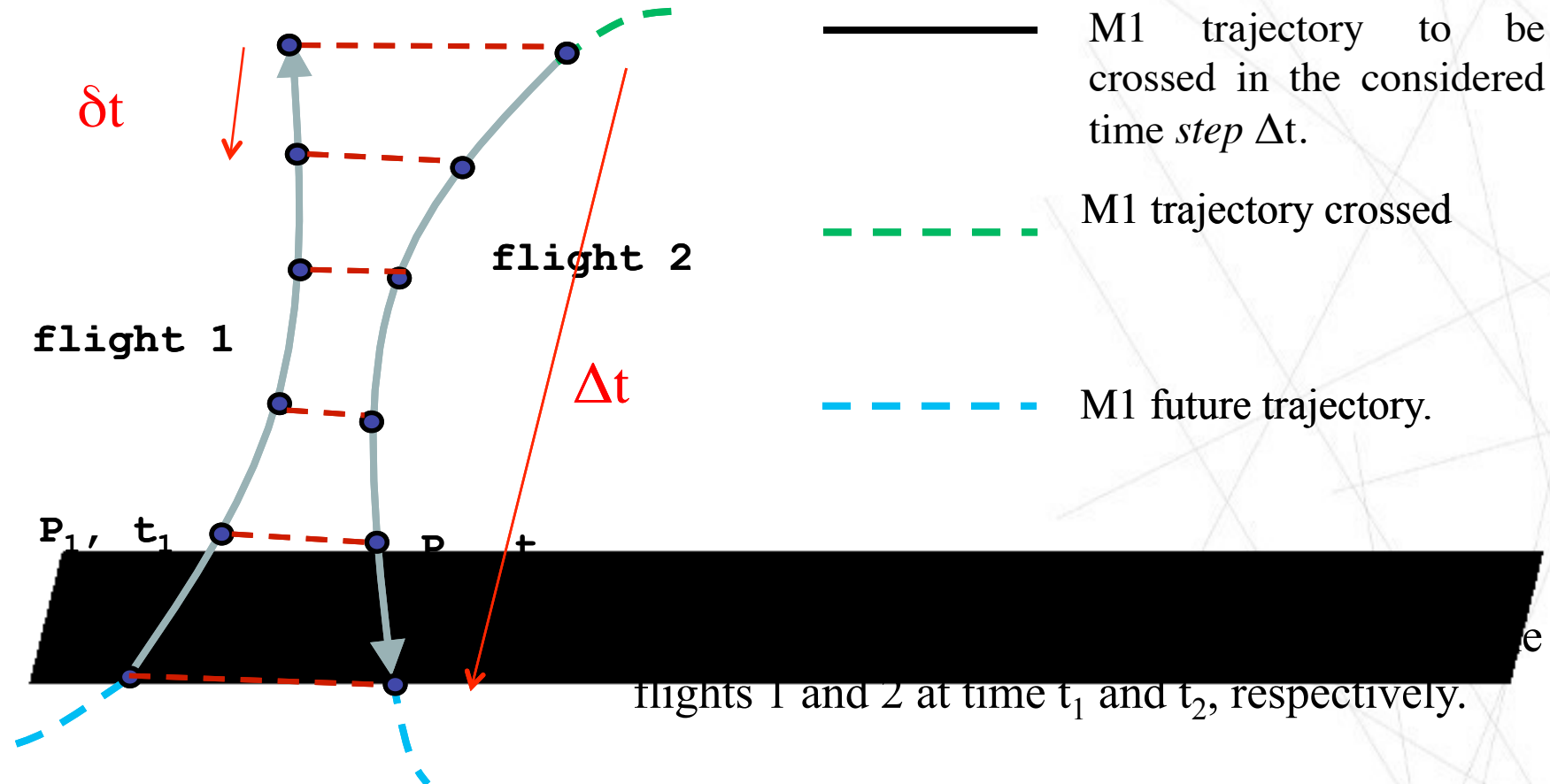
A random number of INTERNAL navigation points is hit by a shock
We construct around these points **an area that can not be crossed by any flight** in the current time-period. This area is defined as a circular area of a certain radius.

At the moment all shocked area are totally included in the sector.

Distributed.



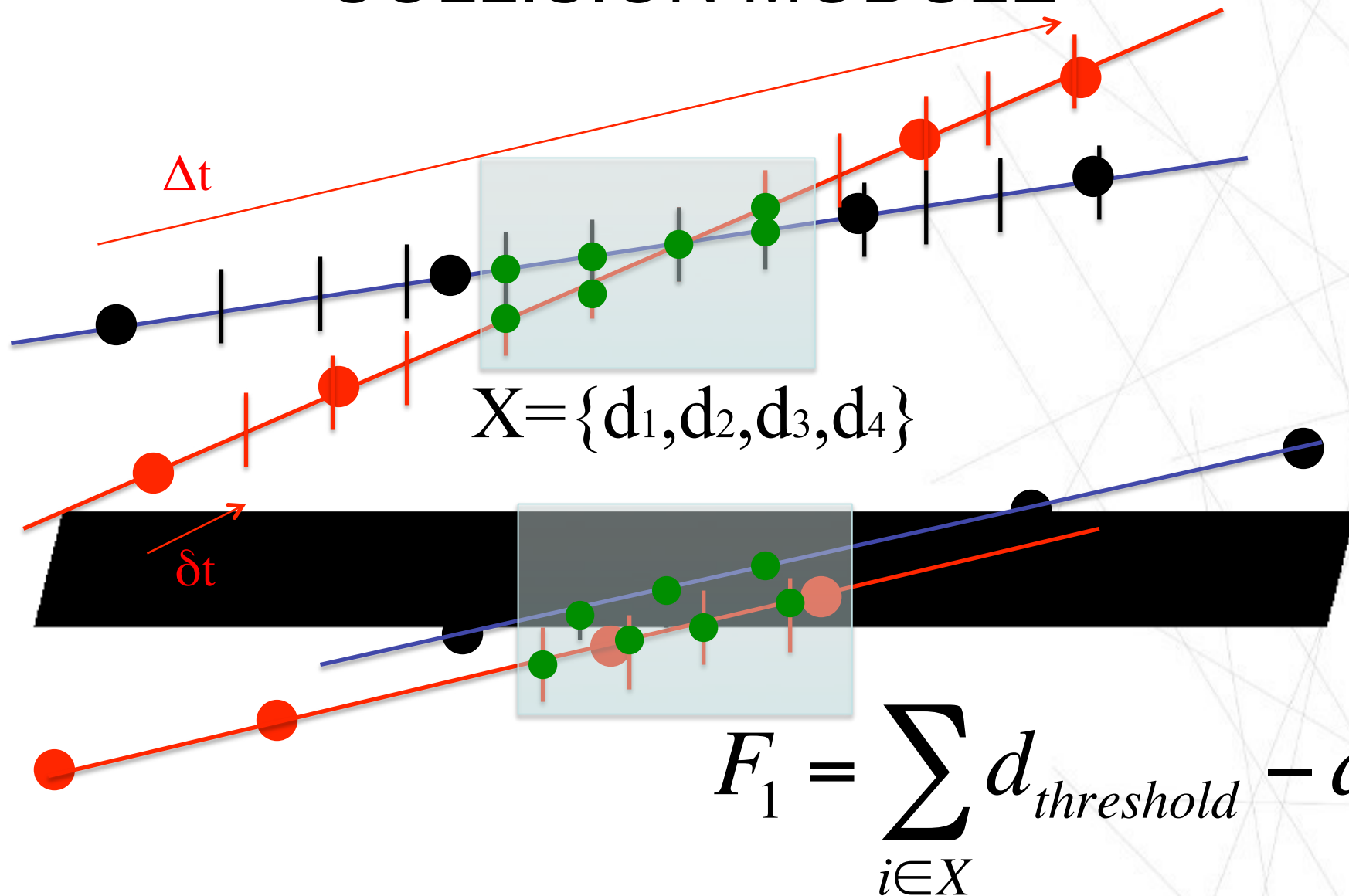
COLLISION MODULE



COLLISION IF:

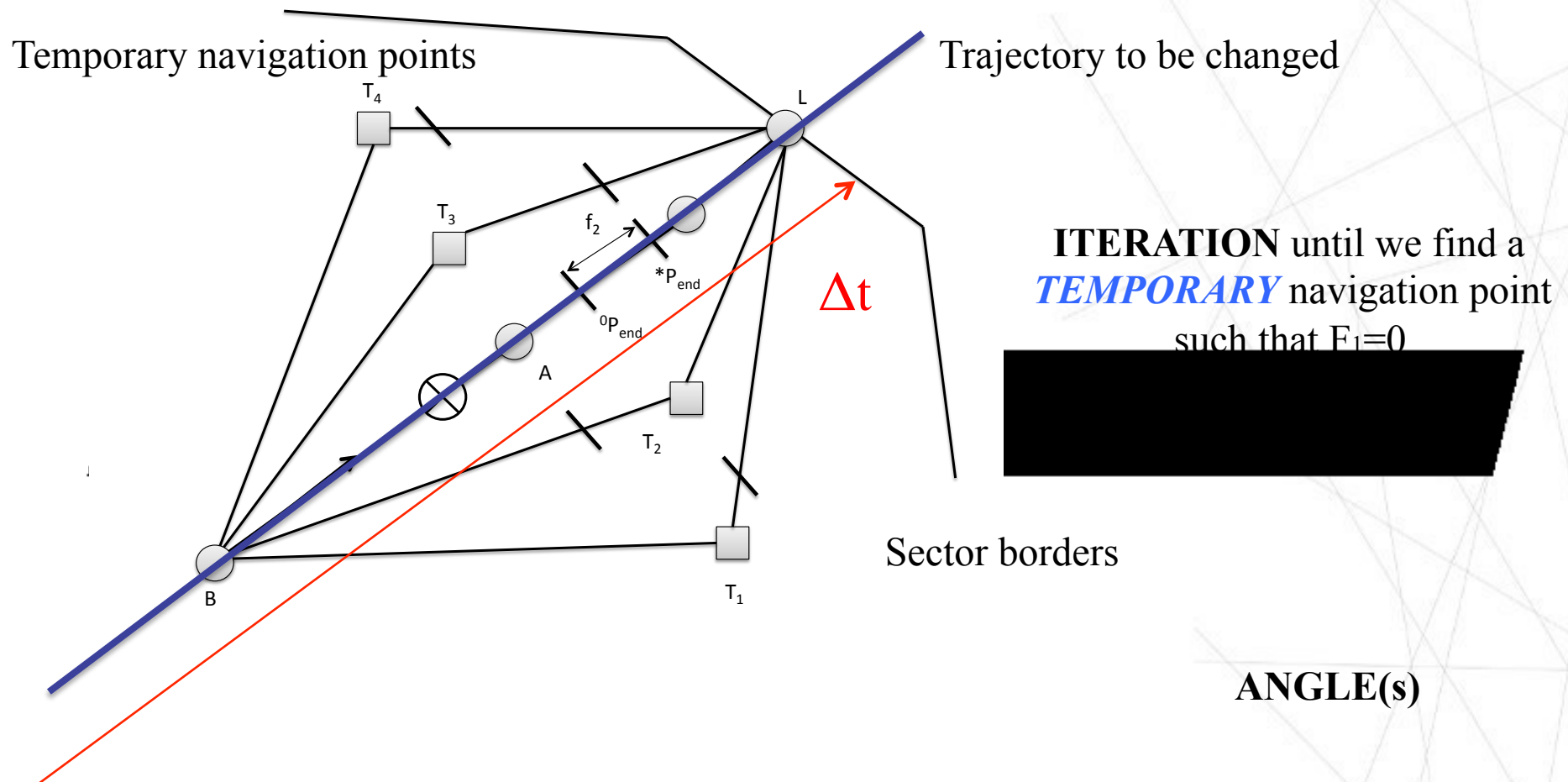
$$\text{dist}(P_1, P_2) < d_{\text{thresh}}$$

COLLISION MODULE



DE-CONFLICTING MODULE

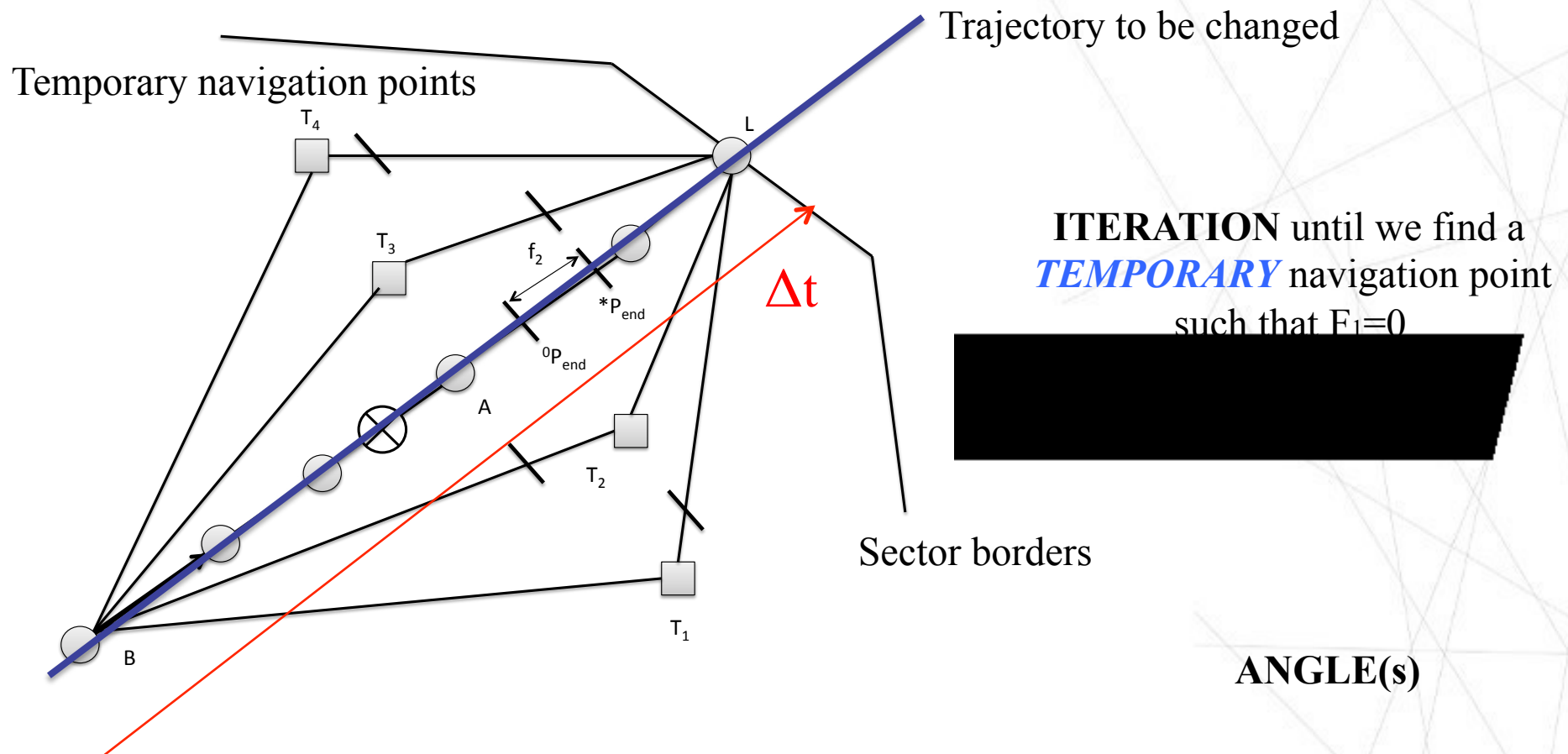
STEP 1: RE-ROUTING 1





DE-CONFLICTING MODULE

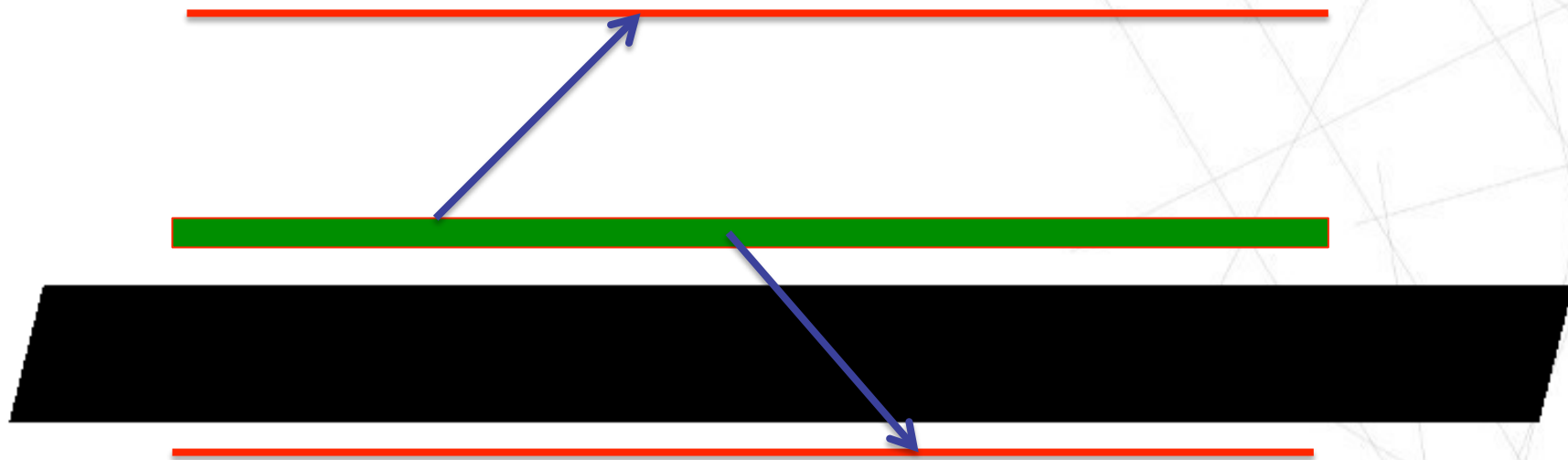
STEP 1: RE-ROUTING 2





DE-CONFLICTING MODULE

STEP 2: CHANGE of FLIGHT LEVEL

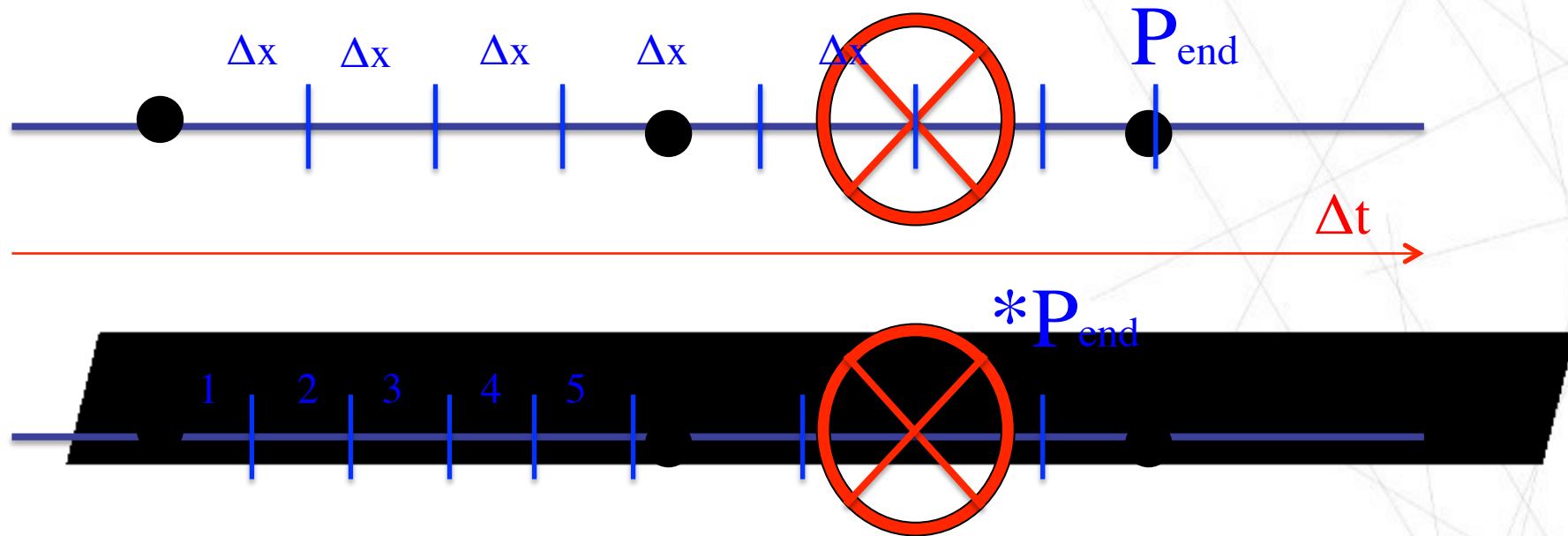


We choose the FL where F_1 , summed for all flights in that level, is the **smallest**. (10FL available)



DE-CONFLICTING MODULE

STEP 3: VELOCITY CHANGE



Slow down !!!!

$$F_2 = dist(P_{end}, {}^*P_{end})$$



DIRECTS MODULE

The flight trajectory of the aircraft is changed with probability p by allowing that the aircraft directly reaches the planned exit point from the sector, whenever this does not imply a trajectory conflict. In the case of direct the aircraft remains on the same flight level.

*We are not completely satisfied by this implementation.
It seems to be more appropriate for ACCs rather than sectors*



EXPECTED OUTPUT

```
data_M3 — cipolla@lagash: ~/Work/Ricerca/SESAR/Programming/Python/Elsa_Test/src_old — ssh — 160x30
[6]+ Done nedit ListCompanies.dat
KISHmac:data_M3 micciche$ mv nets.pdf nets_business.pdf
KISHmac:data_M3 micciche$ ssh -Y cipolla@lagash.dft.unipa.it
cipolla@lagash.dft.unipa.it's password:
Welcome to Ubuntu 12.04.2 LTS (GNU/Linux 3.2.0-41-generic x86_64)

 * Documentation:  https://help.ubuntu.com/

Last login: Thu Oct 3 17:18:56 2013 from kishmac.local
cipolla@lagash:~$ cd Work/Ricerca/SESAR/Programming/Python/
cipolla@lagash:~/Work/Ricerca/SESAR/Programming/Python$ cd Elsa_Test/
cipolla@lagash:~/Work/Ricerca/SESAR/Programming/Python/Elsa_Test$ cd src_old/
cipolla@lagash:~/Work/Ricerca/SESAR/Programming/Python/Elsa_Test/src_old$ export DISPLAY=:0.0
cipolla@lagash:~/Work/Ricerca/SESAR/Programming/Python/Elsa_Test/src_old$ python Main1.py
/usr/lib/python2.7/mpl_toolkits/__init__.py:2: UserWarning: Module dap was already imported from None, but /usr/lib/python2.7/dist-packages is being added to sys.path
  __import__('pkg_resources').declare_namespace(__name__)
openDbConnection: Connecting to root@localhost
useDb: using database ElsaDB_A334
996
463
time step 240.000000 t_w 30
512 1023
Fine Ciclo 0
-----

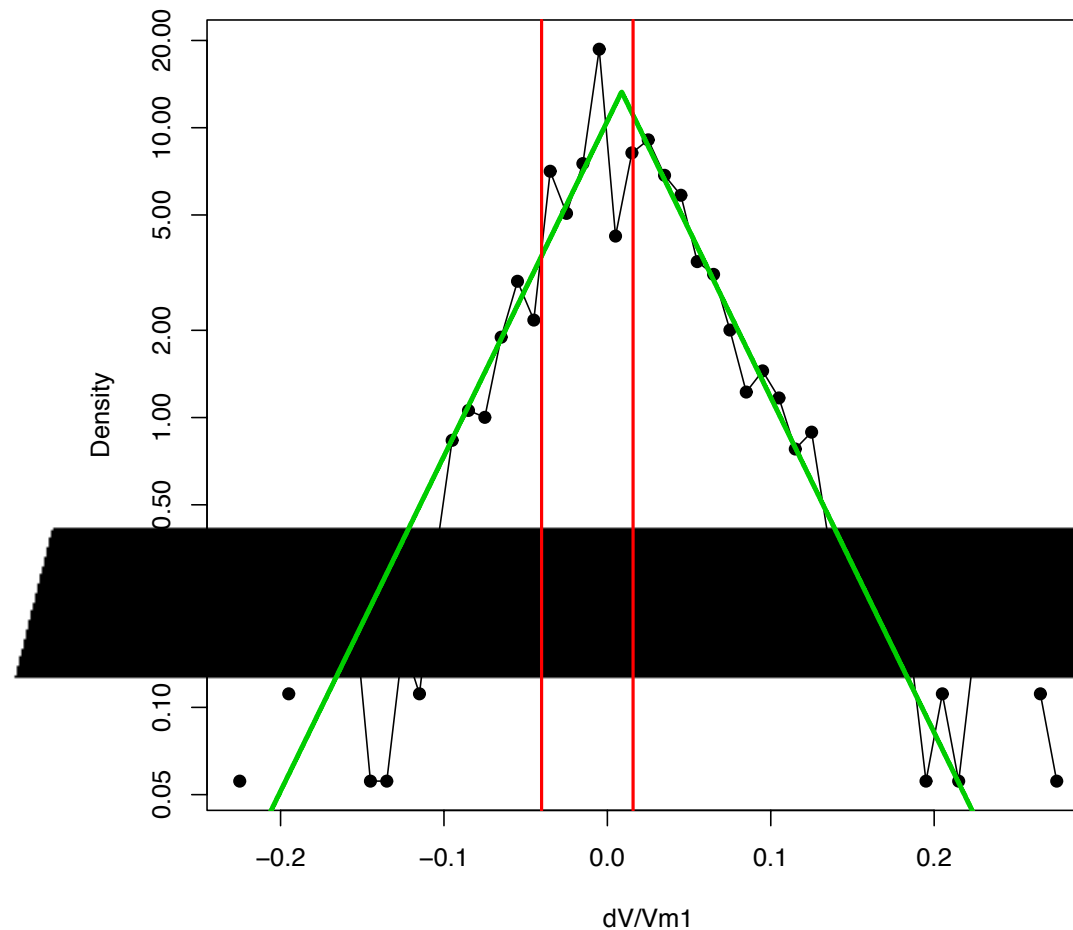
Average Delay 24.221922 Std 21.182492
Rerouting 279 Change flvl 91

cipolla@lagash:~/Work/Ricerca/SESAR/Programming/Python/Elsa_Test/src_old$
```




CALIBRATION: aircraft velocity

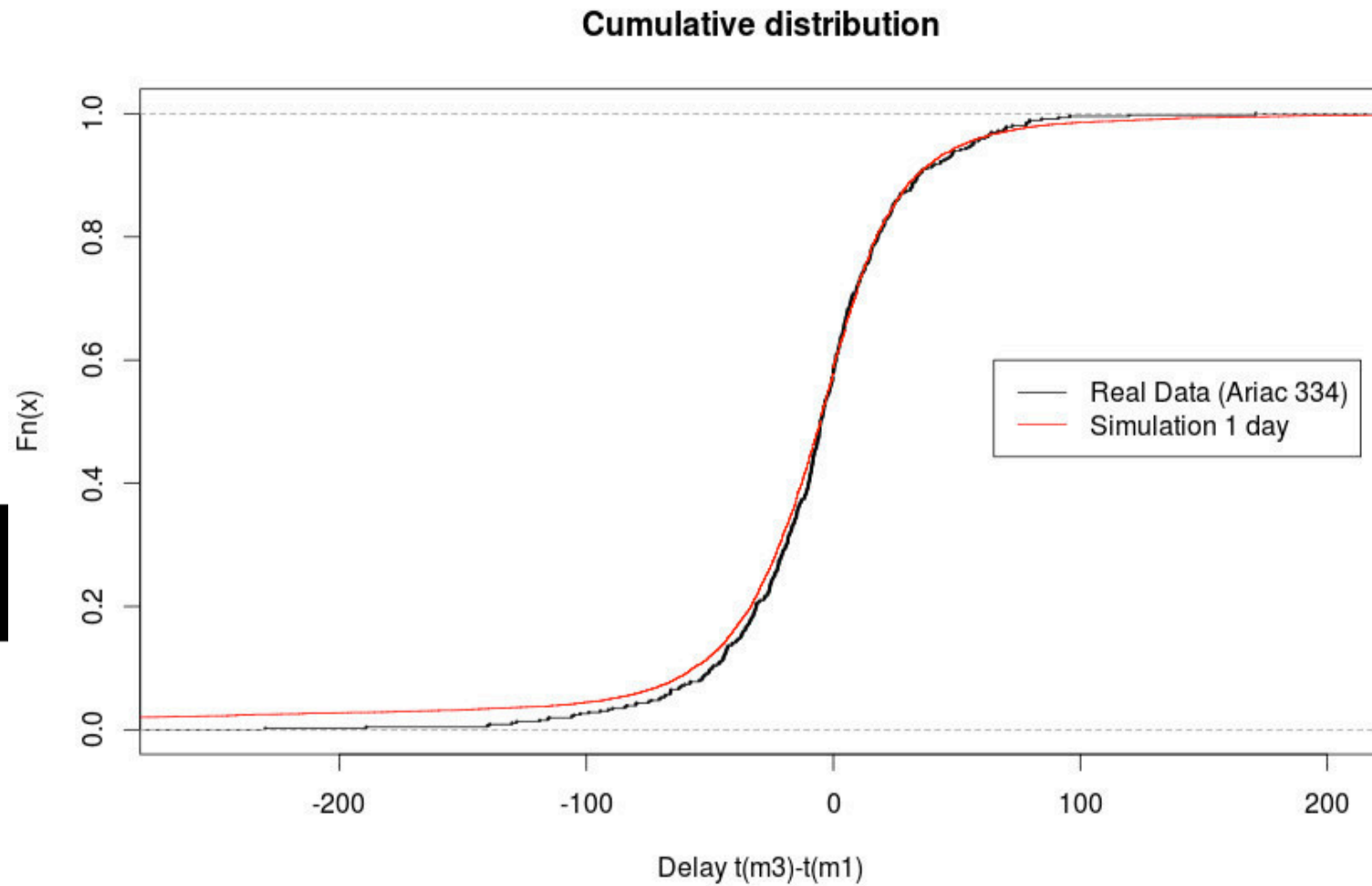
Distribution of percentage variation of velocity



For each aircraft, we modify the planned velocity in each segment according with a laplacian distribution with the same parameters observed in the real

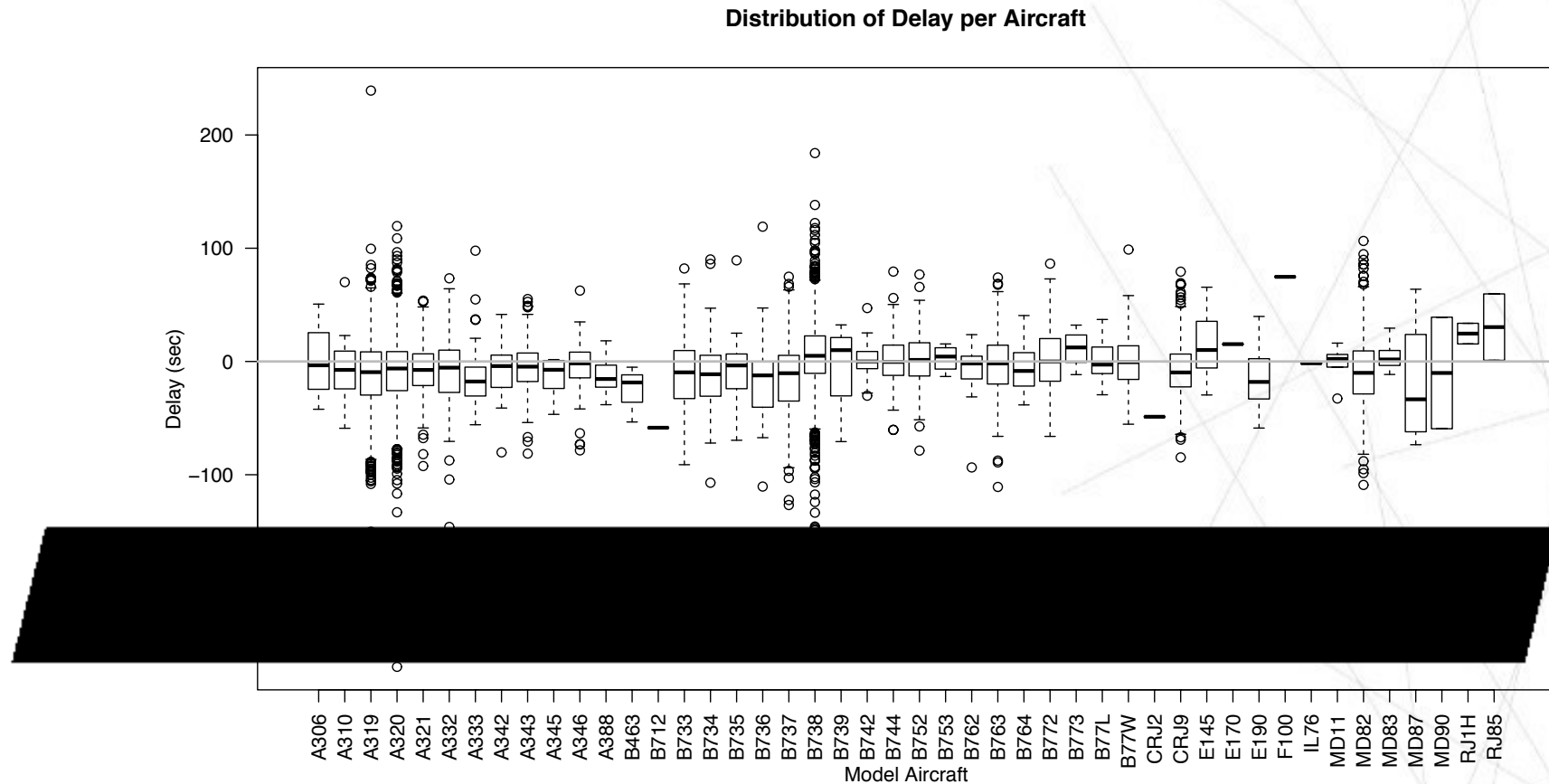


CALIBRATION: aircraft velocity





CALIBRATION: aircraft velocity

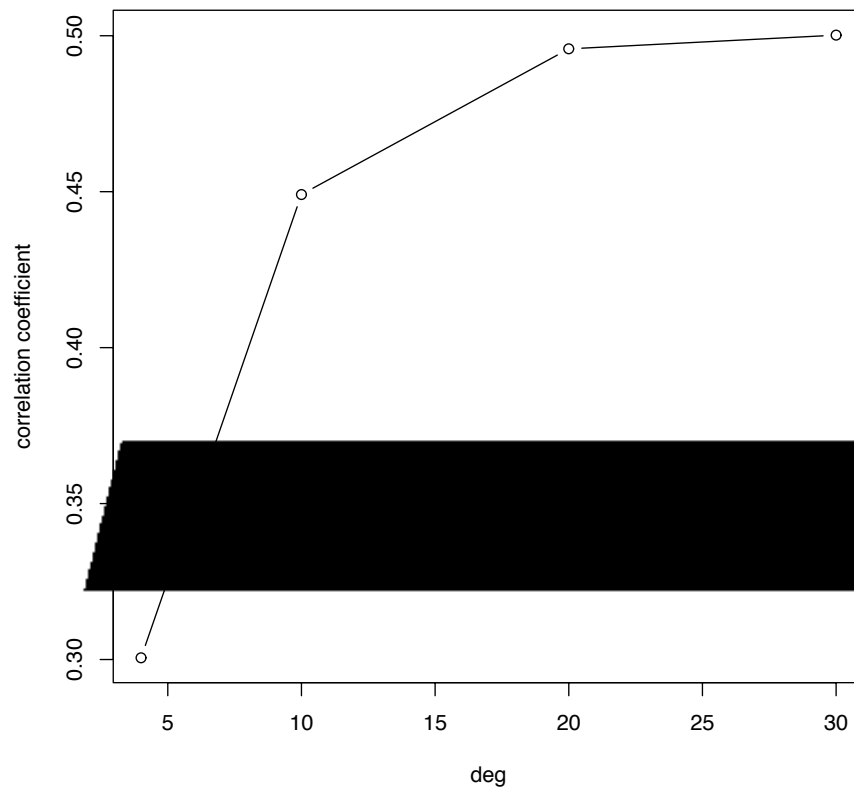


The velocity changes seem to be correlated to the aircraft type.

