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Workload and complexity

Dr. Arnab Majumdar
(a.majumdar@imperial.ac.uk)

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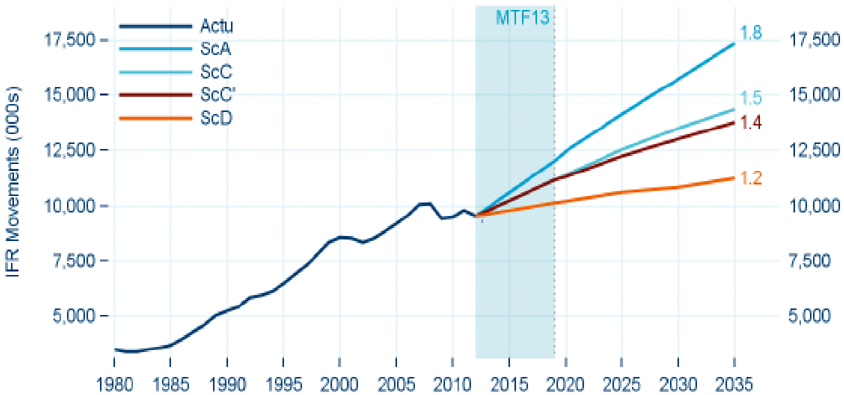
Agenda

1. What is airspace capacity and what is the link to workload?
2. What is workload and how do we measure it?
3. What is complexity?
4. A workload model based on ATC clearances
5. The Metroplex problem

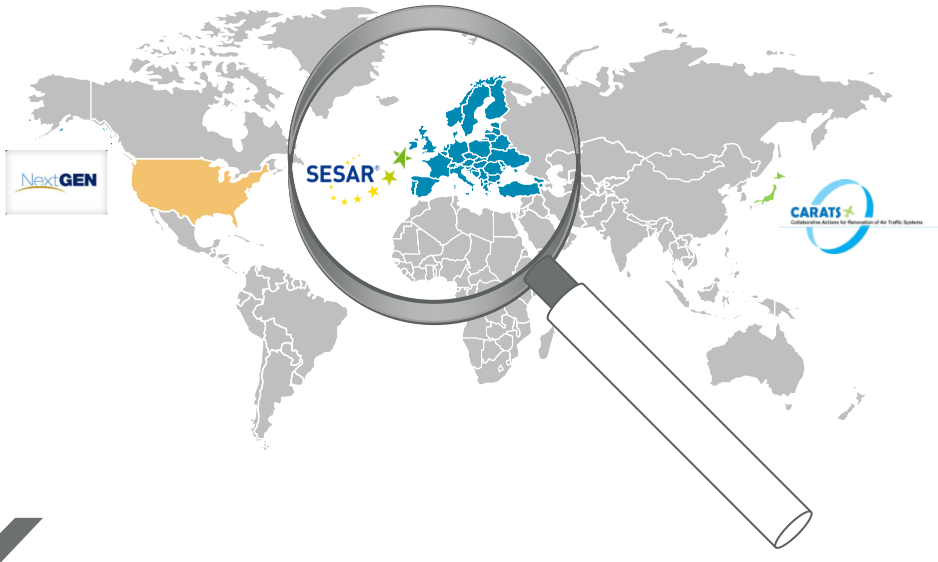
What is airspace capacity and what is the link to workload?

Background

Increased traffic forecasts



Modernisation initiatives



Are ATM modernisation initiatives able to produce significant capacity increases?

Source: Eurocontrol STATFOR

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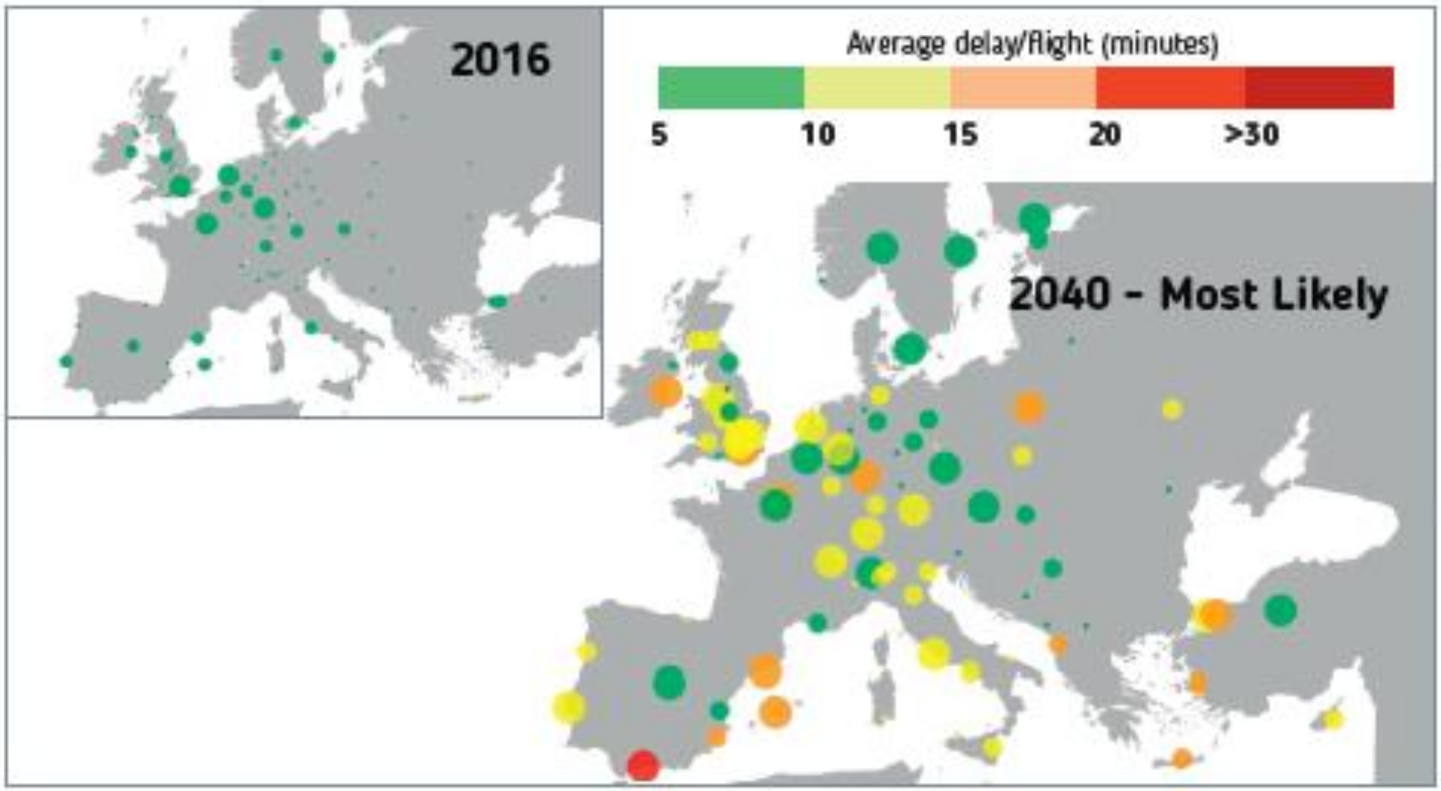
What about future growth?

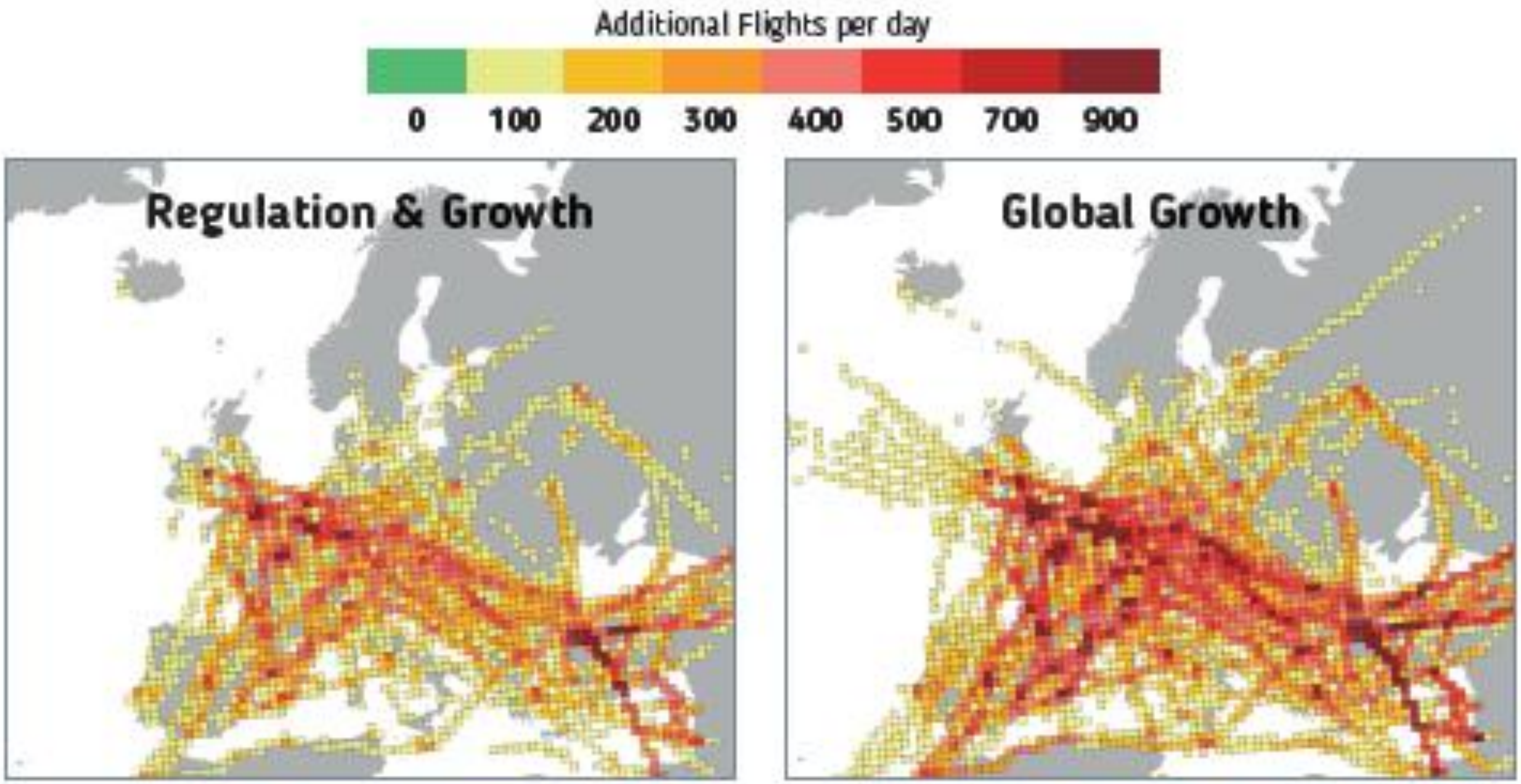
From Eurocontrol's (2018) "European aviation in 2040: challenges of growth"

Figure 14 / The congestion challenge means degraded performance at a significant number of airports.



Growth along major areas of Europe

Figure 15 / Between 2017 and 2040, flights will increase most in what is already the most-challenging airspace.



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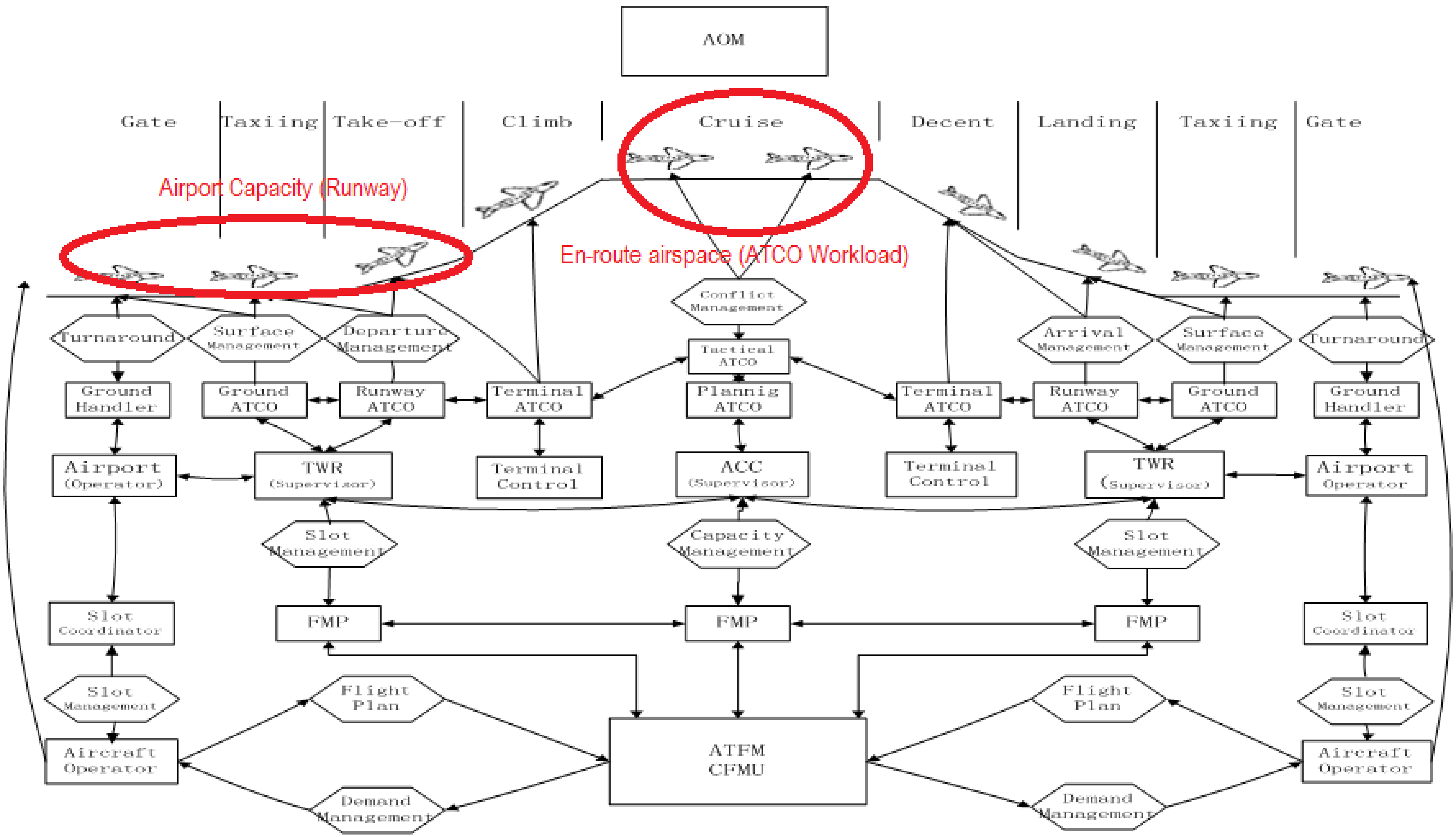
Current ATM system Capacity



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What constrains capacity? Airport Surface

On the airport surface, capacity is fundamentally constrained by the runway capacities.

