3rd International Conference on Research in Air Transportation - ICRAT 2008
June 01 -04, 2008 - Fairfax, Virginia, U.S.A.

Optimal departure aircraft trajectories minimising population annoyance

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3rd June 2008

UPC

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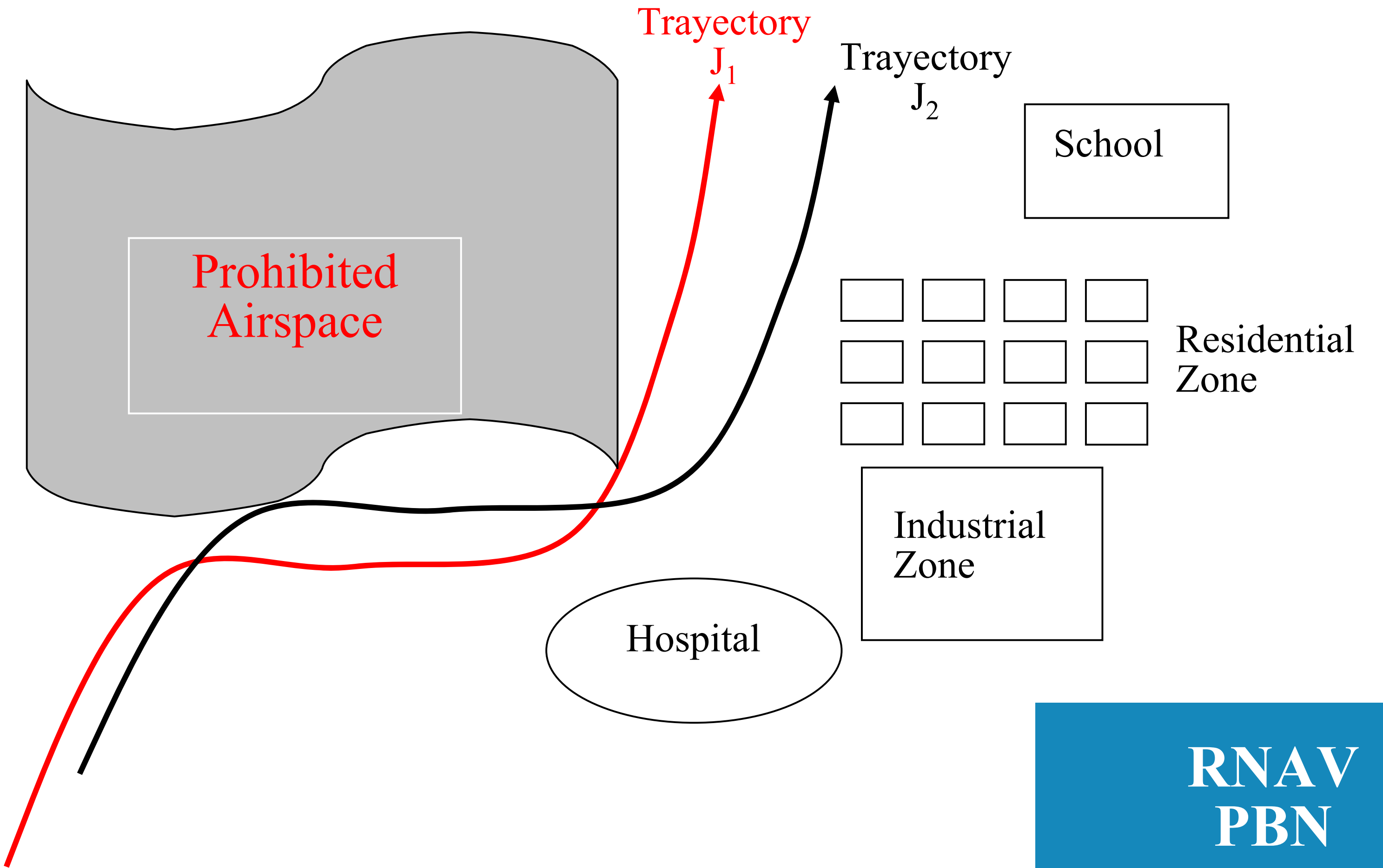
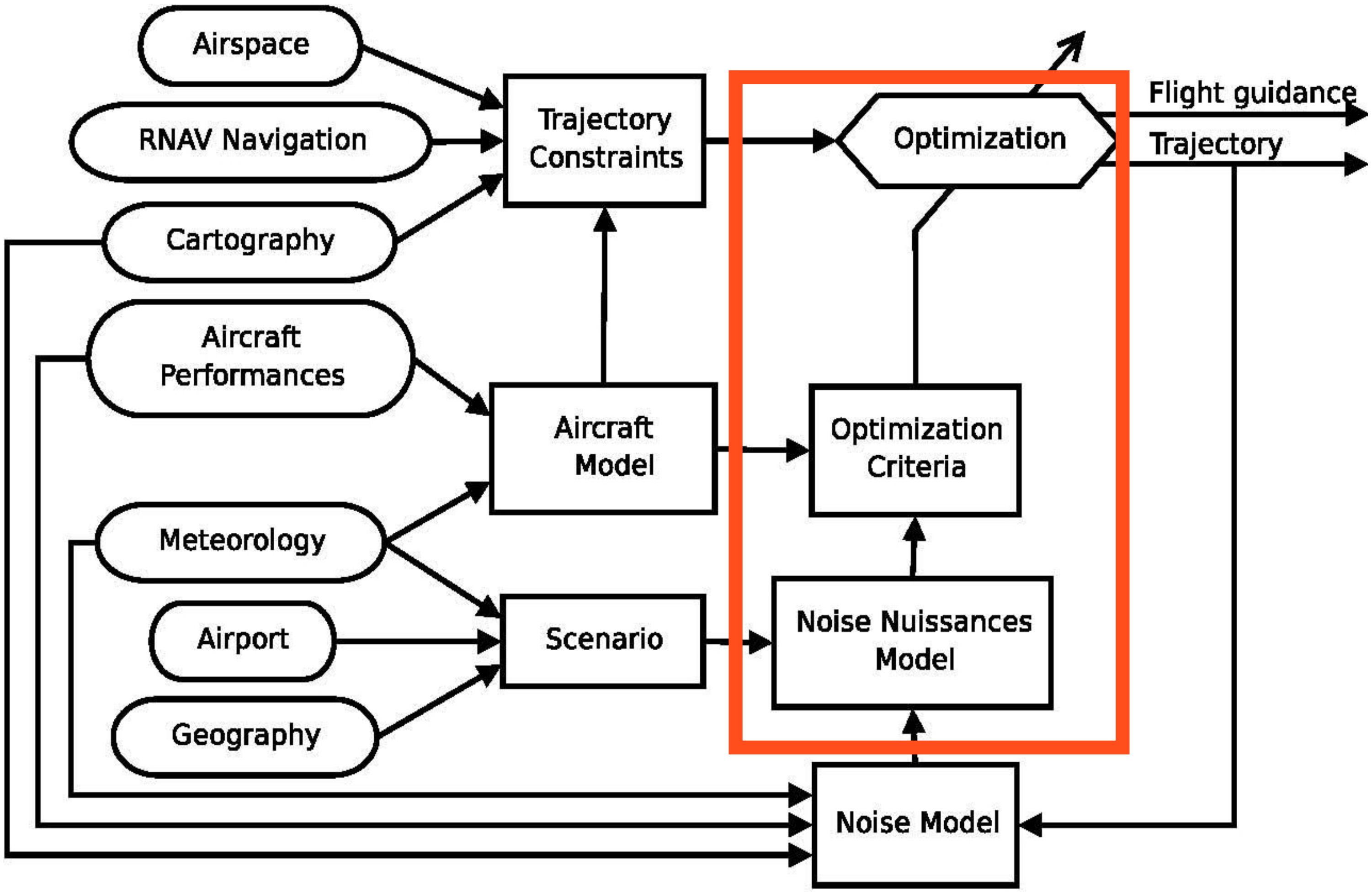
Introduction