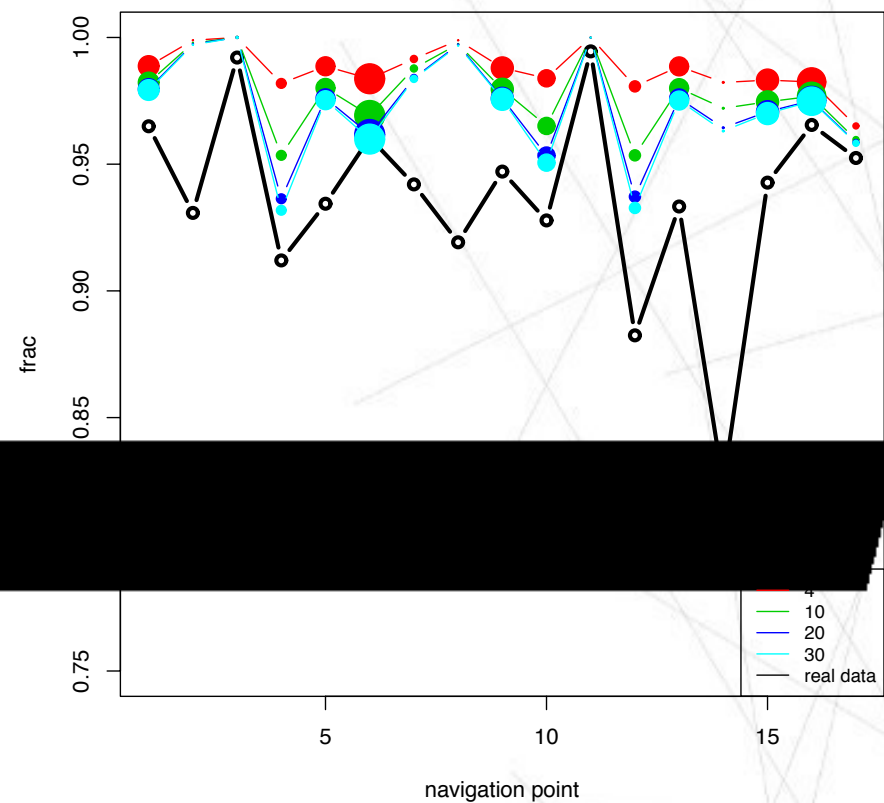


CALIBRATION: deviation angle

Correlation FRAC simulation and real data All Airac



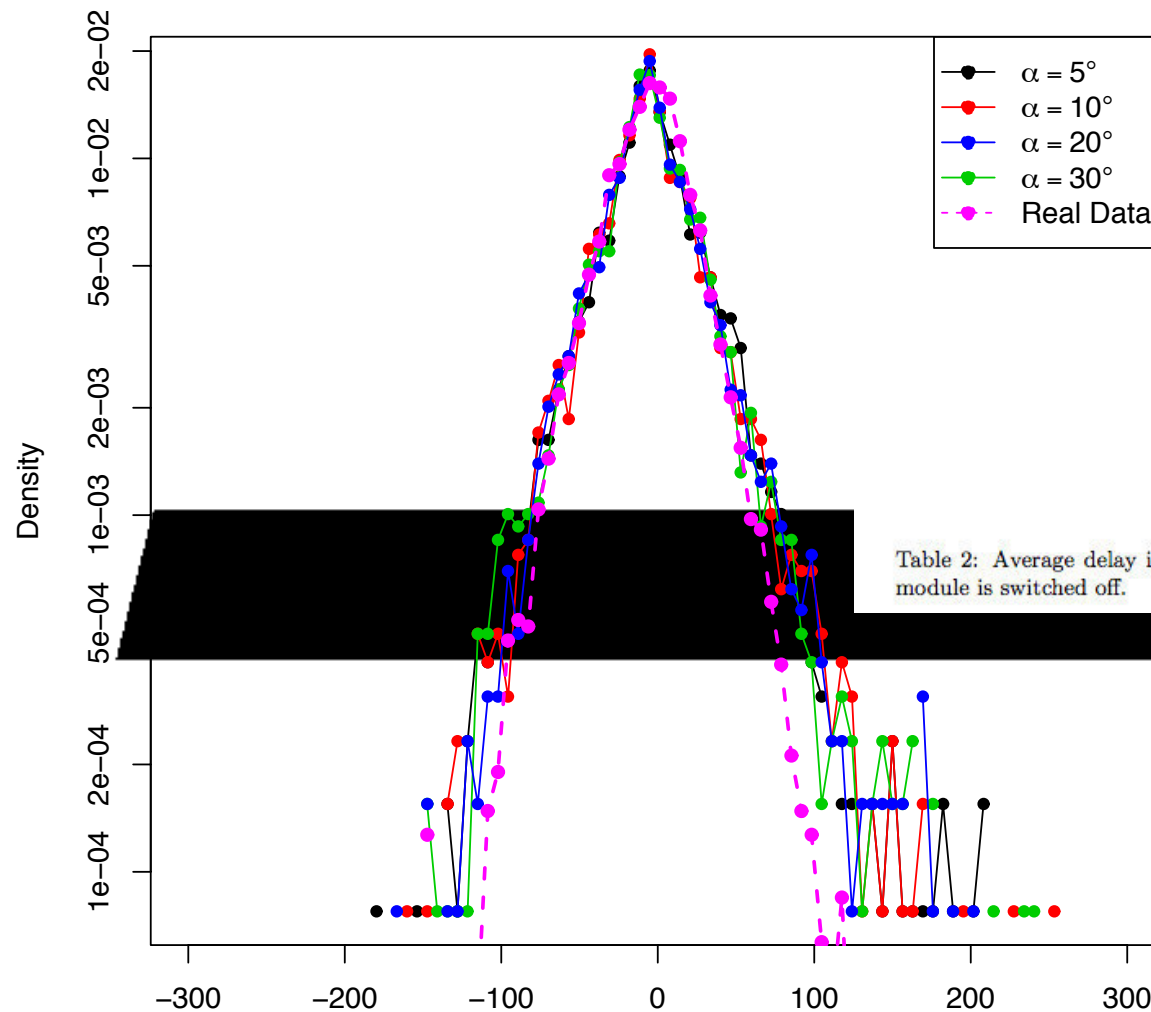
FRAC simulation and real data Airac 334





CALIBRATION: deviation angle

Distribution of delay in simulation – All Airac 334



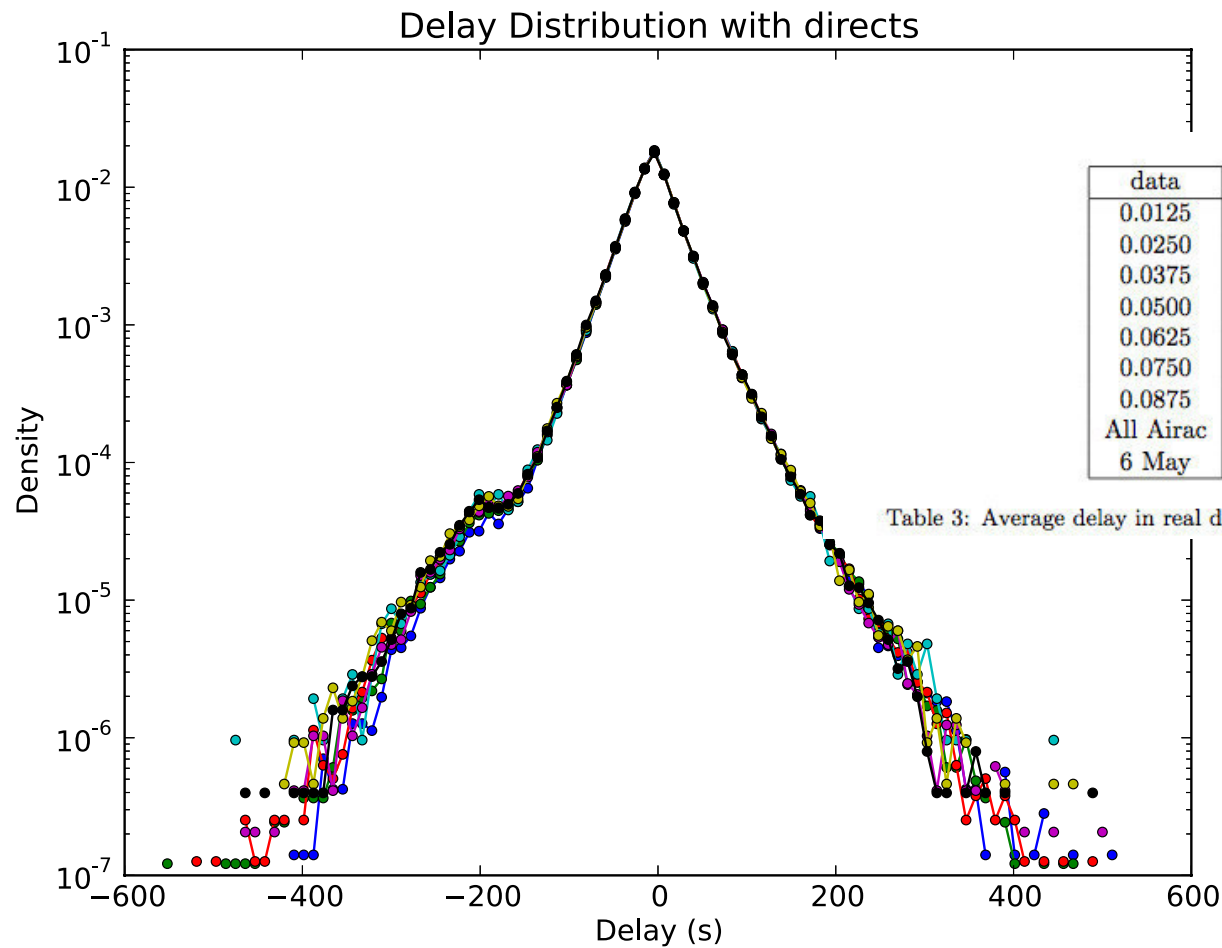
data	mean	std
05°	-3.544530	36.09029
10°	-3.548267	36.15088
20°	-3.494078	36.22802
30°	-3.491880	36.24689
All Airac	-6.049288	30.98976
6 May	-11.288182	27.79068

Table 2: Average delay in real data and simulations for different values of α . Here the directs module is switched off.

	Reroute	Std Reroute	Jump	std Jump
5°	7,097	2,738	14,539	3,451
10°	11,425	3,444	11,150	3,174
20°	13,624	3,753	9,210	2,929
30°	14,145	3,813	8,552	2,812



CALIBRATION: directs



data	mean	std
0.0125	-4.73117601902	38.1191981827
0.0250	-5.06026143539	38.6260137368
0.0375	-5.36149965895	39.0106440878
0.0500	-5.54470217962	39.1474409518
0.0625	-5.42217287567	39.1247419803
0.0750	-5.53811471208	39.5093837970
0.0875	-5.60144230686	39.2817945032
All Airac	-6.049288	30.98976
6 May	-11.288182	27.79068

Table 3: Average delay in real data and simulations for different values of p and $\alpha = 20^\circ$.





PLANNED SIMULATIONS

In order to determine the spatial localization of shocked areas, we fix the center C of the sector and we identify the maximum circle centered in C and fully contained in the sector. Let us call R its radius. We assign the center of the shocked area by assigning its polar coordinates from C , i.e. the distance r from C and an angle θ measured from some reference line. The angle θ is always extracted from a random uniform distribution. We have then the three following possibilities:

- **UNIFORM** - The distance r is obtained extracting two numbers x, y from a random uniform distribution in the range $[-R, R]$ and accepting the value $r = \sqrt{x^2 + y^2} < R$.
- **GAUSSIAN** - The distance r is extracted from a normal (gaussian) distribution in the range $[0, R]$. The distribution is centered in zero. We consider only the right side of the distribution. The standard deviation of the distribution can assume the following values: $\sigma = 10, 15, 20, 25, 30, 35, 40, 45$. This is done for each value of n .
- **POWER-LAW** - The distance r is extracted from a power-law distribution $\mathcal{P} = Nr^{-\gamma}$ for $r \in [x_{min}, R]$ with $x_{min} = 0.2$ NM. The γ parameter can assume the following values: $\gamma = 0.01, 0.05, 0.1, 0.4, 0.6, 0.8, 1, 1.2, 1.4, 1.6, 1.8$. This is done for each value of n .

**What happens when shocks are
*spatially concentrated?***



PLANNED SIMULATIONS

In the last set of simulations we used again an uniform distribution for the geographical localization of the shocks but we temporally distributed them in a short time window of three hours. We then moved this window over the 24 hours of the considered day.

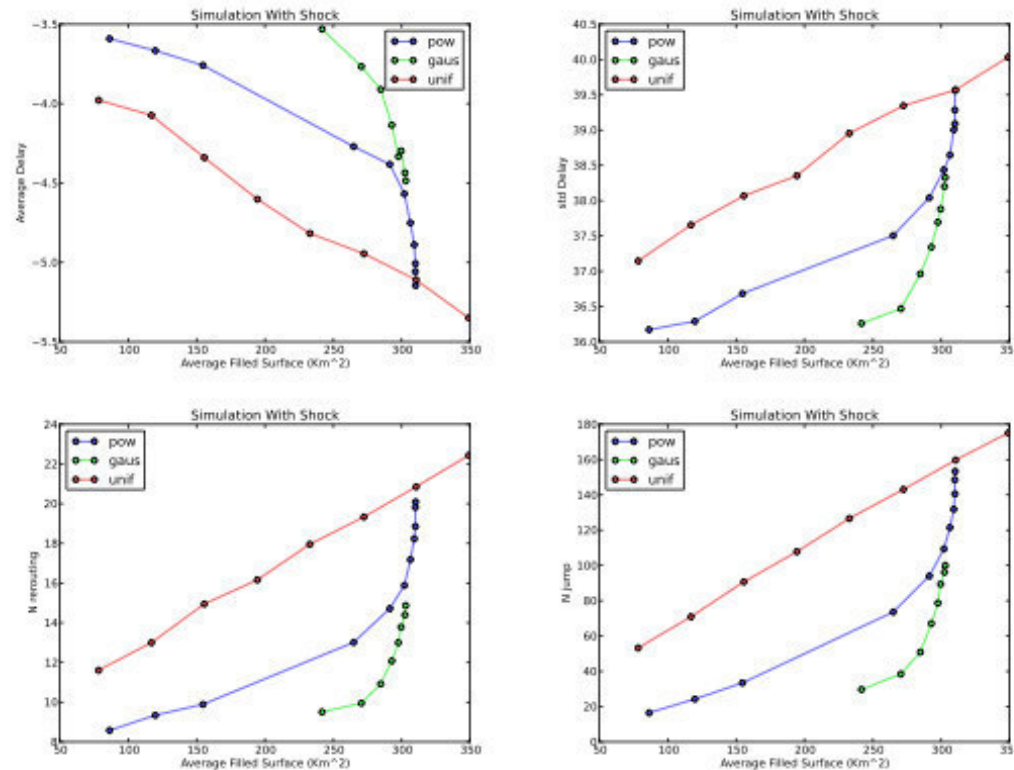
We tested how the system reacts when the shocking areas are temporally concentrated. In fact, the number of active aircraft changes across the day-time and It has two peaks: one around 8AM and one around 9PM.

**what happens when shocks are
*temporally concentrated?***



SIMULATIONS (no velocity change – no directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt



5 km

Figure 22: Shocked area of radius 5 km. In the top panels we show the average and the standard deviation of delay for the three considered distributions. In the bottom panels we show the average number of reroutings and flight level changes for the three distributions considered. These data are shown for 8 different values of the average number n of shocks per time-step mentioned above in the case of the uniform distribution. In the case of power-law and gaussian distribution we have fixed $n = 4$ for all the mentioned values of γ and σ .

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



SIMULATIONS (no velocity change – no directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt

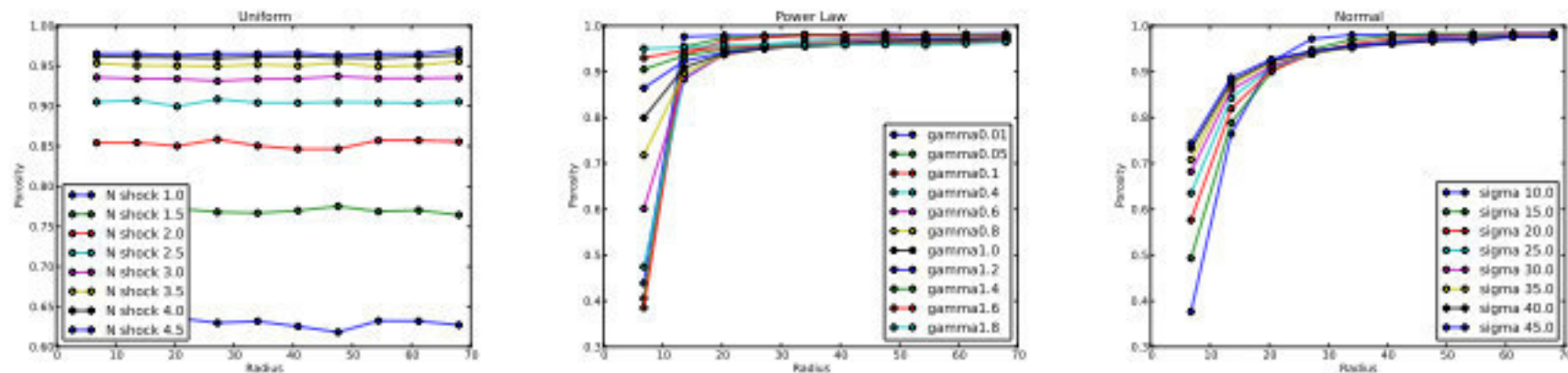


Figure 23: Shocked areas of radius 5 km. The figure shows the radial porosity [15] for the three different considered distributions: uniform in the left panel, power-law in the central panel and gaussian in the right panel. These data are shown for 8 different values of the average number n of shocks per time-step mentioned above in the case of the uniform distribution. In the case of power-law and gaussian distribution we have fixed $n = 4$ for all the mentioned values of γ and σ .

5 km

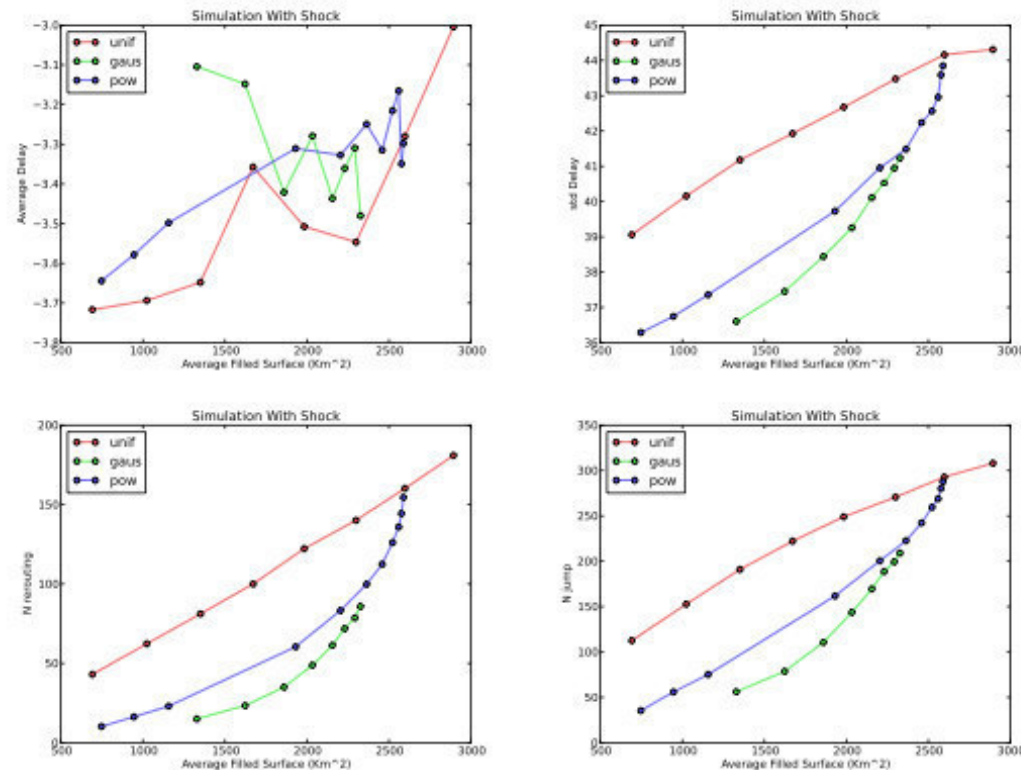
Porosity=available/total surface

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



SIMULATIONS (no velocity change – no directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt



15 km

Figure 24: Shocked area of radius 15 km. In the top panels we show the average and the standard deviation of delay for the three considered distributions. In the bottom panels we show the average number of reroutings and flight level changes for the three distributions considered. These data are shown for 8 different values of the average number n of shocks per time-step mentioned above in the case of the uniform distribution. In the case of power-law and gaussian distribution we have fixed $n = 4$ for all the mentioned values of γ and σ .

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



SIMULATIONS (no velocity change – no directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt

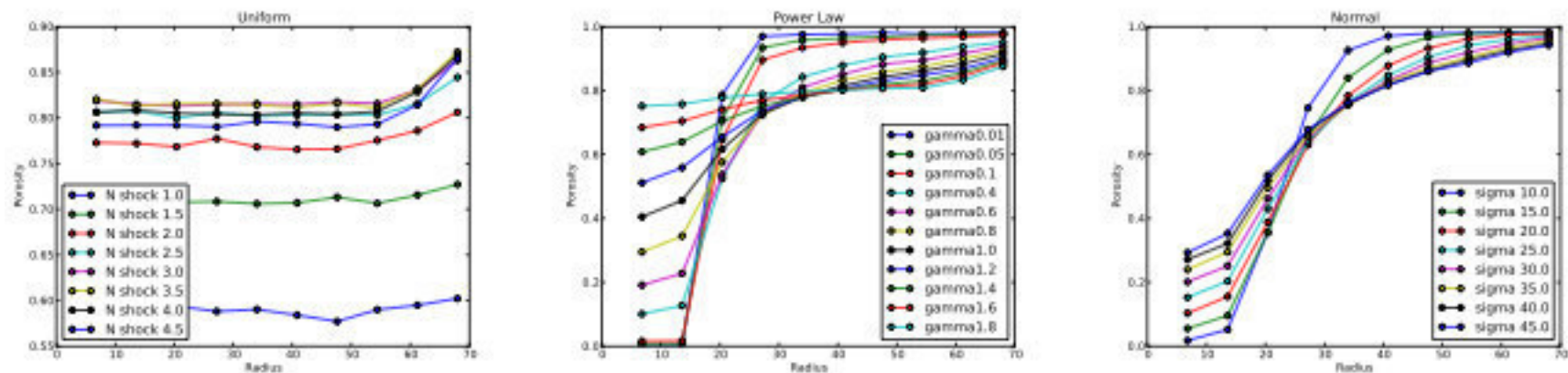


Figure 25: Shocked areas of radius 15 km. The figure shows the radial porosity [15] for the three different considered distributions: uniform in the left panel, power-law in the central panel and gaussian in the right panel. These data are shown for 8 different values of the average number n of shocks per time-step mentioned above in the case of the uniform distribution. In the case of power-law and gaussian distribution we have fixed $n = 4$ for all the mentioned values of γ and σ .

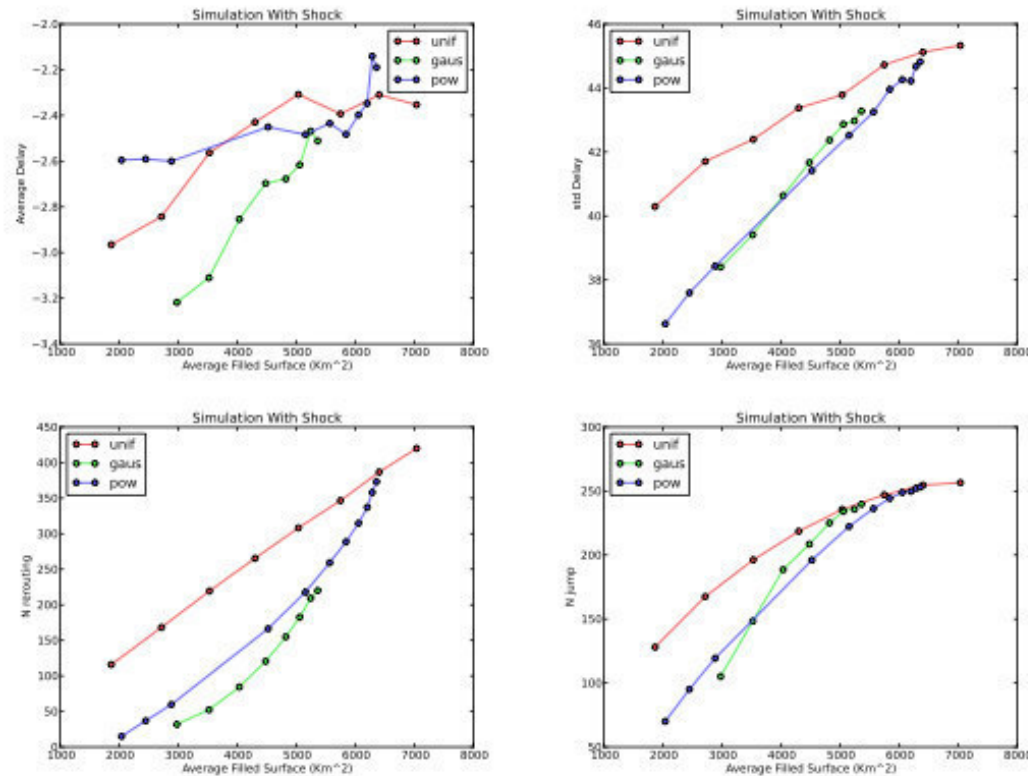
15 km

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



SIMULATIONS (no velocity change – no directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt



25 km

Figure 28: Shocked area of radius 25 km. In the top panels we show the average and the standard deviation of delay for the three considered distributions. In the bottom panels we show the average number of reroutings and flight level changes for the three distributions considered. These data are shown for 8 different values of the average number n of shocks per time-step mentioned above in the case of the uniform distribution. In the case of power-law and gaussian distribution we have fixed $n = 4$ for all the mentioned values of γ and σ .

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



SIMULATIONS (no velocity change – no directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt

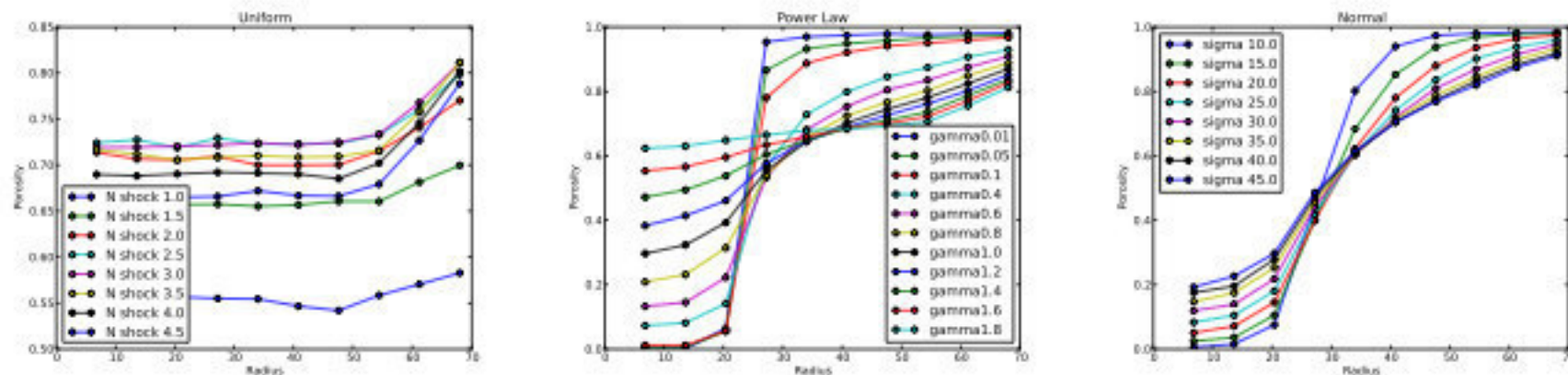


Figure 27: Shocked areas of radius 20 km. The figure shows the radial porosity [15] for the three different considered distributions: uniform in the left panel, power-law in the central panel and gaussian in the right panel. These data are shown for 8 different values of the average number n of shocks per time-step mentioned above in the case of the uniform distribution. In the case of power-law and gaussian distribution we have fixed $n = 4$ for all the mentioned values of γ and σ .

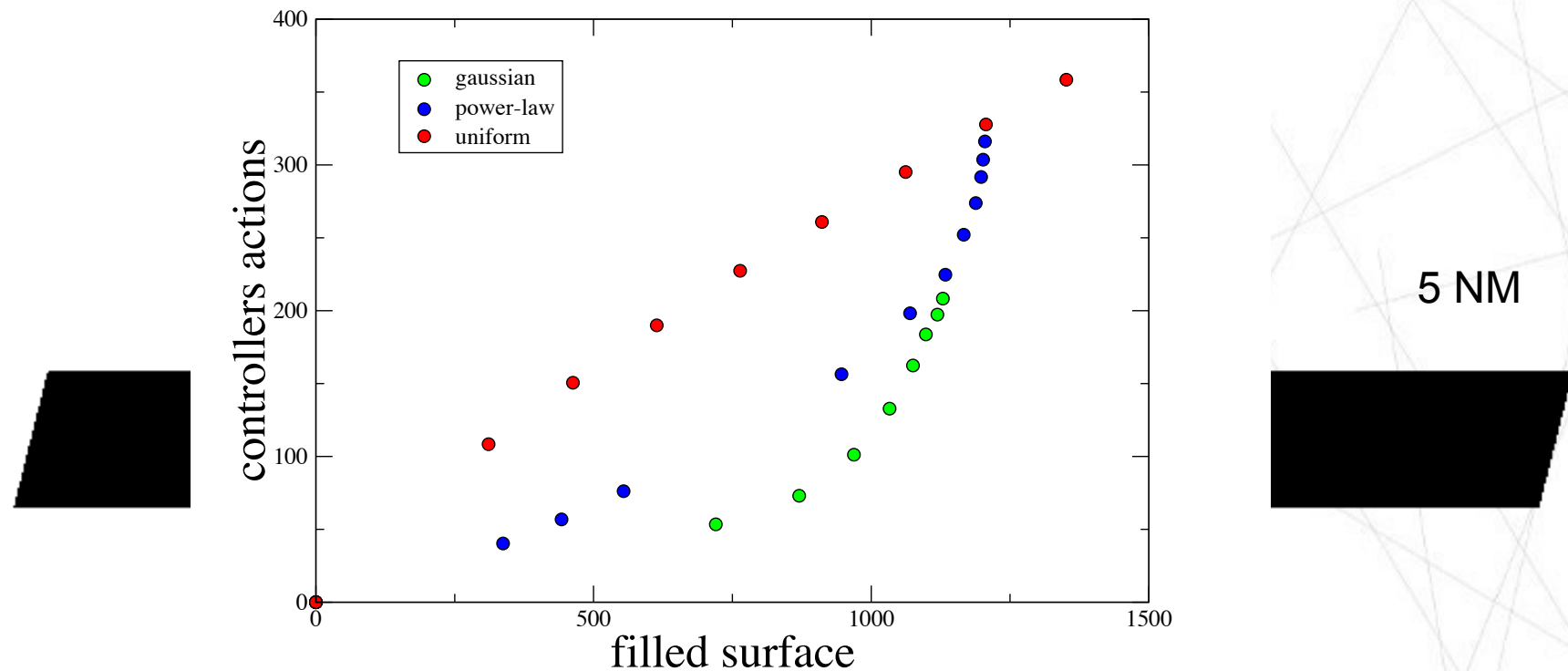
25 km

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



SIMULATIONS (no velocity change – no directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt



100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



SIMULATIONS (no velocity change – no directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt

parameter n	filled area	average re-routing	std re-routing	average level change	std level change
1.0	311.0	78.4	8.42	24.1	4.59
1.5	462.9	107.8	9.36	32.0	5.40
2.0	613.8	133.0	9.93	39.8	5.867
2.5	763.9	156.1	10.2	47.4	6.43
3.0	911.2	175.4	10.4	54.8	6.76
3.5	1062.0	192.6	10.8	63.5	7.21
4.0	1206.6	209.6	10.2	71.0	7.59
4.5	1351.3	223.7	10.3	79.5	7.87

Table 2.5: Shocked areas of radius 5 NM. The entries of the Table are the average number of aircraft that are re-routed or change their flight level, for the uniform distribution. The directs module is switched off.

parameter σ	filled area	average re-routing	std re-routing	average level change	std level change
10	720.2	35.1	4.15	12.0	3.324
15	870.3	48.6	5.32	16.2	3.73
20	968.9	69.0	6.82	21.3	4.394
25	1033.1	92.4	7.993	27.1	4.72
30	1075.2	112.9	8.53	32.9	5.31
35	1098.4	127.3	9.36	36.9	5.72
40	1119.1	135.8	9.43	39.9	5.72
45	1129.0	143.0	9.79	42.0	5.93

Table 2.7: Shocked areas of radius 5 NM. The entries of the Table are the total number of aircraft that are re-routed or change their flight level, for the gaussian distribution. The directs module is switched off. Data are obtained for $n = 4$.

parameter γ	filled area	average re-routing	std re-routing	average level change	std level change
0.01	337.0	28.1	3.84	9.91	3.08
0.05	442.4	39.9	5.15	12.5	3.37
0.10	554.1	54.1	6.22	15.8	3.86
0.40	946.5	109.9	9.32	31.3	5.32
0.60	1069.9	137.0	9.39	40.1	5.72
0.80	1133.6	152.9	9.87	46.1	6.42
1.00	1166.6	169.0	10.1	52.4	6.62
1.20	1188.3	181.3	10.3	57.4	7.08
1.40	1197.9	191.4	10.3	62.0	7.19
1.60	1201.5	198.0	10.4	64.8	7.33
1.80	1204.8	204.1	10.6	67.9	7.41

Table 2.6: Shocked areas of radius 5 NM. The entries of the Table are the total number of aircraft that are re-routed or change their flight level, for the power-law distribution. The directs module is switched off. Data are obtained for $n = 4$.

For each of the 2000 simulations we

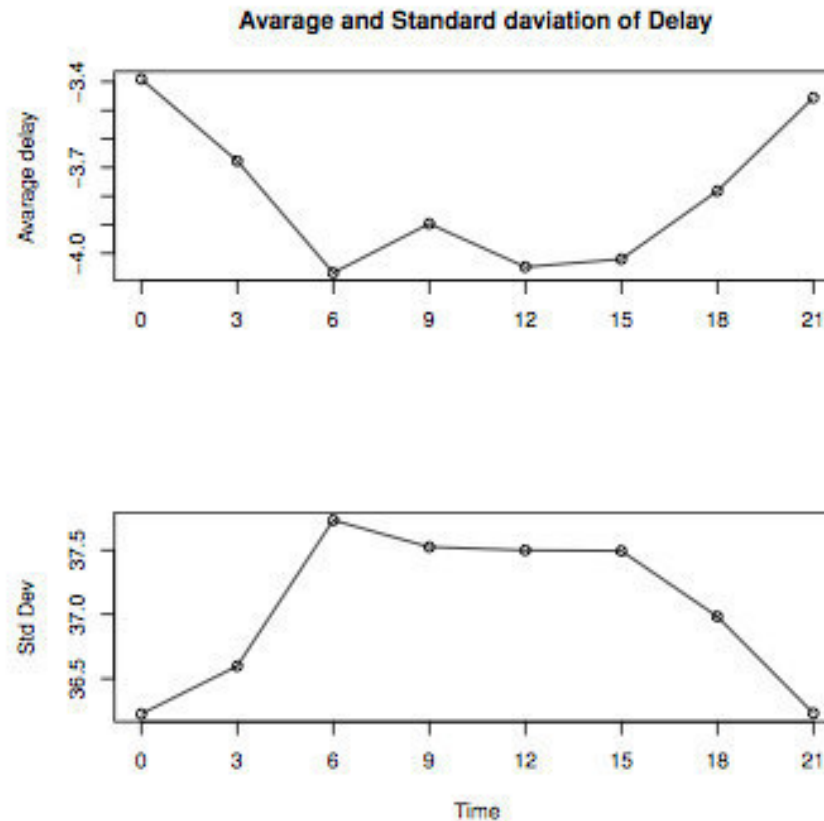
average (first and third column) and standard deviation (second and fourth column) of these averages over all 2000 simulations.

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



SIMULATIONS (no velocity change – no directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt



5 km

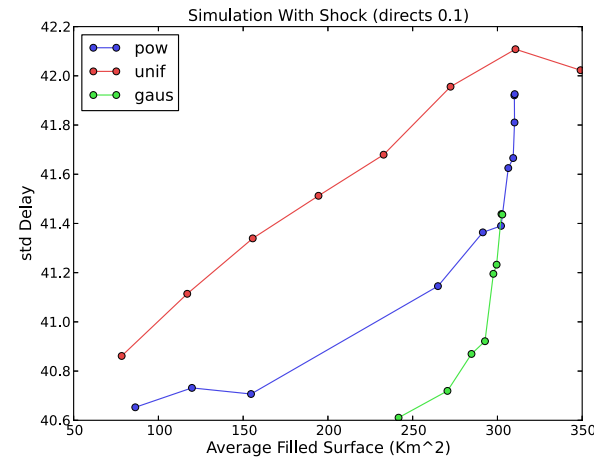
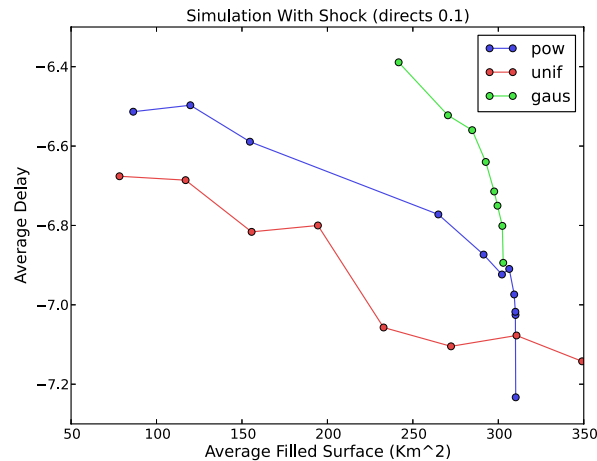
Figure 19: The Fig. shows the average (top panel) and standard deviation (bottom panel) delay for the uniform distribution when shocks are temporally concentrated in a time windows of 3 hours.

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors

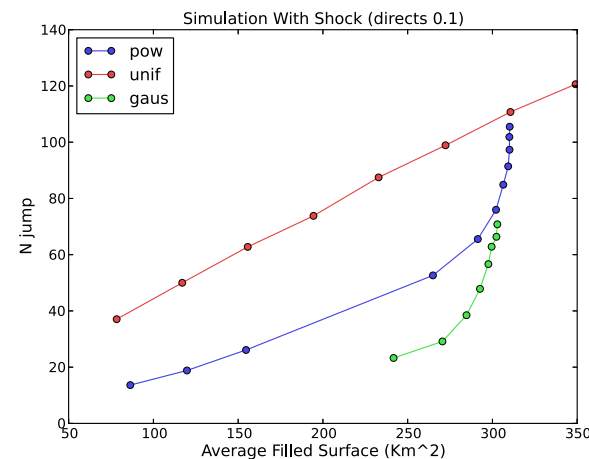
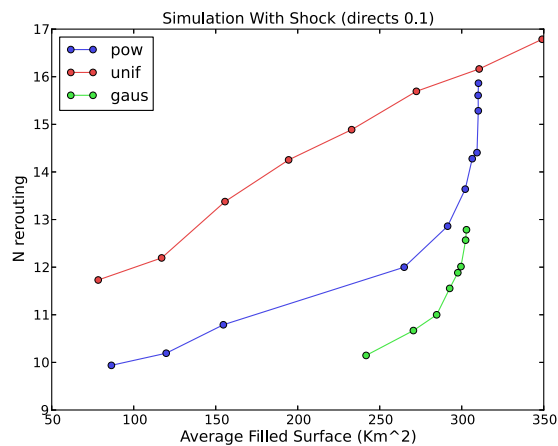


SIMULATIONS (no velocity change – directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt



At this size of the shocking area we are qualitatively very close to the no-rerouting case



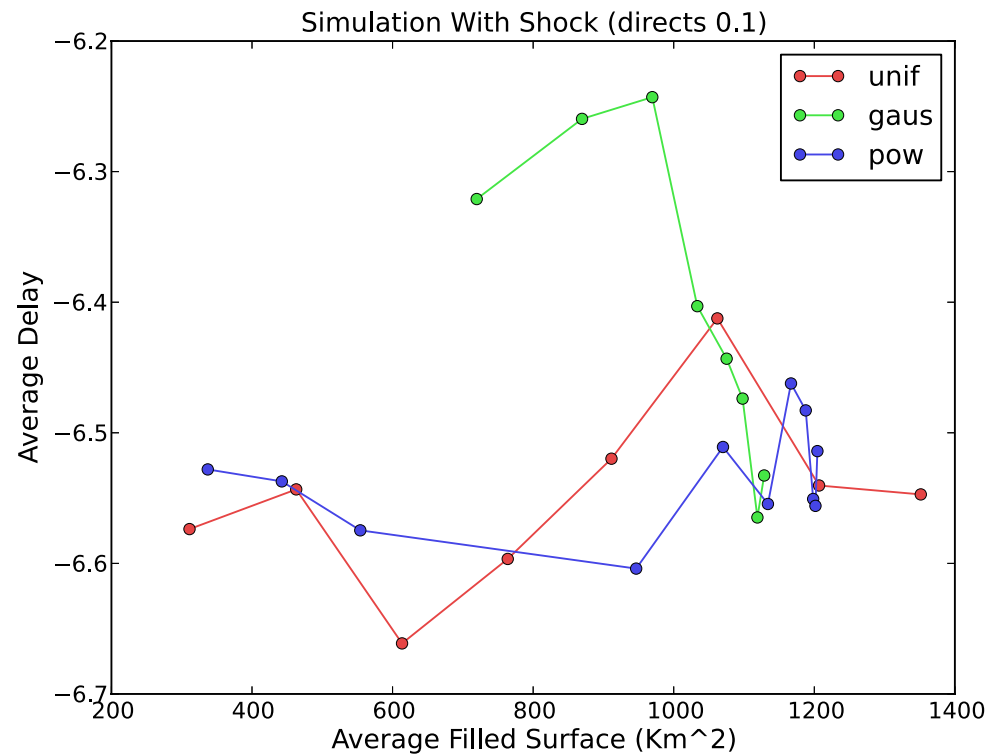
5 km

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



SIMULATIONS (no velocity change – directs)

452 aircraft/day - 3000 iterations RE-ROUTING 1 – duration = Δt



10 km

Here things change a lot !!

Is the directs strategy appropriate?

100% of M1 flight plans are delayed (+/- 900 sec) by hand to simulate interaction with other sectors



PLANNED SIMULATIONS

What happens when the number of aircraft increases?

**With or without
checked areas!**

CAPACITY stress-test

**Even at the level of single sectors
By randomly changing the real departure times**



TO BE IMPLEMENTED

Priority 1: Capacity stress-test

- **all AIRAC in one day**

Priority 2: Multi-sector (<10)

- **repeat above**
- **SHOCK areas over different sectors**
- **trace the propagation of delay through sectors**



FEEDBACK from WP4: VALIDATION

Features of the re-routing

Weight of the strategies: re-routing, flight-level, velocity

Features of the re-routing

Features of the weather events





Conclusions

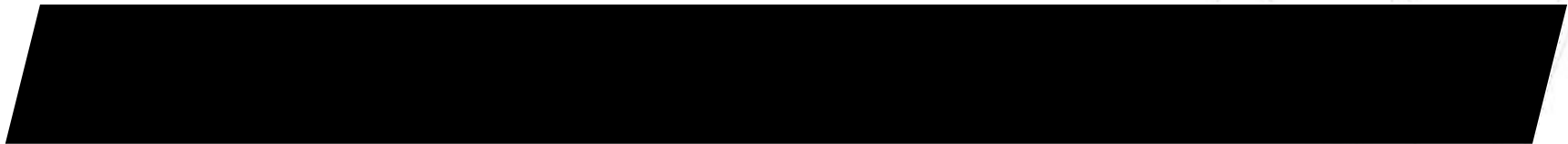
The main results obtained with our model is that, counter-intuitively, the larger the porosity the smaller the delay (the greater the anticipation) we observe in the simulated trajectories. As also indicated in appendix B, this result seems to revert when we start considering shocked areas with larger radius.