Other factors:

i)meteorology,

ii)separation minima,

iii)landside limits, e.g. stands

iv)ATCO workload.

Heathrow Third Runway!

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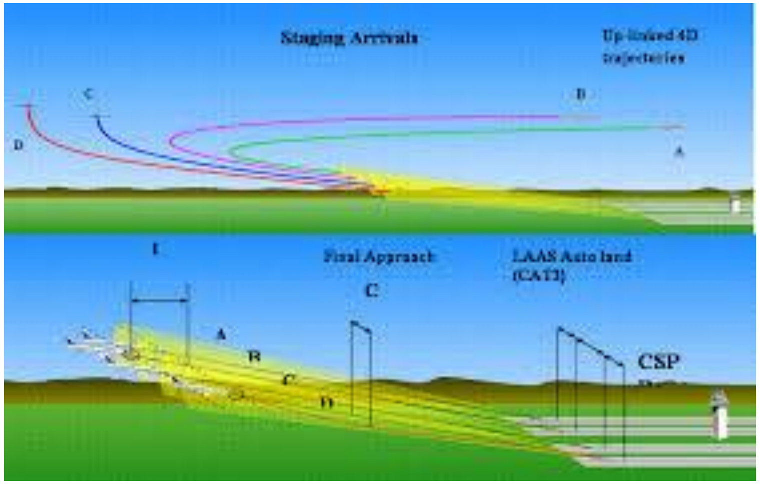
What constrains capacity? –TMAs and en-route

TMAs are similar to that of airports:

- geometrical limitations and
- temporal separation between flights



En-route airspace:

- **Air traffic controller workload is the main capacity bottleneck**

What is airspace capacity?

Airspace capacity is the ability to contain aircraft within a given airspace volume.

✓ Spatial and geometric;

X Says nothing about

- Time
- Directionality etc.

Static airspace capacity

Airspace capacity is the number of aircraft that can be "packed" into a given volume of airspace, given safety minima separations.

- fundamentally on the spatial-geometrical airspace limitations

Occupancy is the metric used to indicate the capacity.

Confusion as to what is occupancy:

- as an instantaneous count of flights; or
- as the number of aircraft during a given time period.

Delays based capacity?

Capacity is defined as the level of traffic that generates less delay than a certain threshold:

- delay as a proxy of congestion
- not focused on determining what actually constraints airspace capacity, instead it specifies what performance indicates airspace shortages.

Air traffic delays are a measure of insufficient capacity rather than a measure of maximum capacity

For en-route ACCs, ATFM en-route delays are used as the metric for delay.

Dynamic airspace capacity

Based on traffic per unit of time.

- capacity is no longer a static characteristic of the airspace but the ability to process aircraft through time or a transportation rate

EUROCONTROL defines airspace capacity as the "*maximum number of aircraft going through any given geometrical airspace for a given time period, based upon the spatial control constraints that govern the internationally specified separation between any two aircraft given their performance characteristics*".

Occupancy capacity

- **instantaneous number** of aircraft.

Widely used but Inconsistently defined:

- Either an instantaneous count of flights or
- number of aircraft during a given time period.

Used in the US and Europe to set sector capacity thresholds.

MUAC (Maastricht) defines:

- Occupancy Traffic Monitoring Value (OTMV) as the maximum number of flights in a sector during 1-minute intervals:
- Sustained - associated with a smooth flow of traffic over a long time period
- Peak - a spike of traffic that should not be handled for > 3 minutes.

Instantaneous capacity vs period of time capacity

Instantaneous definition vs capacity definition over a period of time (e.g. flights controlled over a 30 minutes period) allows for:

- a more precise evaluation of ATM components workload:
- point-in-time workload excesses can be identified rather than an aggregated view through a time interval (e.g. 30 minutes).

What do controllers do? (1)

"In an en-route ATC environment, involving high-speed and high-altitude cruise between take-off and landing, the system that confronts the controller comprises of a large number of aircraft coming form a variety of directions, at diverse speeds and altitudes, heading to different directions".

Two main goals to ensure that aircraft:

I) under their jurisdiction adhere to ICAO mandated separation standards, e.g. 1000ft vertically and 5nm horizontally;

II) reach their destinations in an orderly and expedition manner.

What do controllers do? (2)

These goals require controllers to perform numerous tasks, e.g.:

a) Monitoring air traffic;
b) Anticipating conflicts between aircraft;
c) Resolving conflicts between aircraft;
d) Minimizing disruption to the flow;
e) Communicating with aircraft;
f) Hand-off aircraft to neighbouring sector.

Controllers use:

- Radar screen for information;
- RT for communications;
- Coordination systems;
- Safety nets;
- Other tools.

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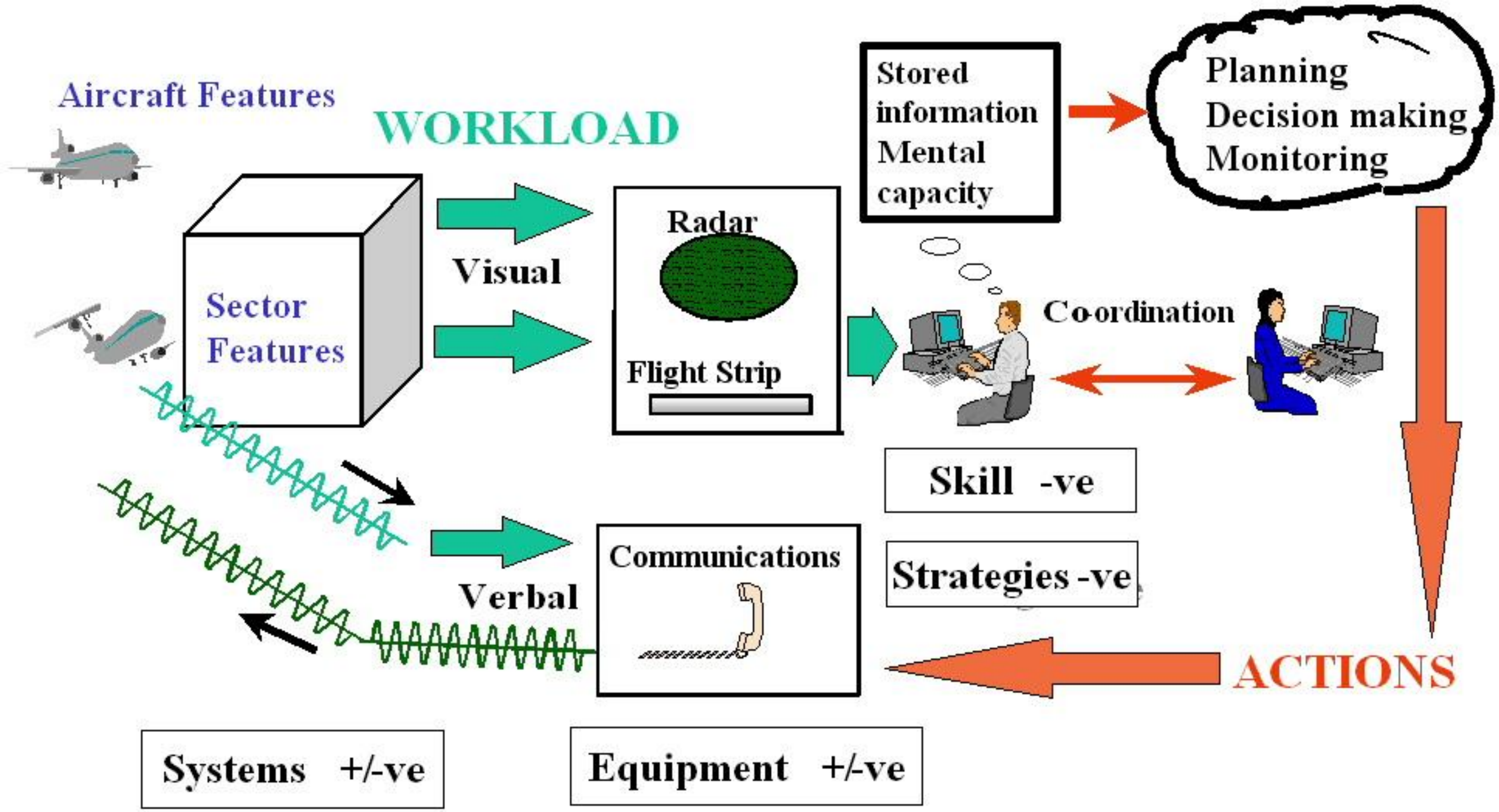
What do controllers do? (3)



3 questions on controller workload

1. What is controller workload?
   - Confusing term.
   - Many definitions.

2. How is it measured?
   - Many methods.

3. What is an acceptable level?

What is workload and how do we measure it?

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What is workload?

No clear definition of workload in the literature.

Certain features noted:

- a multi-dimensional concept involving various demands placed upon the subject and interactions between subject and task;
- a construct that cannot be studied directly but can only be inferred from different quantifiable variables.

Note distinction between:

a) taskload, the objective demands of a task, and

b) workload, the subjective demands as experienced by the subject.

Defining workload: 1

Physical workload:

- lengths our bodies can perform actions required for our work e.g. lift and move materials, work construction.
- limited by our musculoskeletal systems.
- Construction work.

Cognitive workload:

- defined by task demands rather than individual's psychological resources.
- Complex transport operations.

Workload is an **emergent property** from:

individuals' work <=> their resources.

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Task Demands

Traditionally cover:

- task complexity,
- length of task,
- time constraints.

Recently task demands include environment demands

Environmental Demands

Organisational	Conditional
Leadership behaviours/relationships	Temperature
Team dynamics	Humidity
Safety culture	Noise
	Vibration Light

Defining workload: 2

Psychological resources include attentional, visual, memory and decision making systems.

Holisitic definition (Young and Stanton, 2005):

“the level of attentional resources required to meet both objective and subjective performance criteria, which may be mediated by task demands, external support, and past experience”

Good definition BUT ignores:

- neurodiversity
- individual differences in personality
- conditions such as anxiety and depression which limit psychological resources of operators.

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Emotions?

Emotional labour – result of having to regulate emotions during work, even though these may not match our true feelings.

Studied only healthcare and customer services

Flight crews suffer from high levels of emotional labour (Taylor and Tyler, 2000; Hendarish 2016)

Yadav et al. (2015) increases in emotional labour and in workload have a negative safety impact for aircrew.

Need for regulating emotions:

- efficiently during high workload or
- that contribute to high workload.

What about underload?

Barely using an individual's resources or experiencing strain:

- even more poorly defined than workload!

Easier to understand what it is **not**.

- Vigilance – needs high workload;
- Boredom – as there is some level of attentional engagement in the task.

Underload as equally detrimental to task performance as high workloads:

- Evidence indicates lapses and errors

Workload as continuum with high and underload as extremes.

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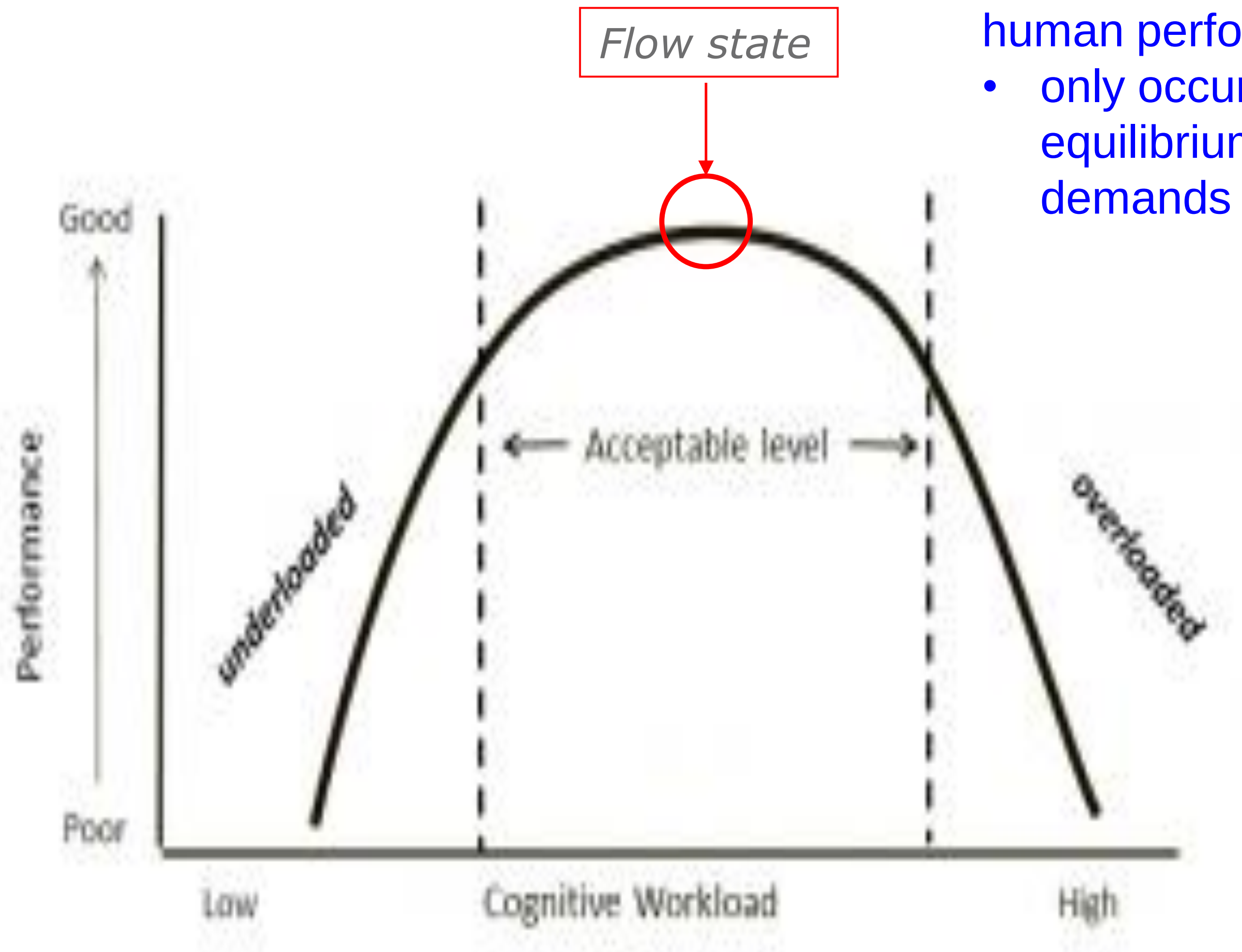
Yerkes-Dodson inverted U adapted for cognitive workload



Flow state is the pinnacle of human performance:

- only occurs with an equilibrium between demands and resources

Workload measurement techniques

Three main measurement techniques based aspects of the multi-dimensional construct:

i) Performance or behaviour,
ii) Subjective measures.
iii) Physiology and

No universal measure that is suitable for all aspects.
Dissociation between measures of different aspects of the same construct.

Individual may increase effort to maintain a certain level of performance in the face of increased demand:

- increased workload not captured by primary performance measures;
- other types of measures might be more appropriate.

Advice is for researchers to use a battery of techniques if possible.

Assessing workload : Behavioural measures

Behavioural measures refer to assessing workload through task performance.