For relatively small shocked areas the model optimizes the flight trajectories giving rise to overall negative delays. This effect is also present when we do not have shocked areas and the model is therefore simply de-conflicting the trajectories. Whenever the model modifies a flight trajectory, it is therefore able to provide an optimization in terms of delay. Small shocks uniformly distributed leave more room for optimization rather than small concentrated shocks. We must however admit, that this optimization might be done at the cost of changing the flight trajectory many many times, which might not be acceptable for airlines

On the other hand, when individual shocks are large (radius > 15 km) the model capacity to optimize trajectories degrades. In this case, large shock uniformly distributed leave less room for optimization rather than large concentrated shocks. In fact, large concentrated shocks tend to overlap with each other and therefore increasing the number of shocks only marginally reduces the available space for aircraft, in this case.



The End





Model F

Reward mechanism

In Model A, the order of the flights is shuffled at each time step in order to avoid that the trajectory changes are always performed on the same flight. In Model F we will label flights with a flag indicating whether they are change-prone or change-averse.

Change-averse

mi
po

Change-prone companies would be those that does not have to minimize flight duration or fuel consumption and therefore are more prone to accept trajectory deviations maybe in exchange for some kind of reward.



Model F

We plan to perform different experiments to investigate how this depends on the following features of the system:

1. absence of navigation points grid, as compared with the actual scenario
2. mono-directional trajectory flows inside much larger sectors



Strategic Layer of the Agent-Based Model

Roma, March 2014



ELSA

Empirically grounded agent based models for the future ATM scenario

- 1 Input from operational experts
 - Flight plan
 - Capacities
- 2 Description of the models
 - Network
 - Agents
 - Parameters
- 3 Results from model 1.0
 - Pure population
 - Mixed population
 - Real airspace
- 4 Results from Model 2.0
 - Calibration
 - Results

INPUT FROM OPERATIONAL EXPERTS



Preparation and submission of flight plans

Input from WP4: input for the strategic layer have been collected during interviews with people from the Alitalia Operation Center (OCC).

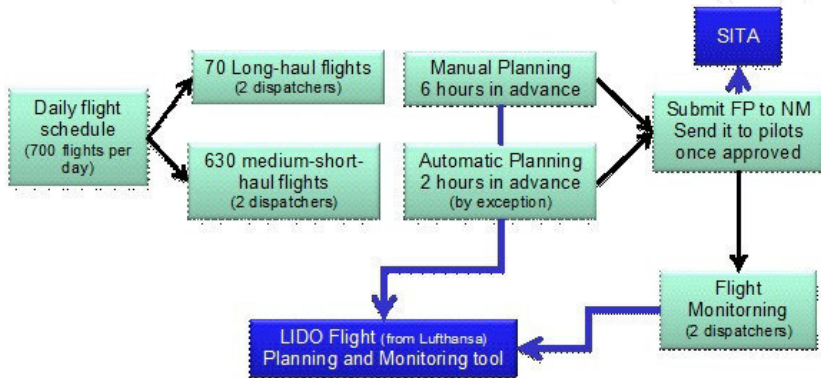
Preparing the flight plans

- Starts by collecting information like weather, aircraft performances, etc. between 2 and 6 hours before time departure.
- Minimization of the cost (mainly fuel and ATC fees) and safe execution based on these informations.
- no information on the other flights.
- Flight plan in ICAO format submitted through a dedicated system (SITA).
- The CFMU recalculates the flight plan using their own model and accept or reject the flight plan,
- The CFMU gives a reason for the rejection but no alternative routes.
- The company submits another flight plan.



Preparation and submission of flight plans •

Alitalia OCC workflow



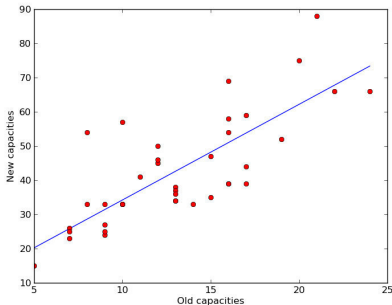


SUPPLEMENTARY INFORMATION NOT TO BE TRANSMITTED IN FFS MESSAGES

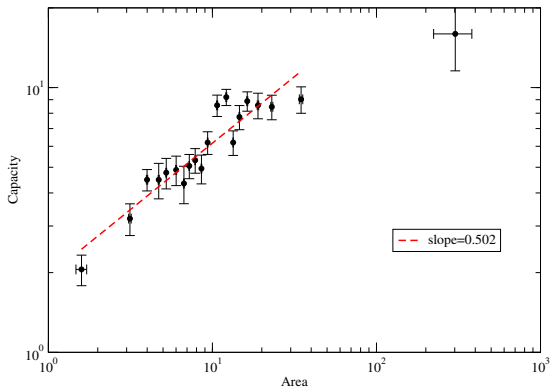
Estimating sector capacity from DDR data

Two definitions of the capacity (model 1/model 2):

- Maximum number of flights in the area at any given time.
- Maximum number of of flights present in the airspace during one hour.



$$C_{model2} \simeq 2.8 C_{model1}$$



DESCRIPTION OF THE MODELS



Model 1 and model 2 •

The strategic layer can be used with two different models.

Model 1

- Model 1 does not include the navpoint structure. The companies build flight plans based on the sector network.
- $\Rightarrow$ allows a deep comprehension of the mechanisms of the model by providing a smaller set of parameters and allowing some analytical computations.
- Model 1 is mainly meant to be used on simplified, generated networks.

Model 2

- Model 2 includes the navpoint structure. The companies build flight plans based on the navpoint network, as in reality.
- $\Rightarrow$ allows to run the model on more sophisticated and realistic supports.

Two types of agents

- Airline Operator (AO),
- Network Manager (NM).

Sequence

- AOs submit flight plans to NM, which are trajectories on a static network,
- NM checks the occupancy of the airspace and reject or accept the flight plans,
- The satisfactions of AOs are computed.

Optionally:

- Some sectors are shut down,
- the corresponding AOs resubmit new flight plans,
- satisfactions are recomputed.



Model 1: Network and flight plans •

Flight plans

Sequence of **sectors**, with time of departure.



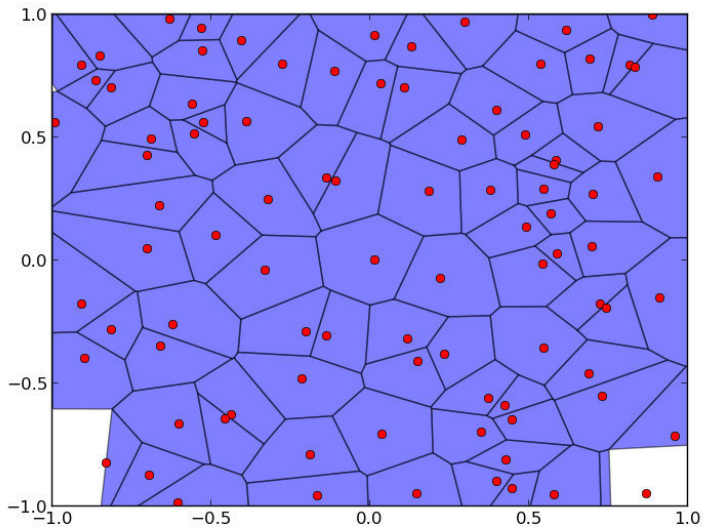
Model 1: Network and flight plans •

Flight plans

Sequence of **sectors**, with time of departure.

Network of sectors

- Can be generated (based on a Voronoi tessellation) or can be the real network (a single country for instance).
- Capacities drawn from a given distribution.
- Crossing times are taken either from a normal distribution or based on the geometrical distance between centroids of sectors.
- Crossing times are real numbers: continuous time model.
- Unit of time is given by the average crossing time.





Model 2: Network and flight plans •

Flight plans

Sequence of **navpoints**, with time of departure.



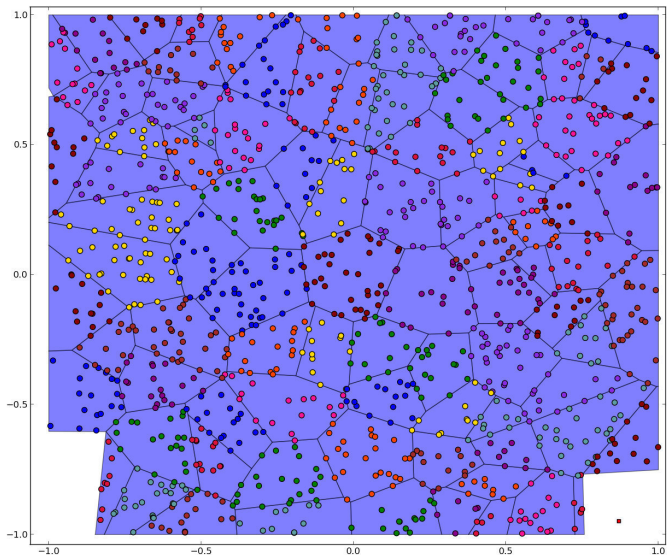
Model 2: Network and flight plans •

Flight plans

Sequence of **navpoints**, with time of departure.

Network of navpoints + network of sectors

- The networks are superimposed: each navpoint belongs to one sector.
- Flights flow through the navpoint network.
- Trajectory of sectors built from trajectory of navpoints.
- Unit of time is explicit: minutes.



- Defined by a cost function.
- chooses at random a couple origin/destination,
- finds best paths on the network of sectors,
- selects k couples (path, time of departure) based on minimal cost function,
- submits them to the NM.

$$c(\mathbf{p}, t) = \alpha|\mathbf{p}| + \beta(t - t^0)$$

Remarks

- Desired time t^0 is a parameter of the model. Presently, distribution is in a “wave” pattern or taken from data.
- Can only be shifted delayed: $t > t^0$ of a quantity $\tau = 1$.
- $|\mathbf{p}|$ is the weighted length of the trajectory.

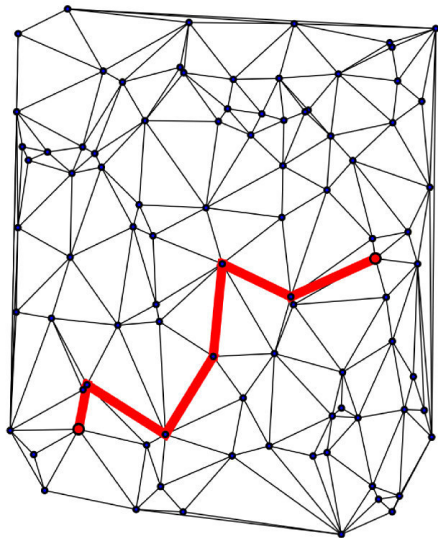
Description: agents (AO) •

- Defined by a cost function.
- chooses at random a couple origin/destination,
- finds best paths on the network of **navpoints**,
- selects k couples (path, time of departure) based on minimal cost function,
- submits them to the NM.

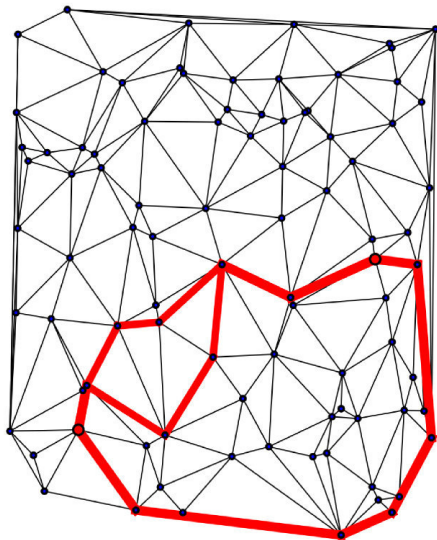
$$c(\mathbf{p}, t) = \alpha|\mathbf{p}| + \beta(t - t^0)$$

Remarks

- Desired time t^0 is a parameter of the model. Presently, distribution is in a “wave” pattern or taken from data.
- Can only be shifted delayed: $t > t^0$ of a quantity $\tau = 1$.
- $|\mathbf{p}|$ is the weighted length of the trajectory.



- $\alpha \gg \beta$,
- “Low-cost company”,
- wants best trajectories,
- shifts in time.



- $\alpha \ll \beta$,
- “Traditional company”,
- wants punctuality (because of waves),
- takes several routes.

Network Manager (NM)

- Receives a flight plan from a company at random;
- checks if a sector would overreach its capacity if the FP were allocated;
- approves or rejects the flight plan;
- if accepted: allocates the flight plan (recompute all current loads);
- if rejected: the company submits another flight plan, with a higher cost.

Network Manager (NM)

- Receives a flight plan from a company at random;
- checks if a sector would overreach its capacity if the FP were allocated;
- approves or rejects the flight plan;
- if accepted: allocates the flight plan (recompute all current loads);
- if rejected: the company submits another flight plan, with a higher cost.

Remarks

- No global optimization,
- no counter-propositions.

Network Manager (NM)

- Receives a flight plan from a company at random;
- **convert the navpoint path into a sector path;**
- checks if a sector would overreach its capacity if the FP were allocated;
- approves or rejects the flight plan;
- if accepted: allocates the flight plan (recompute all current loads);
- if rejected: the company submits another flight plan, with a higher cost.

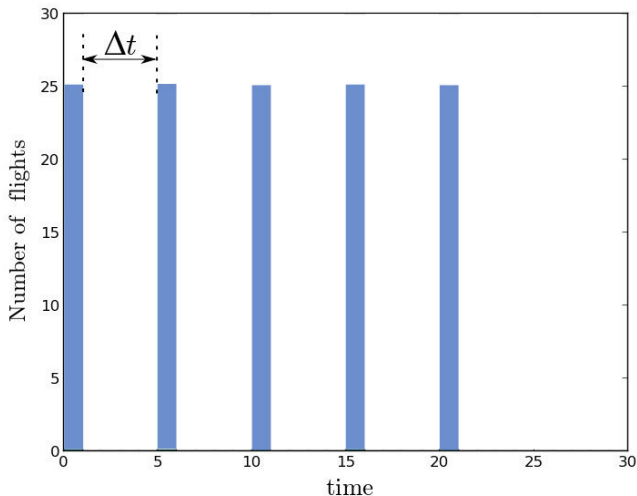
Remarks

- No global optimization,
- no counter-propositions.



Departure times pattern ●

Informed by graphs in use by the Alitalia Scheduler. Time window of 24 units of time.



Variables

- Number of flights,
- Ratio β/α ,
- Time between two waves Δt ,
- Fraction of flights f_S when there are two different types of companies.

Variables

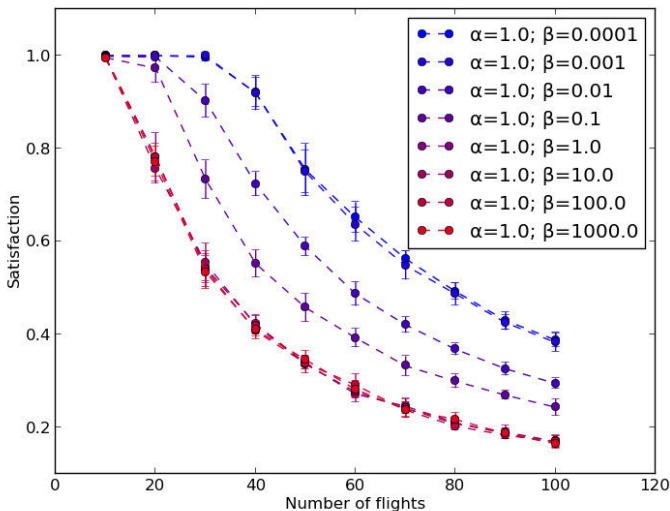
- Number of flights,
- Ratio β/α ,
- Time between two waves Δt ,
- Fraction of flights f_S when there are two different types of companies.

Output Metric

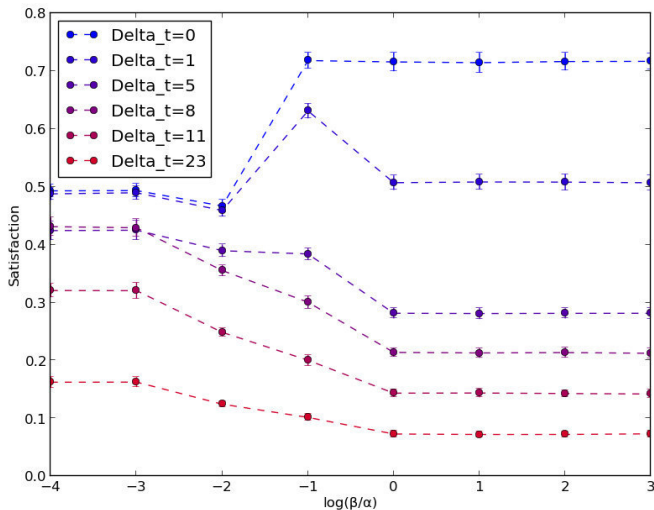
- Satisfaction: $c(p_{best})/c(p_{accepted})$,

RESULTS FROM MODEL 1.0

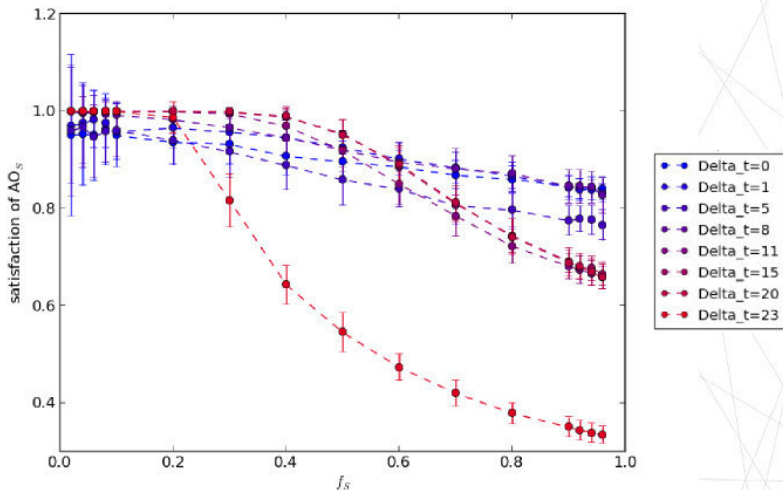
Total satisfaction against number of flights ($\Delta t = \infty$)



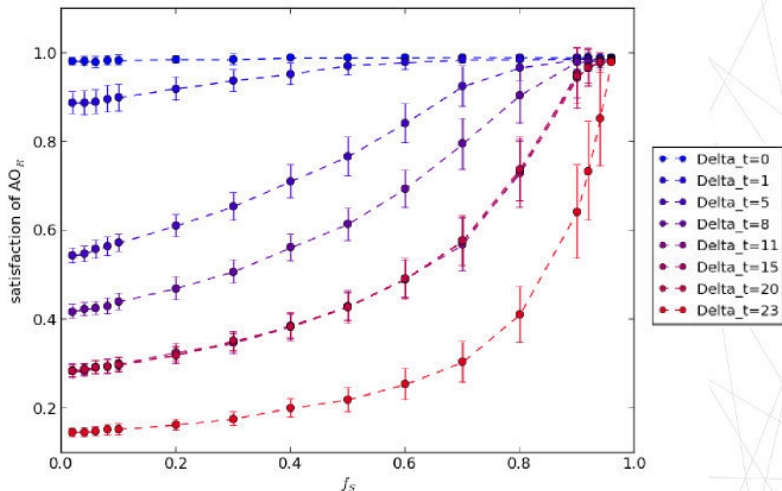
Total satisfaction against type of company (120 flights)



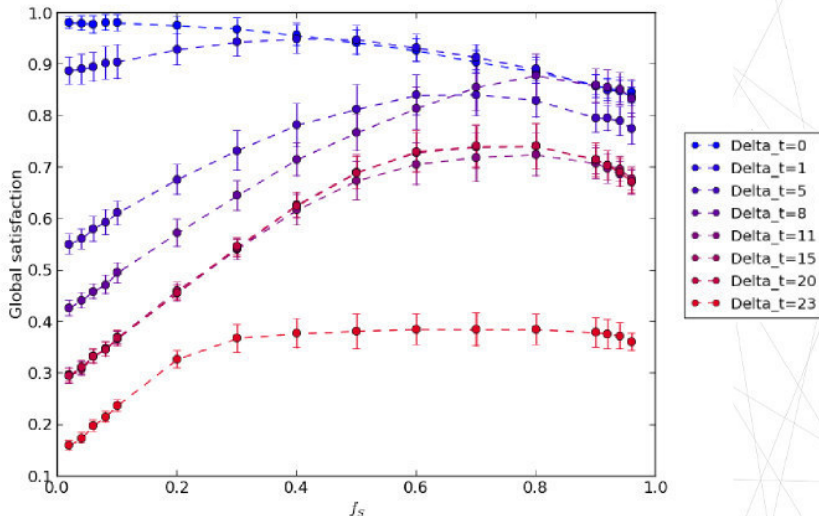
Satisfaction of “Shifting” companies against their fraction



Satisfaction of “Rerouting” against fraction of “Shifting” Companies



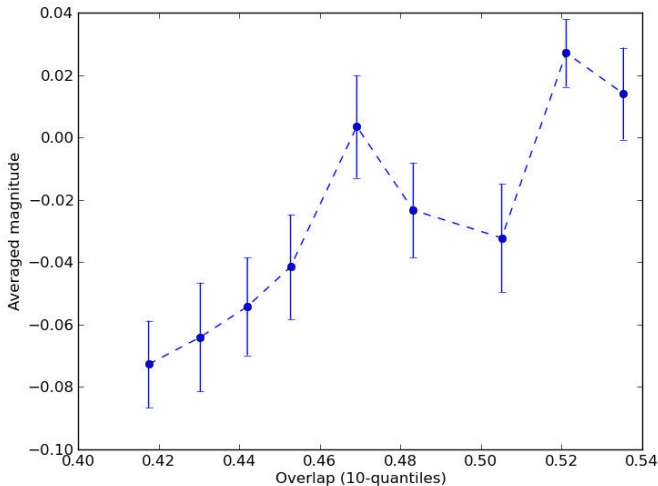
Total satisfaction against fraction of “Shifting” Companies



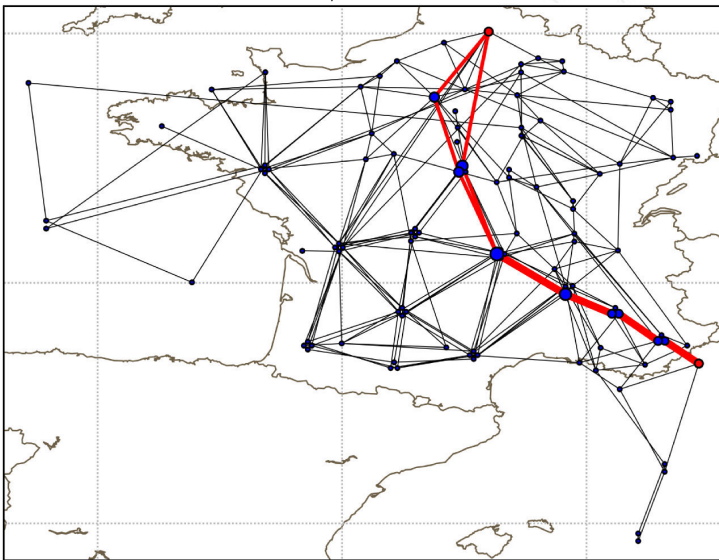


Generalization

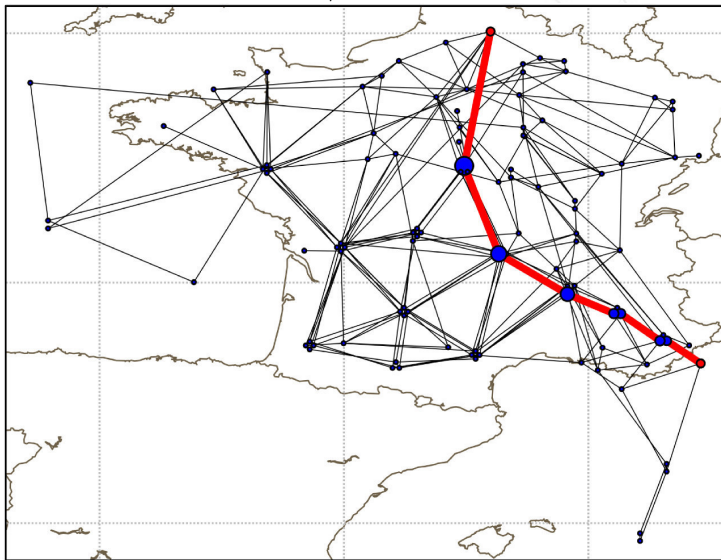
Average difference of satisfaction between S and R companies when $\Delta t = 0$ against topological overlap between shortest paths.



$$\beta/\alpha = 1$$



$$\beta/\alpha \ll 1$$



Main interest

- The model allows to understand the main issues which arise from the existence of different strategies for the choice of flight plans.

Main interest

- The model allows to understand the main issues which arise from the existence of different strategies for the choice of flight plans.

What we have learned so far

- Pseudo-jamming transition;
- Dominant strategies depend on the departing times pattern;
- Dominant strategies depend on the fraction of populations;
- “The loner, the better” effect;
- Maximum satisfaction usually does not imply a monopoly.

RESULTS FROM MODEL 2.0



Calibration of explicit parameters •

Setup on real airspace

- The model is set up on the real network of navpoints and sectors of France.
- we use a 2d slice of sectors at high altitude;
- we take the crossing times between navpoints from traffic data (average on one day);
- we compute the capacities from the data (number of flights crossing the sector in one hour).

Additional calibration

- We fix the number of flights to the number observed in the data;
- we fix as well the source/destination to the ones observed in the data;
- we take the real departure time as proxies for the desired departure times.

At this point, only three parameters of interest remain:

- The ratio β/α in the pure population case,
- the fraction f_S in the mixed population case,
- the number of routes available per sector N_{sp} .

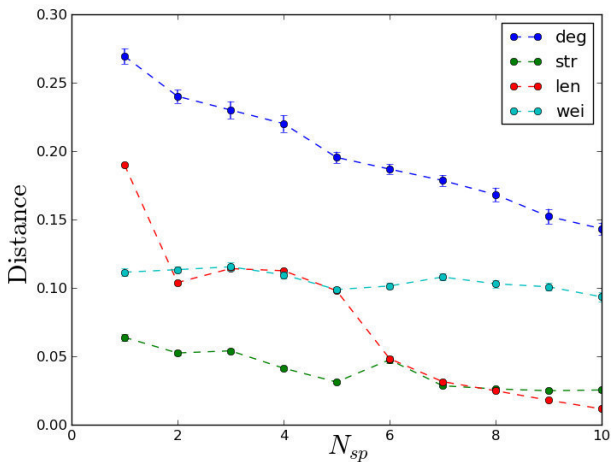
At this point, only three parameters of interest remain:

- The ratio β/α in the pure population case,
- the fraction f_S in the mixed population case,
- the number of routes available per sector N_{sp} .

We need to define some targets to hit order to do a quantitative calibration.

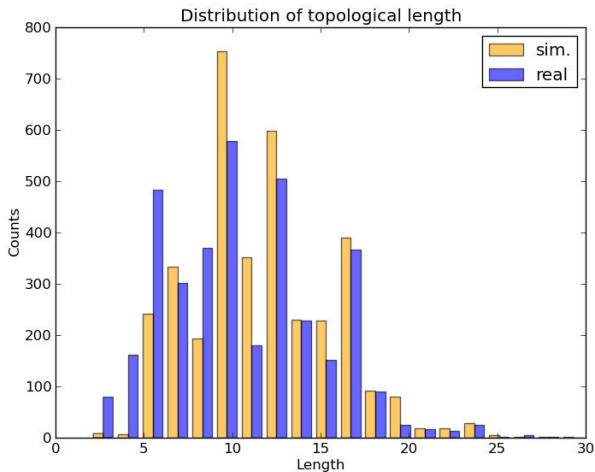
Candidates:

- Degree,
- strength,
- number of navpoints crossed by the flights,
- weights of edges.

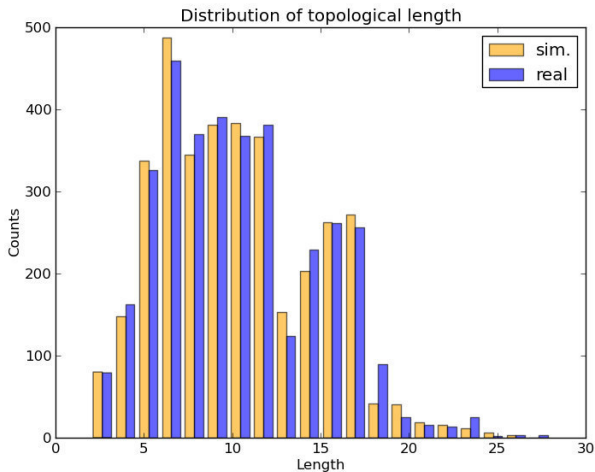


⇒ all targets are reached at $N_{sp} = 10$.

$$N_{sp} = 1$$



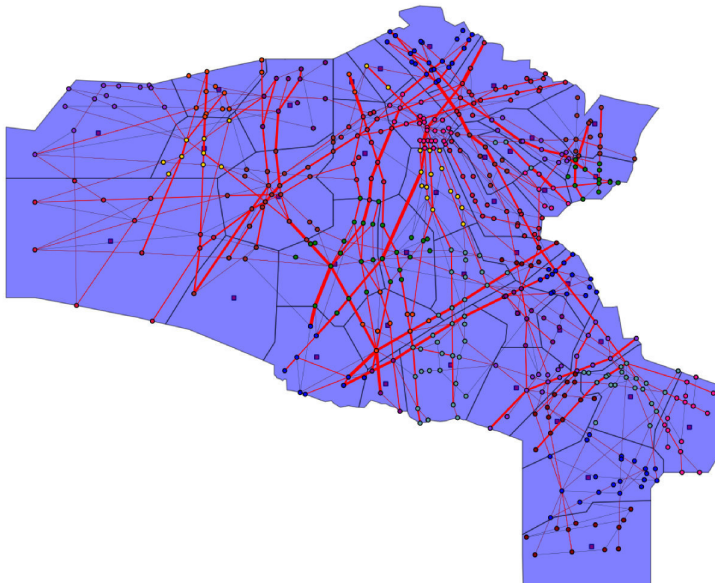
$$N_{sp} = 10$$

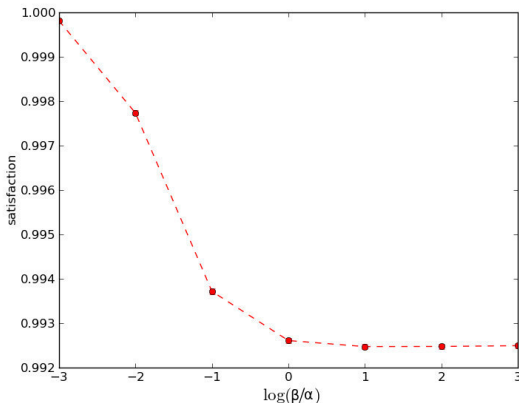




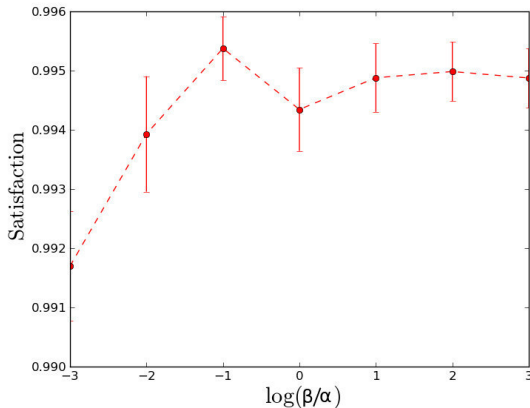
Example: May 6th, 2010 ●

Only 289 flight plans have been rejected, and only 27 flights, over 3584.



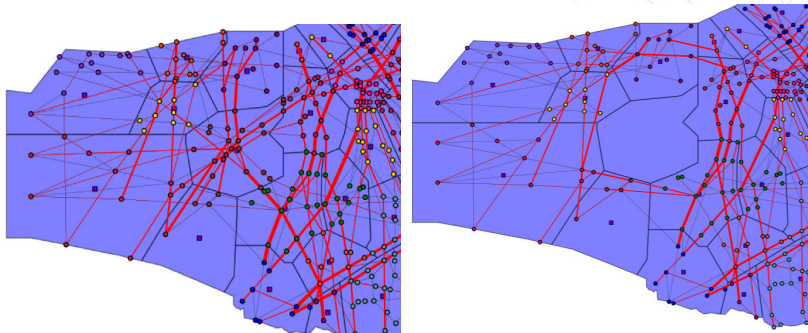


- Companies of type S has the advantage.
- Indeed, companies of type R **cannot have any advantage** because they only have one sector path available.



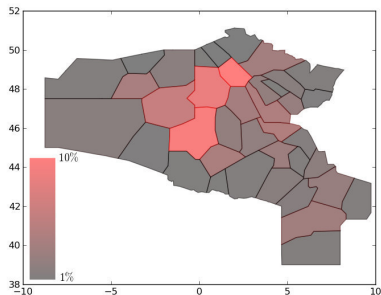
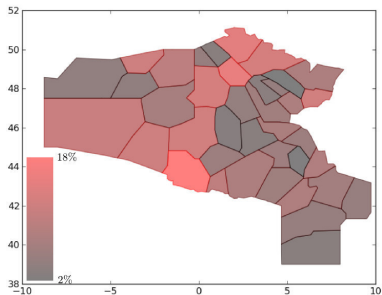
- Companies of S and R have their own advantage.

After all submissions ($\Rightarrow$ M1 trajectories), we close a sector at random.



Companies having a canceled flight resubmit a new bunch of flight plans to the NM. Satisfaction is recomputed with respect the initial best flight plan.

We close one after the other each sector of the airspace and see how much it affects the global satisfaction.



- Model 2 can be straightforwardly calibrated on real data for most parameters.
- The model can be used as a scenario simulator where we apply different constraints to the network in order to see the reaction of the companies.
- In particular, sectors which are crucial can be easily highlighted.

Appendix A Workshop presentations – Invited speakers

The presentations included in this appendix are the following:

4. Functional and Multi-layer representations of Air Transport networks

Content: The presentation contains an analysis of delay propagation on a multi-layer network built by considering both functional and physical links between the nodes.

Workshop Site: Rome (20/3/14)

Author: [REDACTED] - Innaxis

5. Serious Games for Research Purposes

Content: This presentation contains an overview of games that were used for research purposes. In particular the author analysed how ATM related games, like the Virtual Air Traffic Simulator Network (VATSIM) can be exploited to test new operation concepts and scenarios.

Workshop Site: Rome (20/3/14)

Author: [REDACTED] – “Sapienza” University of Rome

6. Human Mobility: from Individual Behaviour to Network Dynamics

Content: The objective of the research presented is to understand from empirical data on individual mobility (complex system) the emergence of macroscopic 'universal' statistical laws on human mobility (statistical physics for complex systems), their meaning and their applicability distinguishing between cognitive aspects and physical dynamics.

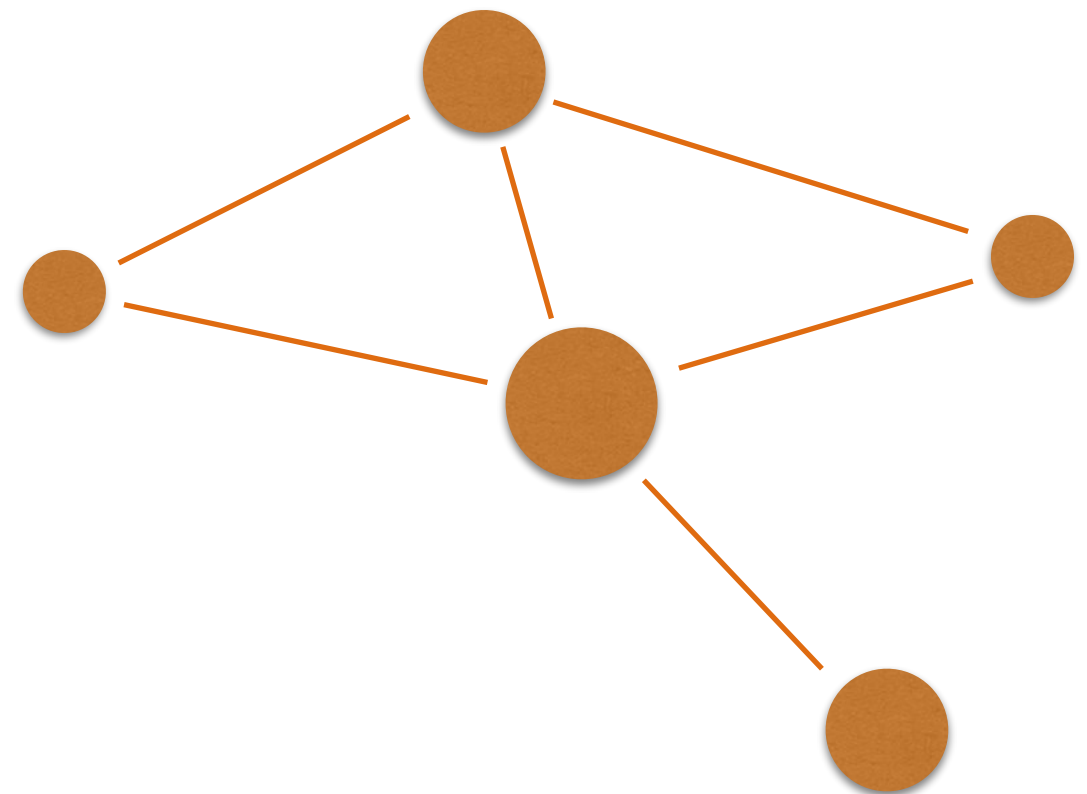
Workshop Site: Rome (20/3/14)

Author: [REDACTED] – University of Bologna

Functional and Multi-layer representations of Air Transport networks:

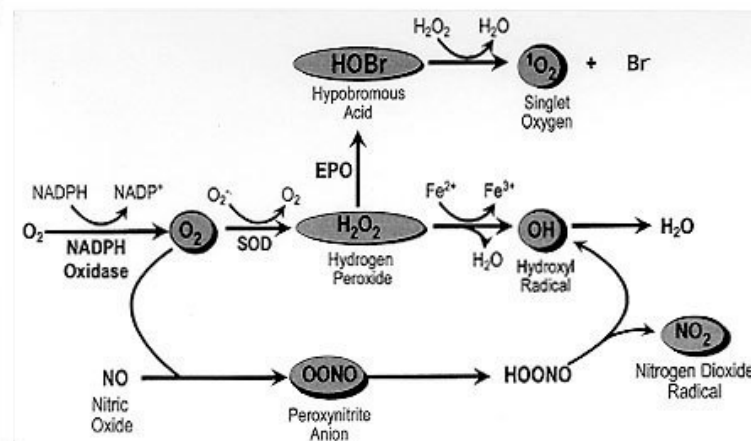
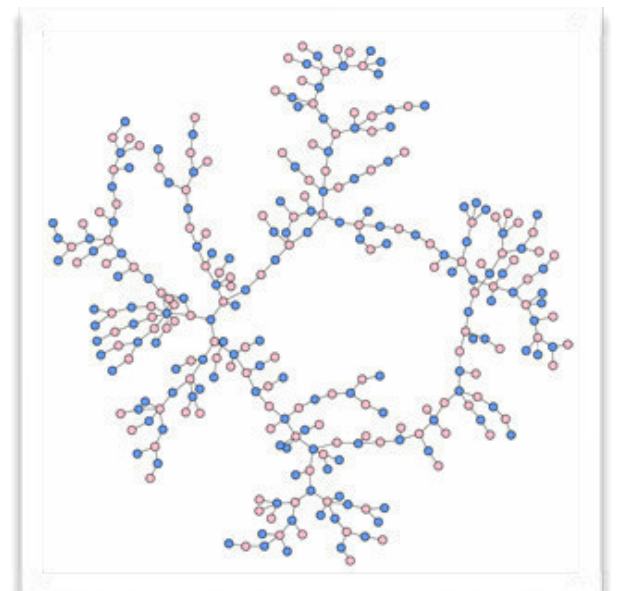
Have we got the basics right?

The story so far ...



1998:

Birth of complex network theory



Analysis of the Air Transport network

Country	Period	Nodes	Links	γ	γ_B	L	L_{rand}	C	C_{rand}	Refs.
World	11/2000	3883	27051	1.0	0.9	4.4	—	0.62	0.049	[34]
World	11/2002	3880	18810	2.0	—	4.37	—	—	—	[35, 36]
US	—	215	*116725	2.0	—	1.403	—	0.618	0.065	[37]
US	10-12/2005	272	6566	2.63	—	1.9	1.81	0.73	0.19	[38]
Austria	—	134	9560	2.32	—	—	—	0.206	0.01	[22]
China	—	128	1165	4.161	—	2.067	—	0.733	—	[23]
China	28/11/2007–29/3/2008	144	1018	—	—	2.23	1.88	0.69	0.098	[39]
India	12/1/2004	79	442	2.2	—	2.259	2.493	0.657	0.0731	[40]
India	12/2010	84	*13909	0.71	0.54	2.17	2.55	0.645	0.18	[41]
Italy	16/7-14/8/2005	42	—	1.6	0.4	1.987	3.74	0.10	0.17	[42]
Italy	11/2005	42	—	1.1	0.5	2.14	3.64	0.07	0.14	[42]
Italy	6/2005–5/2006	42	310	1.7	0.4	1.97	—	0.1	—	[43]
Italy	—	33	105	—	—	1.92	—	0.418	—	[44]
Spain	—	35	123	—	—	1.84	—	0.738	—	[44]

Country	Weight	β	β_b	θ	Refs.
Worldwide	Available seats	1.5	0.8	0.5	[35, 36, 49]
US	Number of passengers	1.8	—	—	[38]
India	Number of flights	1.43	—	—	[40]
4 European airlines	Number of flights	(1.06 – 1.18)	—	—	[50]
China	Number of flights	—	—	0.5	[23]
Europe	Number of flights	1.39	—	—	[51]

The first problem:

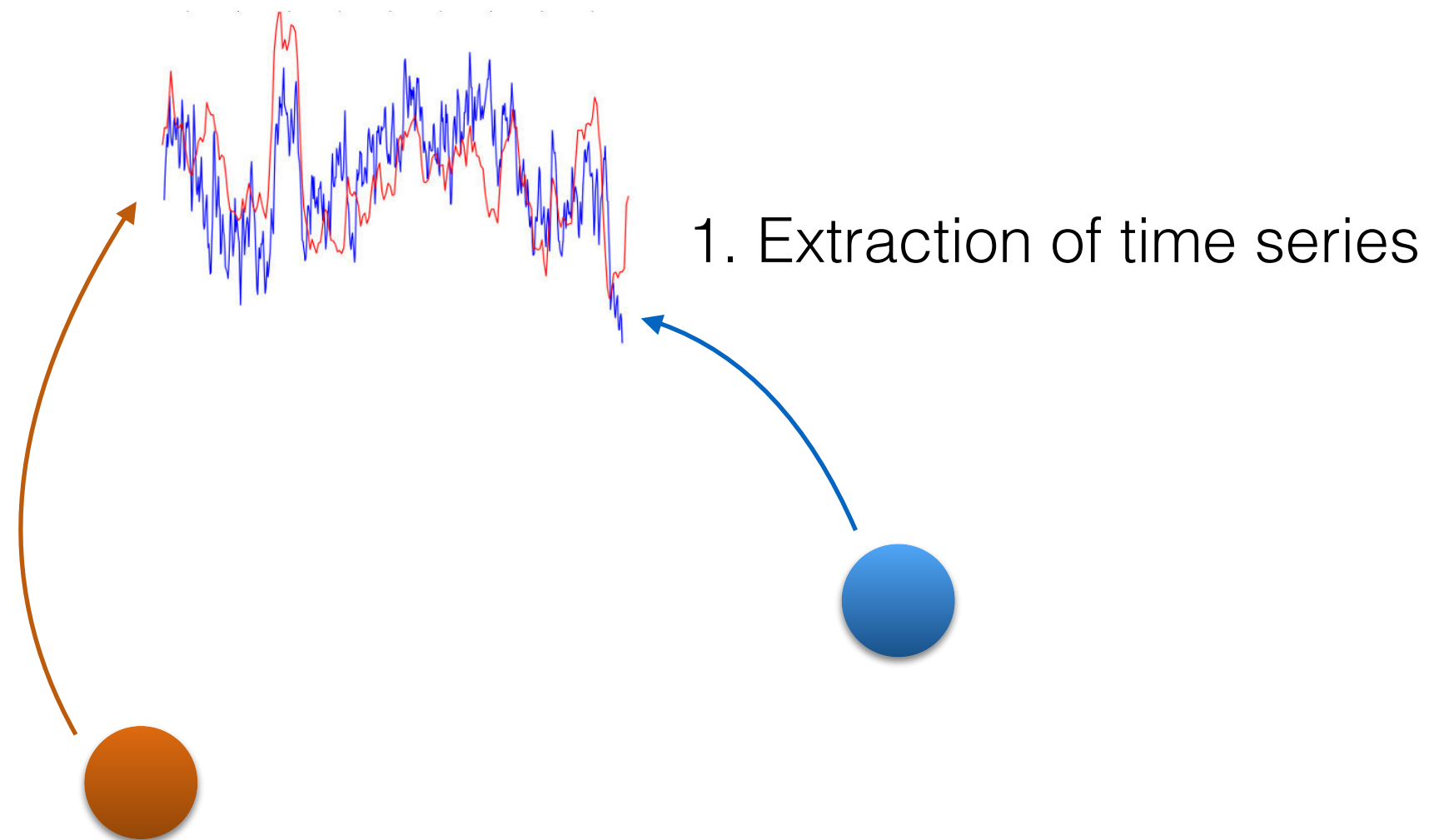
the structure is not always explicit (or measurable)

the *hardware* structure may not be relevant

A classical example:



Birth of functional representations



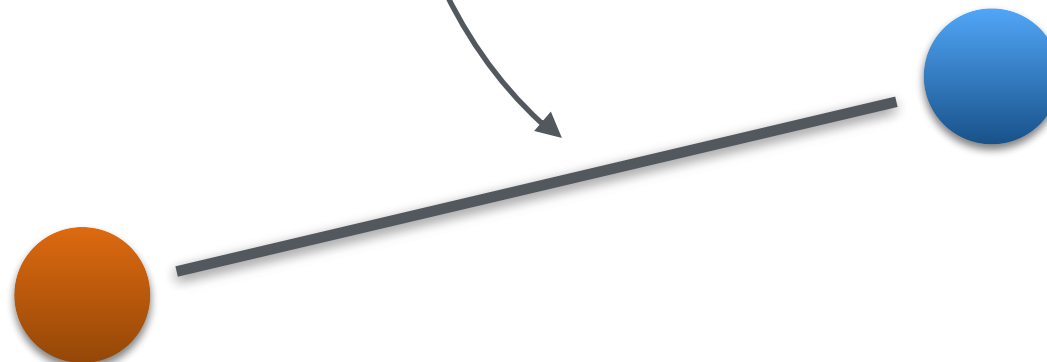
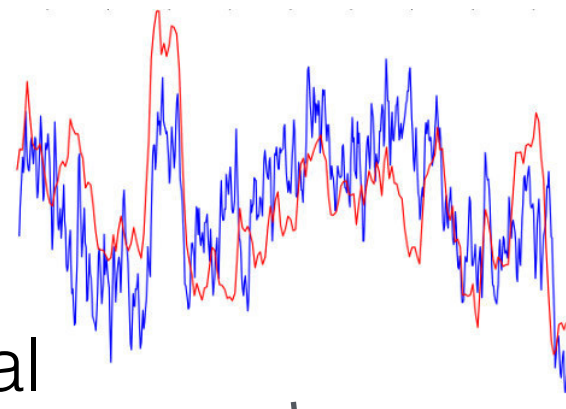
Birth of functional representations

2000:

2. Analysis of functional connectivity

Linear correlation
synchronisation
causality

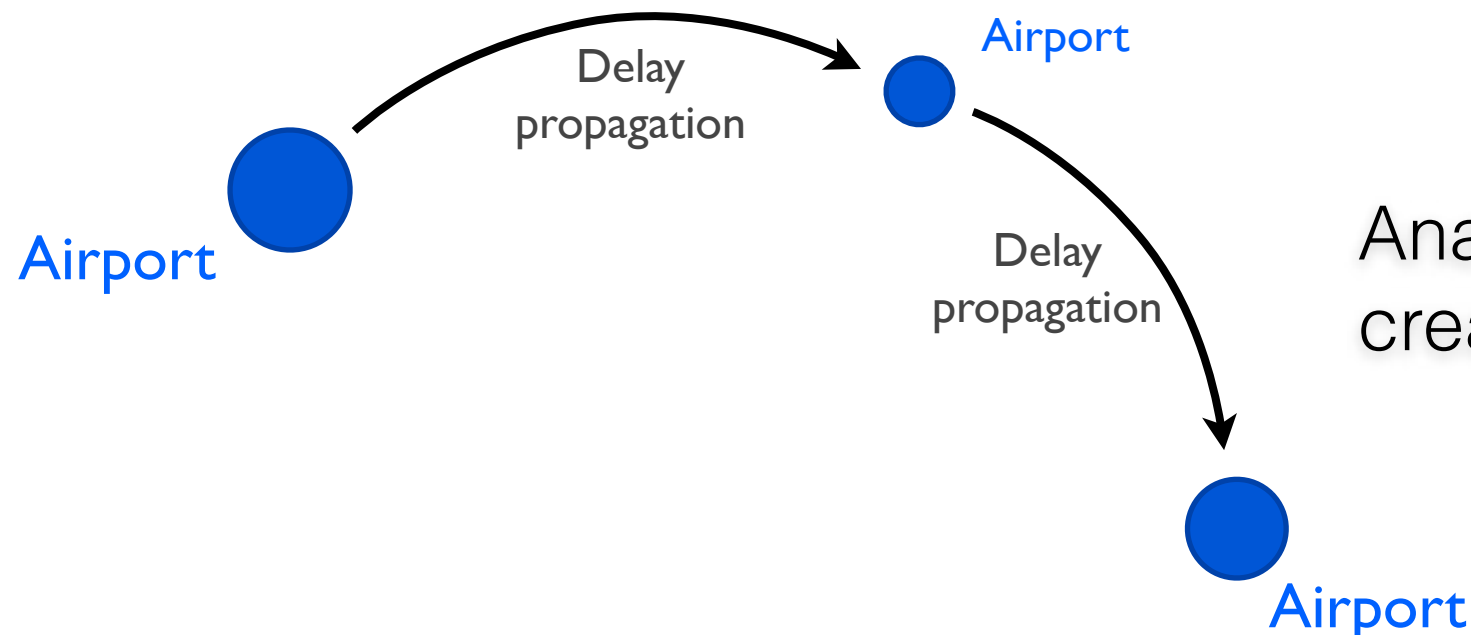
...



Functional analysis of the AT network

POEM

Passenger-Oriented Enhanced Metrics



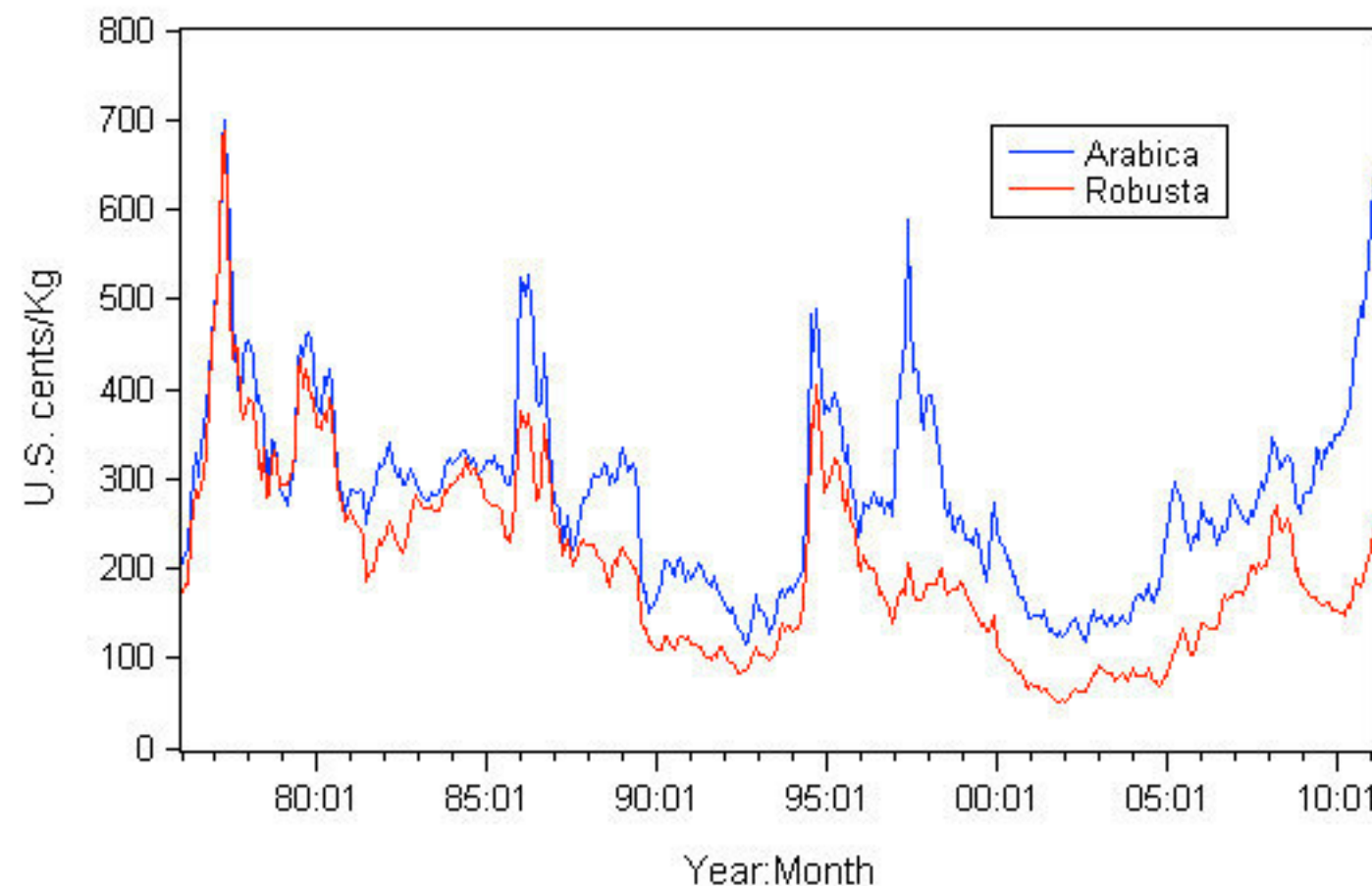
Analysis of the **global structure** created by delay propagation

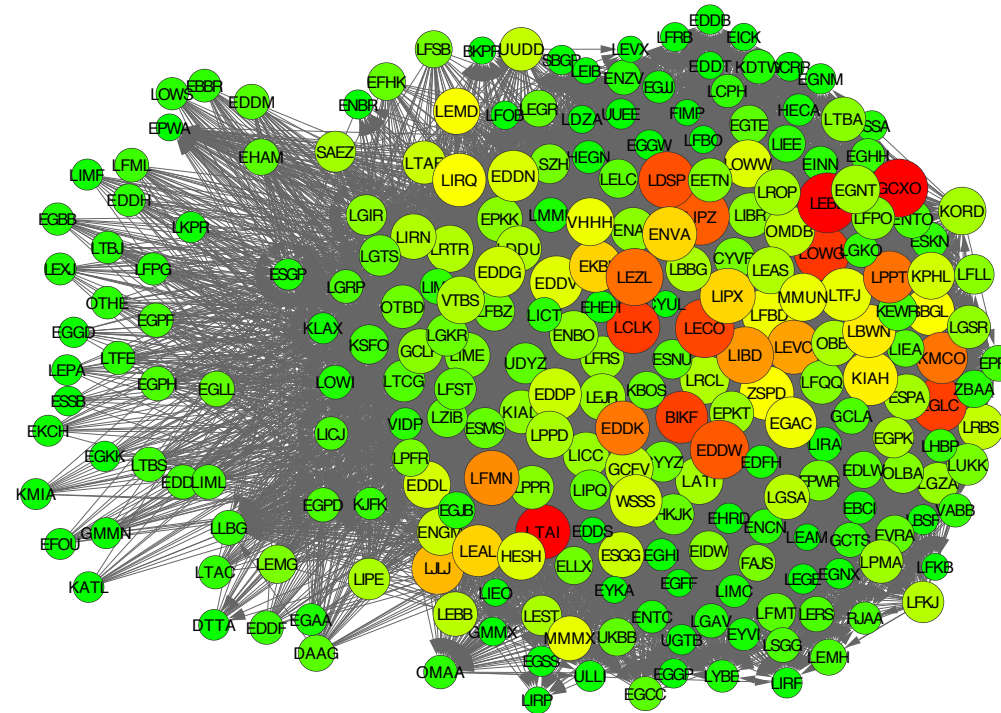
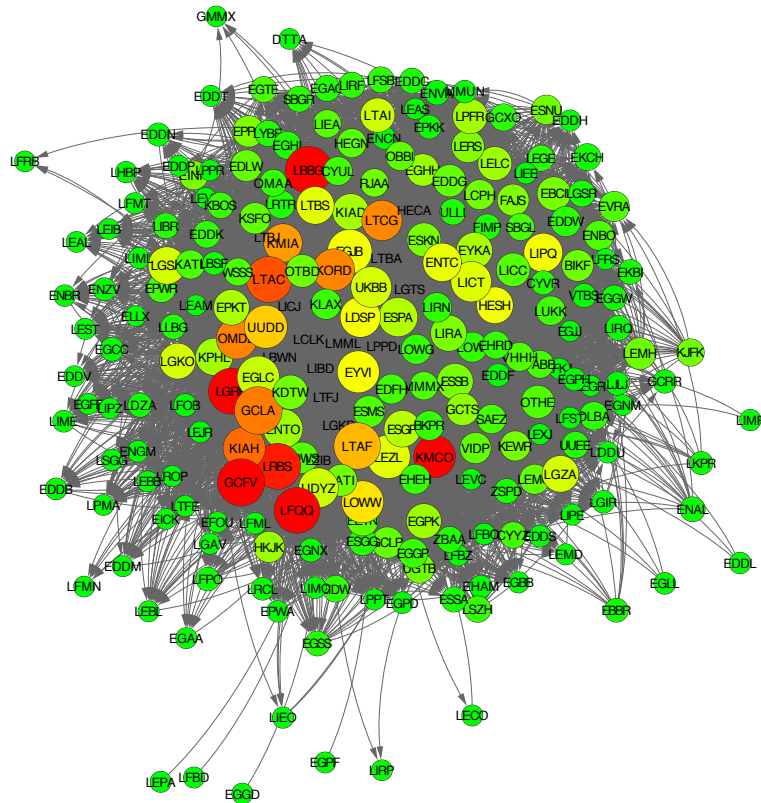
Granger causality

Measure assessing if one time series “drives” (is causal to) a second one

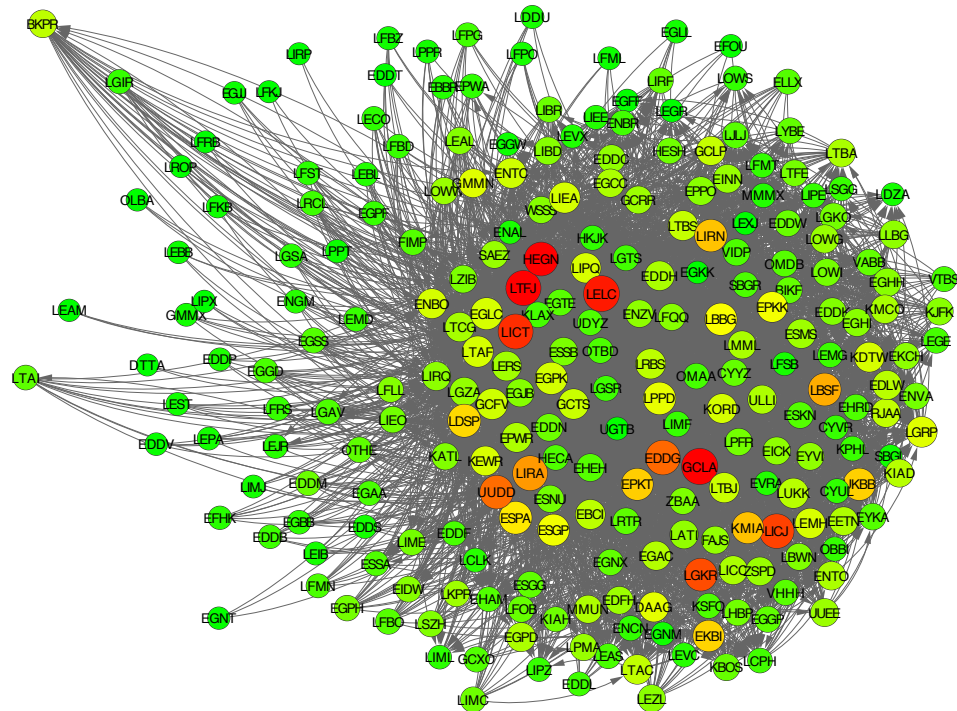
Checks whenever there is a "surprise" in the explanatory variable that leads to a later increase in the outcome variable

Fig 2. Coffee Prices (January 1976 - March 2011)

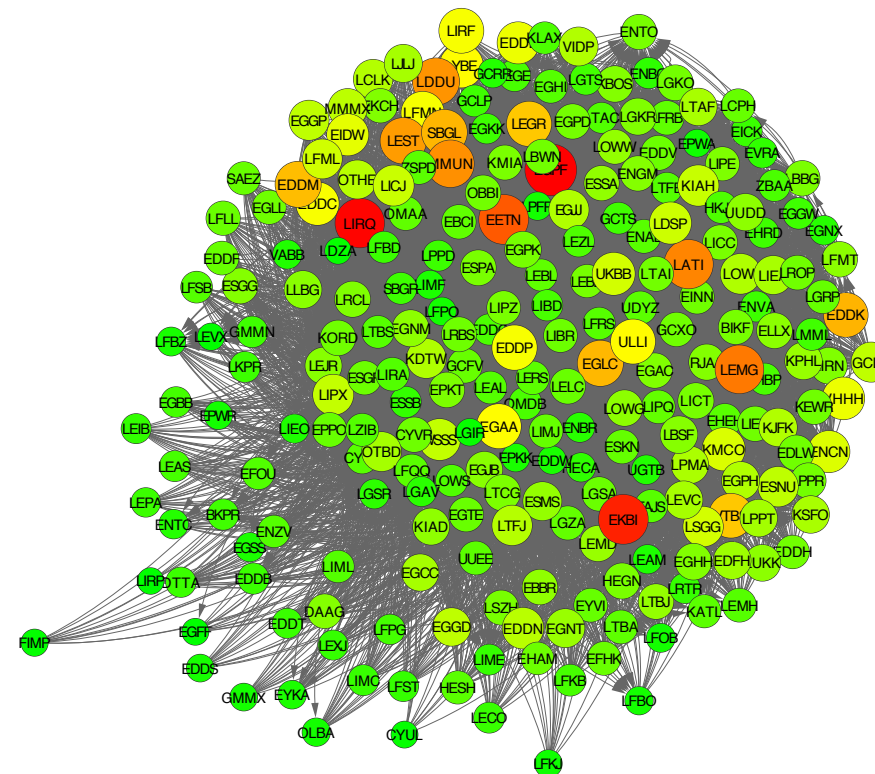




Baseline



Flight
network

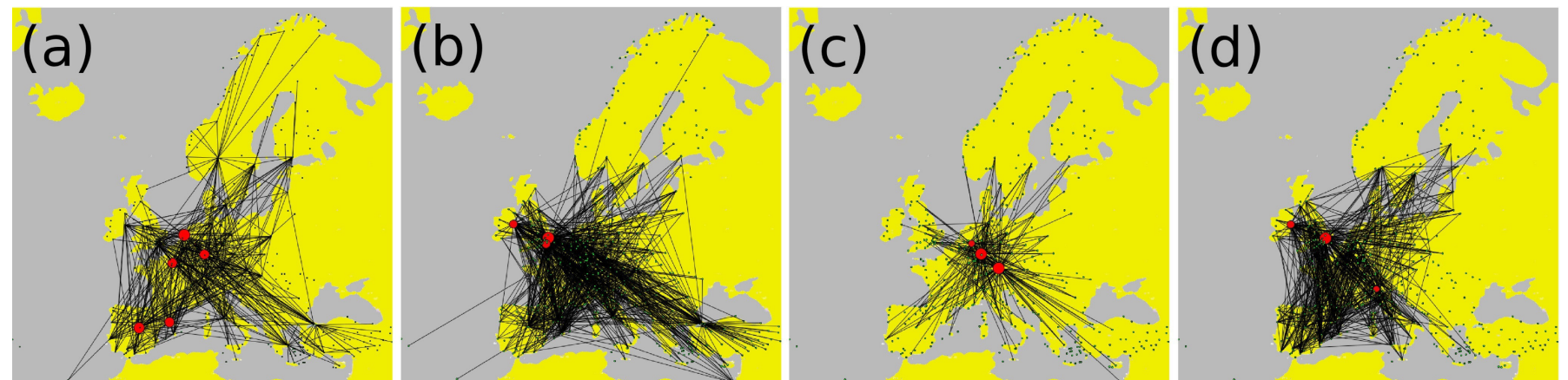


Airline
optimization

Pax
network

What about multi-layer structures?

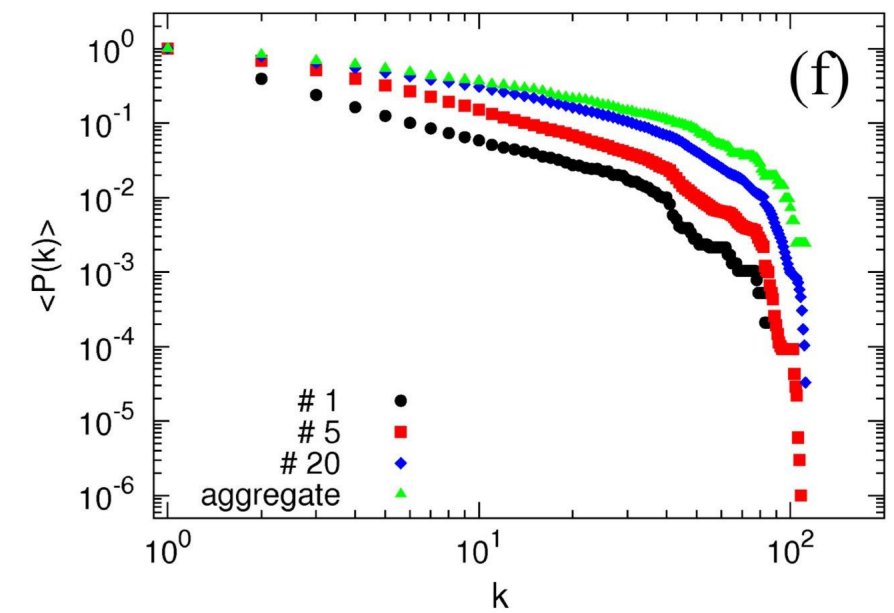
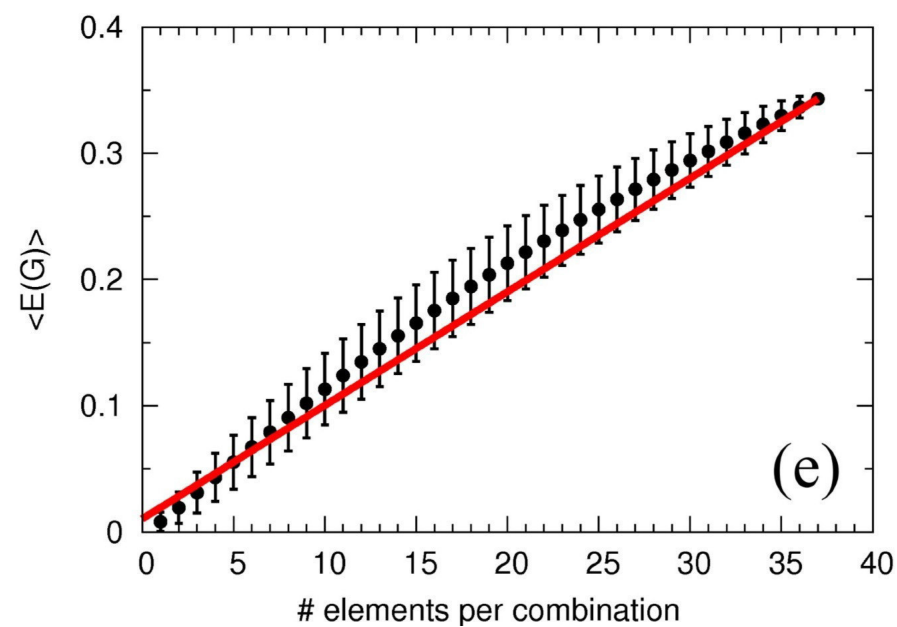
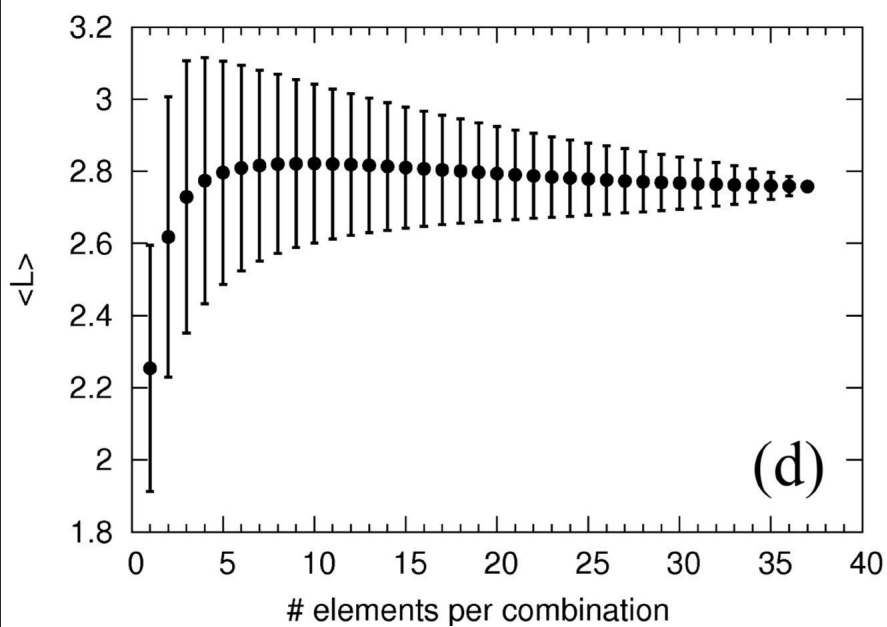
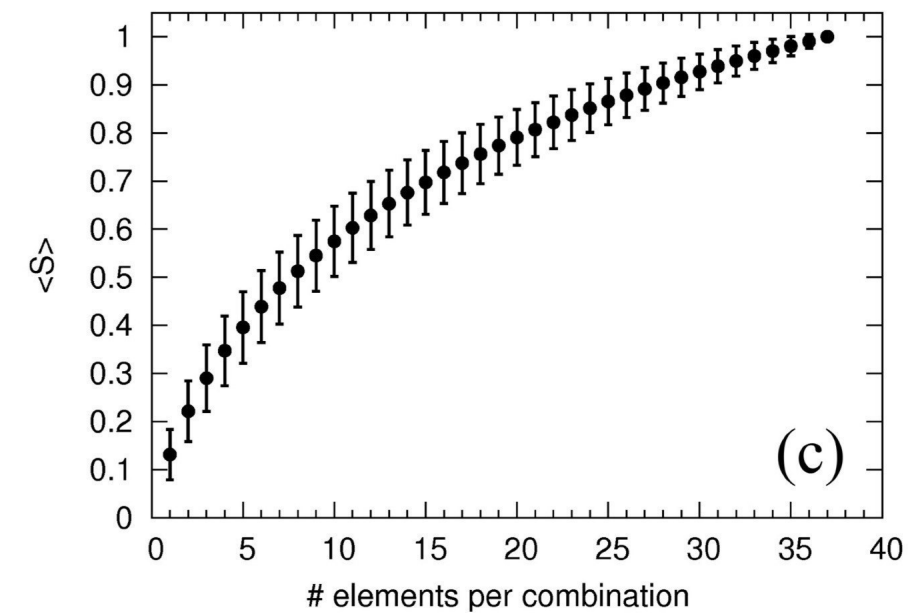
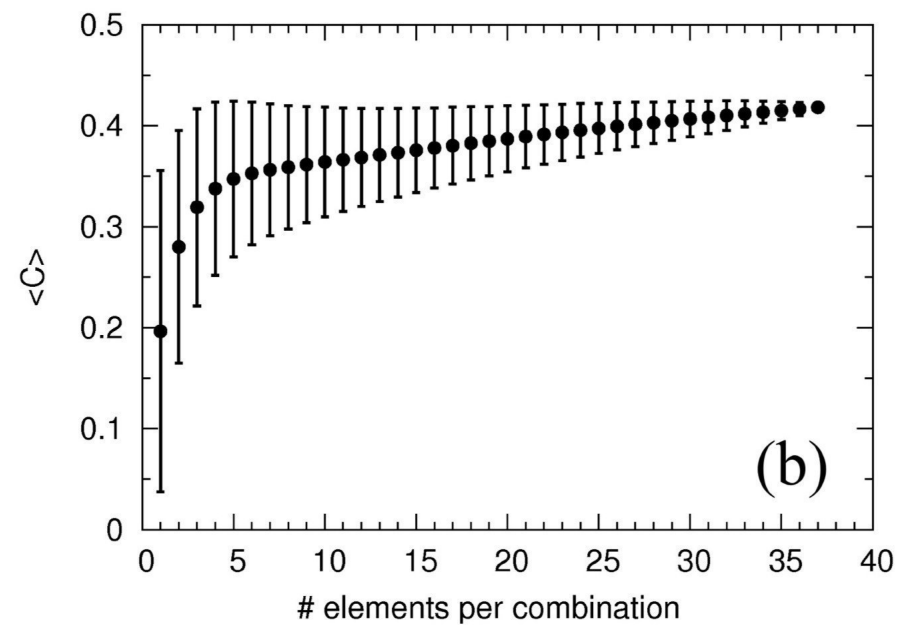
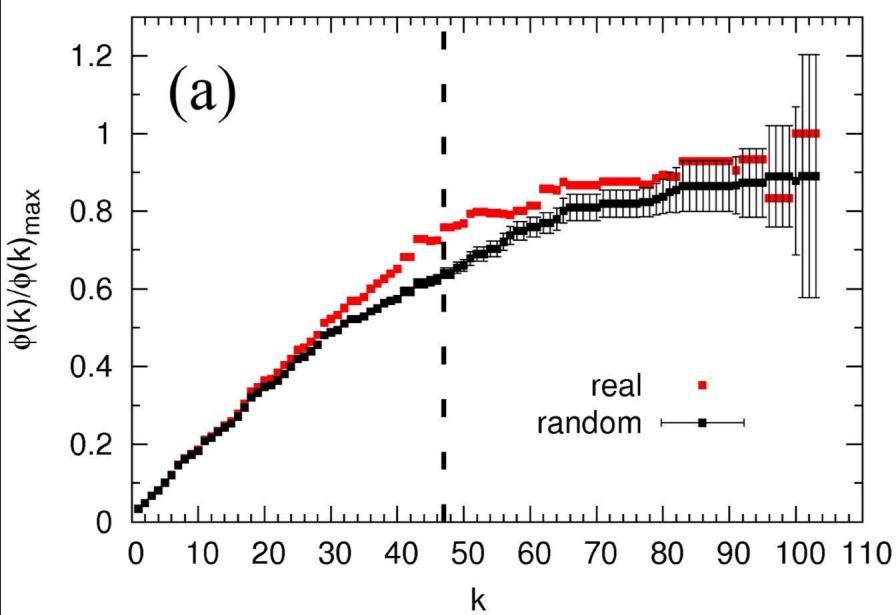
We usually analyse the
projected networks ...