Tasks can either be:

- ecologically valid, e.g. driving task or
- reflect a pure manipulation e.g. N-back task.

Behavioural measures either use

- singular task e.g. driving, or a dual task paradigm e.g. driving
- singular and and arithmetic or visual search and auditory memory.

Premise is: task difficulty ⇧, performance 🡻

Primary task measures

i) Primary task and secondary task measures;
ii) No standardized performance measures.

Primary task measure derives its measure from some quantifiable feature of the task whose workload is under consideration.

Primary task performance measures:

- not useful in non-overload situations and
- inadequate metrics of workload in aircrew studies on their own.

Recording of the primary task performance:

- subject matter experts to rate performance;
- logistical issues

Secondary task measures

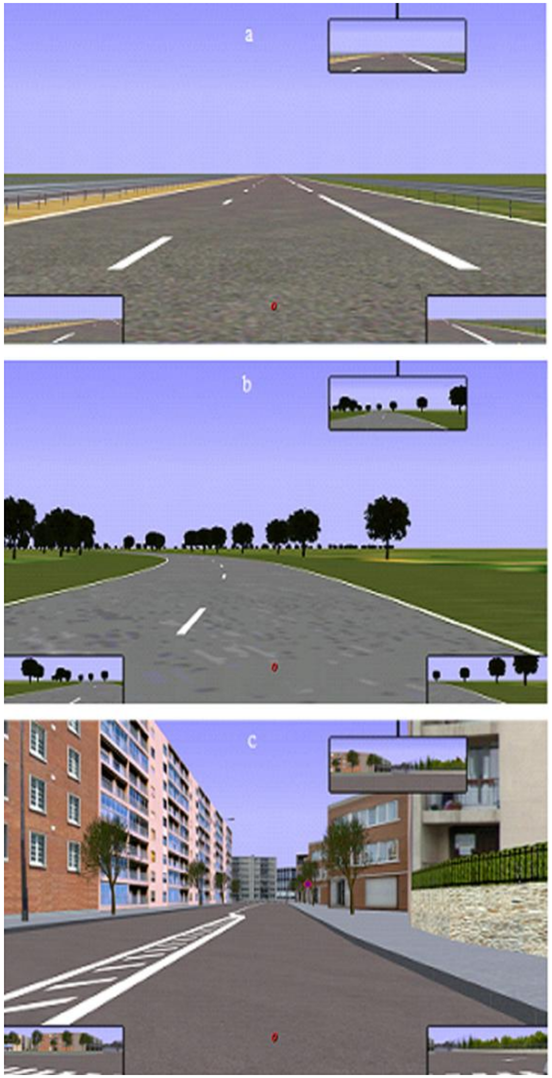
Secondary task measures involve the artificial insertion of activity to determine the amount of spare cognitive capacity of the subject with the idea being that performance on the secondary task will decline as some function of the primary task demands.

- existence of discrete mental resource pools so the choice of secondary task should specifically interfere with the cognitive demands (e.g. spatial, verbal, numerical) of the primary task;

- secondary tasks not in competition for the same cognitive resources may not be sensitive to changes in the demands of the primary task.

ATC is complex - so what secondary tasks?

Behavioural measures: examples



Driving task from Faure, Lobjois and Benguigui (2016).

Participants driving behaviour was measured by steering reversal rate (SRR)-number of corrections left or right a driver makes during each minute.

- Drove + mental arithmetic calculations or Reaction Time tasks

As difficulty increased, so did SSR

Seen when having to do arithmetic calculations

N.B. No simulation of interactions with other drivers

Fig. 1. Illustration of the three driving environments (a – Highway; b – Rural driving; c – Urban driving).

Subjective measures (1)

Subjective measures give a description of the inner experience of the subject to give an indication of the demands on cognitive resources.

Subjective measures of workload do not often correlate with objective ones:

- may not necessarily be that one is right and the other is wrong.
- multi-faceted nature of the construct, the disagreement between measures may simply imply that they are measuring different aspects.

Bearing in mind the inherently subjective nature of workload:

- objective assessments of task demands and performances at best measures objective taskload.

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Subjective measures (2)

National Aeronautics and Space Administration - Task Load Index (NASA-TLX)

Subjective Workload Assessment Technique (SWAT)

Both developed for aircrew

NASA-TLX is a multidimensional scale where the overall workload is a function of six dimensions on a continuum

SWAT is also a multidimensional scale but the overall workload is a function of only three dimensions at three discrete levels each.

NASA-TLX (1)

The NASA-TLX method includes two steps:

I) rating. The rating step requires the subject to rate task(s) according to six dimensions: mental demands, physical demands, temporal demands, effort, performance and frustration level. The subject rates each dimension's contribution to perceived workload on a 20-point scale to yield a score out of hundred.

II) weighting. Subject chooses, in each fifteen pair-wise comparisons amongst the six dimensions, the one deemed more important in creating the workload of the task to derive a weight for each dimension. Each dimension's score out of a hundred from the rating step is then weighted accordingly and added up to give a final workload score 0 to 100.

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NASA-TLX (2)

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Mental demand	How much mental activity was required? Was the task easy or demanding, simple or complex?
Physical Demand	How much physical activity was required? Was the task easy or demanding?
Temporal Demand	How much time pressure did you feel due to the pace of the task? Was the pace slow or rapid?
Overall Performance	How successful were you in performaing the task and how satisfied were you with your performance?
Frustration Level	How irritated, stressed, or annoyed were you versus relaxed, content or complacent during this task?
Effort	How hard did you have to work (mentally and physically) t oaccomplish your level of performance?

Assessing workload: Self reports

NASA-TLX the predominant tool for self-assessing workload

De Winter (2014): Reviewing 4300 studies on workload found 70% used the NASA-TLX.

Flaws with the technique e.g:

- Scale, score and bias problems

de Waard and Lewis Evans (2014) and de Winter (2014):-

- Researchers are now using NASA-TLX scores as synonymous with workload

Alternative scales e.g. SWAT and the work profiles questionnaire has been found to have greater diagnosticity and sensitivity than the NASA-TLX

Physiological measures

Physiological measure is based on the premise that workload strain induces quantifiable bodily changes such as in:

- blink rate and duration
- blood pressure,
- heart rate,
- pupil dilation and
- saliva
- EEG
- EOG

Whilst there is evidence all of these measures can detect workload, a combination is best.

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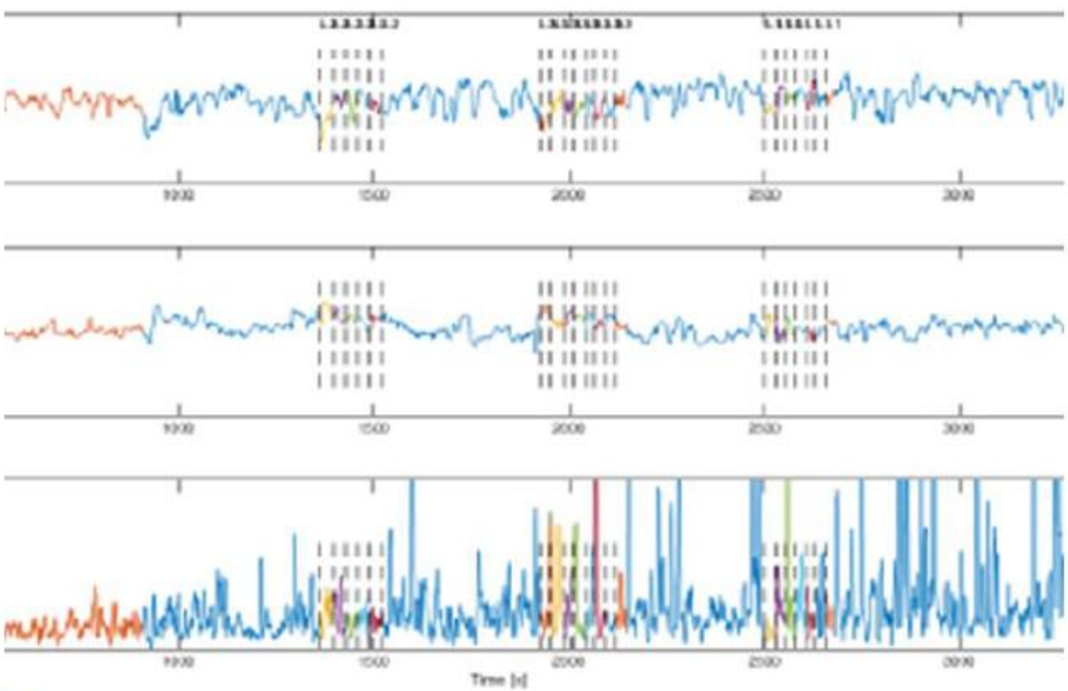
Cardiovascular measures



A whole session of experiment tasks for one participant

- Vertical lines mark the Stroop test sessions (screens)
- Level 2 first, Level 3 and Level 1 give 3 levels of classification

The cardiovascular measures on graphs are

1. Mean pressure
2. Cardiac output
3. Heart rate variability HRV

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Assessing workload : Physiological measures

Ryu & Myung (2005) assessed workload in students through a dual task paradigm of mental arithmetic and visual tracking tasks:

- EEG data could only detect high and low workload on arithmetic whereas
- HRV and EOG data could only detect medium and high levels of workload on the tracking task.

May need several physiological measures as not all measures are sensitive to all task types

Used to be that these measures need to be done online and are often too disruptive in the intense operational environment.

But wearables are coming!

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Wearable devices: Why are they needed?

Prior methods are unsuitable for assessing workload in complex safety critical systems in real time.

- Self reports would require multiple assessments every hour to assess workload over a 8-12 hour shift, this is intrusive and impractical.

- Behavioural measures can be ecologically valid for some contexts e.g. driving but can they be be used in contexts such as aviation, mining, energy and search and rescue?

Physiological measures can detect workload, however often used in laboratory conditions as well as being cumbersome and intrusive with the exception of HR/HRV.

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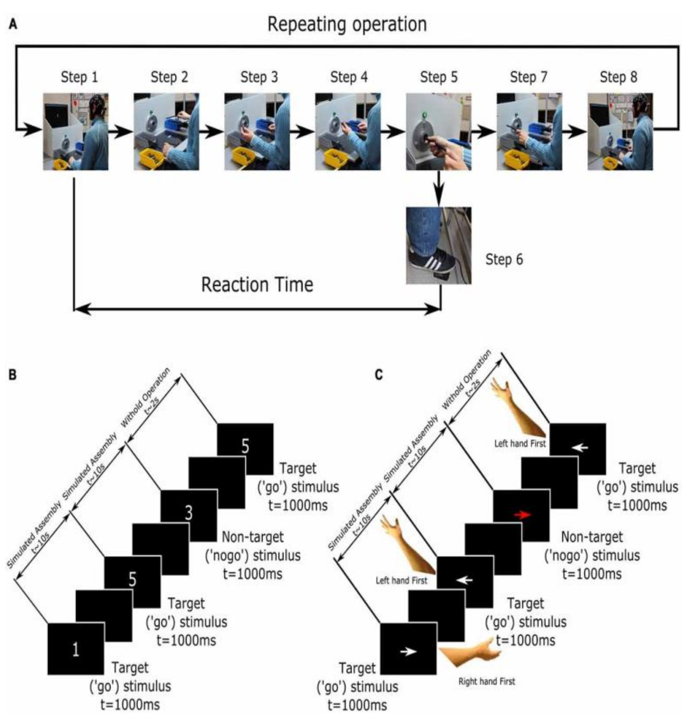
First wearable: Mbraintrain Smarting EEG

Wearable EEG.

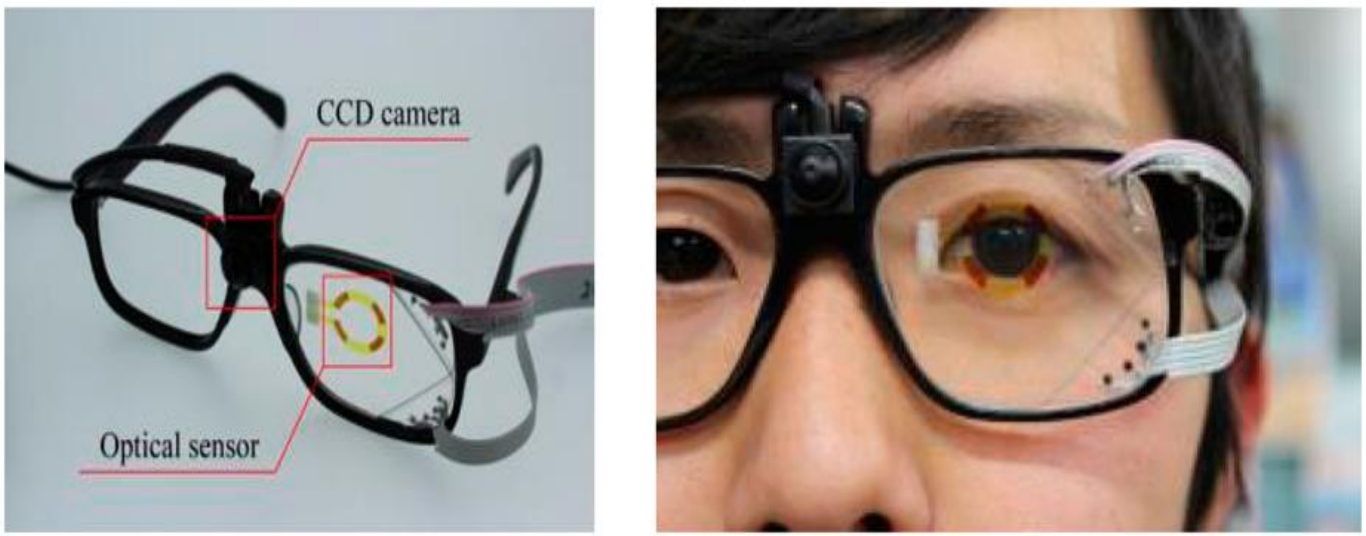
Used in a series of manufacturing studies by Mijovic et al (2016,2017,2018)



Across all three studies Mijovic et al (2016,2017,2018) found the device to be sensitive to task demands.

Second wearable:Ocular device by Sampei et al (2016)

Sampei et al developed a device to measure workload through blink information



(a) (b)

Using a variety of sensors, photovoltaic cells, cameras etc.

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Second wearable:Ocular device by Sampei et al (2016)

5 participants required to complete mental calculations of 3-4 digits. This occurred for 8 minutes, with 2 minutes being used to complete the NASA-TLX. Iterated 6 times.

Sampei et al (2016) found eye blink data to correlate with NASA-TLX scores through stepwise regression.

This was only found for 3/5 participants.

Design and usability of the device

Need far more data and field testing.

What is complexity?

What is complexity?

The term complexity refers to the level of difficulty of the ATCO job.

Air traffic complexity is the main contributor to ATCO workload along with the psychological state of the ATCO.

In general, the more difficult the task:

- more complex the mental operations are and
- more mental processing power and capacity is used.

When this happens the human tends to experience higher workload levels.