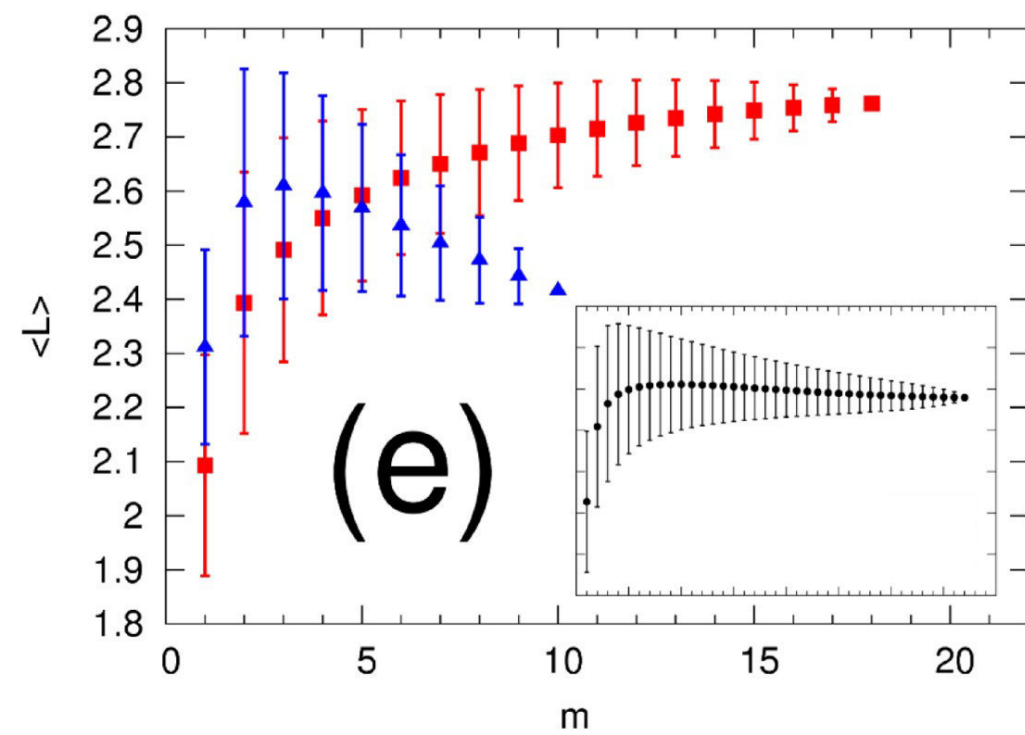
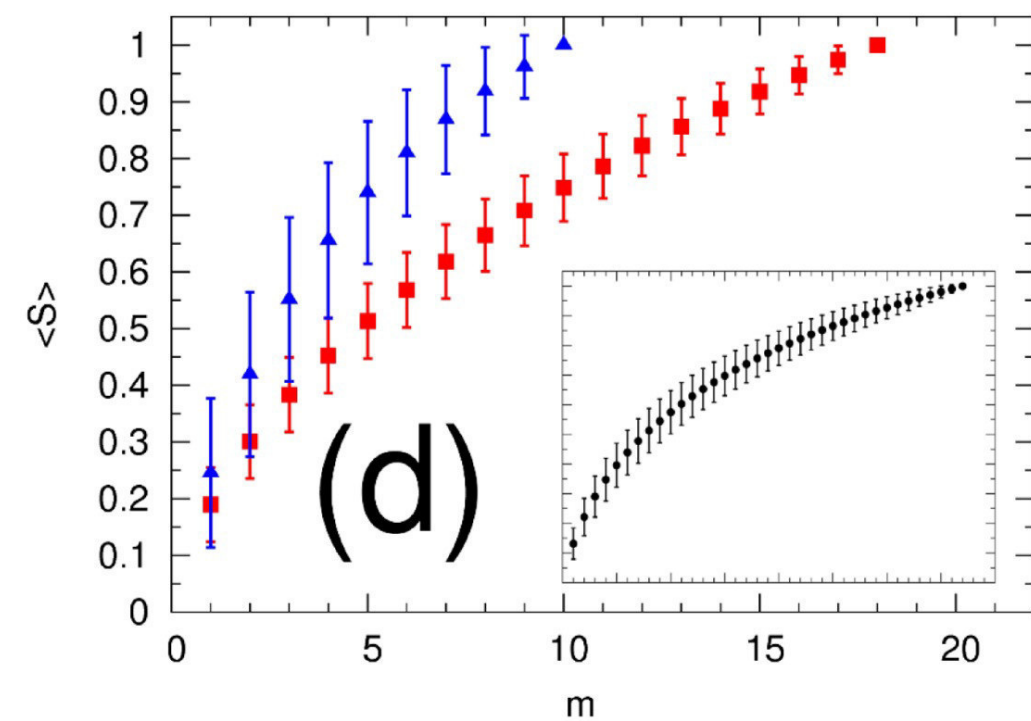
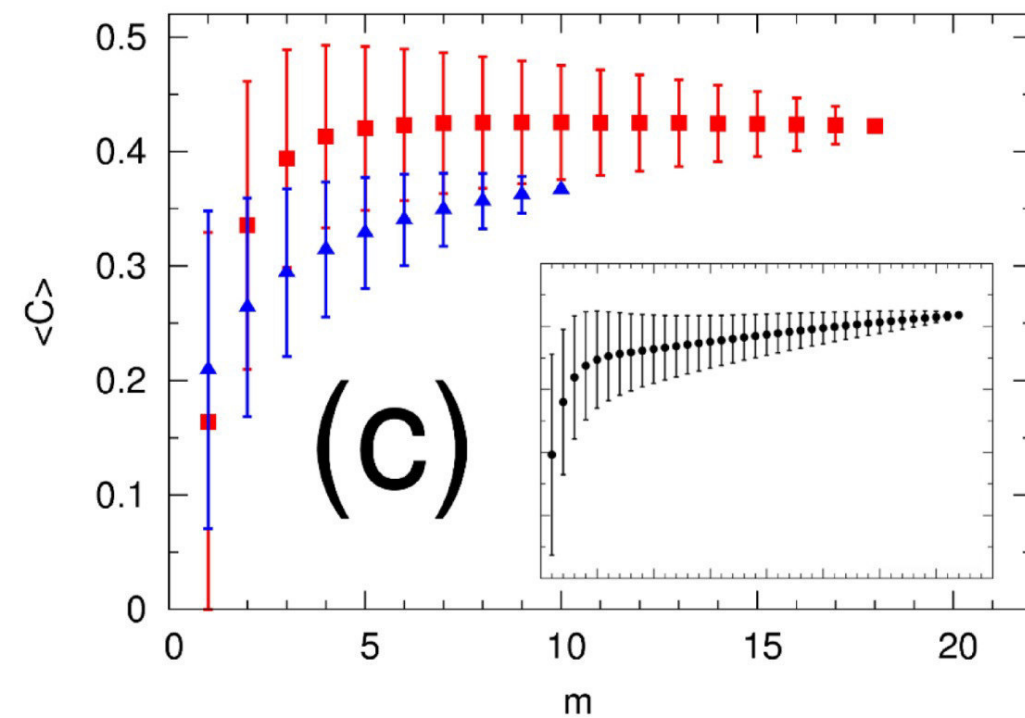
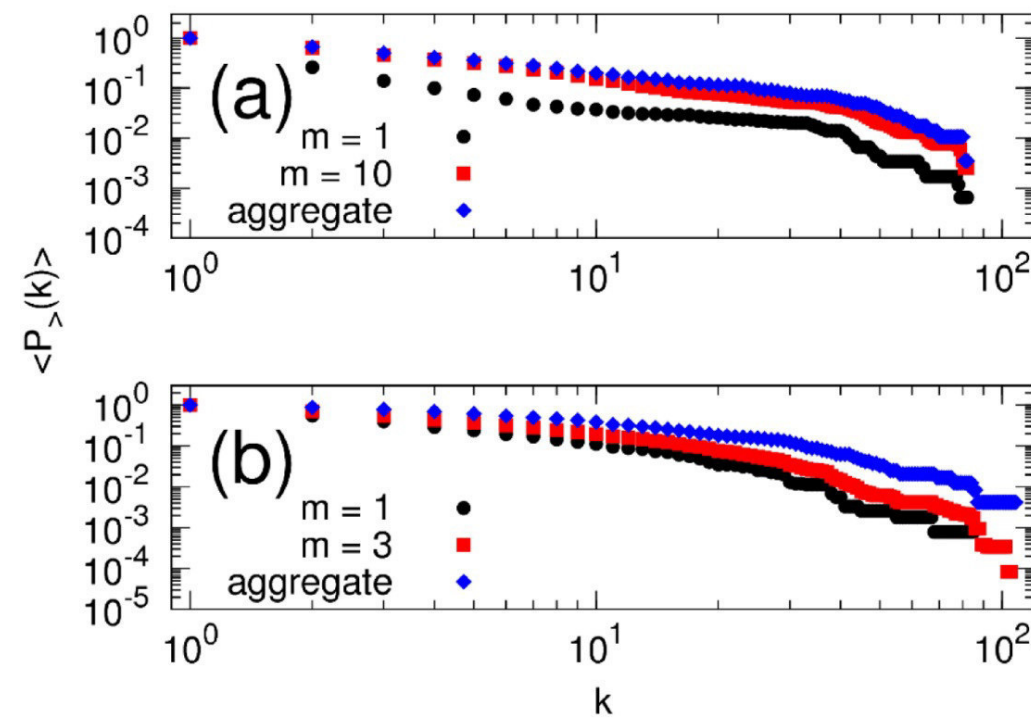


... but the real network is
created by airlines

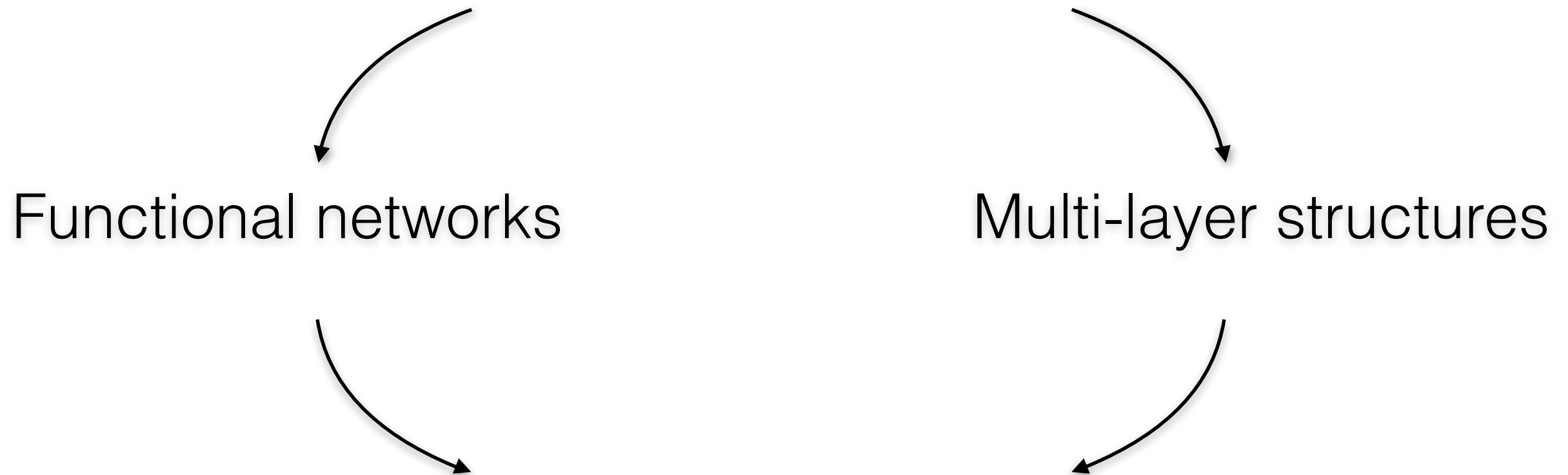
2010:







Networks of explicit links

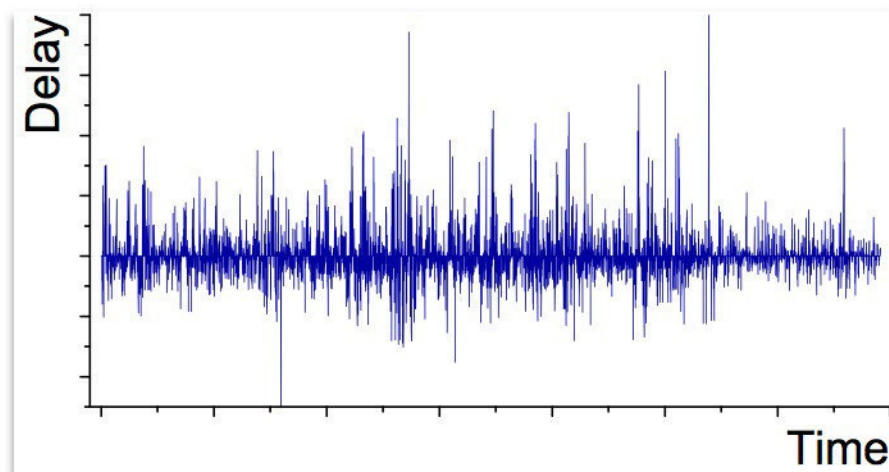


What about multi-layer functional networks?

Is the multi-layer structure of a functional network relevant?

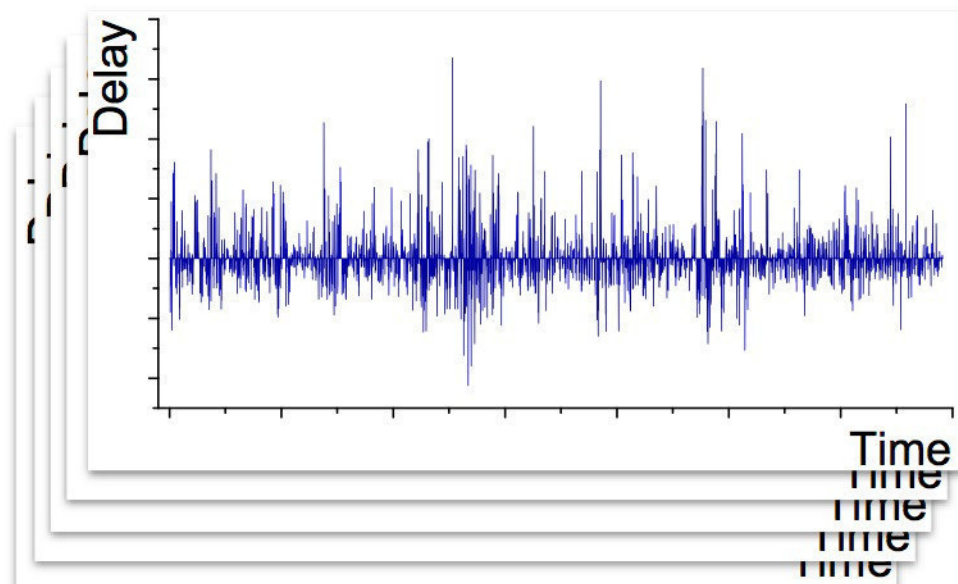
Can we disregard layers?

Would the resulting dynamics be similar?



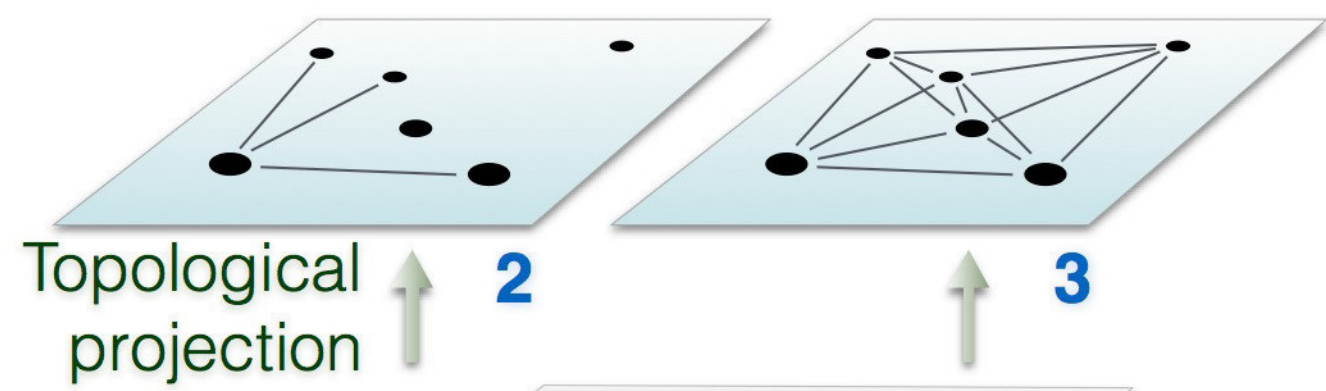
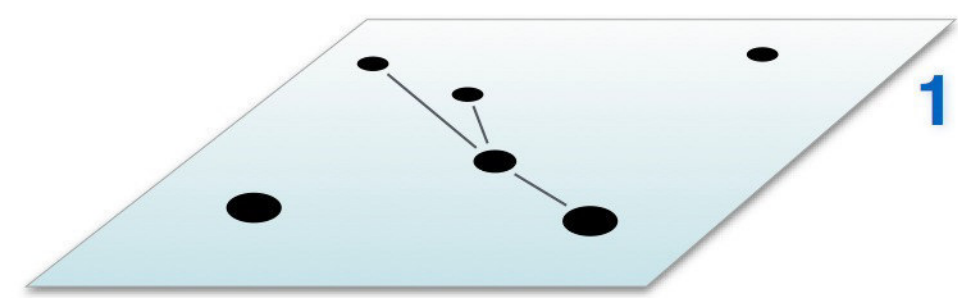
Airport delay time series

↑
Dynamical
projection

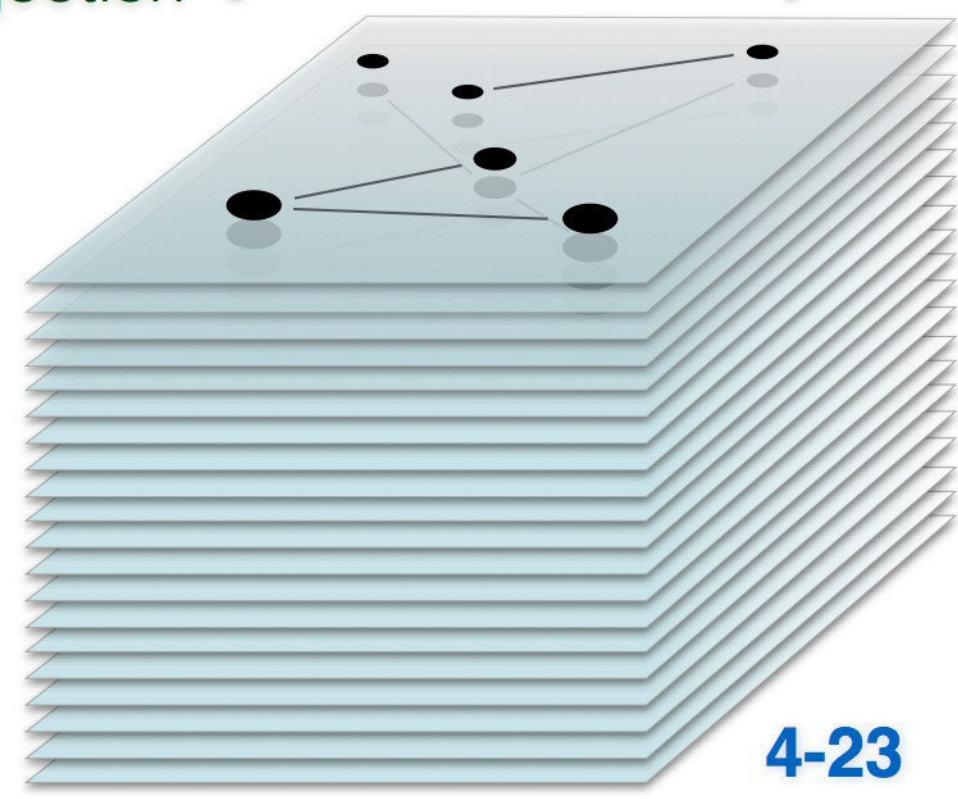


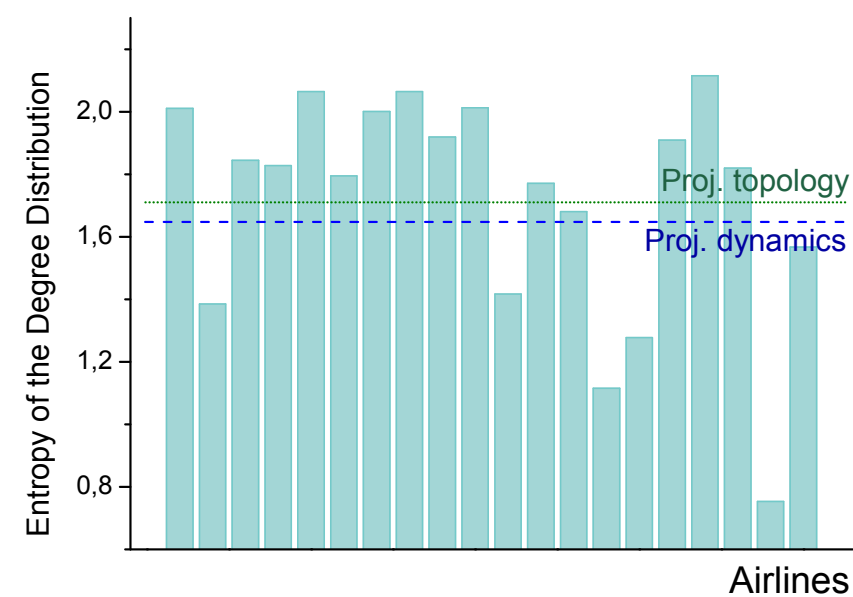
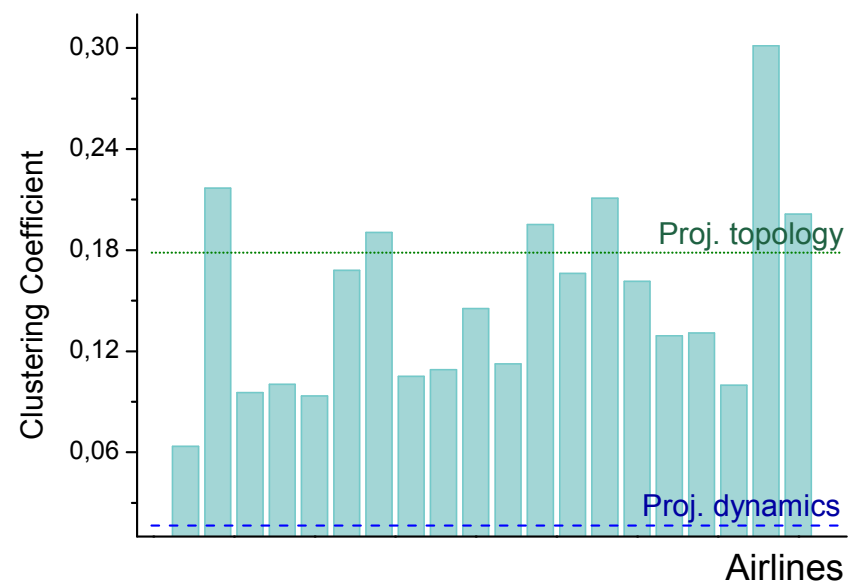
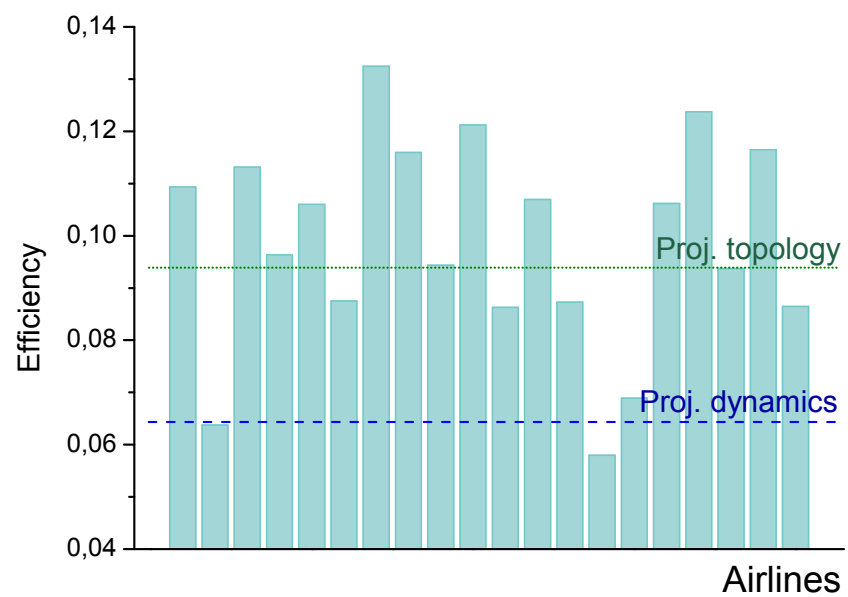
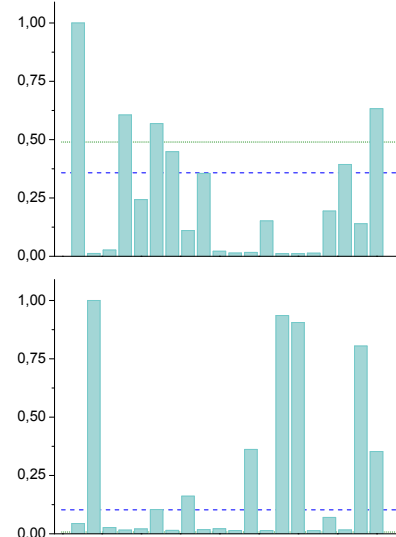
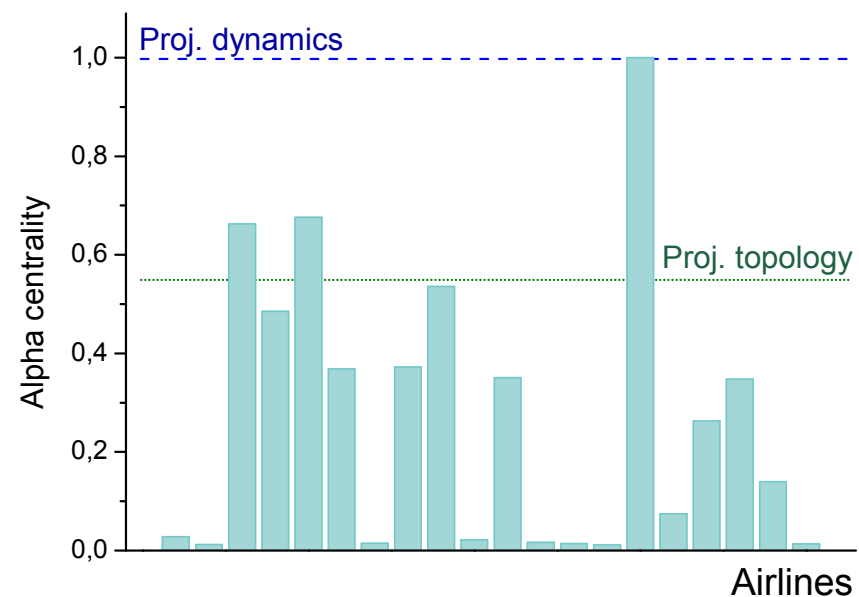
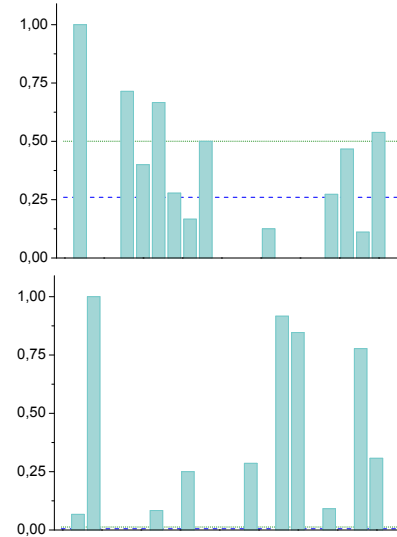
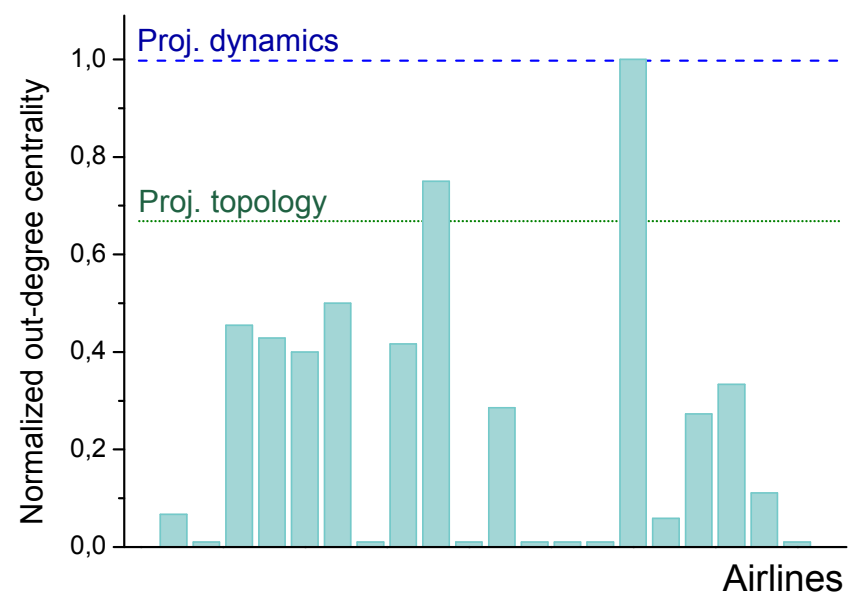
Airline delay time series

LC
MI
→
GC
TE

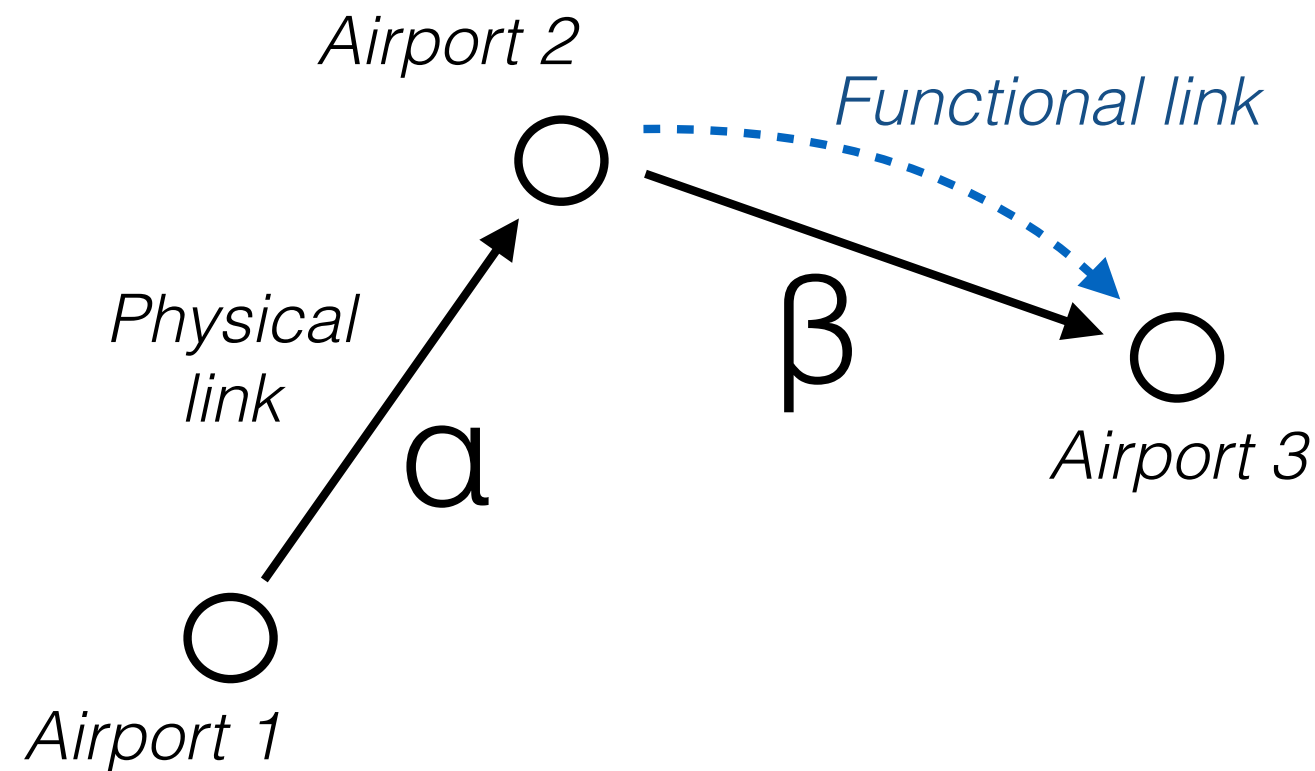


LC
MI
→
GC
TE





Dynamical model of delay propagation



Random walk on the physical network

Delay of each agent defined as:

$(\alpha, \beta) * \text{Previous delay}$

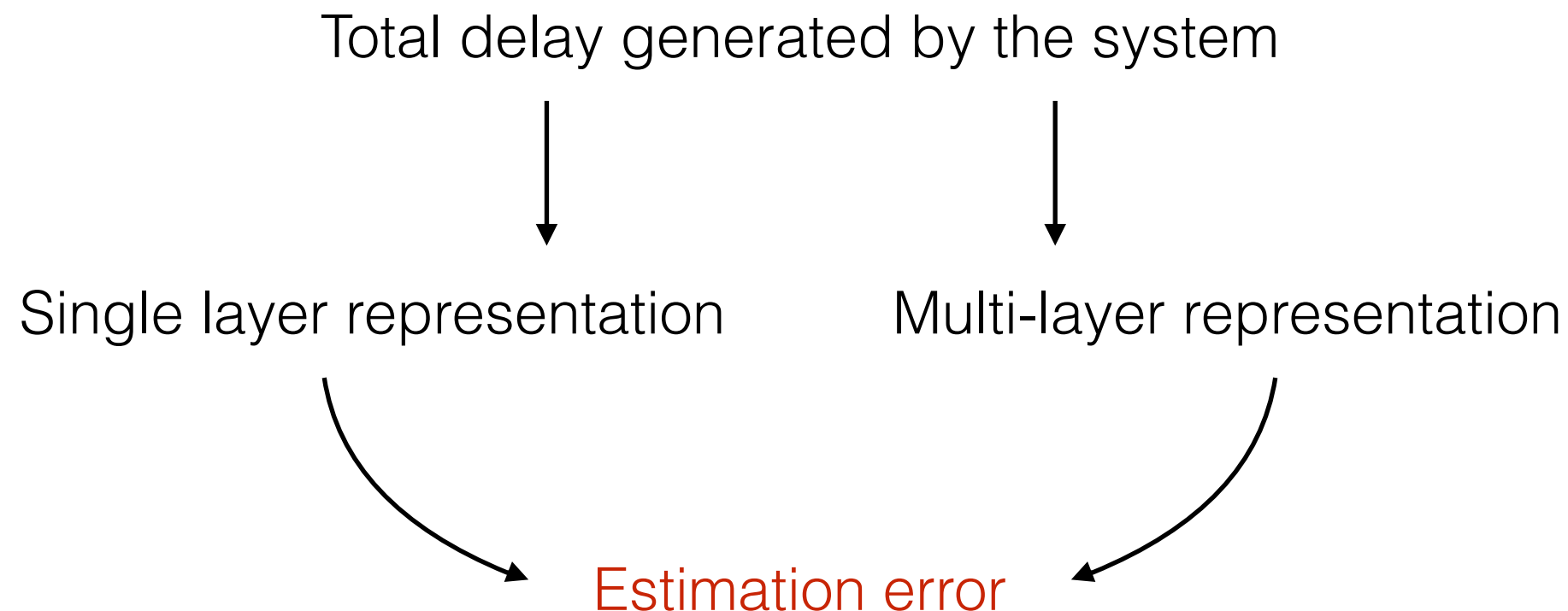
Random term

Negative delays are eliminated

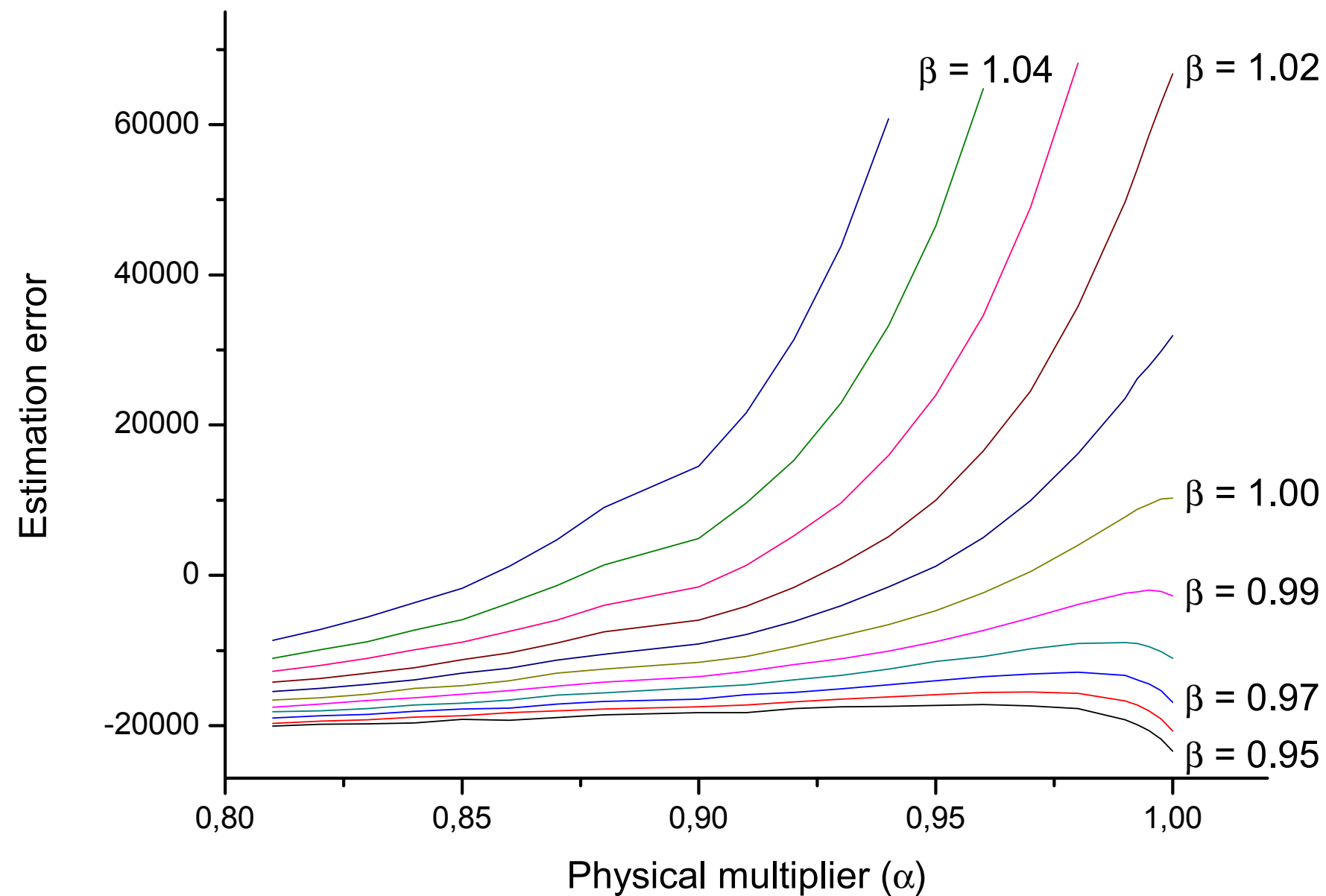
Dynamical model of delay propagation

Random walk on the physical network

Delay of each agent defined as: $(\alpha, \beta) * \text{Previous delay}$
Random term
Negative delays are eliminated



Comparing single vs. multi-layer dynamics

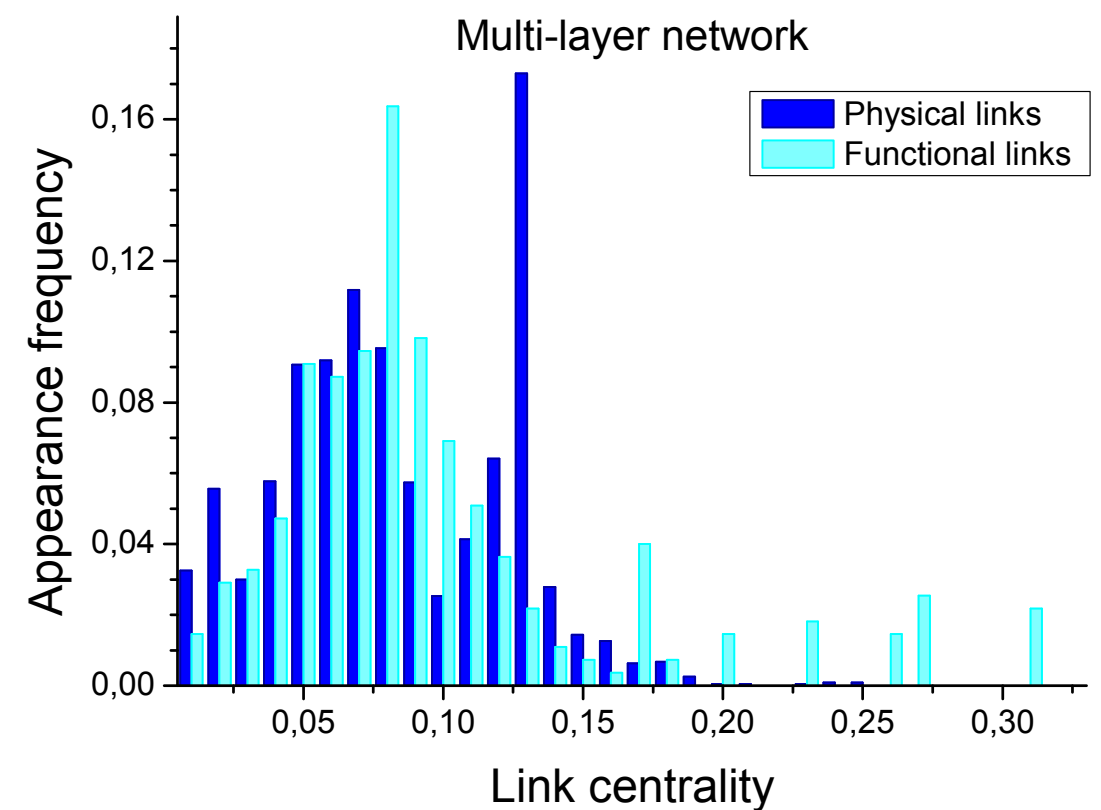
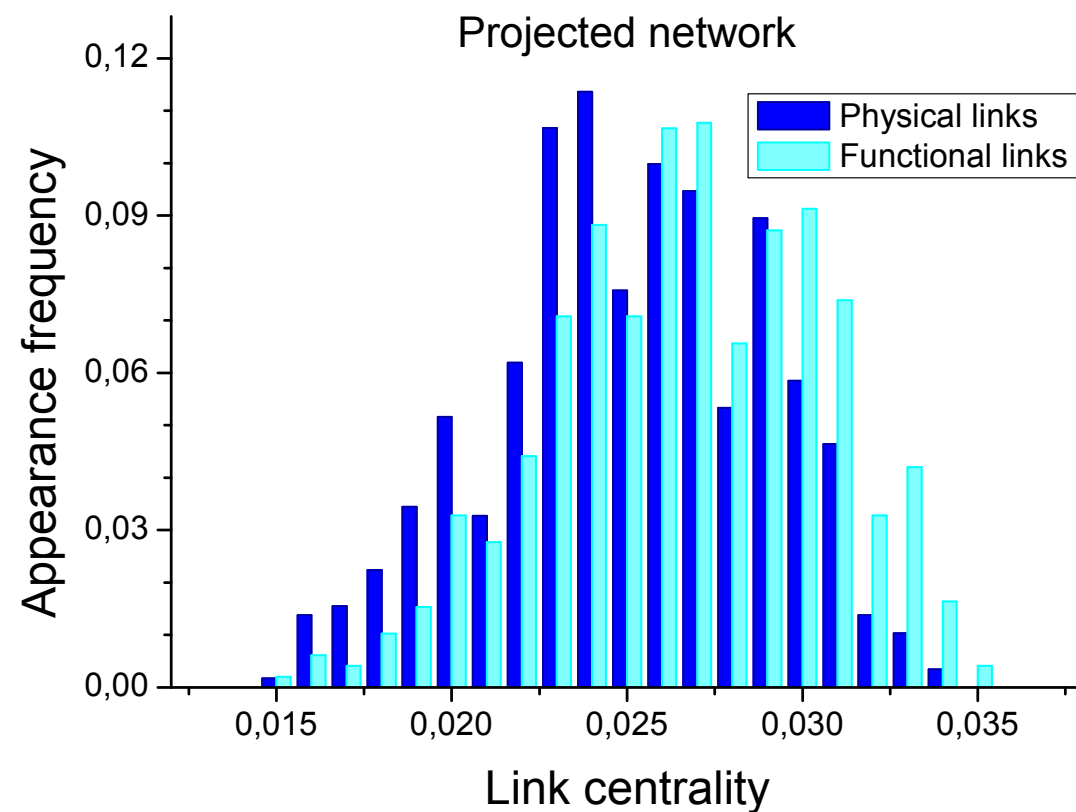


Error of the same order of magnitude than the observable (total delay)

Why such difference?

Distribution of links importance

calculated as α -centrality over the row-normalised adjacency matrix



The importance of key functional links is lost in the projection

Have we got the basics right?

Disregarding the multi-layer structure results in an erroneous assessment of the structure and dynamics of the system

Wrong understanding of delay propagation

Other *layers* to be considered: aircraft, crews, *etc.*



One network does not fit all!

M. Zanin

Multi-layer structure of functional networks: the example of air transport

In preparation

M. Zanin and F. Lillo

Modelling the air transport with complex networks: A short review

Eur. Phys. J. Special Topics 215, 5–21 (2013)

A. Cardillo, J. Gómez-Gardeñes, M. Zanin *et al.*

Emergence of network features from multiplexity

Scientific Reports 2 (2013)

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 314087

Thank you

SERIOUS GAMES FOR RESEARCH PURPOSES



Sapienza University of Rome



www and Science

39% of the whole population of Earth (ca. 3 billion people) is accessing Internet;

77% in the developed countries.

MAIN QUESTION:

Can we use them to do Science?

ANSWER:

Yes, but we need to be clever...



Citizen Science

DEFINITION:

Citizen science is scientific research conducted, in whole or in part, by amateur or nonprofessional scientists.

Traditional applications are found in Astronomy, Ornithology, Zoology, Botany, Climatology, etc.



interdisciplinary
communication
natural science
lab
biology
synchronous
fun
field
issues
data
habitat
engage
hands on
biodiversity
experiment
problem solving
science education
conservation biology
distance learning
environmental science
asynchronous
investigate
creativity
ecosystems
explore
questions
21st century
migration
species
inquiry
experience

citizen science



Citizen Science projects

Lots of projects (see wikipedia article for a non up-to-date list)

- Christmas Bird Count, which began in 1900 (Ornithology)
- Cicada Watch (Entomology)
- eBird (Ornithology)
- Fraxinus (Genetics)
- The Hazelnut Project (Botany)
- NatureWatch (Ecology)
- EveryAware (Environment)
- OPAL (<http://www.opalexplorenature.org/>) REALLY WORTH a LOOK!

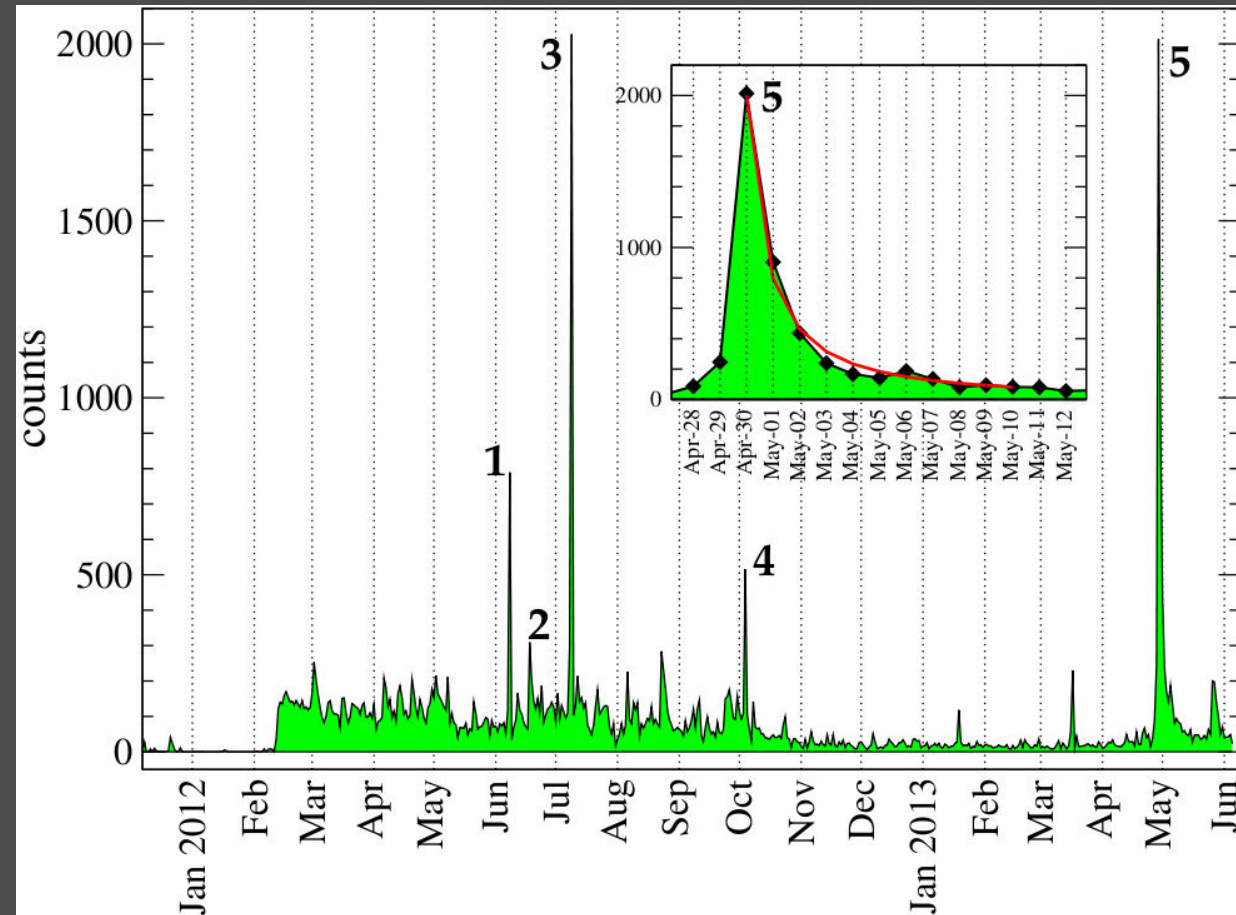
Lots of investments and the recent creation of the European Citizen Science Association (ECSA)

BIG PROBLEM: PARTICIPATION

Among common people the interest in Science fades out with time

WideNoise daily usage:

WideNoise is an App we developed to measure noise level.



- (1) case study in Rome (9th June 2012);
- (2) launch of the Heathrow activities (19th June 2012);
- (3) Antwerp test case (10th July 2012);
- (4) Birmingham workshop (5th October 2012);
- (5) article in German regional newspaper (29th April 2013)

WEB-BASED GAMES



Luis Von Ahn

(the one who conceived the CAPTCHA)

“Massive-scale online collaboration”
talk at TED.com



Von Ahn's Ph.D. thesis is the first work on Games With A Purpose (**GWAP**), which are games played by humans that produce useful computation as a side-effect.

The most famous example is the ESP Game:

Two players are shown an image and asked to enter a word that describes it. The players can't see each other's guesses. The aim is to enter the same word as your partner in the shortest possible time.



4 months, 13,630 players, 1,271,451 labels, 293,760 different images!

MMORP-GAMES



Jane McGonigal:

“Gaming can make a better world” talk at TED.com

ABSTRACT:

Games like **World of Warcraft** give players the means to save worlds...

What if we could harness this gamer power to solve real-world problems?

100M players, 7.7M subscribers, 6.2M active players in 2013.

Collectively, all the **World of Warcraft** gamers have spent 5.93 million years solving the virtual problems of Azeroth.

Second biggest wiki in the world, with nearly 80,000 articles, is the World of Warcraft wiki.

To solve real problems:

World without Oil game where one has to survive, 1700 test players who changed their behavior with respect to the environment.

VIRTUAL AIRSPACES

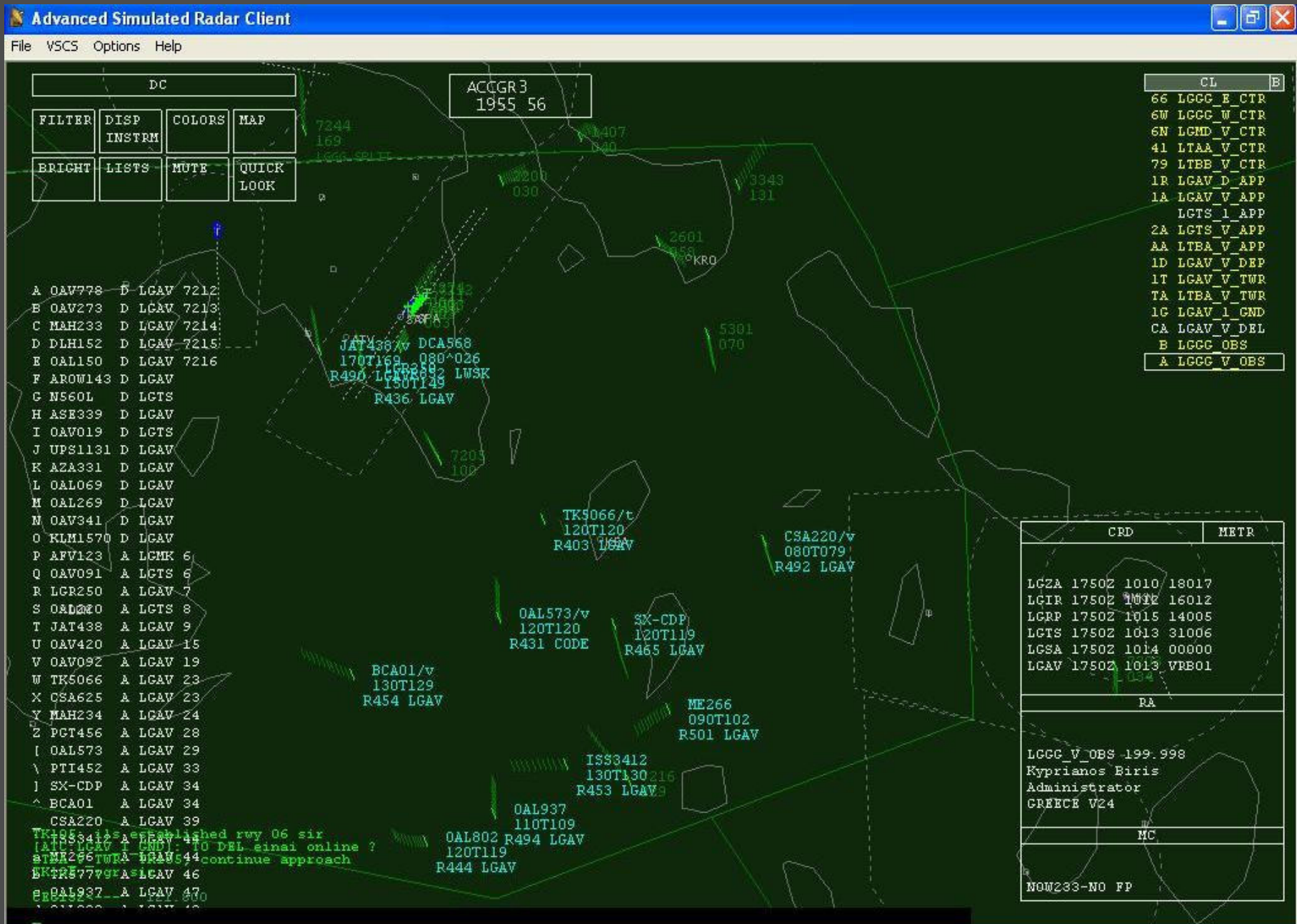
- Virtual Air Traffic Simulation Network (VATSIM)
200k registered users, mostly USA;
- International Virtual Aviation Organization (IVAIO)
151k registered users, 40k active, 8k connections/day, 900 users peak, mainly Europe;
- Virtual Skies Network
seems currently down...

Members are given a choice to fly online as either a pilot or to be an air traffic controller and direct traffic, all of which follow real world procedures.

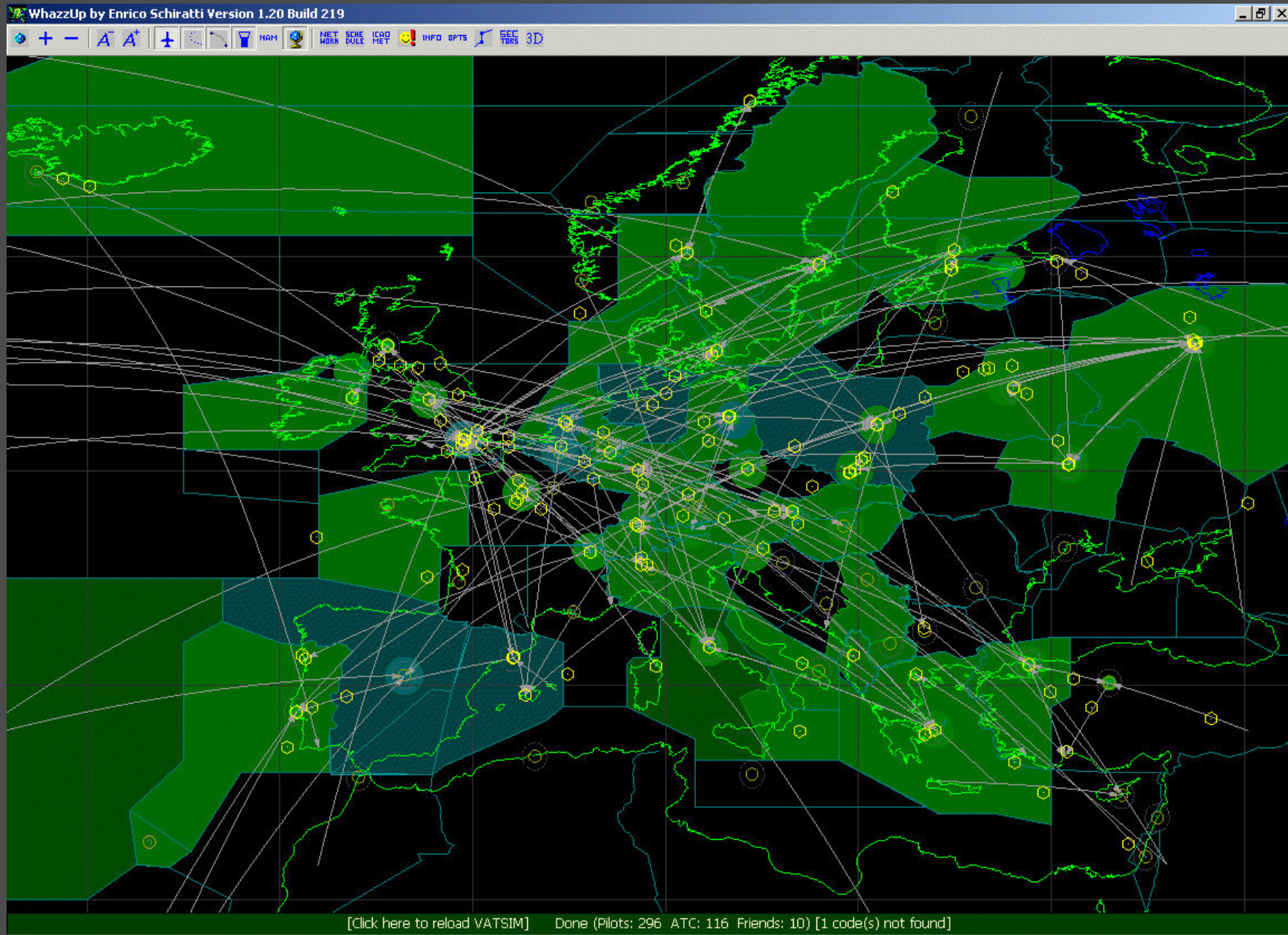
To become ATC, players must pass a training phase.

Available data? Compare with real AT? Inject critical situations?

VATSIM ATC interface



VATSIM Opensky event 2002



peak of 798 concurrent connections

A platform for web-based experiments



tribe

experimental tribe

is a web platform for gaming and social computation. It helps researchers to realize web games/experiments and it let people join, while enjoying, the scientific research.

Login



facebook

Sign up through Facebook



Home

Experiments

Development

About

Credits

Forums

Profile

XTribe trailer released @ Lagrange Prize Awarding Ceremony

Submitted by admin on Fri, 2013-06-28 16:13

Meet XTribe



0:00 / 2:54

YouTube

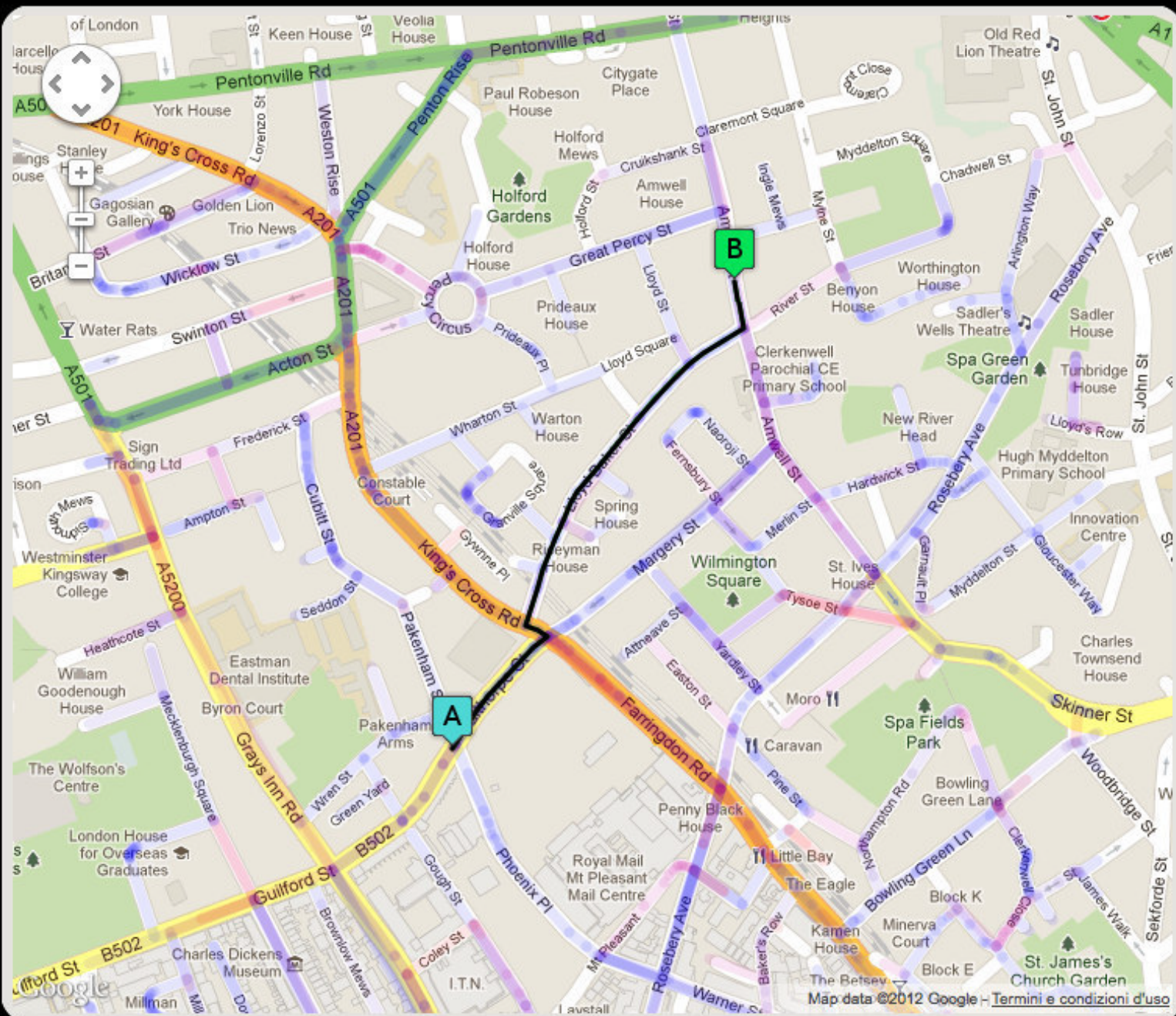


www.shutterstock.com · 67389178

<http://www.xtribe.eu>

, Workshop ELSA, Rome, March 20th 2014

City Race



City Race

Score: good!



Exact score is 1.00

	You	Google
Distance (m)	570	571
Time (s)	1min 15s	1min 15s
Speed (km/h)	27.35	27.40

Play Again

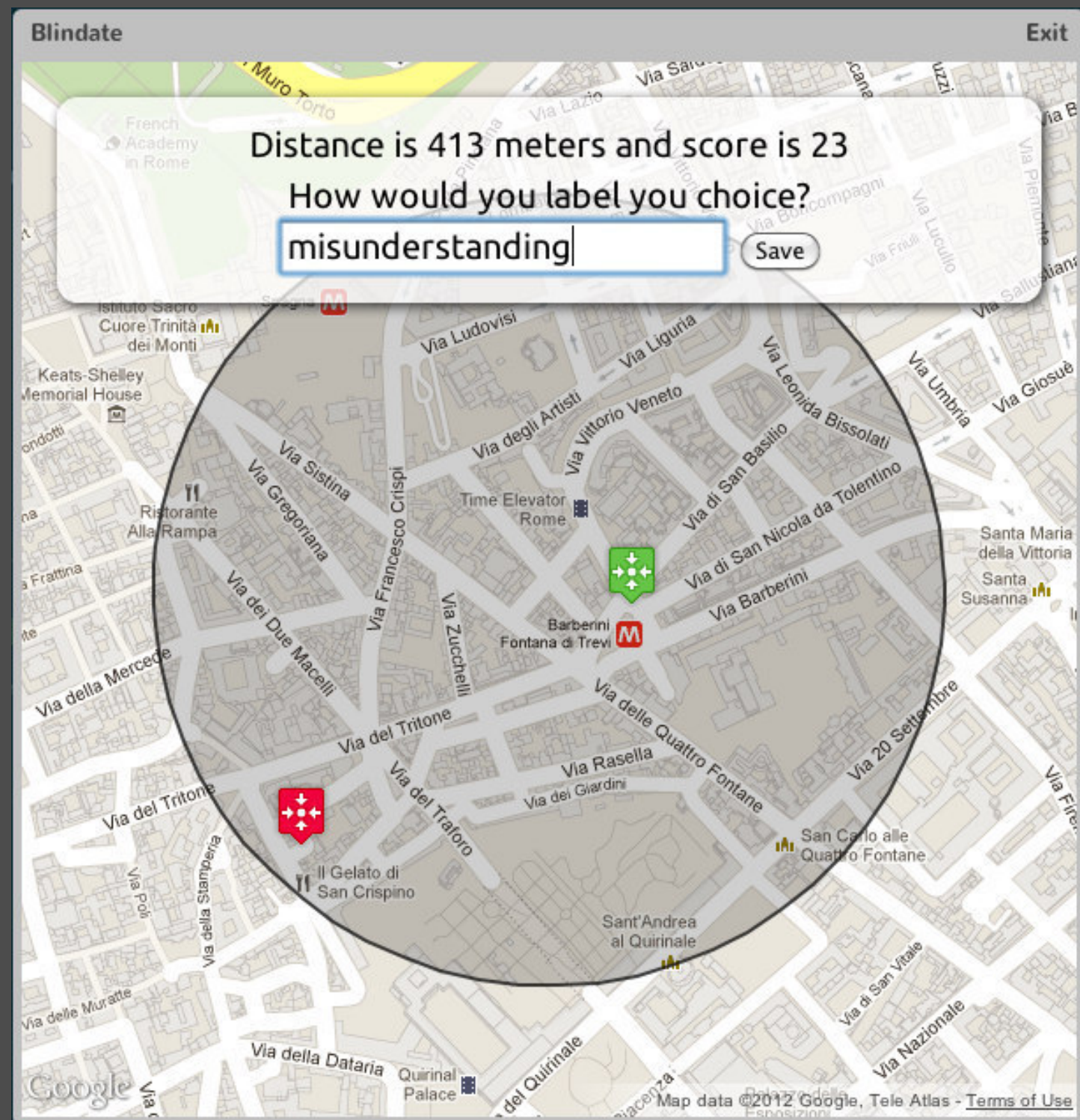
Without traffic information:

1.00.

	You	Google
Time (s)	2min 6s	2min 6s
Speed (km/h)	16.29	16.31

You lost your friend in town.
Where would you go to meet him/her again?

A map of City Focal Points



ELSA Workshop, Rome March 20, 2013

HUMAN MOBILITY:
from Individual Behavior
to Network Dynamics

cc

Complex Systems Group, Physics of the City Laboratory
Physics and Astronomy Department, Bologna University

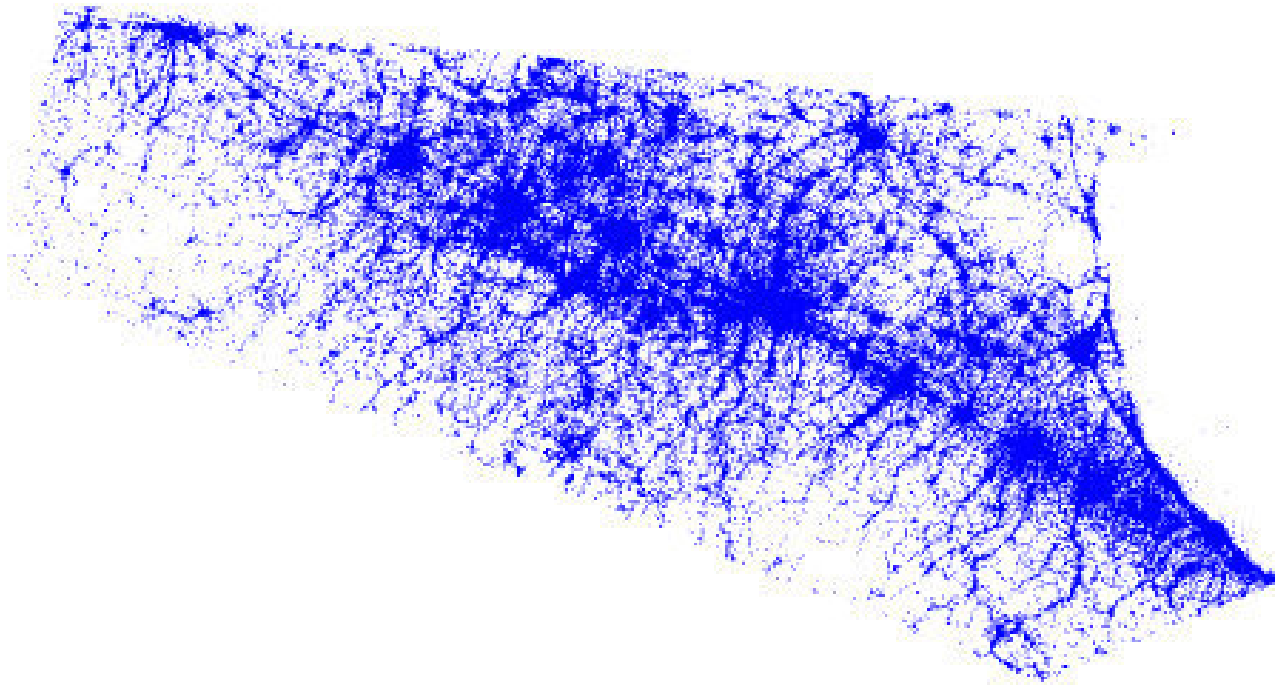
Main goal

To understand from empirical data on individual mobility (complex system) the emergence of macroscopic 'universal' statistical laws on human mobility (statistical physics for complex systems), their meaning and their applicability distinguishing between cognitive aspects and physical dynamics.

To develop a statistical-dynamical physics approach to human mobility (thermodynamics, state function, critical phenomena, phase transitions,...) in order to forecast (now-cast) and to describe the appearance of critical states (congestion).

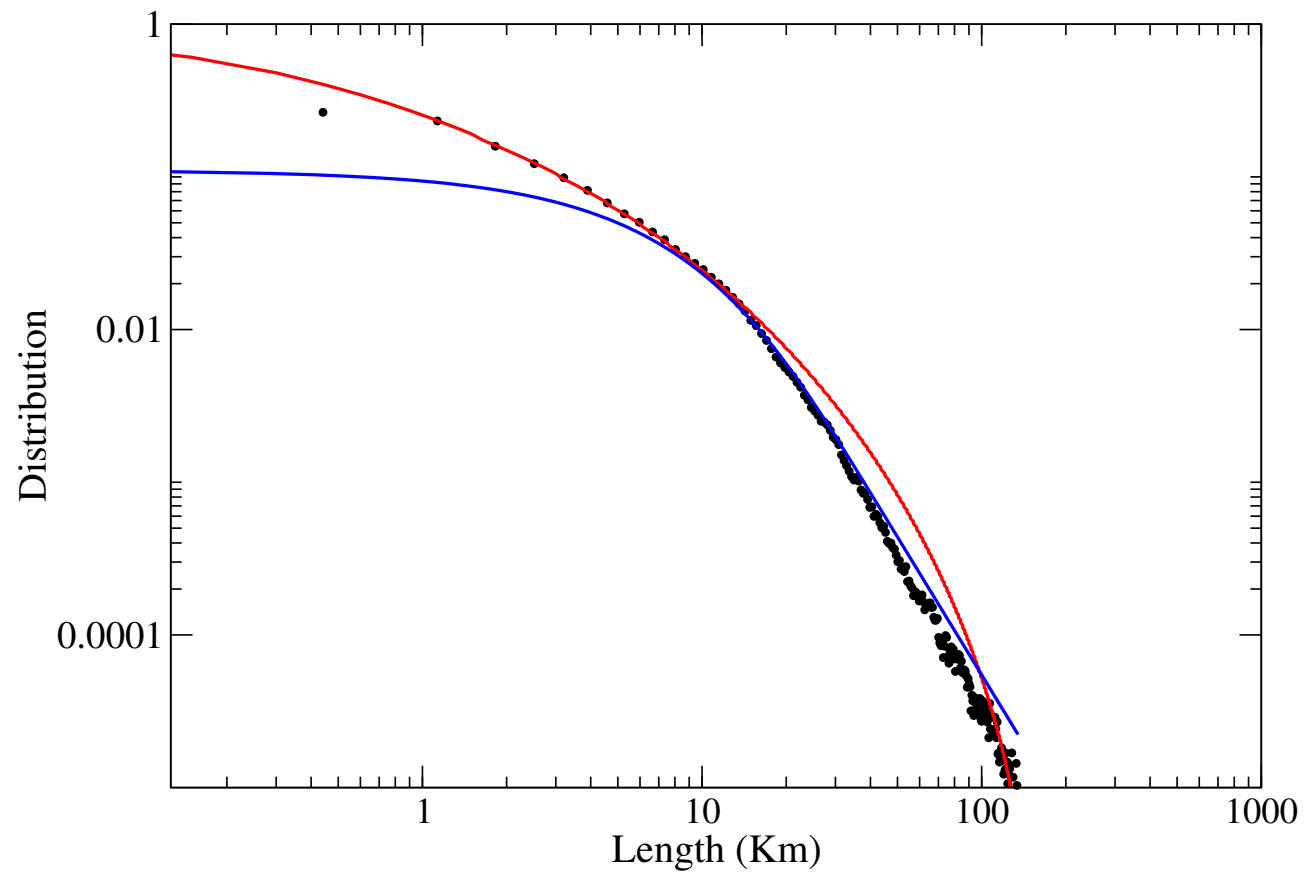
Microscopic data: Octotelematics data base

GPS data from single vehicle: a sampling of trajectories at a spatial scale of 2 Km or a time scale of 30 sec. $\simeq 2\%$ of italian vehicle population involved (i.e. 800,000 vehicles).

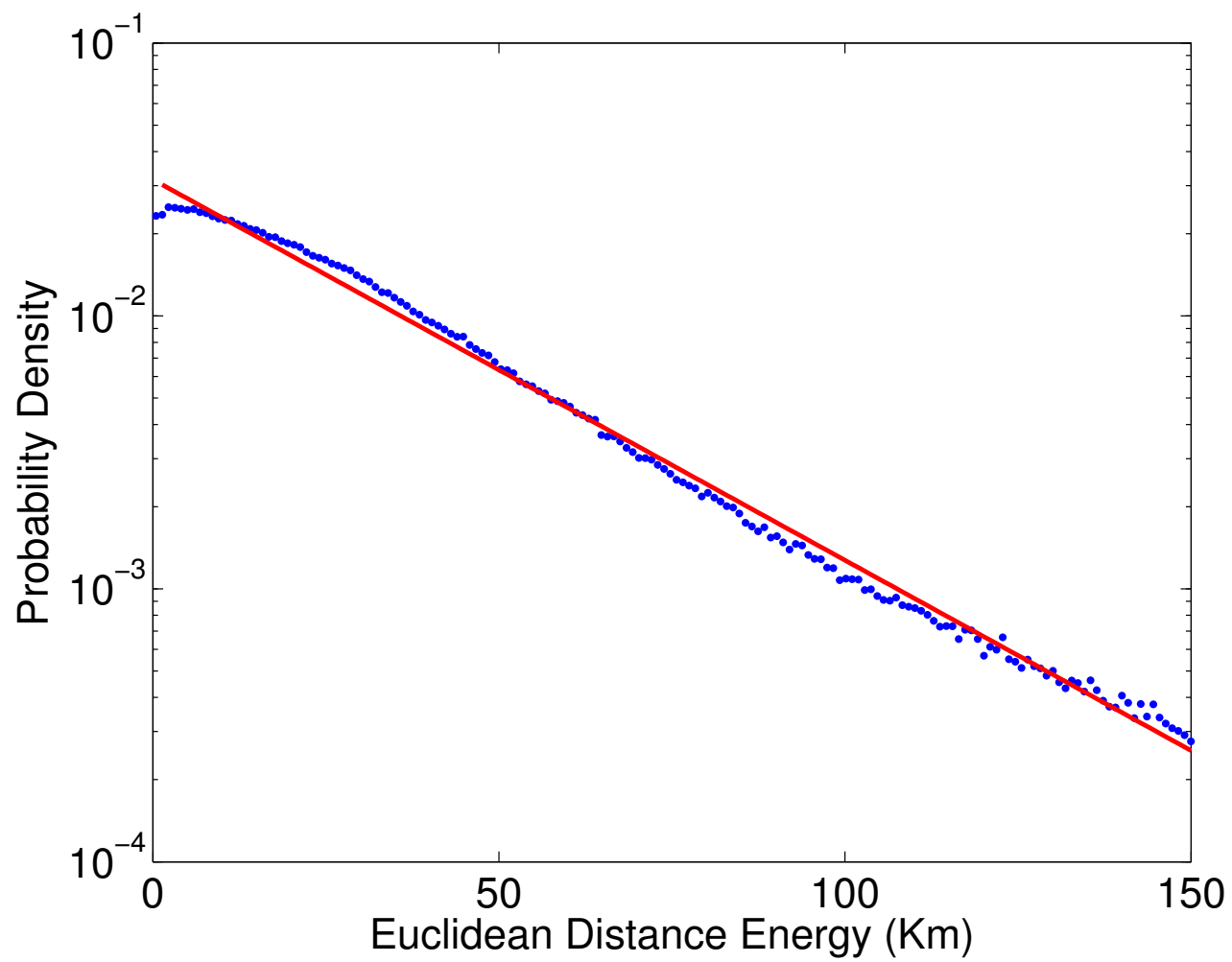


Examples of statistical laws

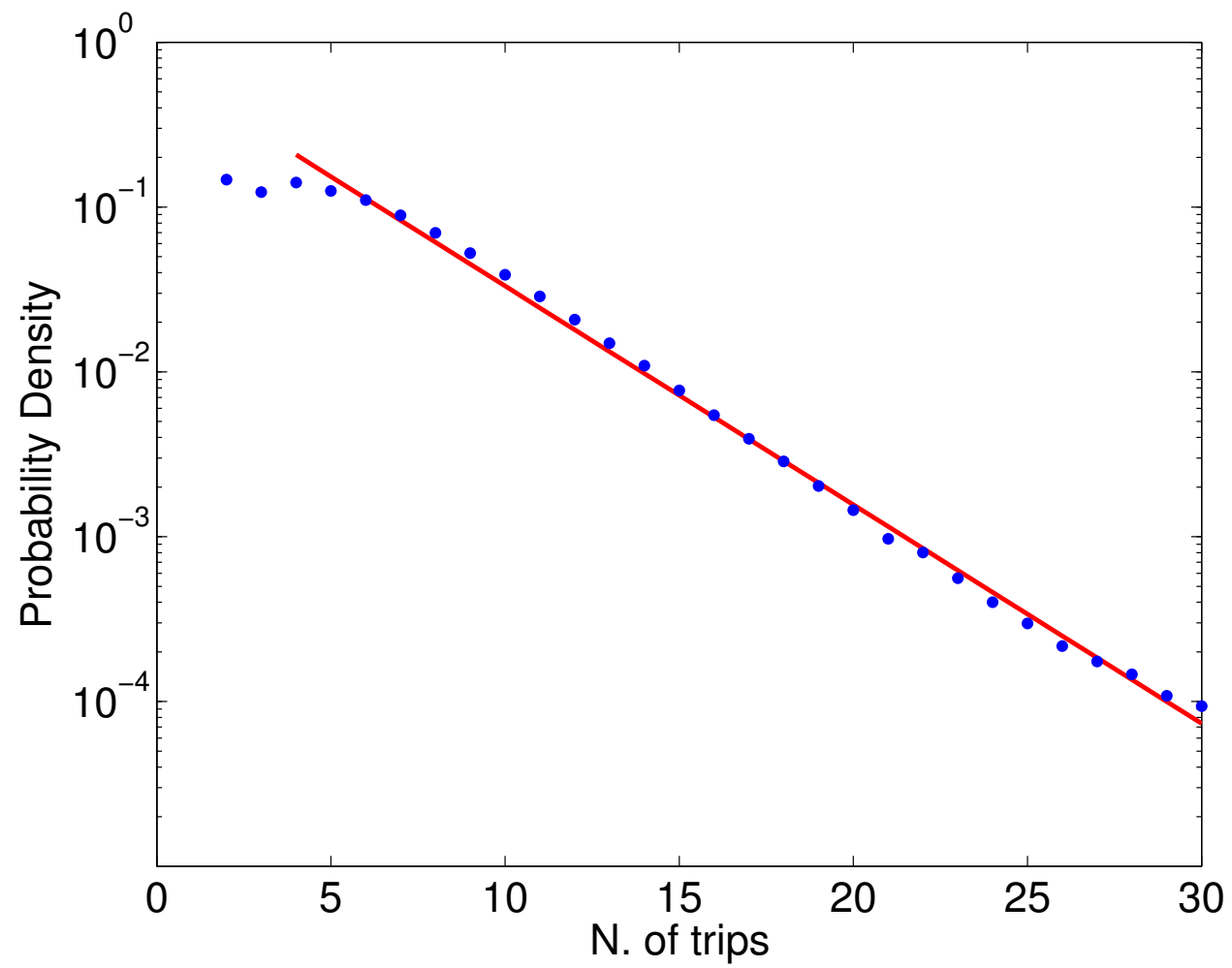
Trip length distribution (A.Bazzani et al JSTAT 2010)



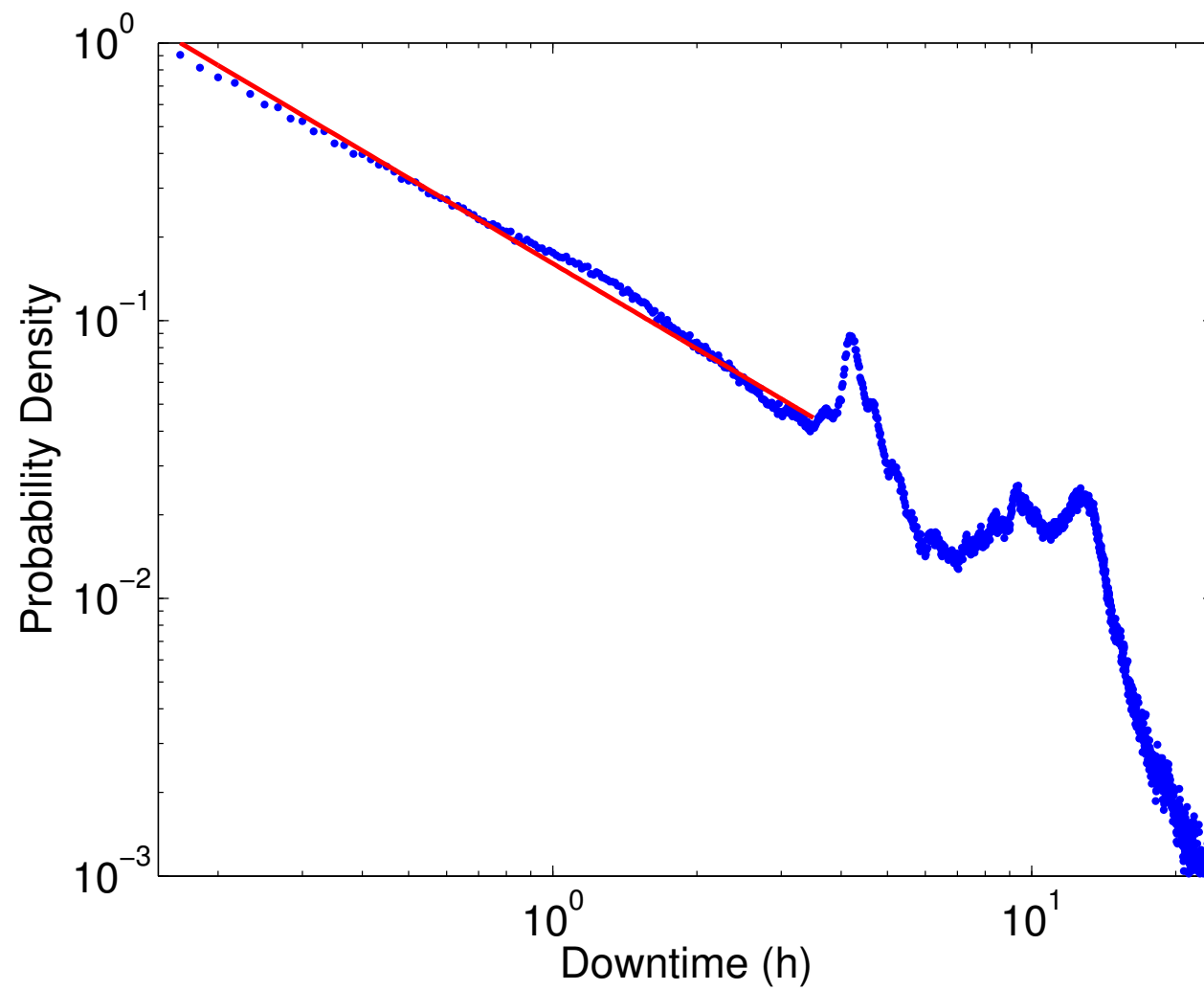
Daily mobility length distribution



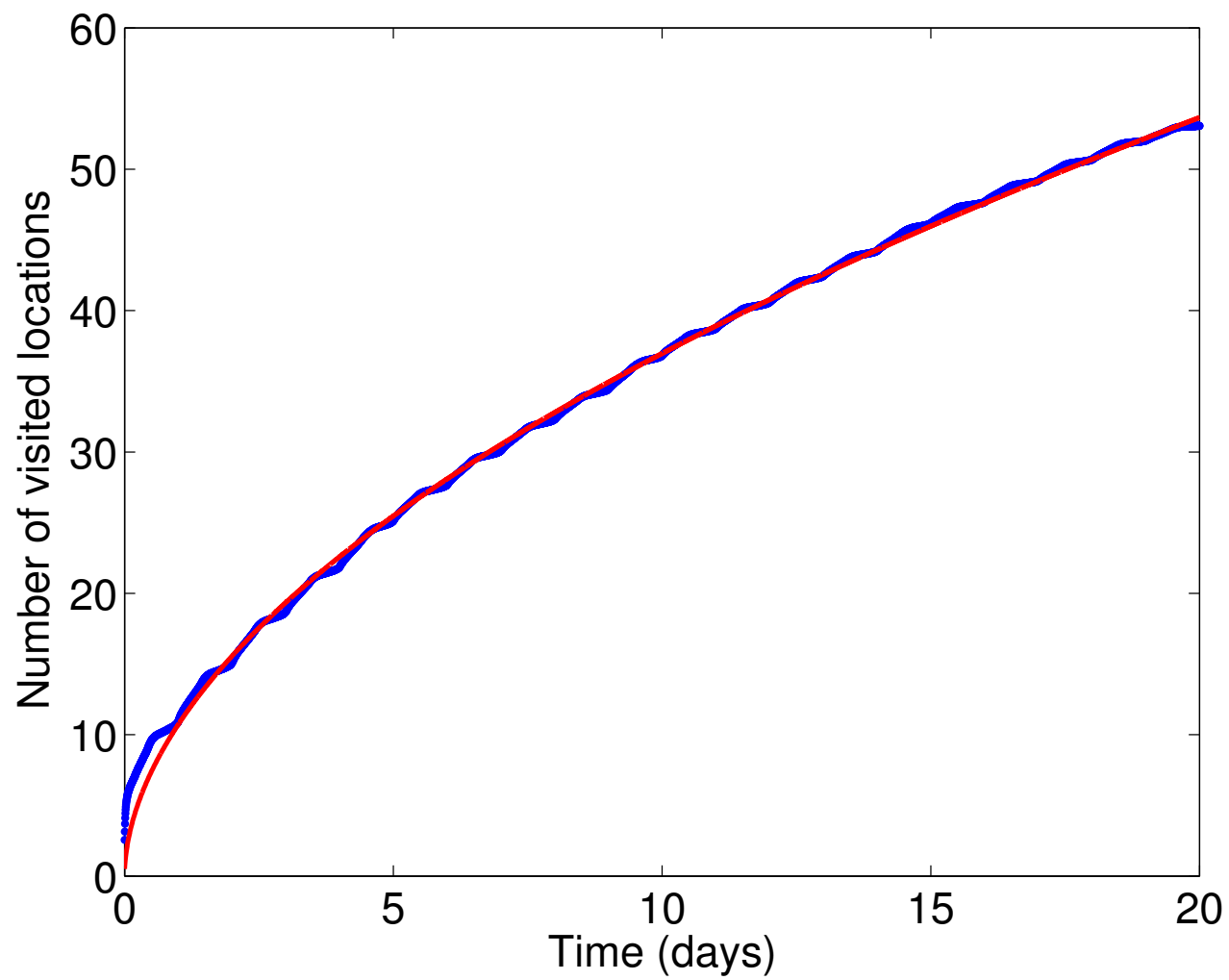
Daily activity distribution



Daily mobility time distribution



New activities evolution



Question: how this laws relate to individual dynamics?