Elements of complexity

- objective complexity - embeds the quantifiable and observable factors of the air traffic situation and

- perceived complexity - accounts for subjective perception of each ATCO of the objective complexity factors.

Given the relationship between objective complexity and ATCO workload, several studies have attempted to find the most important objective complexity factors affecting the current ATCO activities and even those envisaged in the future.

The objective complexity factors belong to one of the following groups:

- air traffic scenario complexity,
- structural complexity and
- system complexity.

Air Traffic Scenario complexity

Encompasses:

- air traffic pattern factors and
- other operational air traffic scenario characteristics such as the weather and the number of special flights and emergencies.

Dynamic in nature.

Air traffic patterns:

i) cruise/ ascend/ descend;

ii) Aircraft speeds;

iii) Aircraft sizes;

Structural complexity (1)

Represents the objective complexity associated with stationary airspace factors e.g.:

- airspace sectorisation characteristics and
- network of routes i.e. the airspace design

Encompass:

- special use of airspace,
- sector geometry,
- sector size,
- requirements for lateral and longitudinal separation,
- radar coverage,
- the number of FLs available

Structural complexity (2)

Structural complexity factors are of paramount importance in the generation of ATCO workload

Correlation has been determined between the structural and air traffic complexity factors, suggesting that:

- adequate airspace design decreases the difficulty associated to control the air traffic pattern.

The structural complexity factors are uniquely associated with each individual airspace.

- objective complexity factors associated to different airspaces are not transferable between them.

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ATC system complexity

ATC system complexity (or cognitive complexity) is:

- the difficulty associated with the operation of the ATC systems.

- Archaic ATC systems lead to higher system complexity than modern ATC systems, thus increasing workload

- Introduction of new technologies in ATC system.

System complexity includes:

- poor communications quality or ATC system failures.

Objective complexity

Objective complexity depends on:

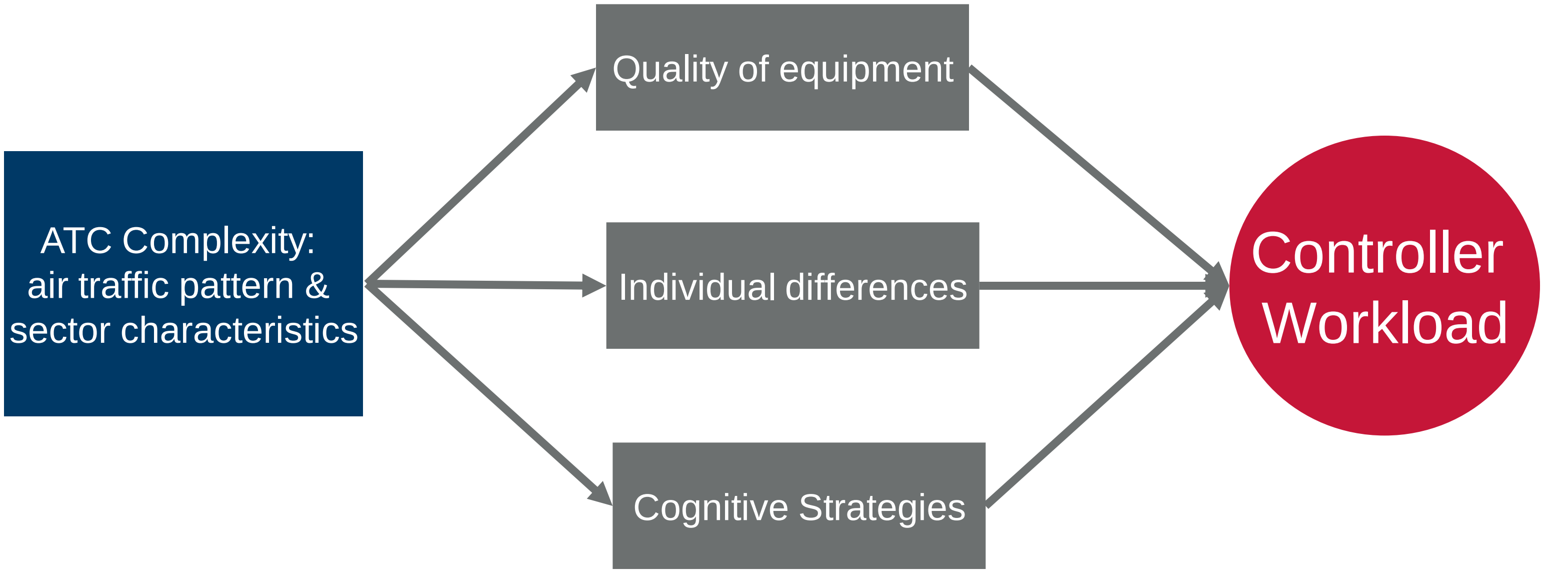
- instantaneous air traffic scenario, the eventualities of the real operations (weather and quality of equipment) and
- static structural factors of the airspace in control.

Same combination of these factors can however produce different perceived complexities by different ATCOs:

- due to the differences and subjectivities of the ATCOs cognitive processes.

Air Traffic Control Complexity - What determines workload?

Key: Impacts of complexity factors on workload



Source: Mogford et al. (1995)

Sperandio (1971) effect

- Workload is not imposed on a passive controller BUT is managed actively

Proposed model in which changes in strategy:

i) allow controllers to regulate how task demands are transformed into workload

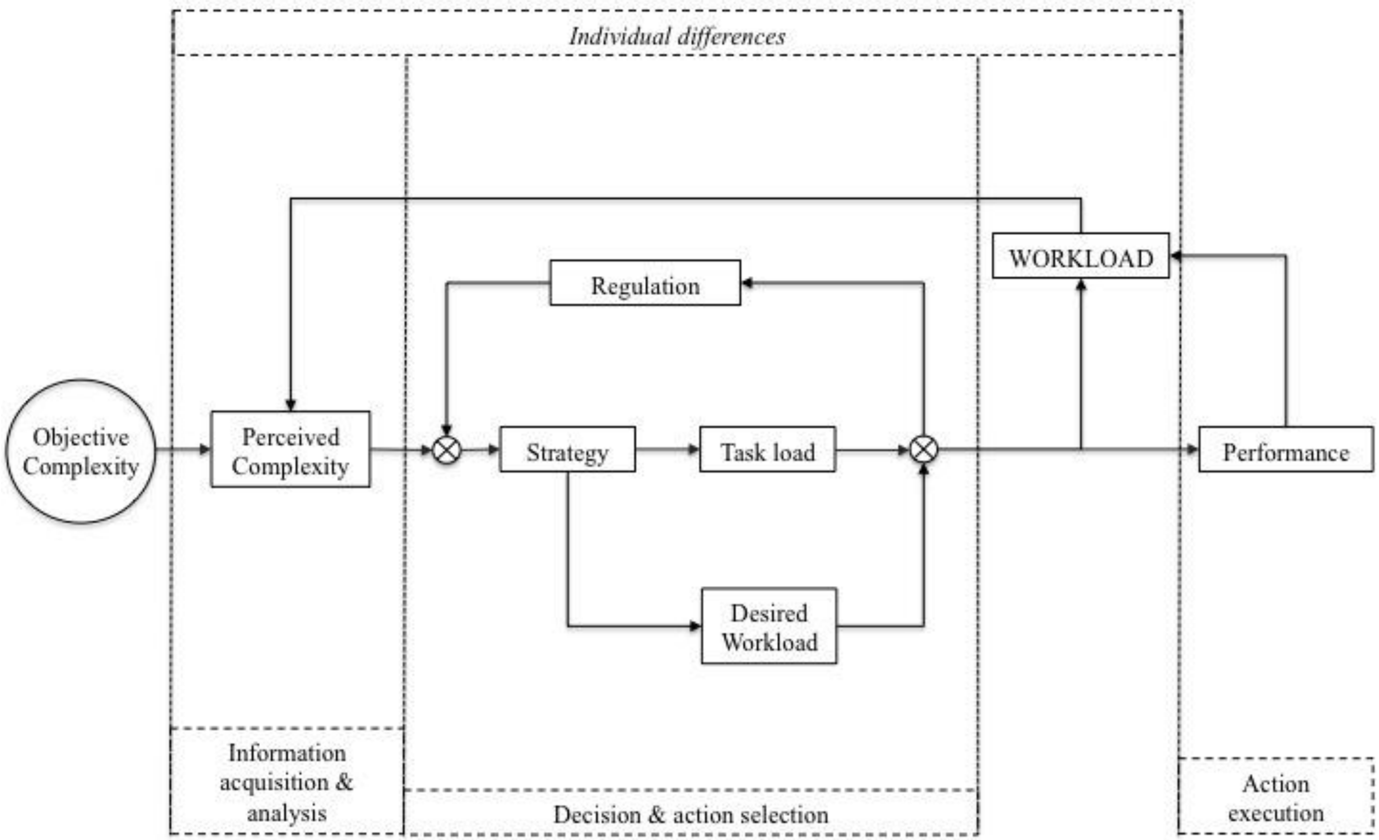
ii) keeps workload within acceptable limits.

Also noted that:

iii) effect of controller actions on system is fed back to controller such that future task demands are actively regulated.

Rouse et al. (1993) similarly modelled workload as a feedback control process driven by subjective mental workload

Objective complexity and workload



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A workload model based on ATC clearances

The problem of capacity estimation

Airspace capacity estimation is crucial for the efficient development of the ATM system.

Main objective of airspace capacity estimation is to identify the maximum amount of air traffic demand that ATC can safely control.

These estimations are especially important for an accurate performance of the ASM/ATFCM functions.

These functions protect the ATC function from over-deliveries, ensuring a safe flow of traffic

En-route controller workload affected by ATC complexity
- objective (air traffic and sector)
- subjective or perceived

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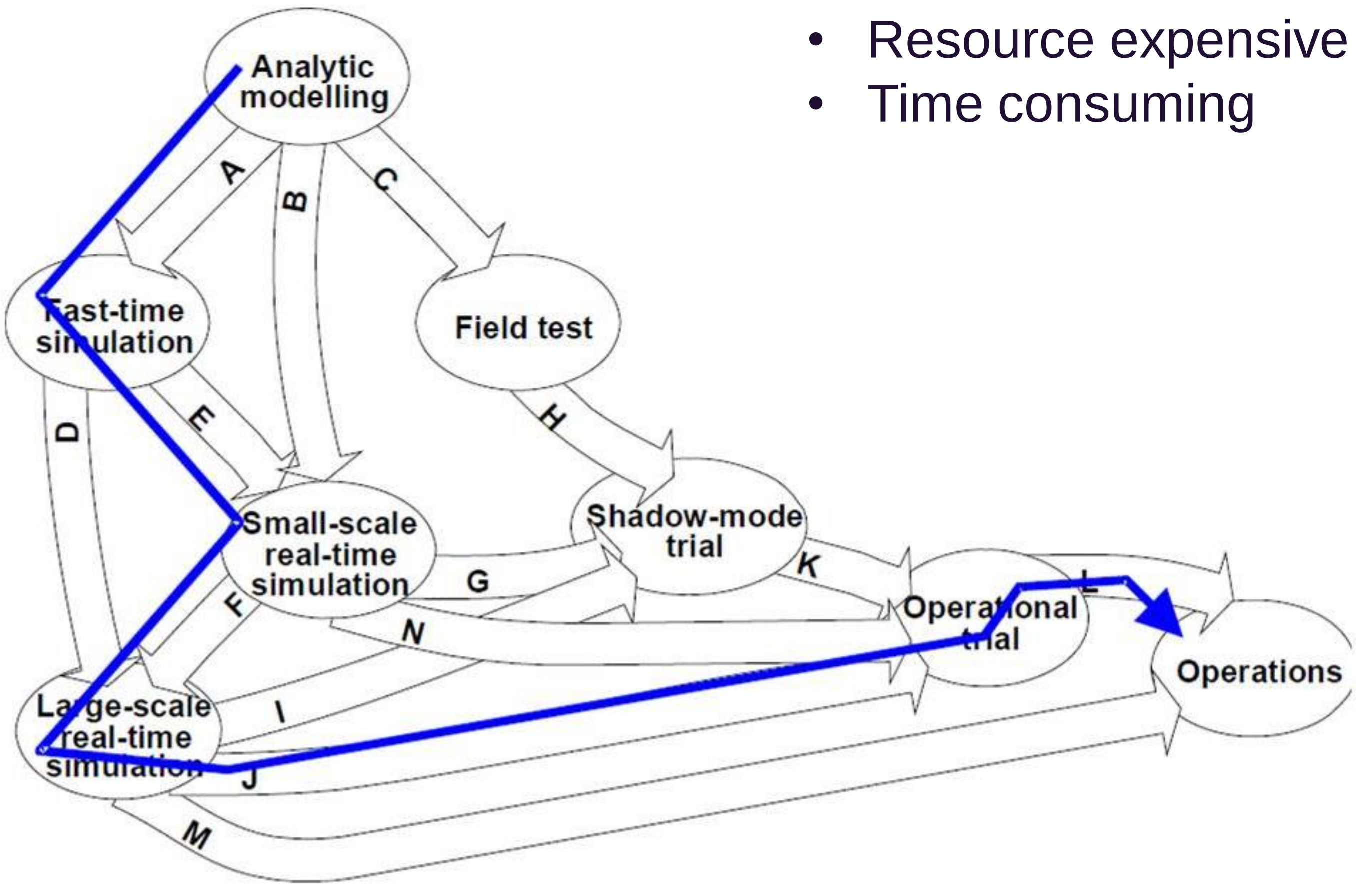
MAEVA scheme for assessing capacity



- Resource expensive
- Time consuming

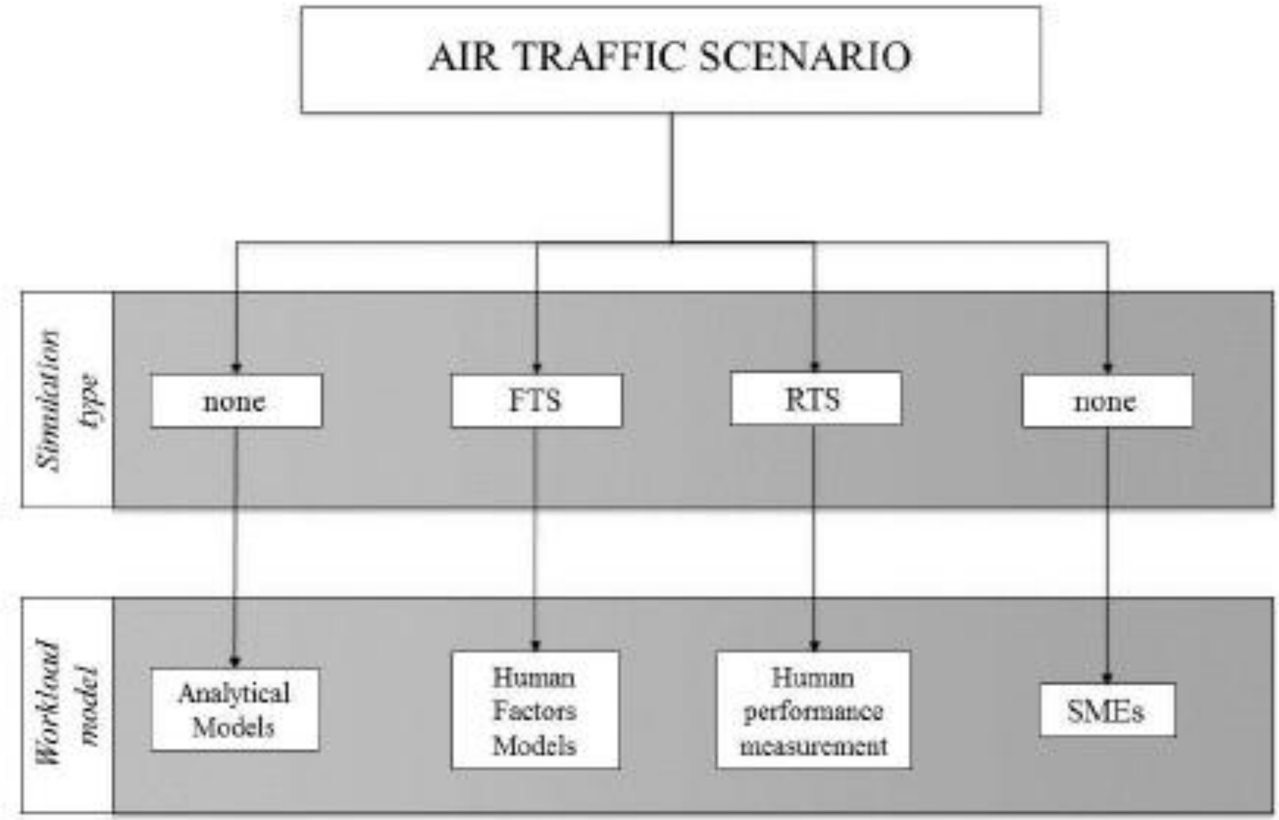
Workload modelling

Workload required to accomplish the task load, is not directly observable i.e. is a construct, and has to be inferred from the measurement of other observable magnitudes.