The individuals behavior is highly heterogeneous.

The individual behavior is the result of a strategy: even if we consider individuals as independent particles, we certainly have time correlation in the dynamics.
(A.Bazzani et al JSTAT 2013)

Classifying individual mobility

The problem is still open: which observables are necessary to classify the individual daily mobility. To enroll the individual strategies we have analyzed the GPS signals from an entropic point of view. Two kind of signals have been considered: **time patterns** (at a fixed time scale) and **jump patterns** (focused on the activities longer than a certain time scale)

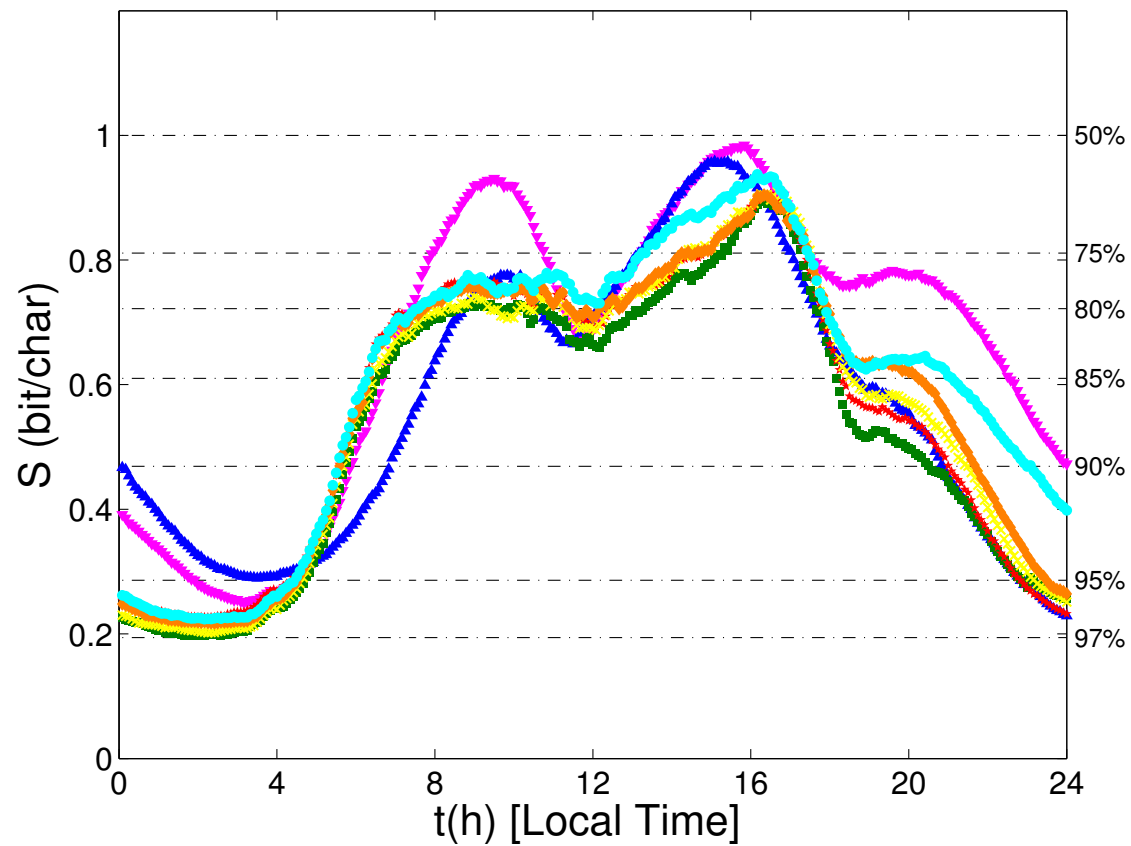
Two definition for Entropy are used: Shannon Entropy

$$S(t_i) = - \sum_{j=1}^N p_j(t_i) \log_2 p_j(t_i)$$

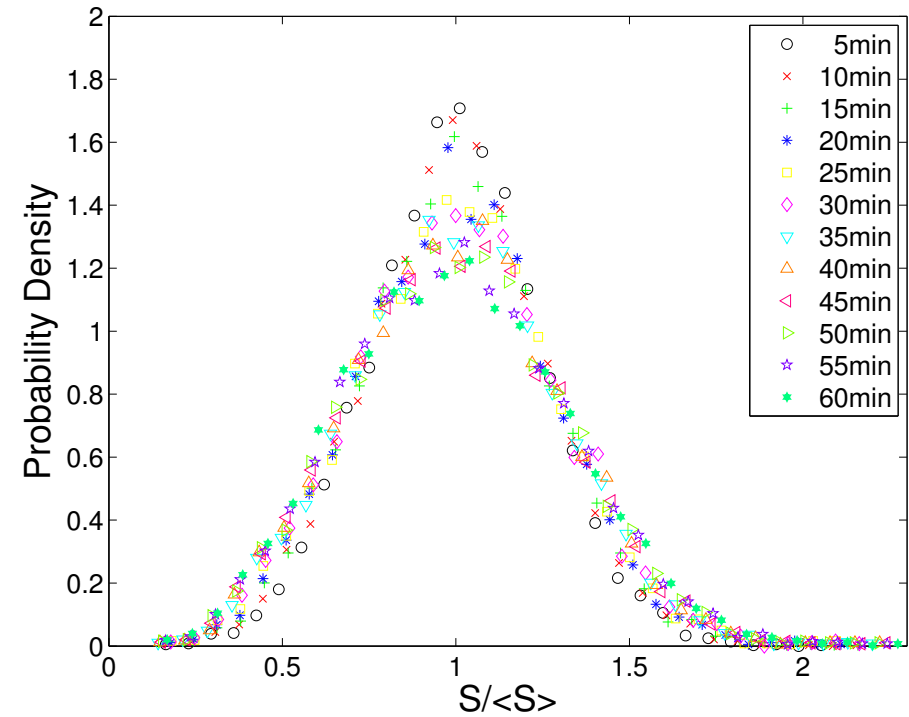
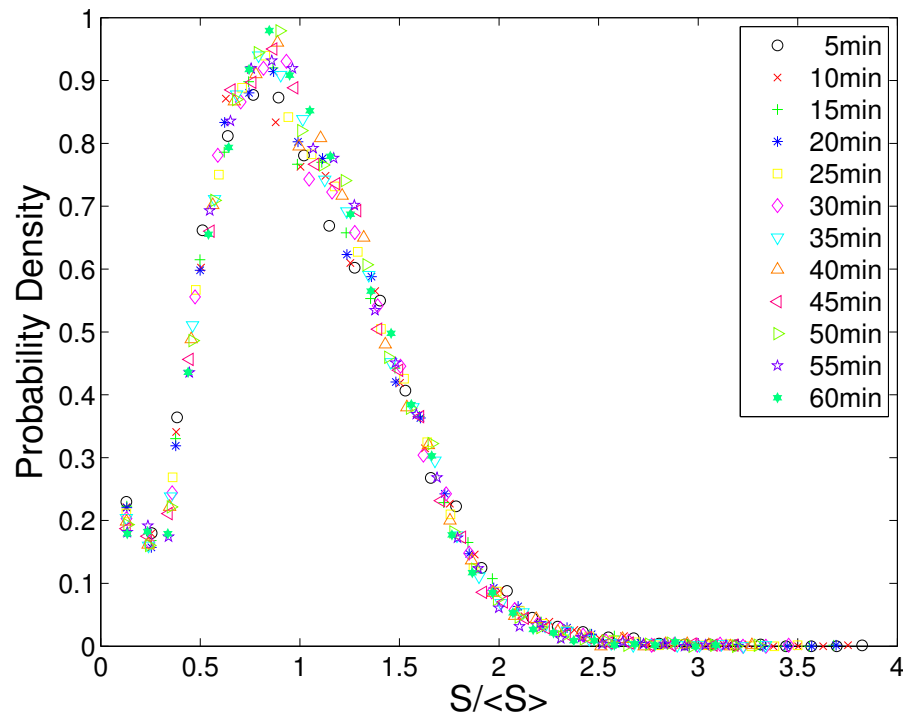
and the compressible Entropy (Lempel-Ziv algorithm estimator).

Time pattern analysis

Circadian rhythms and Entropy

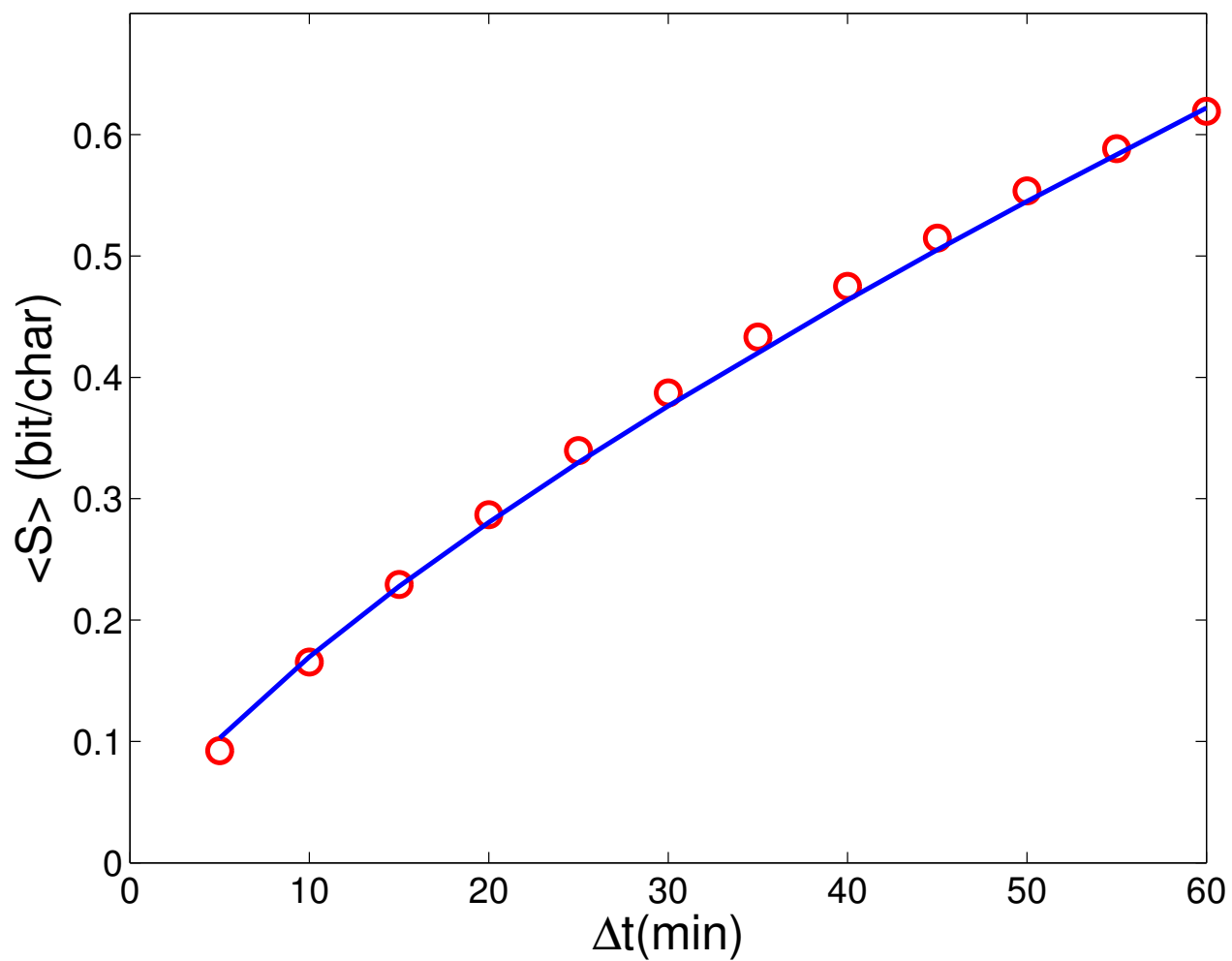


Entropy distributions has a universality character with respect to the time scale (time sampling), depending only on the average entropy.



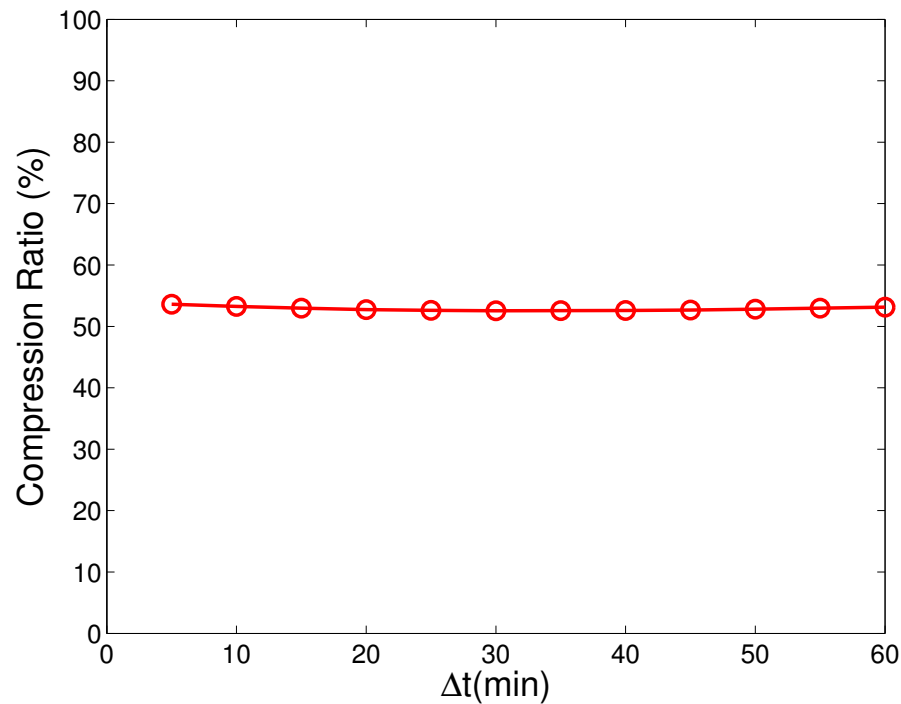
(Left picture) Time patterns, (Right picture) Jump patterns

The average entropy of time patterns is related to the Benford's distribution in the downtimes



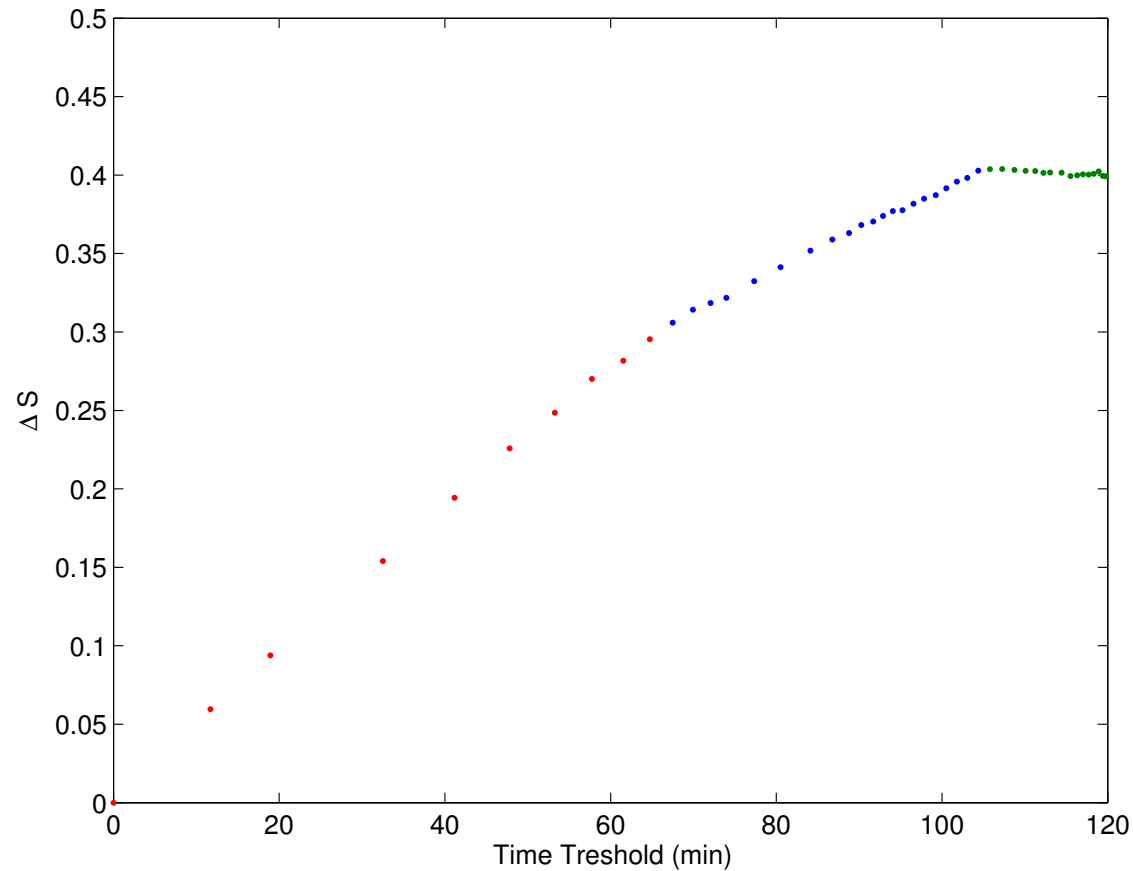
Jump pattern analysis

Existence of a time scale invariant structure for the time activities: this suggests a 'logtime perception' and goes in the direction of the 'Barabasi bursts' approach to human behavior.



Compression ratio versus time scale.

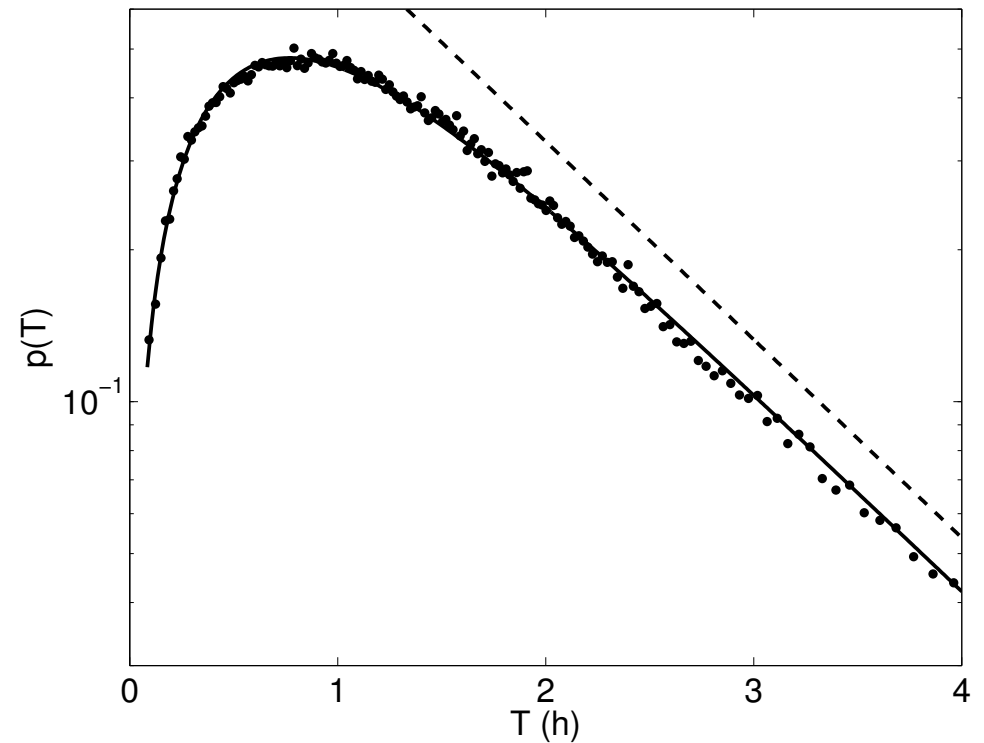
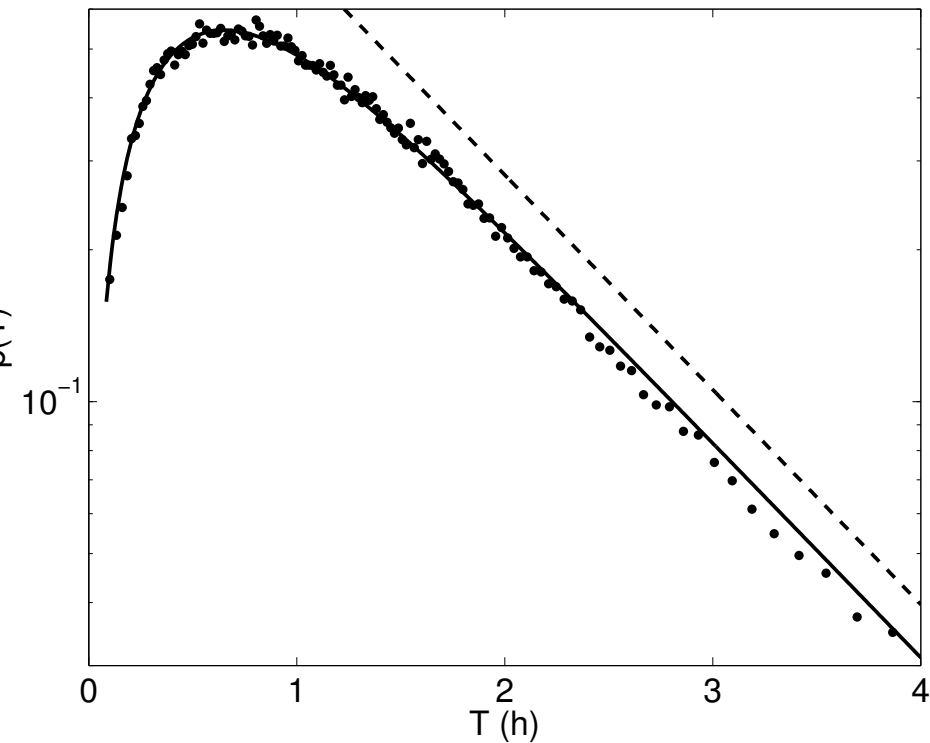
However a iterative shuffling procedure applied to the activities less than a given time scale, points out the existence of three categories for individual activities.



Compression entropy increases with shuffling.

Empirical evidence of a mobility cost function: TTB

We consider the daily mobility of different italian cities, the distribution function of the daily mobility time (TTE) is



TTE computed GPS data(May 2011) for Milan(Left) and Naples(Right).

The model considers a simple master equation for the cumulative probability $P^>(t)$

$$\frac{dP^>}{dt}(t) = -h(t)P^>(t)$$

where the 'risk function' $h(t)$ is given by

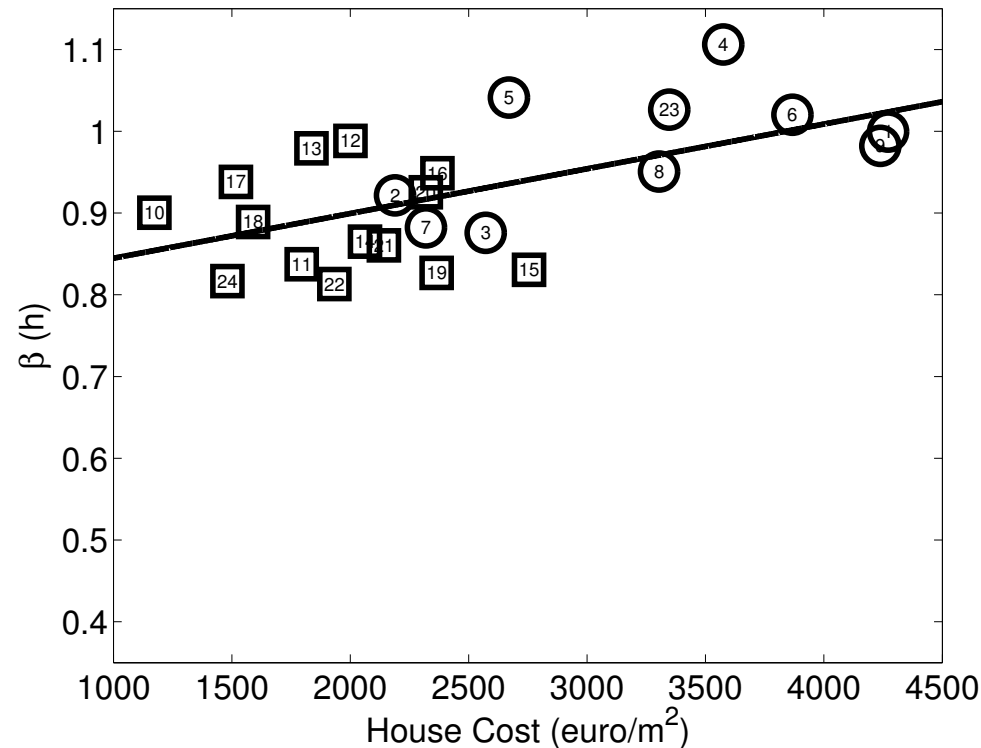
$$h(t) = \frac{1}{\beta}(1 - \exp(-t/\alpha))$$

$h(t)$ is a perceived cost of the performed private mobility. The probability density function TTE distribution reads

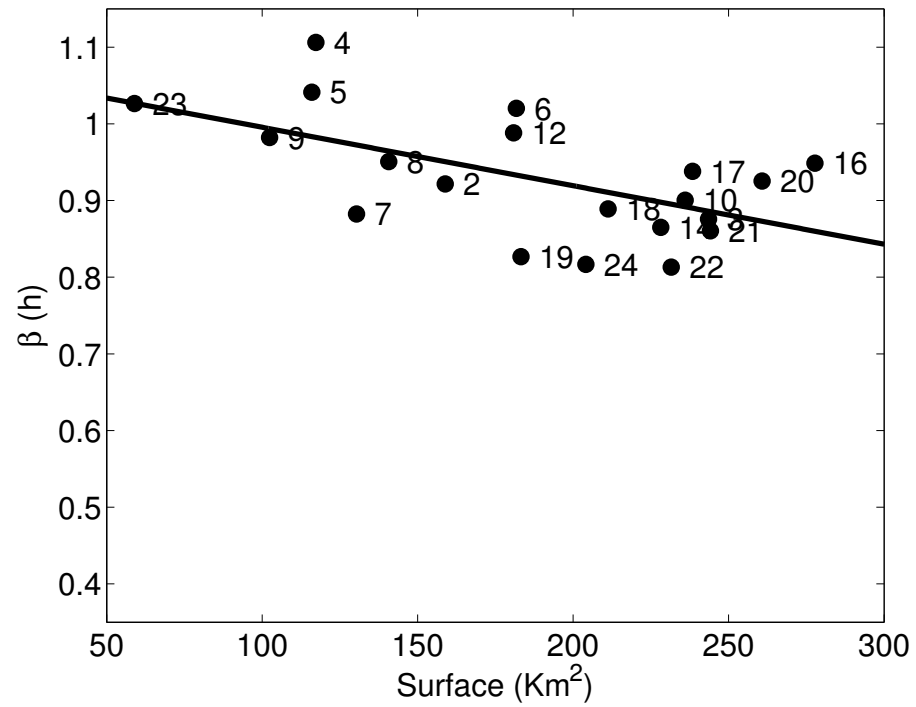
$$p(T) = C_N \beta^{-1} [1 - \exp(-T/\alpha)] \exp(-\alpha \beta^{-1} \exp(-T/\alpha) - T/\beta)$$

Travel Time Budget

The parameter β is proposed as a measure of the Travel Time Budget due to the analogy with average Energy in a Boltzmann distribution. According to our results TTB depends on geographic and economic features.

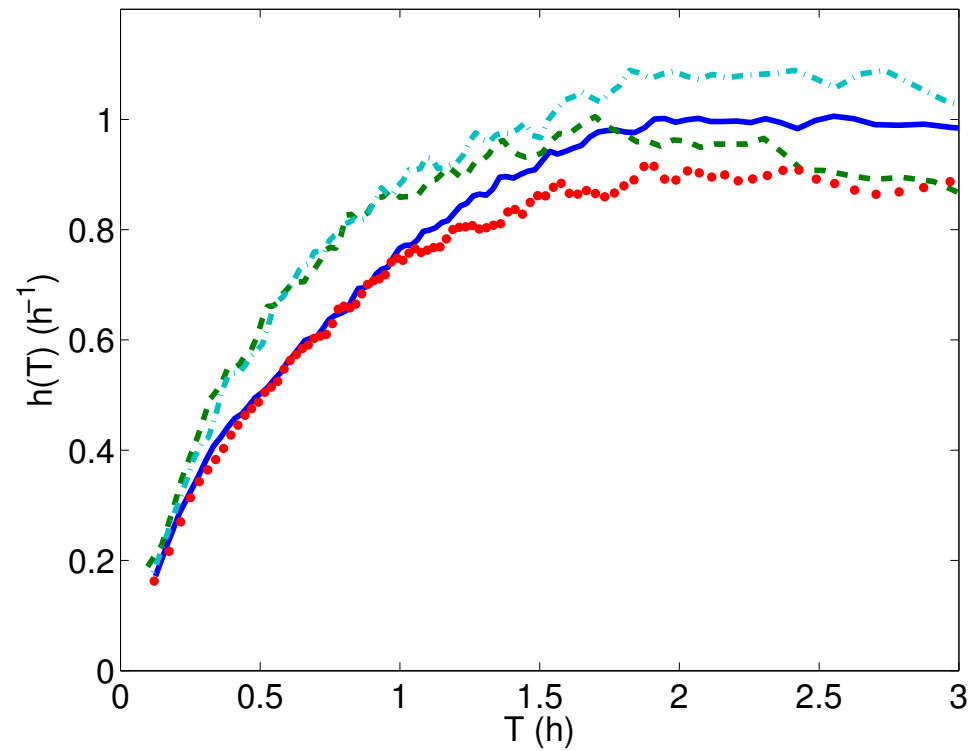


Correlation between the TTB and the house cost per m^2 .



Correlation between the TTB and the municipality surface.

The data suggest that this distribution could be universal for different cities.



Risk function $h(t)$ for different cities computed using GPS data May 2011

Utility Function Model

We propose a simple model based on the concept of **Utility Function**: each trip has an expected utility U (randomly chosen in $[0,1]$) and the perceived cumulative utility of a trip $\mathcal{U}$ during daily mobility is given according to

$$\mathcal{U} = c_1(c_2U - \log(T))$$

Assuming that the decision probability to perform the trip is defined by a logistic model

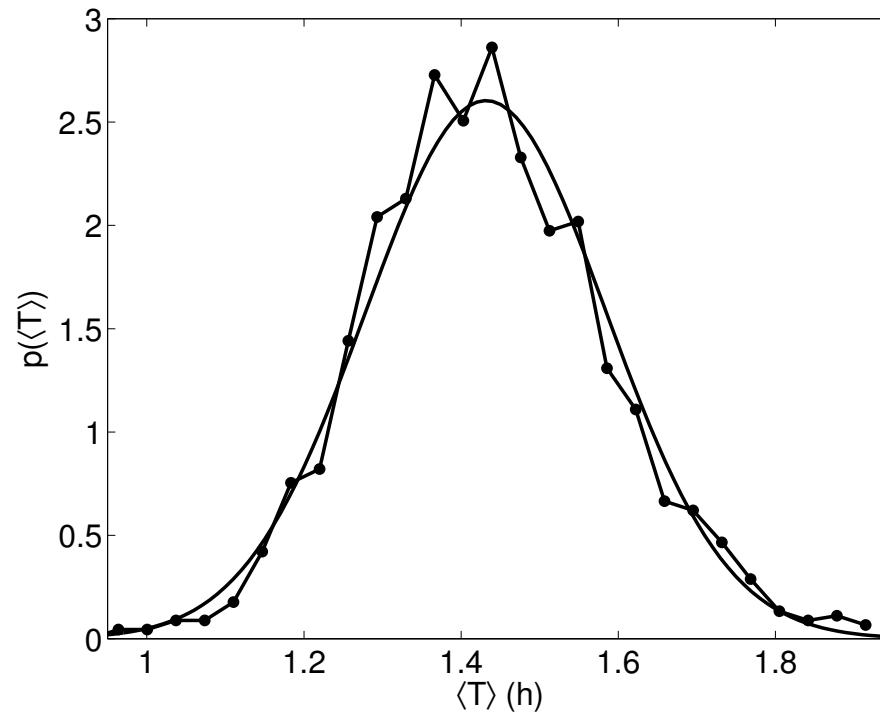
$$p(\mathcal{U}) = \exp(\mathcal{U}) / (1 + \exp(\mathcal{U}))$$

we recover the empirical distribution.

Heterogeneity of the system

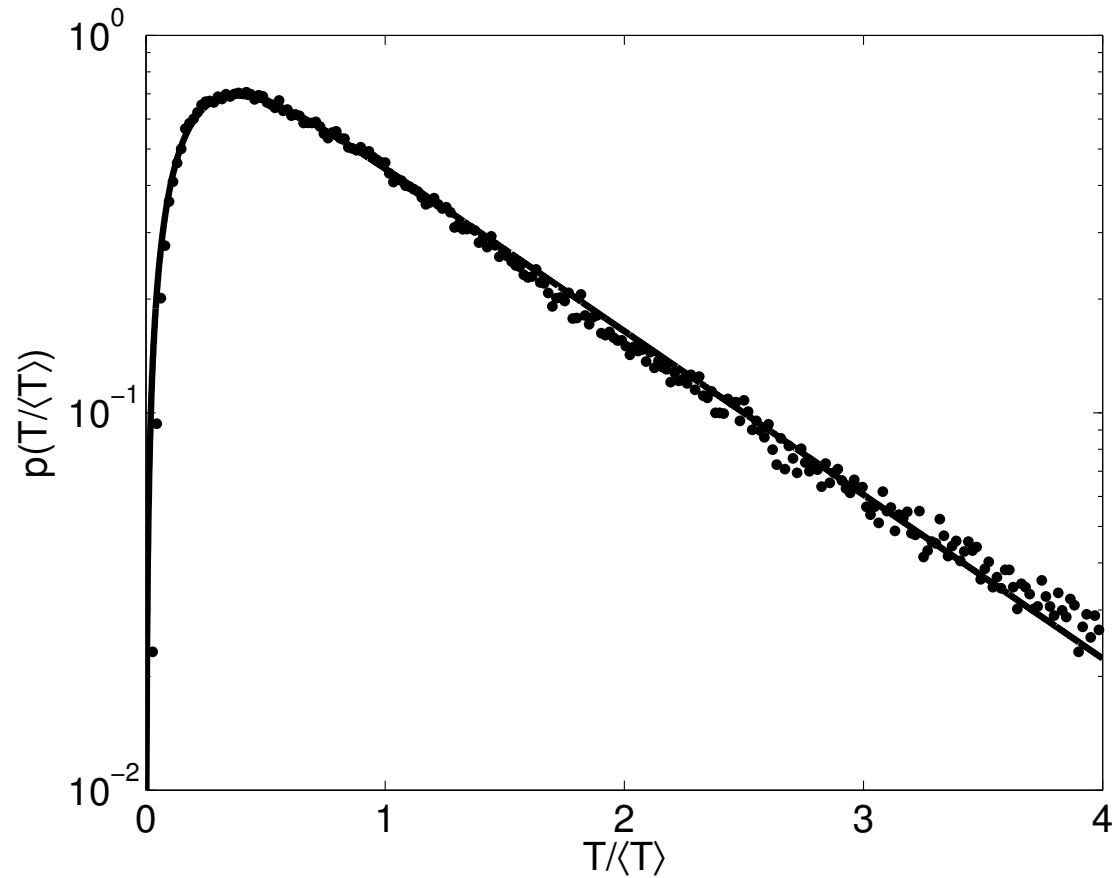
Question: can one apply the ensemble distribution function for TTE to describe the individual mobility?