Regardless of the specific modelling method used to estimate ATCO workload,

- replications of air traffic scenarios are required in order to estimate capacity and generate data to proceed with the workload analysis.

Workload Estimation Methods



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Drawbacks of current capacity estimation

1. Fundamentally focused on ATCO workload modelling (analytical, FTS or RTS)

2. Cannot be used during the operational stages

3. Do not capture other identified factors, e.g. individual aspects or trade-offs

Benefits of the new workload estimation approach

Only input => clearances issued by the ATCO to the controlled flights.

3 benefits of this approach:

- captures the subjectivity of the ATCOs, as it directly analyses their actions;
- does not require post-operation tasks; and
- does not interfere in the ATCO operation, since data can be directly extracted from the system.

Expected to improve the reliability of the workload measurement results.

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Details

J1. Tobaruela G, Schuster W, Majumdar A. and W.Y. Ochieng (2015) Framework to Assess an Area Control Centre's Operating Cost-efficiency: a Case Study, Journal of Navigation, ISSN:0373-4633 Issue 06 / November 2015, pp 1088-1104

J2. Tobaruela, G., Schuster, W., Majumdar, A., Ochieng W.Y., Martinez, L. and P. Hendrixx (2014) A method to estimate air traffic controller mental workload based on traffic clearances, Journal of Air Transport Management 39 (2014) pp. 59-71

J3. Tobaruela, G., Fransen. P. Schuster, W., Ochieng W.Y. and A. Majumdar (2014) Air traffic predictability framework – Development, performance evaluation and application, Journal of Air Transport Management 39 (2014) pp. 48-58

Complexity and workload (1)

Workload estimation model assumes that given a perceived complexity level:

- the ATCO can choose among different strategies depending on his/her individual preferences.
- any of the strategies chosen yields the same workload level as they are used to manage the same perceived complexity

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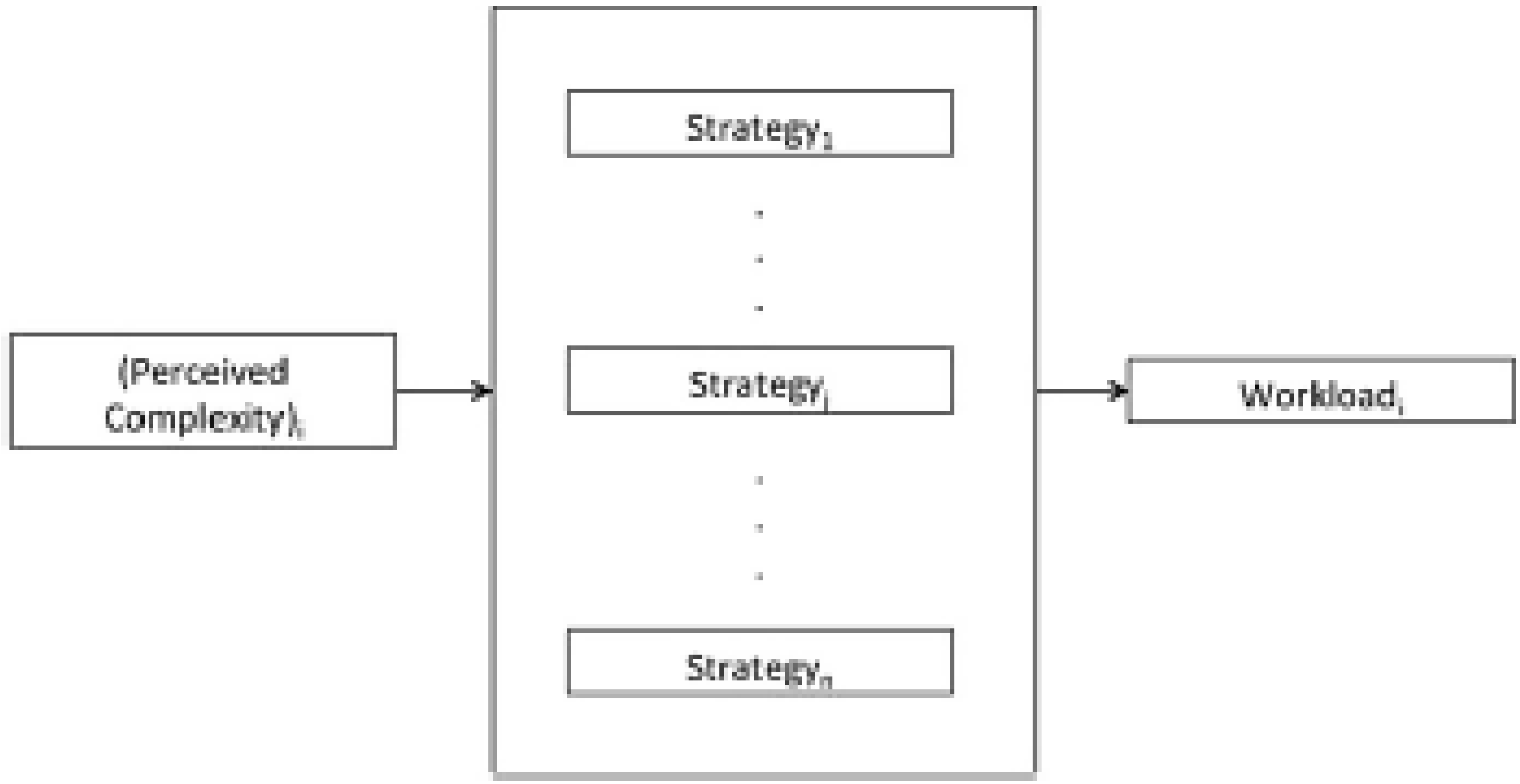
Complexity and workload



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Workload Estimation Model (1)

Workload estimation model calculates the ATCO perceived complexity after a calibration 3 ATCOs in two different stages based on:

- the strategy used and
- characterized by the air traffic clearances commanded

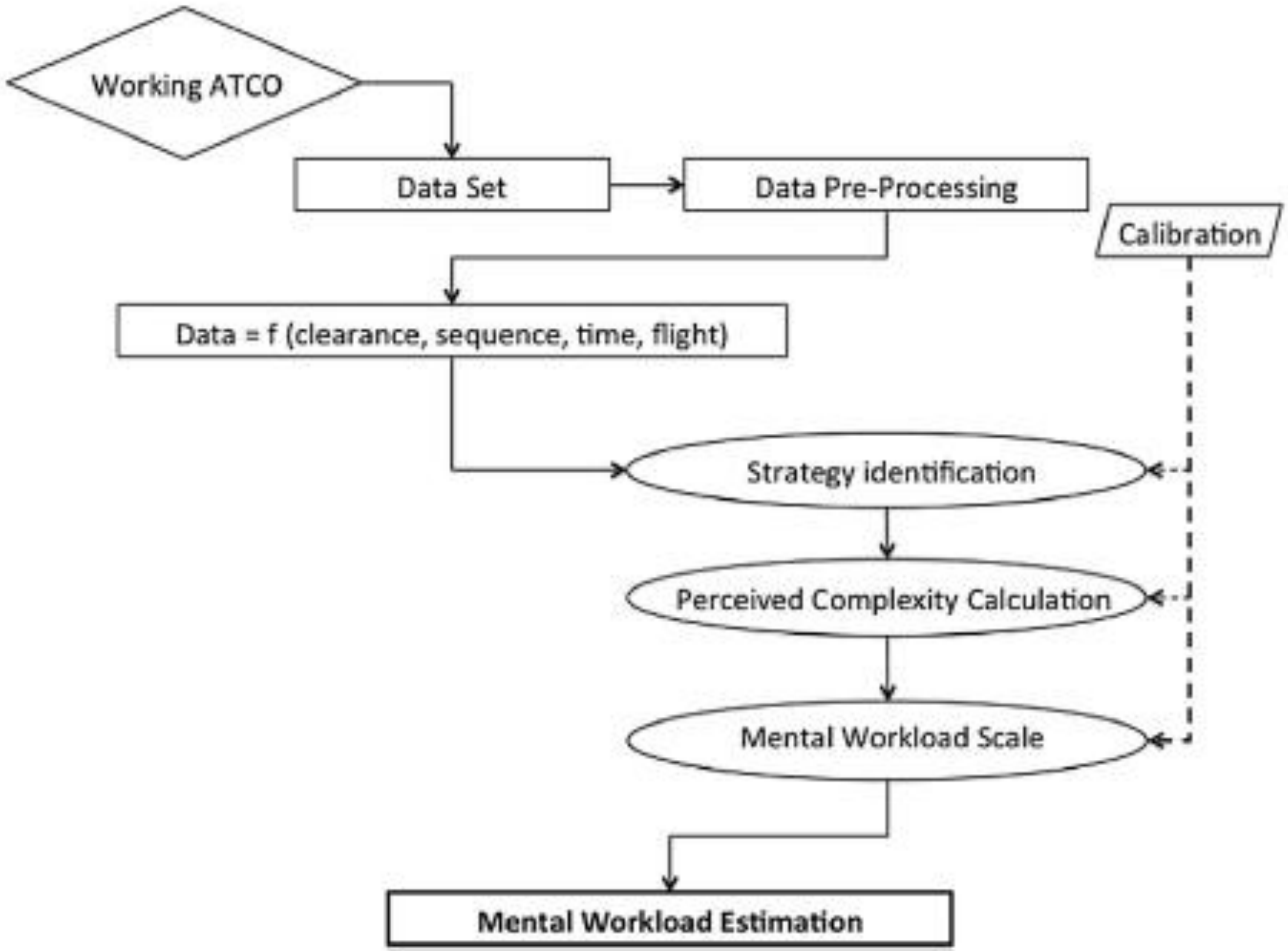
Associates each perceived complexity to:

- a workload level based on an expert-based qualitative ranking from 3 MUAC ATCOs.

Mental workload estimated by the model:

- final result of the cognitive iteration process, i.e. the desired workload.

Workload Estimation Model (2)



ATCO strategy

ATCO strategy used to control traffic uses:

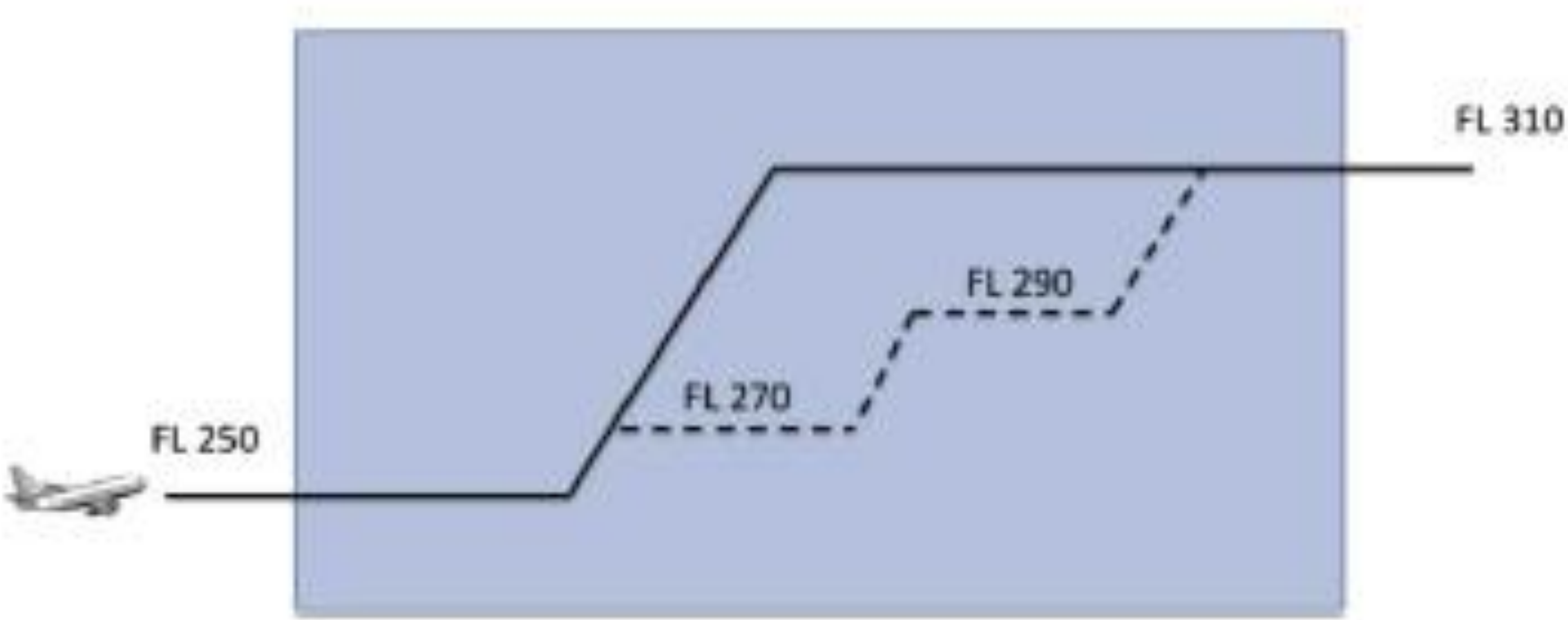
- type and time of clearances, and
- clearance-sequence

Infers the ATCO's perceived complexity, and therefore mental workload.

Logic can be applied both in dimensions:
- vertical and
- horizontal.

ATCO strategy

Climb with two intermediate levels (e.g. FL 270 and FL 290) indicates a higher perceived complexity than a flight directly cleared to e.g. FL 310.



Complexity vector

Complexity Vector to define when:

- perceived complexity associated to an ATCO clearance is occurring and
- how large is the perceived complexity

Estimates perceived complexity:

- each flight and
- for each time of the day (1 min slices)

Individual perceived complexities of all flights:

- summed to generate the total perceived complexity for that time slice:

$$\text{Perceived Complexity}_{\text{per time slice}}$$

$$= \Sigma_i \text{ perceived complexity}_{\text{flight } i}$$

Clearances considered by this model (1)

Direct to point (D2P): a flight is cleared to fly directly to a given point:

- can be located inside or outside of the sector.
- MUAC operations are not airway based i.e. ATCOs use D2P as a first option.

Heading (HDG): Headings are used as a de-confliction clearance.

Speed (SPD): Speed clearances are most commonly used for sequencing tasks.

Cleared Flight Level (CFL): the assigned flight level.

Clearances considered by this model [2]

Transfer Flight Level (TFL): the coordinated FL for transfer to a lower/upper or external sector:

- not a direct clearance to the flight, but an indication to the ATCOs, since the coordinated flight level differs from the one in the flight plan or Letter of Agreement (LoA).
- TFL is finally achieved through CFL issued to pilot.

Assume flight (ASM): Input made to the system when a flight calls in and ATCO assumes under their control.

Cancel assume flight (XASM): Input made when transferring a flight to the next frequency.

Complexity vector

Perceived complexity associated with the ATCO clearance and the start and the end time of application of the perceived complexity value:

Complexity Vector = [Value; Start Time; End Time]

The values of the complexity vector are assigned within a 1-4 scale, ranging from:

1. Low,
2. Medium-low,
3. Medium-high, and
4. High (4).

Scale used to ease the expert-based (ATCOs) qualitative complexity.

Data needed (1)

Sector sequence: a record of the different sector configurations used throughout the day:

- assess a specific airspace volume.

Flight level log: contains the entry and exit flight levels. These altitudes are provided by radar when the flight is assumed i.e. they are not geometrical entry altitudes.

- provides relevant information on the vertical trajectory (ascent, cruise, or descent).

Data needed (2)

Input log: contains all the information relative to the inputs made into the system by ATCOs and contains the following:

- Time
- Sector under control (SEC)
- ATCO role: EC, PC or assistant (additional position)
- Call sign (CS): associated with the clearance
- Departure (ADEP)/destination (ADES) airport
- Clearance type
- Data field: contains complementary information to the clearance type e.g. value of the cleared flight level

Occupancy log: contains the occupancy count per minute

- used as a complementary output to the workload charts

Calibrated perceived complexity vectors

For **MUAC** DECO sector group

Rule		Complexity vector
Occupancy	–	$[1, t_{ASM}, t_{XASM}]$
HDG/D2P	Prior to initial HDG	$[2, t_{ASM}, t_{HDG}]$
	Prior to initial D2P	$[2, t_{ASM}, t_{D2P}]$
	Intermediate HDG	$[3, t_{HDG}, t_{HDG}$ or $t_{D2P}]$
	Intermediate D2P	$[2, t_{D2P}, t_{HDG}$ or $t_{D2P}]$
	After final HDG	$[3, t_{HDG}, t_{XASM}]$
	After final D2P	$[1, t_{ASM}, t_{XASM}]$
SPD	–	$[3, t_{SPD}, t_{SPD}$ or $t_{esumeSPD}$ or $t_{XASM}]$
CFL (ascent)	Prior to initial CFL	$[4, t_{ASM}$, earliest $(t_{CFL}, t_{level})]$
	Intermediate CFL	$[4, t_{CFL}, t_{CFL}]$
	After final CFL	$[1, t_{CFL}$, earliest $(t_{XASM}, t_{level})]$
CFL (descent)	Prior to initial CFL (1 CFL)	$[1, t_{ASM}, t_{CFL}]$
	Prior to initial CFL (>1 CFL)	$[2, t_{ASM}, t_{CFL}]$
	Intermediate CFL	$[4, t_{CFL}, t_{CFL}]$
	After final CFL (no TFL)	$[1, t_{CFL}$, earliest $(t_{XASM}, t_{level})]$
	After final CFL (with TFL)	$[4, t_{CFL}$, earliest $(t_{XASM}, t_{level})]$

Calibrated perceived complexity vectors

Complexity vectors translated to a qualitative mental workload scale based on discussions, replays etc.

Workload level	Perceived complexity
Overload	>80
Very high	70–80
High	60–70
Medium	40–60
Low	20–40
Very low	<20

Workload monitoring in real time

During the execution phase of the ATC:

- crucial that duty supervisors be aware of the workload experienced by ATCOs, in order to carry out ATFCM techniques to match the ATCO needs.
- currently being achieved by means of direct questioning of the ATCOs about their workload.

Workload estimation model => duty supervisor can:

- directly assess the workload of all the ATCOs from their computer in real time.
- Identify workload imbalance situations

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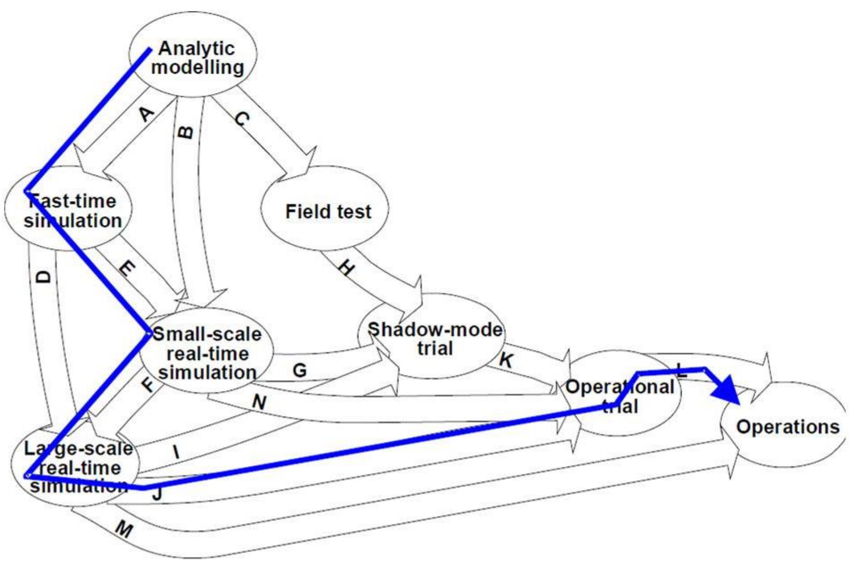
Novelty of the method

From... *To...*

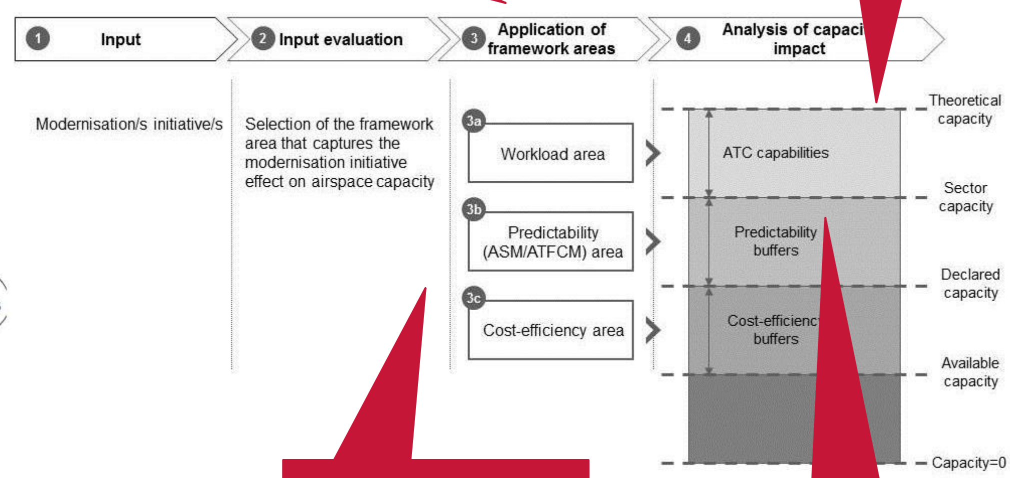
“*MAEVA*” approach



“*Tobaruela G., PhD thesis*” approach

Multidimensional approach

Real-time workload estimation based on ATCOs inputs



Cost-efficiency effect on airspace capacity

ASM/ATFCM effect on airspace capacity

The Metroplex Problem

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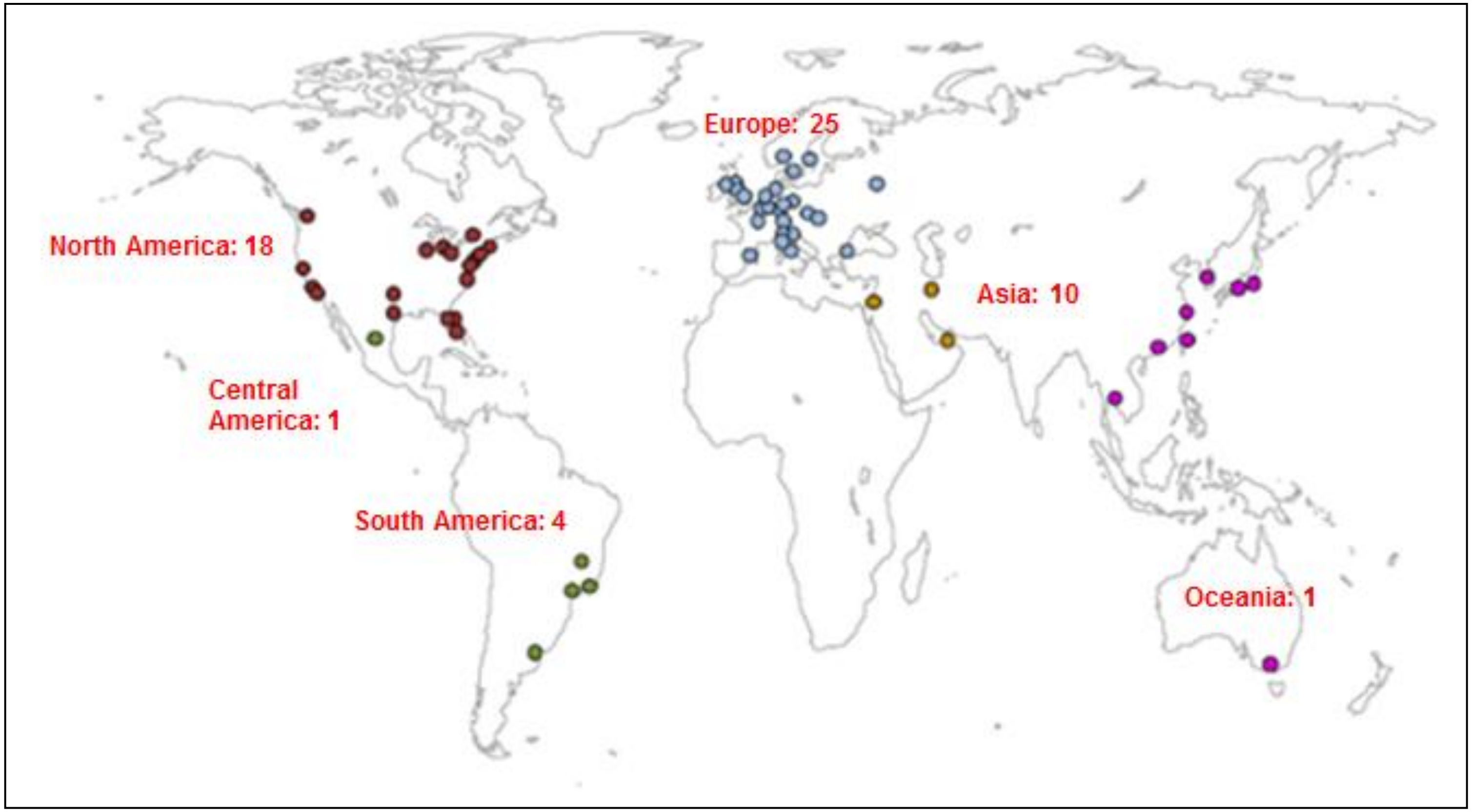
The Metroplex Problem

- Typically major cities (London, New York, Tokyo) are served by several airports effectively creating a Multi-Airport System or Metroplex

- The operations of the Metroplex airports are highly dependent on one another, which renders their efficient management difficult

- When compared to single-airport systems, Metroplex operations are characterized by increased traffic complexity due to the conflicting demands of individual airports for the same airspace resource

What are Metroplex?



Geographical distribution of Metroplex systems worldwide *(adopted from Bonnefoy)*

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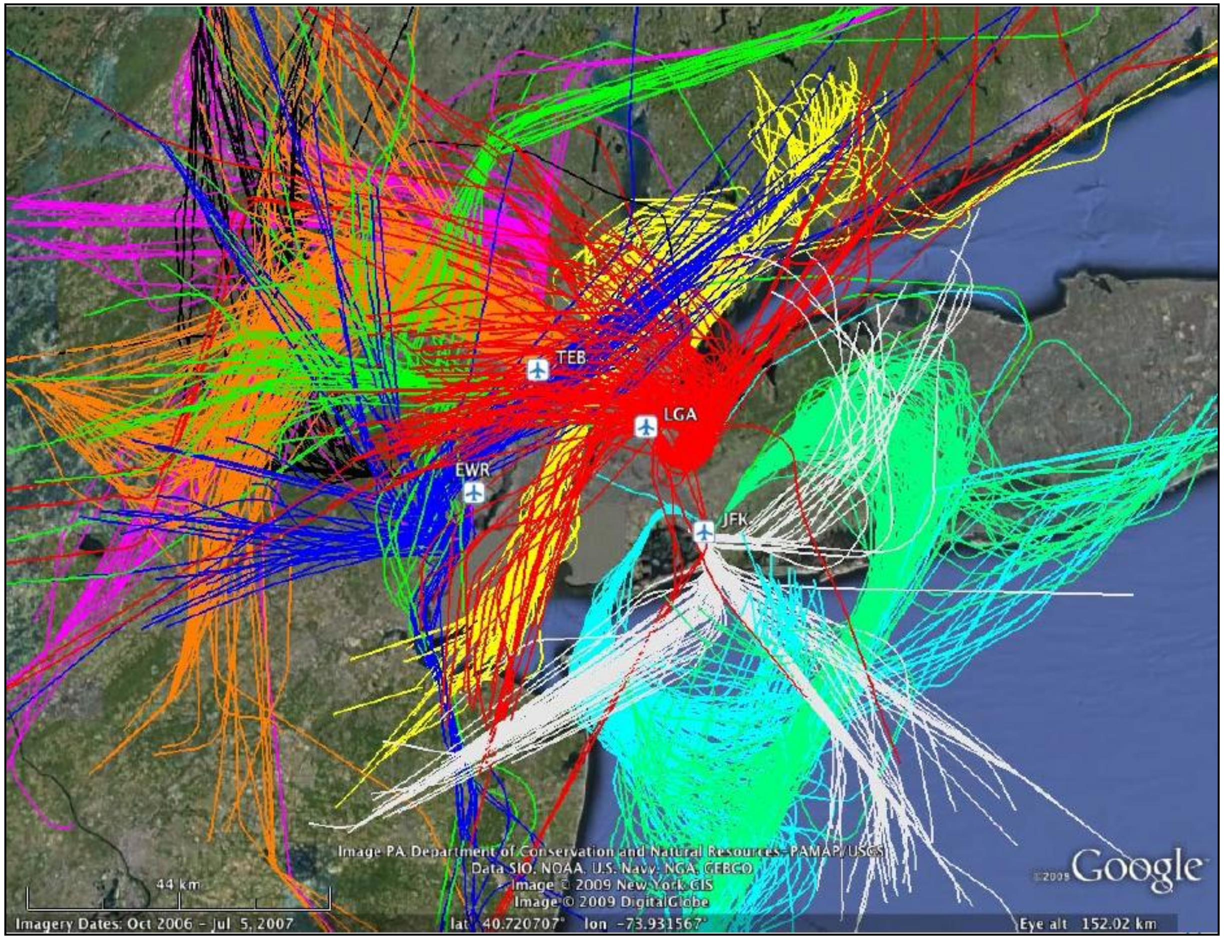
London