The distribution of $\langle T \rangle$ is a measure of the system heterogeneity



Distribution of average individual TTE $\langle T \rangle$.

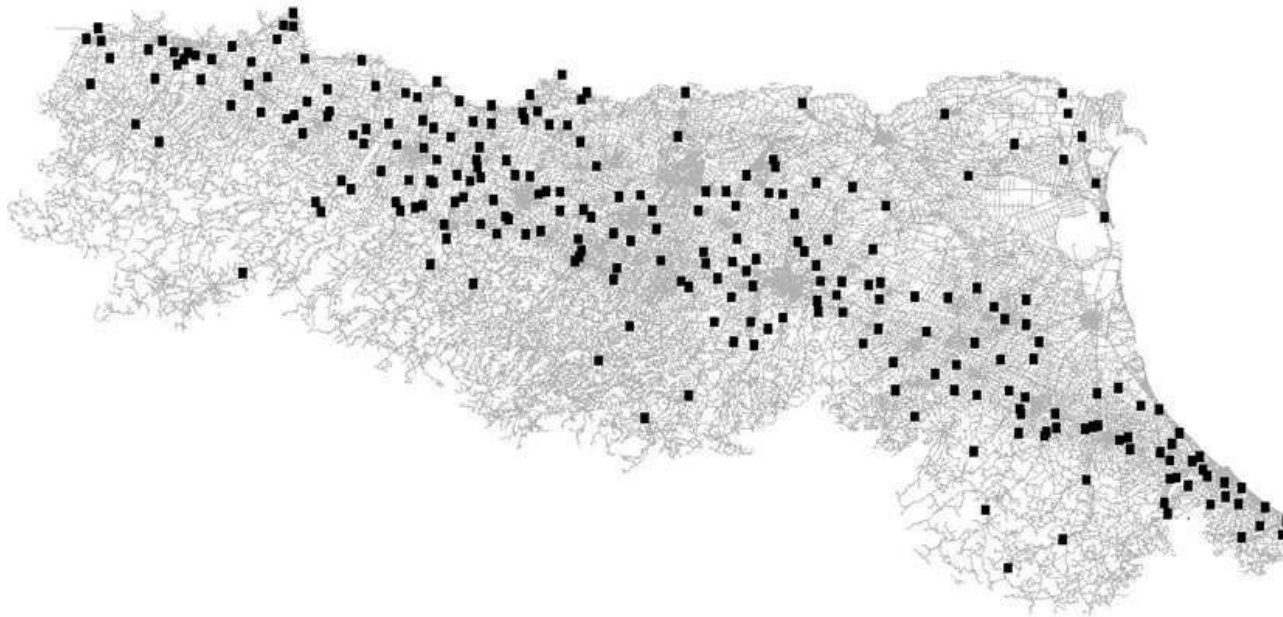
We check the invariance of the TTE distribution once one considers the normalized TTE $T / \langle T \rangle$ for each individual



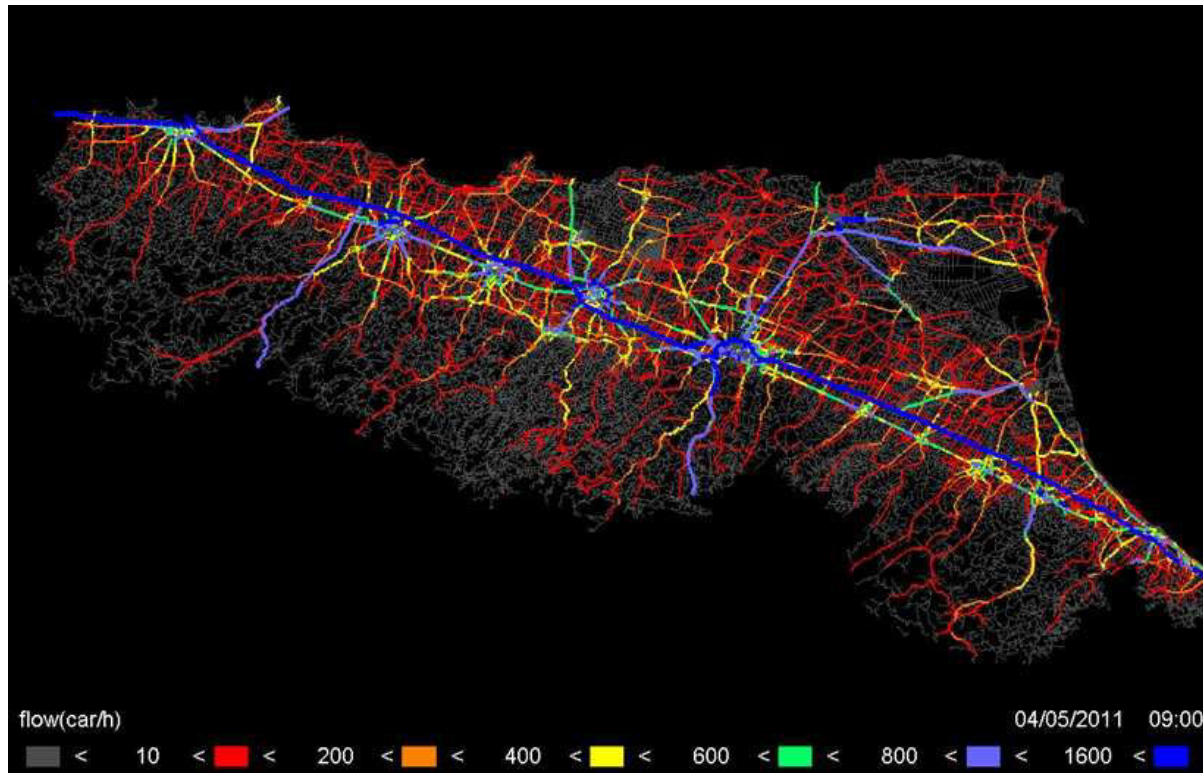
Normalized distribution of individual TTE $T / \langle T \rangle$.

Traffic Flows on a Whole Road Network

Empirical data from magnetic spires in the whole Emilia Romagna region (flow data from magnetic coils)

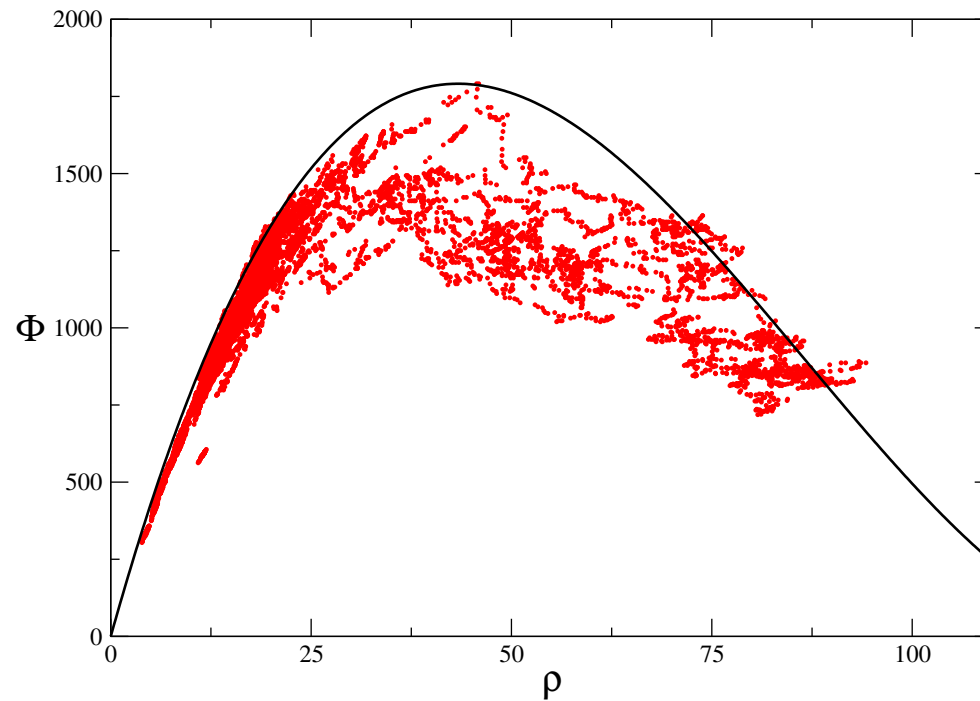


Problem: reconstruct the fluxes evolution in real time on whole network using data fusion and a linear model for the flux propagation.



Emilia Romagna road network: reconstructed of traffic flows at 11:00 a.m., combining GPS data to compute the mobility demand and the flow data to consider the network load.

The flows data allow to reconstruct a fundamental diagram (flow-density), which characterize the road dynamics



Fundamental diagram computed using data from a magnetic coil

Stochastic traffic models on a road network

The traffic dynamics on the network is defined by a stochastic process

$$\begin{aligned} n_k(t + \Delta t) = n_k(t) &+ \Theta(n_k^* - n_k(t)) \sum_j \xi_{jk}^{\Delta t}(t) \phi_j(t) \Delta t \\ &- \sum_j \Theta(n_j^* - n_j(t)) \xi_{kj}^{\Delta t}(t) \phi_k(t) \Delta t \end{aligned}$$

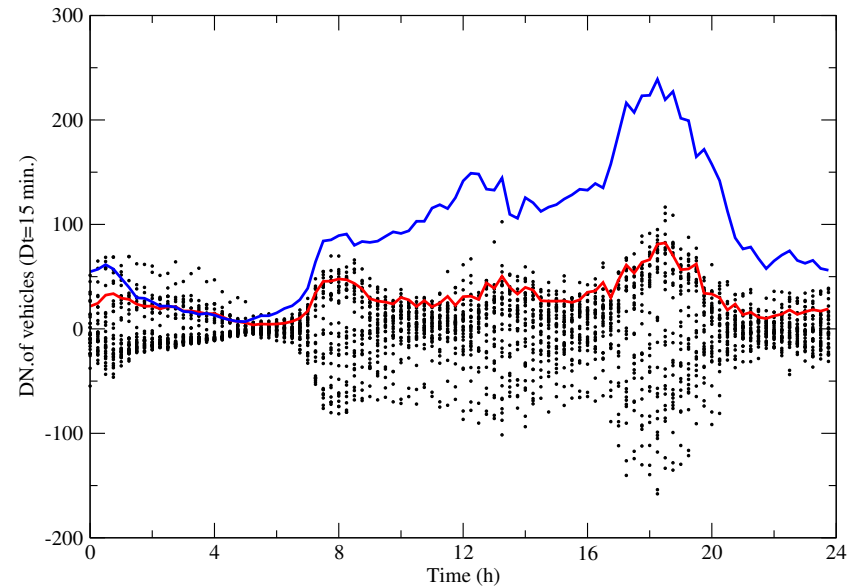
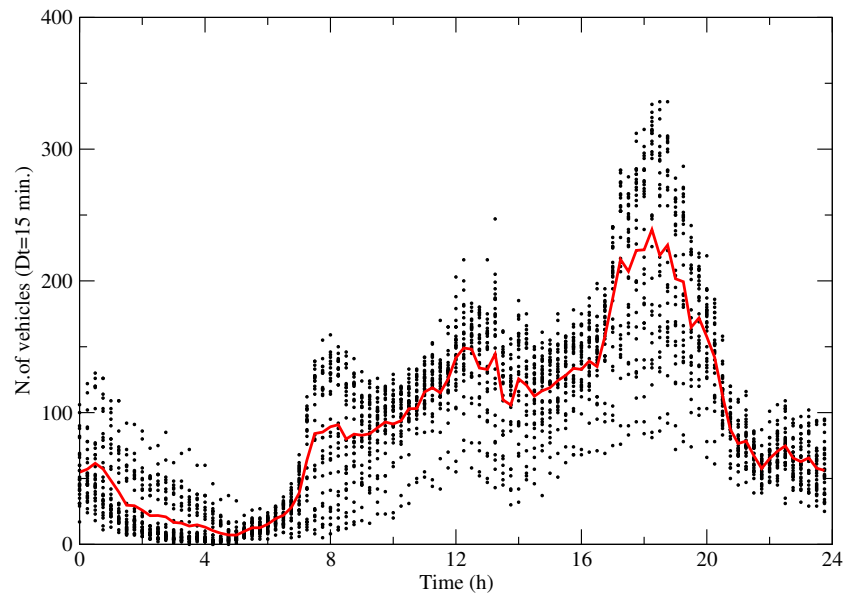
If Δt is small the discrete process is approximated by a continuous stochastic process

$$\begin{aligned} dn_k(t) = &\left(\sum_j \pi_{jk}(t) \phi(n_j) - \sum_j \pi_{kj}(t) \phi(n_k) \right) dt \\ &+ \sum_j \phi(n_j) dw_{jk} - \tau \sum_j \phi(n_k) dw_{jk} \end{aligned}$$

where dw_{jk} is a Wiener process with correlation function

$$< dw_{jk}(t) dw_{j'k'}(t') > = \delta_{jj'} \sigma_{j,kk'}^2 \delta(t - t') dt$$

Flow Data during May 2011: an example



Left picture: flow data with average daily behavior. Right picture: data fluctuations and average standard deviation.

Linearize dynamics near the stable equilibria

To study the effects of the fluctuations on the stability of the stationary solution, we consider the linear noise approximation near the stationary solution. Letting $u_k = n_k - n_k^{eq}$ we get

$$du_k = \sum_j \frac{d\phi}{dn}(n_j^{eq}) \pi_{jk} u_j dt - \frac{d\phi}{dn}(n_k^{eq}) u_k dt + \tau \sum_j \phi(n_j^{eq}) dw_{jk}(t)$$

The corresponding probability distribution function is Gaussian and satisfies the Fokker-Planck equation

$$\frac{\partial \rho}{\partial t} = \sum_k \frac{\partial}{\partial u_k} \sum_j l_{jk} \frac{d\phi}{dn}(n_j^{eq}) u_j \rho(u, t) + \frac{\tau}{2} \sum_{kk'} \frac{\partial^2}{\partial u_k \partial u_{k'}} \sum_j \phi^2(n_j^{eq}) \sigma_{j, kk'}^2 \rho(u, t)$$

whose solution can be explicitly computed determining the average values and the covariance matrix.

An effective dynamics for the j -road can be written in the form

$$dn = -\frac{dV}{dn}(n)dt + \sigma_{eff}(j)\tau^{1/2}dw(t)$$

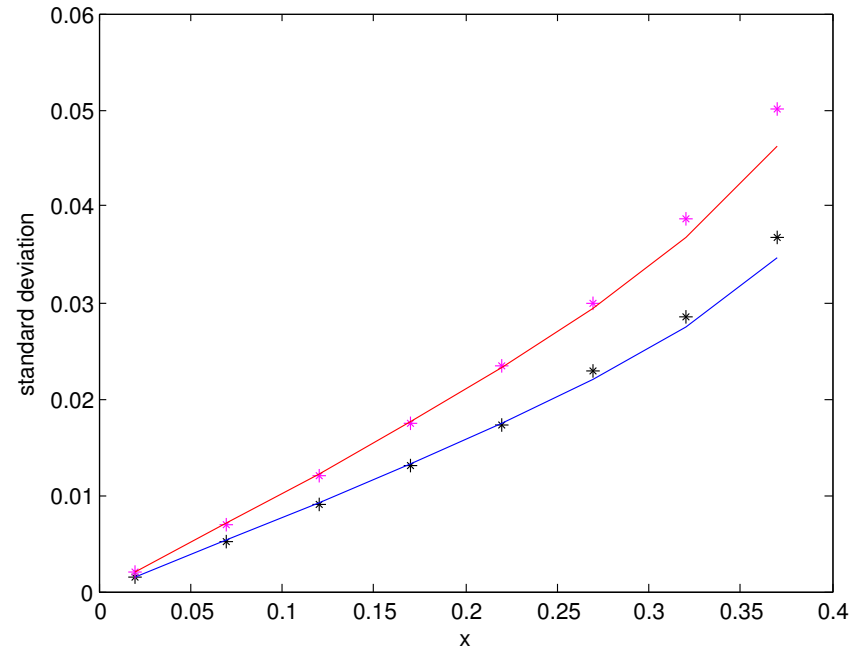
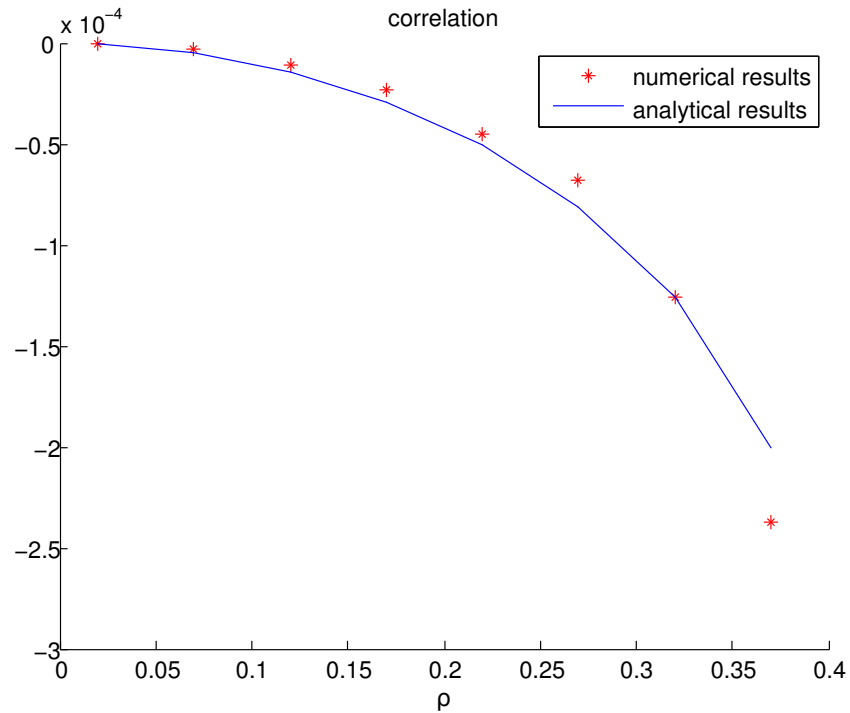
where we set

$$\sigma_{eff}(j) = \sqrt{\frac{d\phi}{dn}(n_j^{eq}) < u_j^2 >}$$

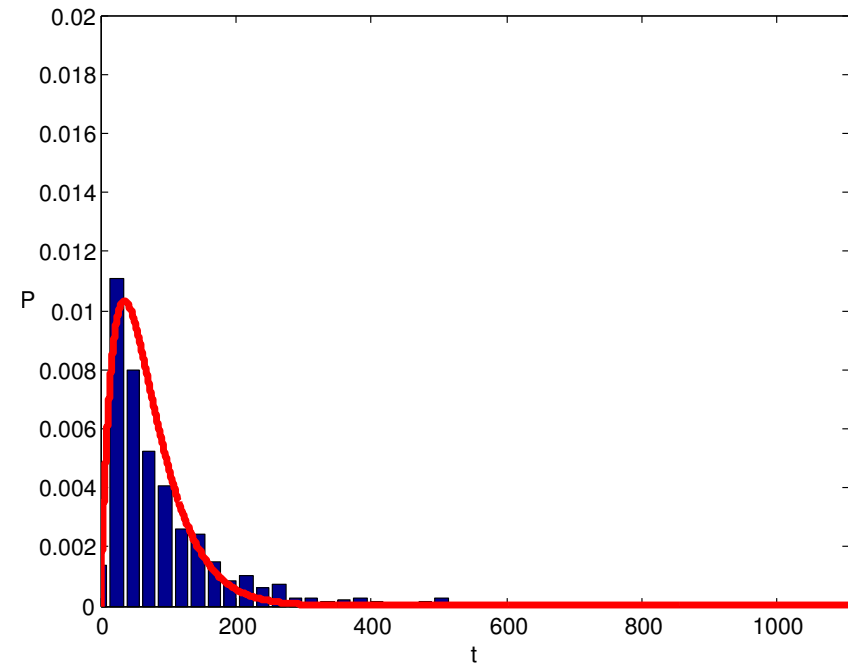
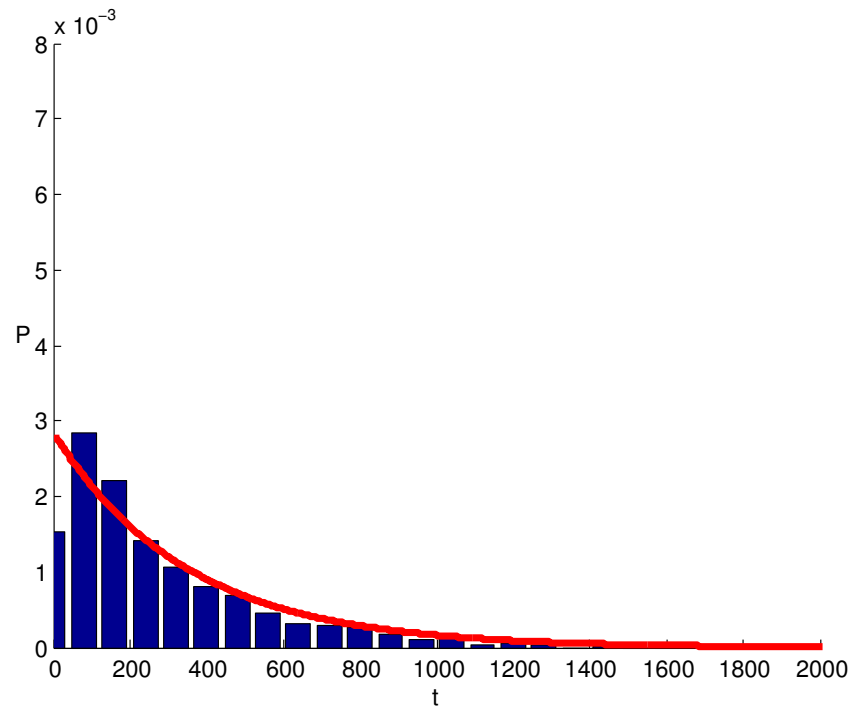
and $V(n)$ is the potential

$$V(n) = -\frac{\beta n^3}{3} + \frac{n^2}{2} - \phi_{in}n$$

Numerical Simulations

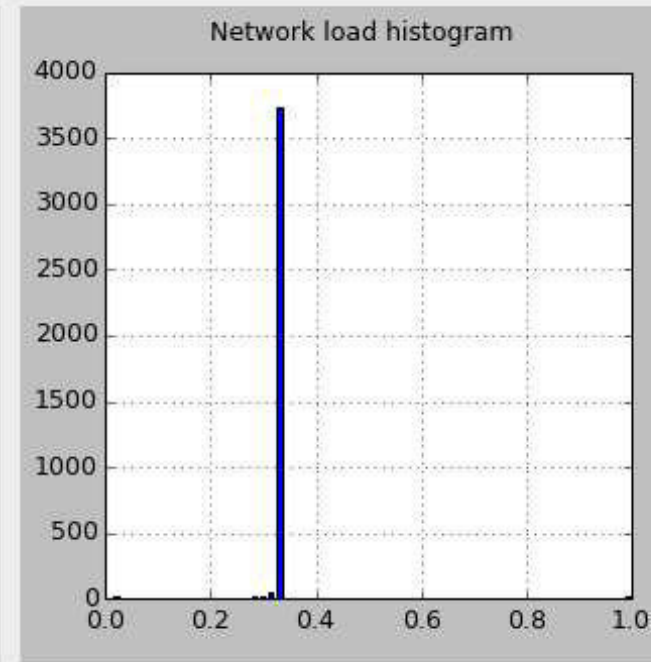
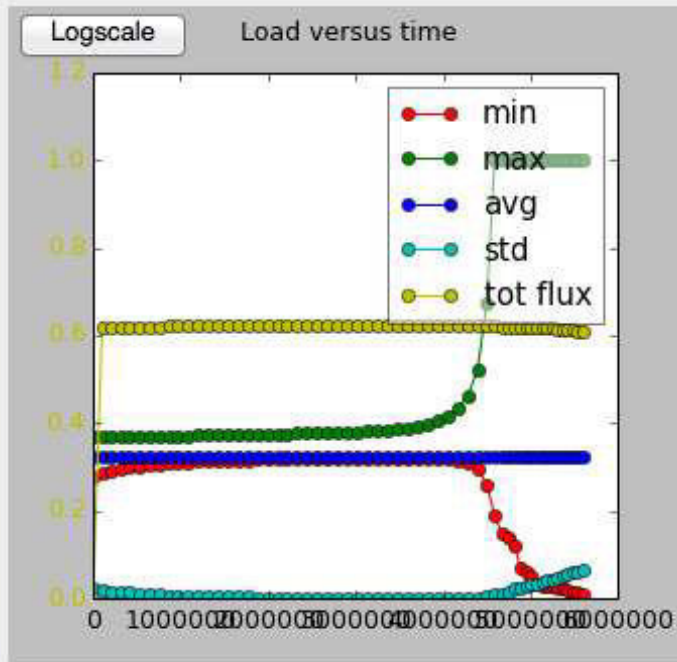
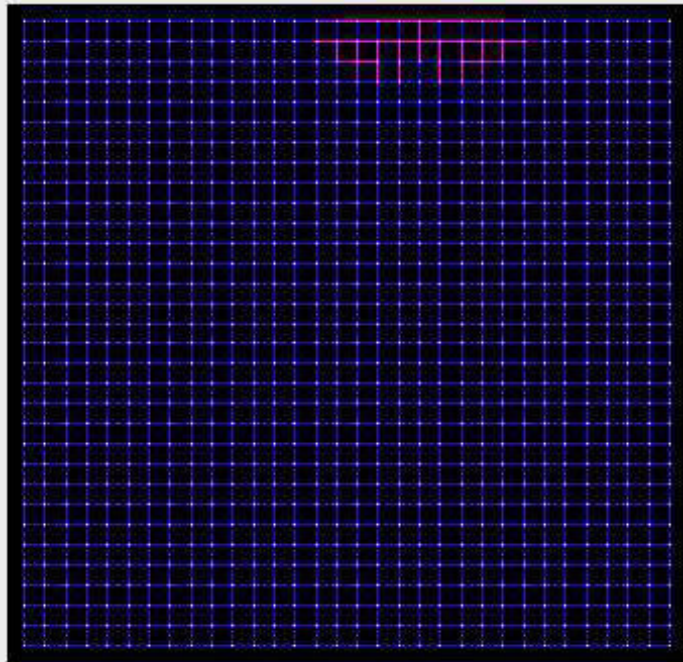


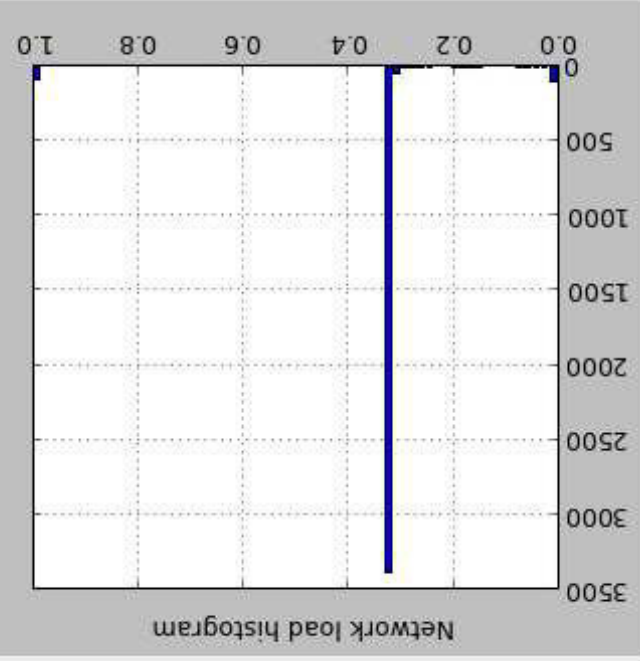
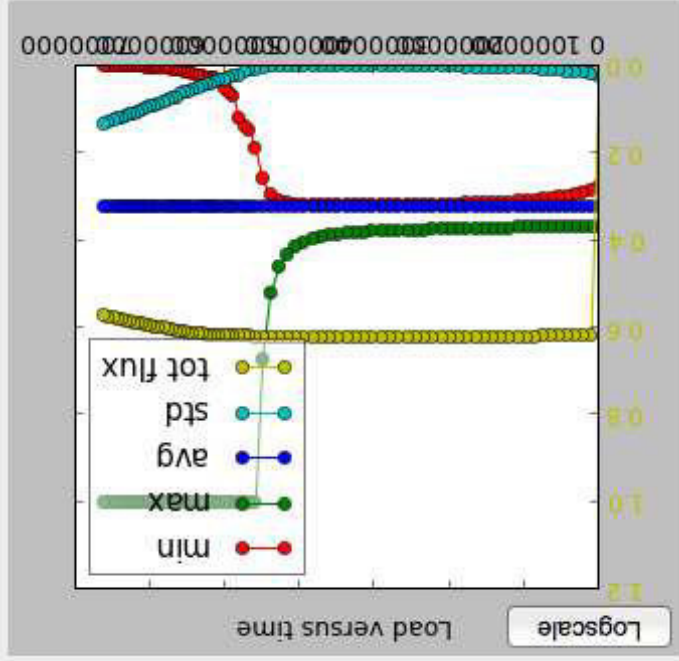
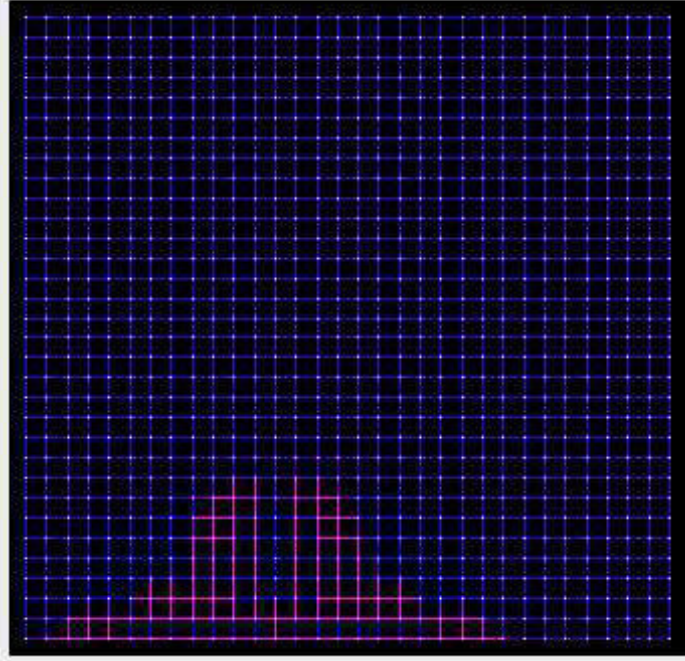
Left: correlation between connected roads. Right: standard deviation of a single road

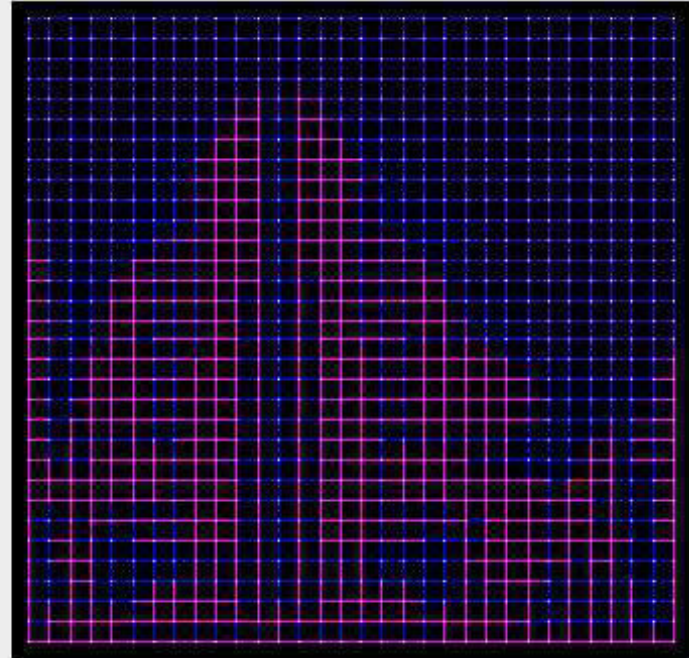
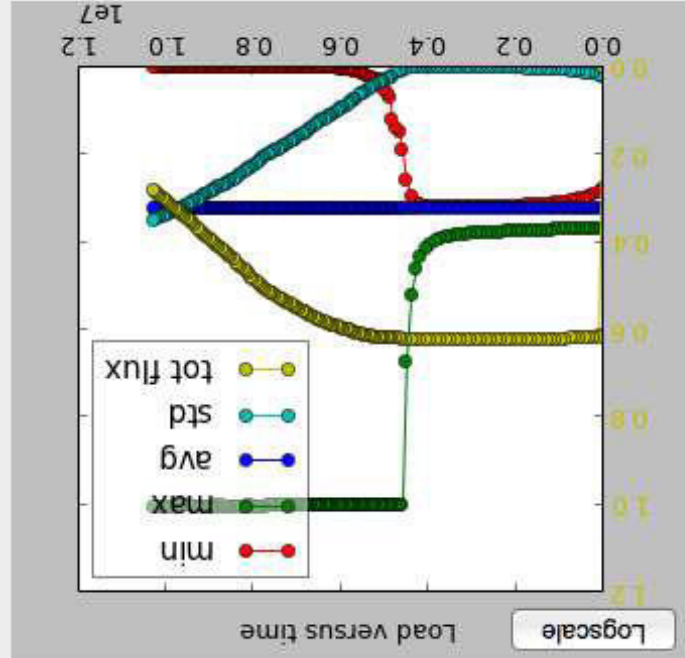
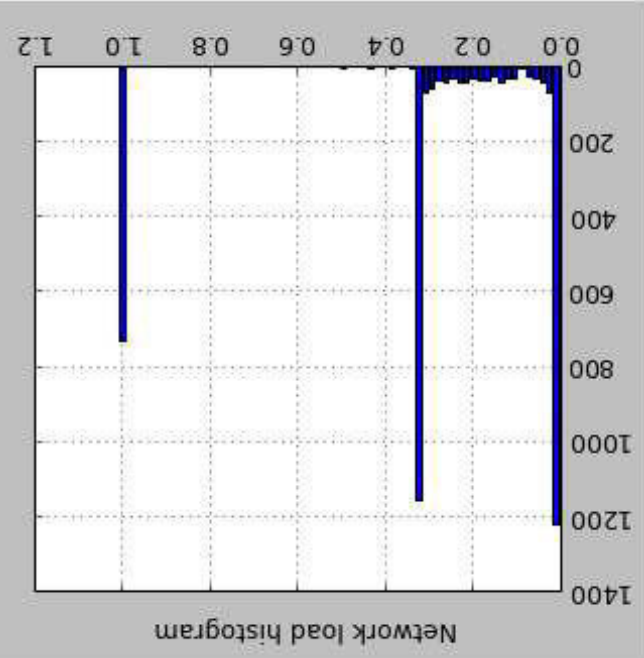


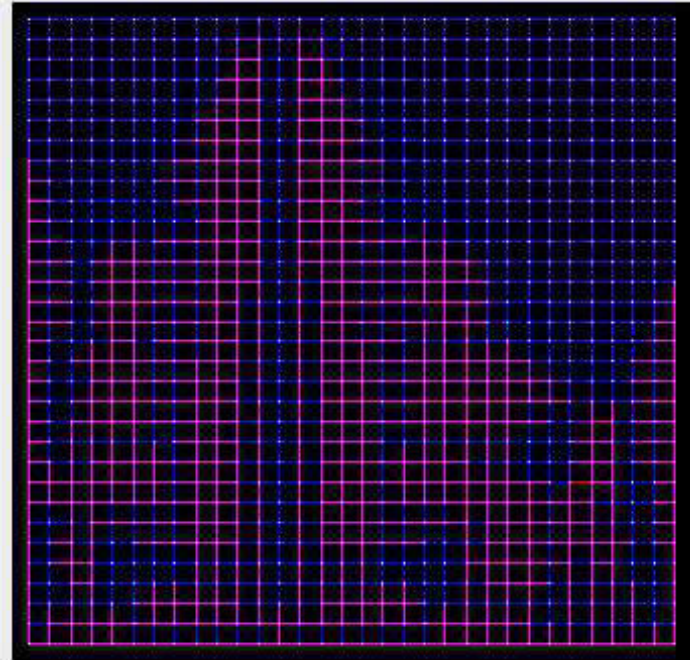
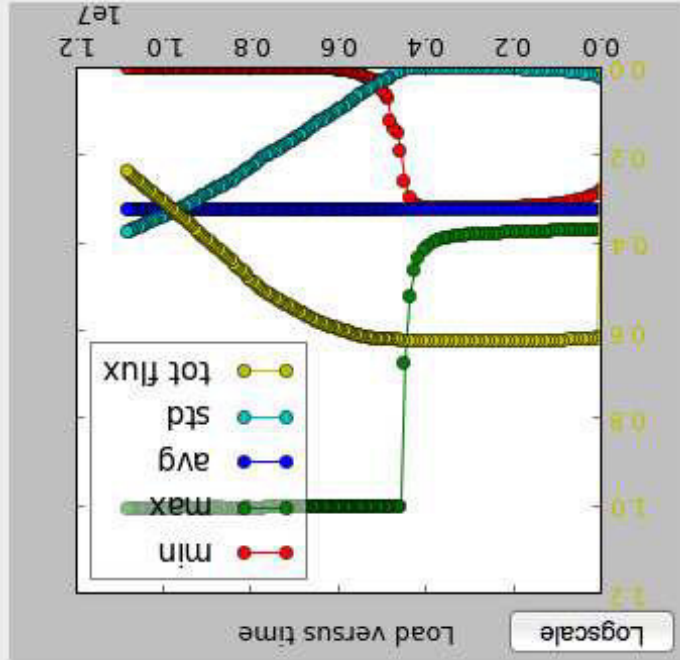
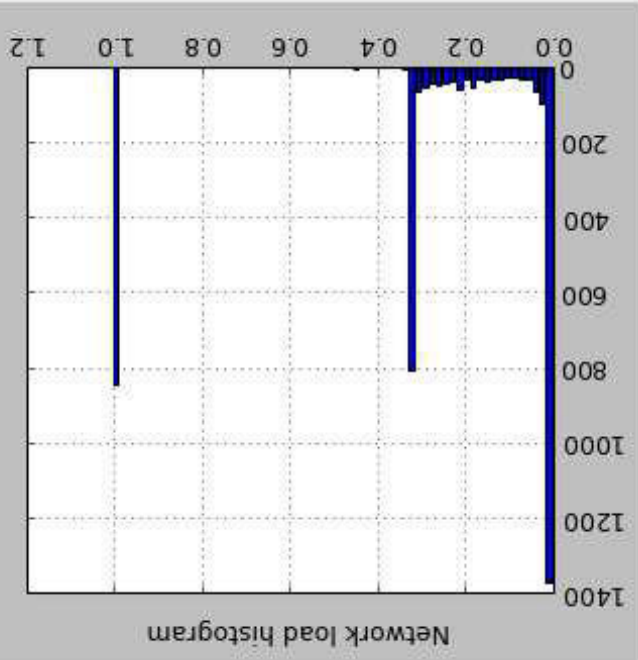
Left: distribution probability for the congestion of a single road. Right: distribution probability for the network congestion.

Congestion dynamics









Remarks

- 1) The Statistical Physics approach allows to describe the macroscopic properties of the stationary states for human mobility;
- 2) Despite the individual heterogeneity 'universal laws' seem to emerge, but the cognitive behaviors are hidden;
- 3) The dynamics at critical states can be a key point to characterize the complexity nature of the systems;
- 4) Model validation and applicability is still a problem.

-END OF DOCUMENT-