New York



Arrival and departure aircraft movements for New York airports *(adopted from O'Neil)*

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Current design

- Static airspace structures (SIDs / STARs) for individual airports
- Segregate the TRACON airspace into sectors that belong to specific airports
- ATC airspace restrictions

ATCo resort to the implementation of ad-hoc measures for the mitigation of potential trajectory conflicts on a FC/FS basis (holding stacks, vectoring)

Sub-optimal utilization of the available system resources

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Solution

Replace current design with:

Dynamic and robust system design to adjust to the dynamic flow patterns throughout the operational horizon

Prerequisites

- The accurate depiction of the significant traffic flow patterns for the different Metroplex airports
- The classification of the spatio-temporal demand that takes into account the uncertainties associated with the ATM system operation

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References

J1. Sidiropoulos S, Majumdar A, K. Han (2018) A framework for the optimization of terminal airspace operations In Multi-Airport Systems, *Transportation Research Part B: Methodologica*l, Vol: 110, Pages: 160-187, ISSN: 0191-2615

J2. Sidiropoulos, S., Ke, H, Majumdar, A. and W.Y. Ochieng (2016) Robust identification of traffic flow patterns in Metroplex terminal areas under demand uncertainty, *Transportation Research Part C: Emerging Technologies* , Vol: 75, Pages: 212-227, ISSN: 0968-090X

Framework components

- The **dynamic route service policy** for dynamic terminal fix selection
- Demand modeling for **classifying arrival and departure flights into dynamic routes** based on their temporal and spatial distributions throughout the operational horizon
- A **distributionally robust optimization extension** of the deterministic framework to account for **uncertainty in the demand prediction**

Methods – Dynamic route service policy

Dynamic route: *"a set of flights that are part of a significant traffic flow pattern and share similar spatial and temporal characteristics during a specific time period of operations"*

Each dynamic route:

- Refers to a specific Metroplex airport
- Either arrival or departure route
- *Location of terminal fixes*

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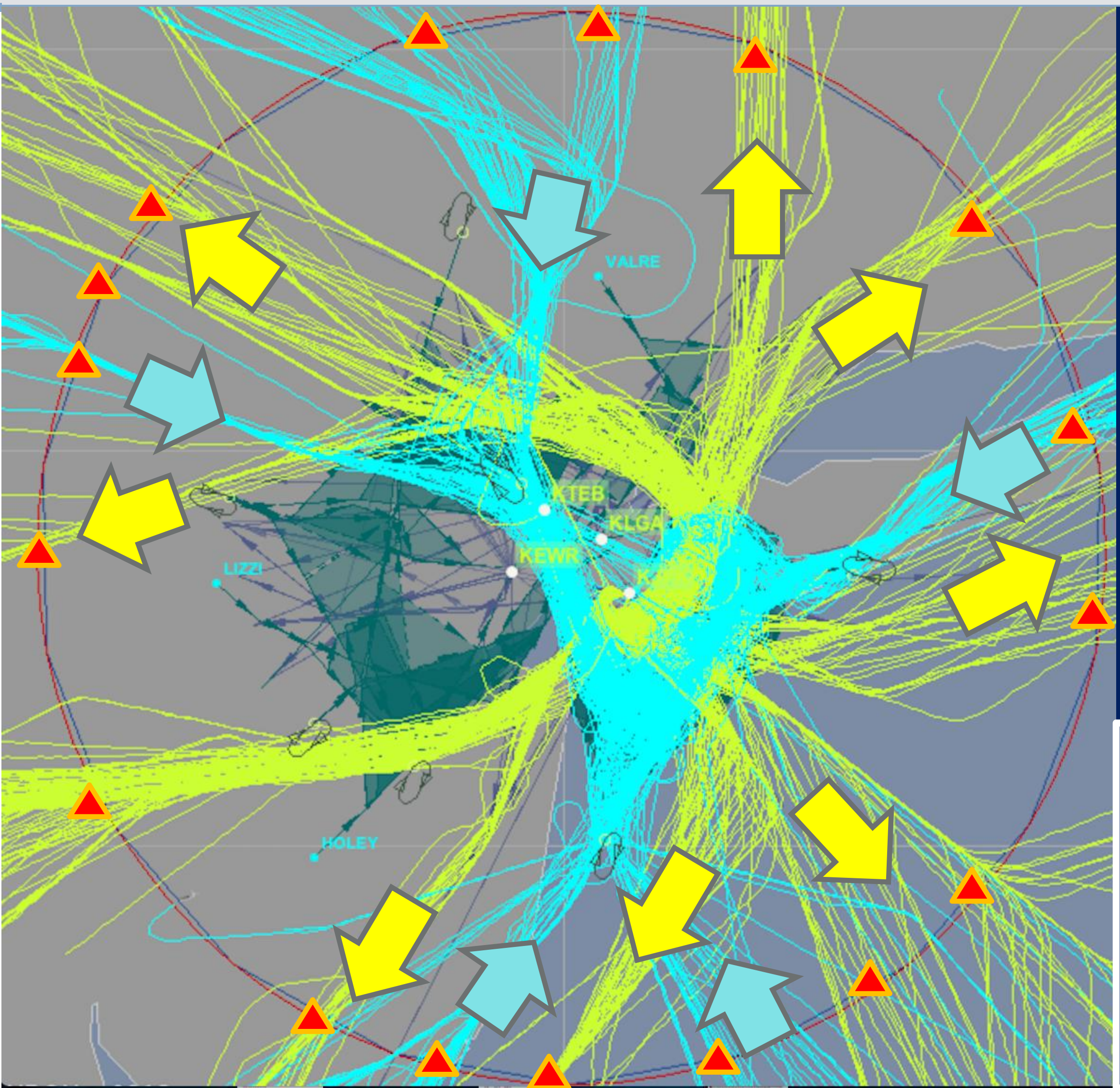
Methods – Dynamic route service policy



Main departure flows

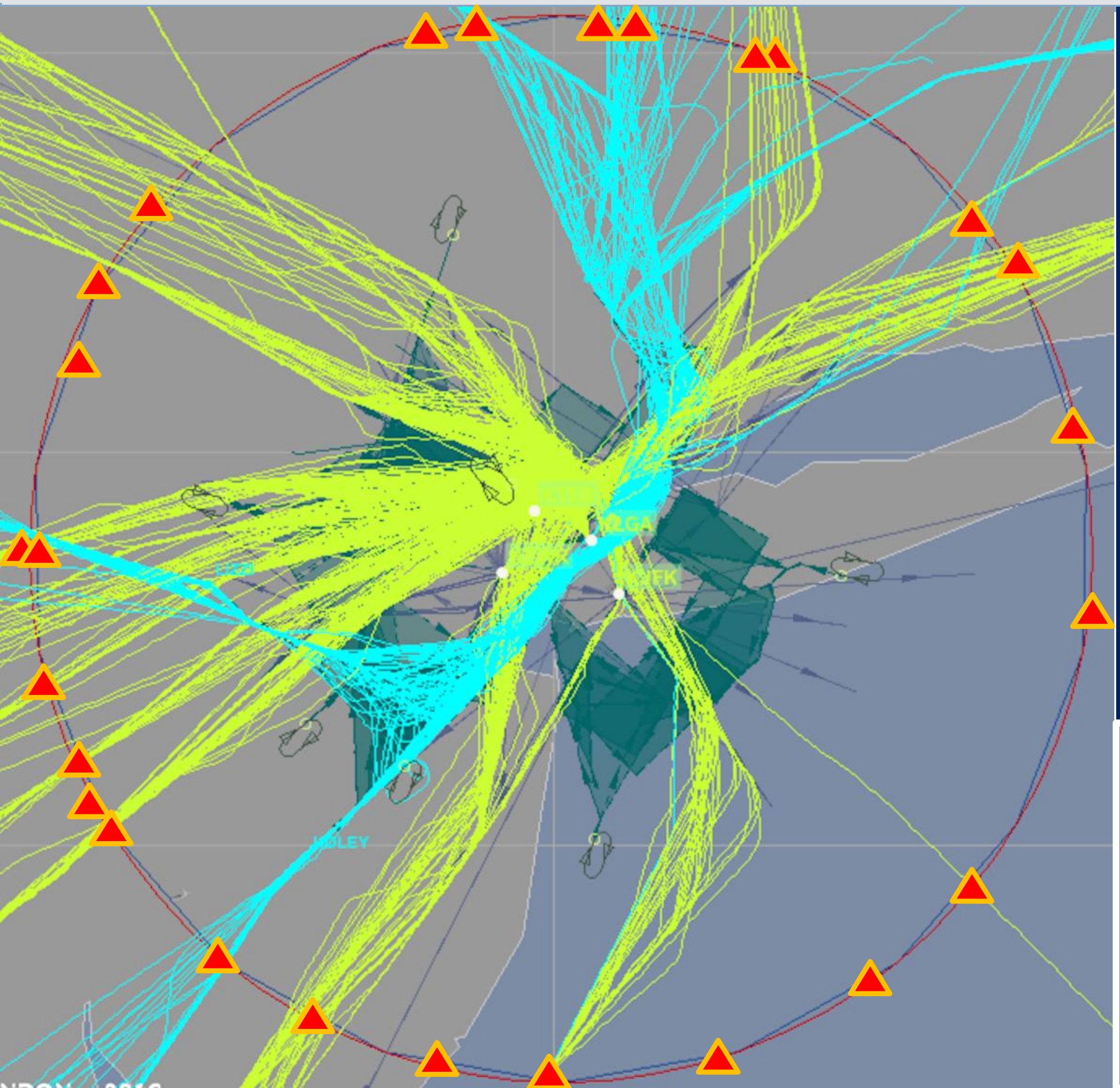
Main arrival flows

Dynamic terminal fixes

TRACON model

- Center: Metroplex geographic centroid
- 70NM radius

Methods – Dynamic route service policy



Main arrival flows

Main departure flows

Dynamic terminal fixes

<u>TRACON model</u>

- Center: Metroplex geographic centroid
- 70NM radius

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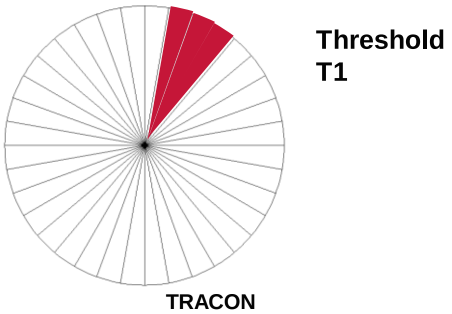
Methods – S-T clustering algorithm

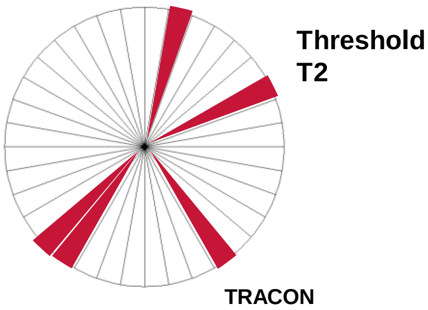
S-T ALGORITHM

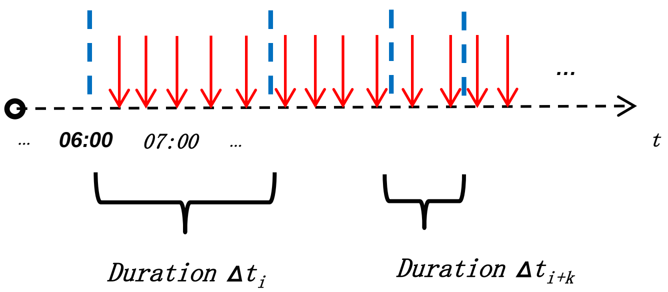
- Inputs
  - Updated demand prediction (**location** AND **time** of entry/exit to/from TRACON for all flights) for given operational horizon

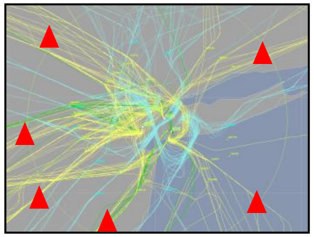
- Objective: Identify significant changes in traffic flows:
  - In individual sectors
  - In the entirety of the TRACON

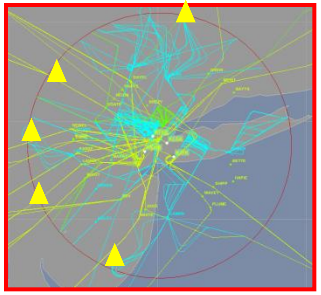
- Features:
  - Considers significance of change (threshold values T1, T2)
  - Assigns flights to distinct operational periods and to dynamic fixes for each operational period











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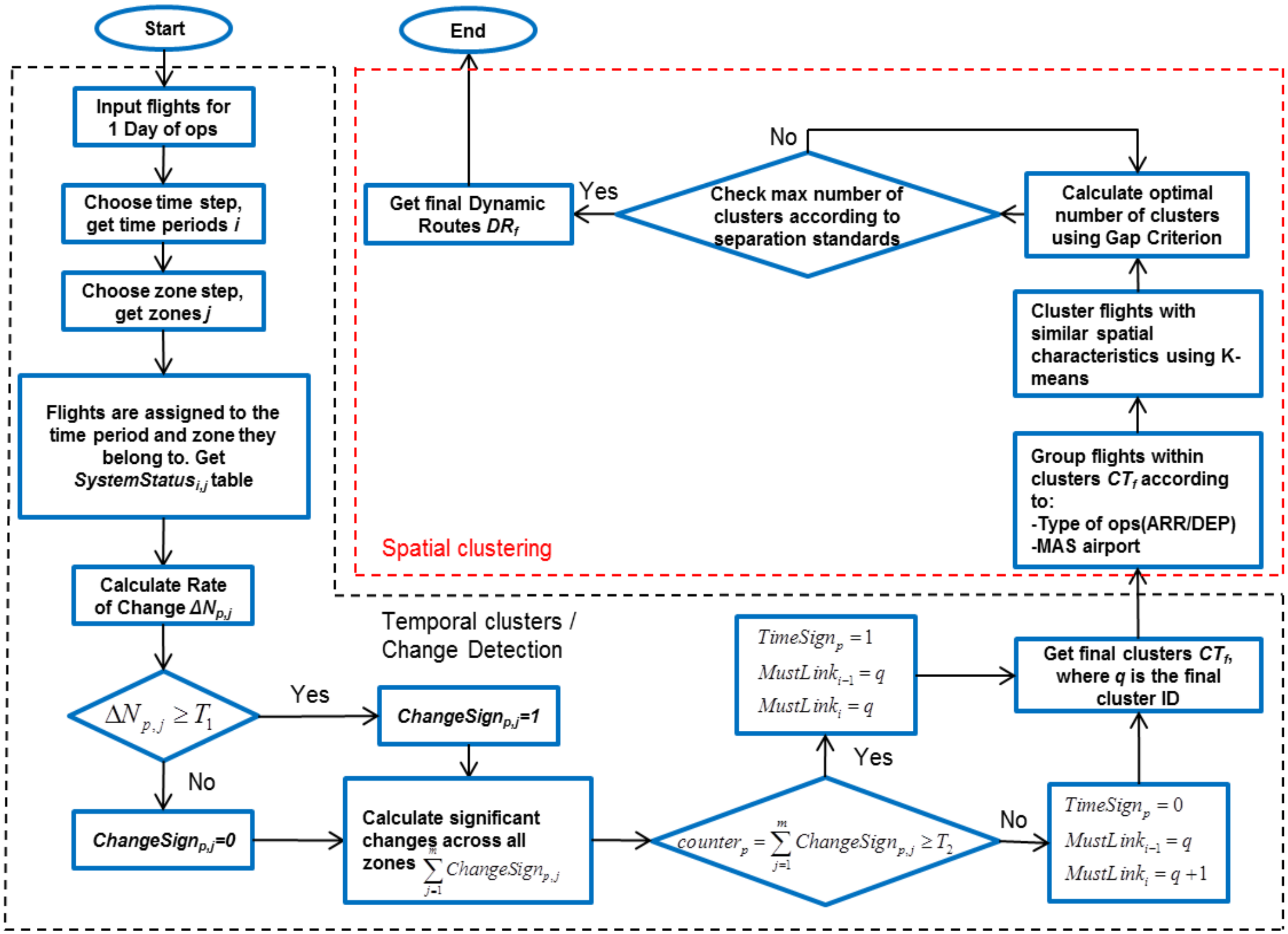
Methods – S-T clustering algorithm



S-T clustering algorithm

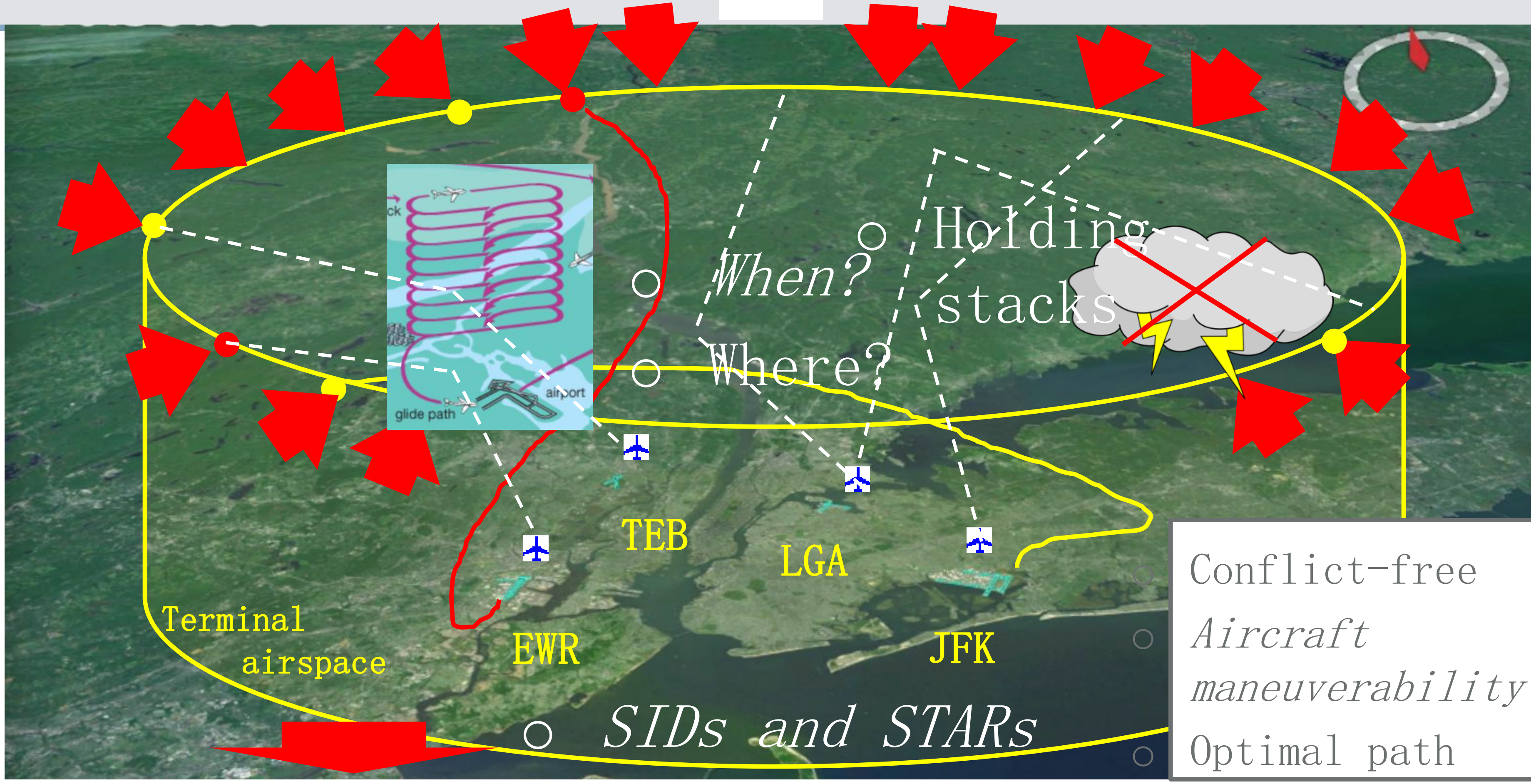
Methods – Demand uncertainty

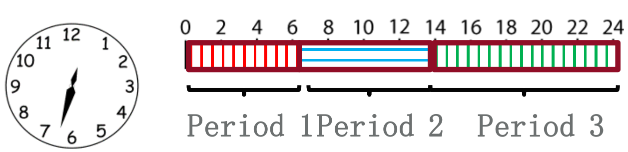
Inherent uncertainties in air traffic demand

- International/domestic demand fluctuates
- Airline compliance to the filed flight plans
- Weather conditions
- Airspace configurations
- Route availability
- Traffic management initiatives (Reroutes, groundholding, etc.)

Model extension to account for uncertainty

Dynamic route concept for terminal design





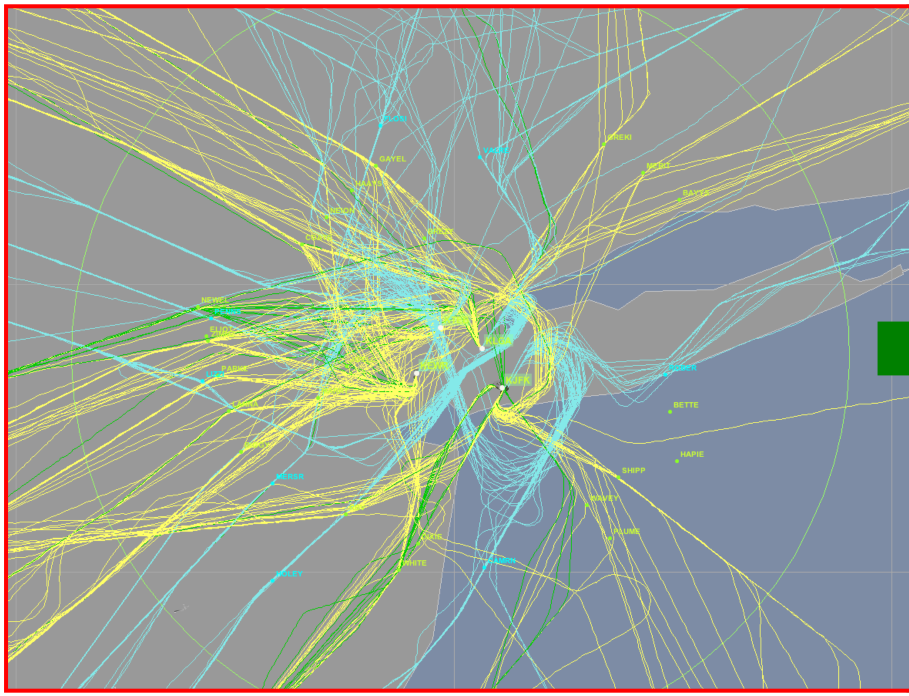
DESIGN

1. Demand modelling

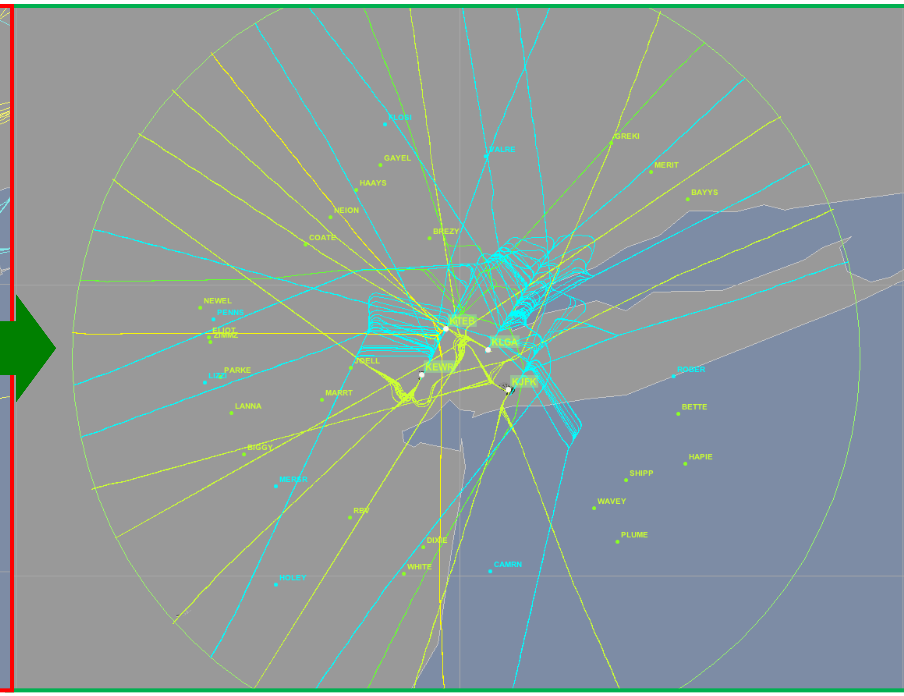
2. Decision maker input

3. Arrival/Departure routes

Current v. New design – Simulation

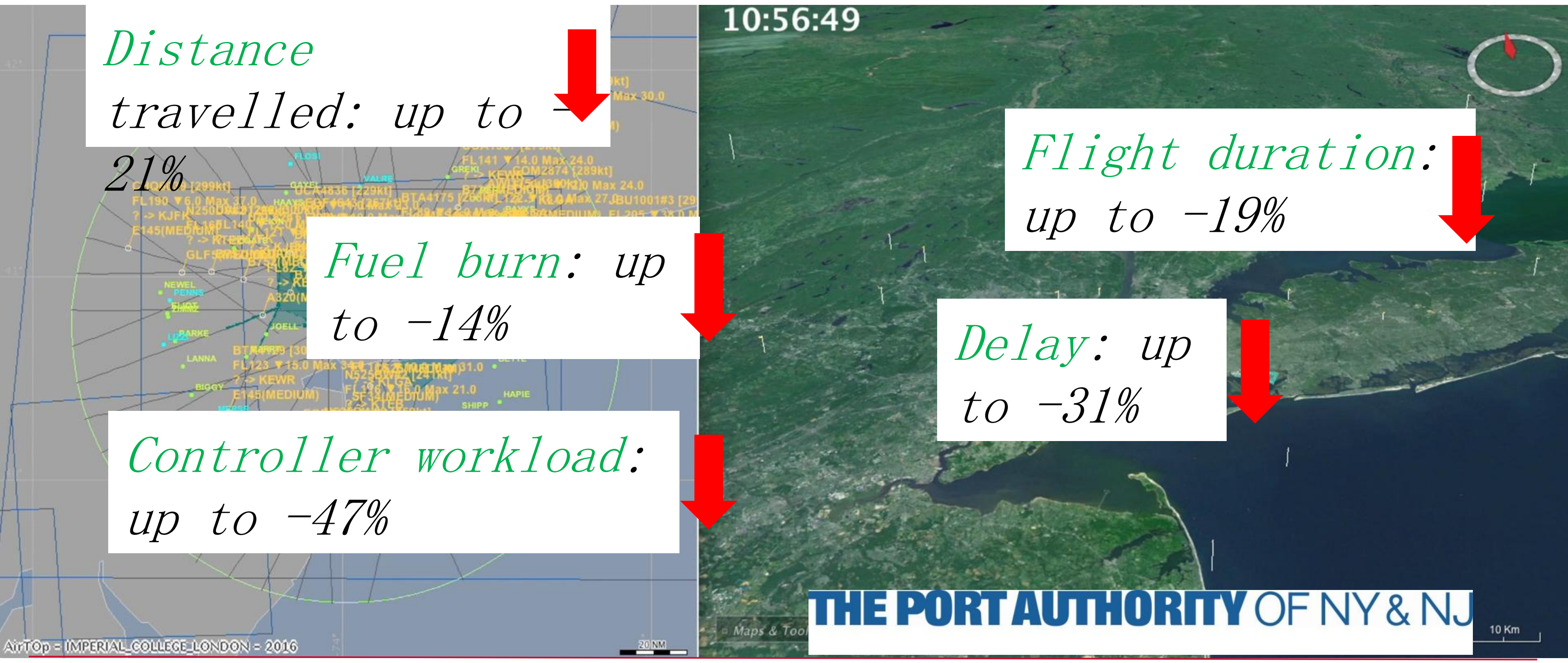


Current



New

Improved system performance!



Distance travelled: up to −21%

Fuel burn: up to −14%

Controller workload: up to −47%

Flight duration: up to −19%

Delay: up to −31%

Conclusions

- Controllers still vital in Air Traffic Control!
- Workload still crucial – still difficult to define
  - recognise need for aspects such as emotions
- Measuring workload has new exciting opportunities
  - the “age of the wearable” is nearly here!
- Nature of complexity under review
  - how to measure it?
  - emerging areas.