RNAV
PBN

Trajectory optimisation framework



Fuzzy logic annoyance model

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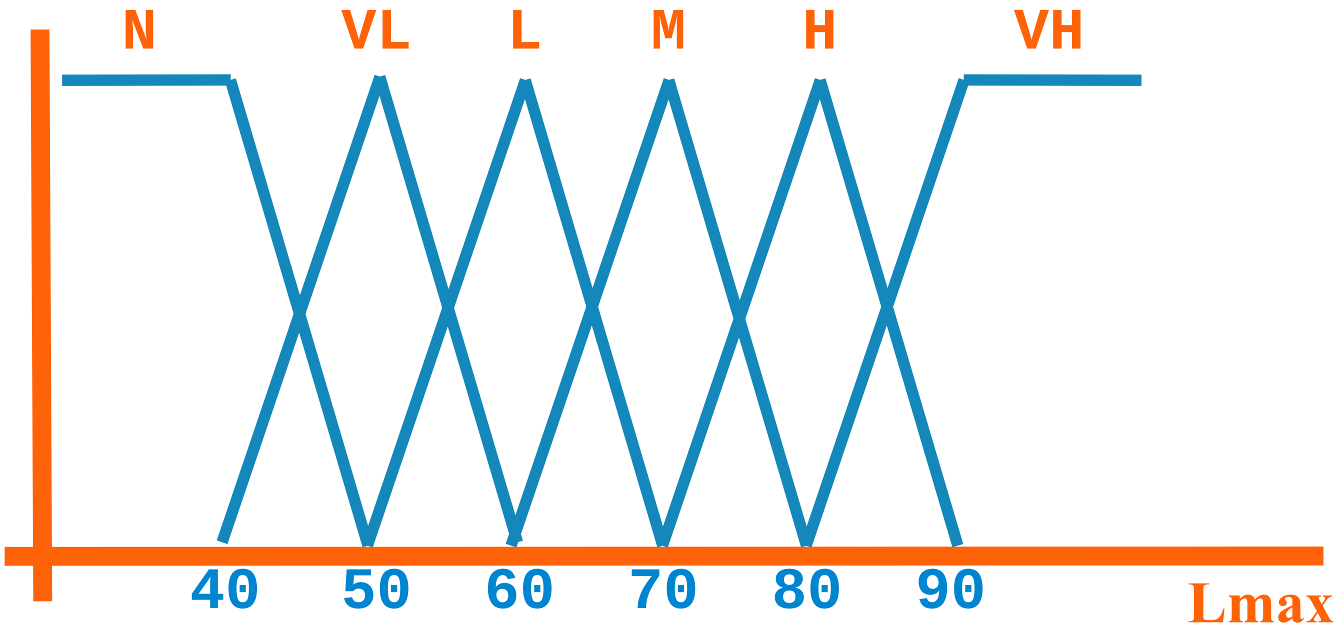
Annoyance ??

- Noise perceived
- Duration of noise
- Time of day
- Frequency of overflights
- Type of zone overflown
- Cultural aspects
- Socio-economic aspects
- ....

Fuzzy logic incorporate vagueness and uncertainty to the model and to the reasoning process.

Fuzzy logic annoyance model

Input	Fuzzy	Rule bases	Defuzzy	Output
Lmax Hour of day Zone Type		Annoyance produced		Normalized annoyance [0,1]



Fuzzy logic annoyance model

- Rule bases

Residential Zone	*Morning*	*Afternoon*	*Night*
No noise	NA	NA	NA
Very low noise	NA	NA	SA
Low noise	NA	SA	MA
Meduim noise	SA	MA	HA
High noise	MA	HA	EA
Very high noise	HA	EA	EA

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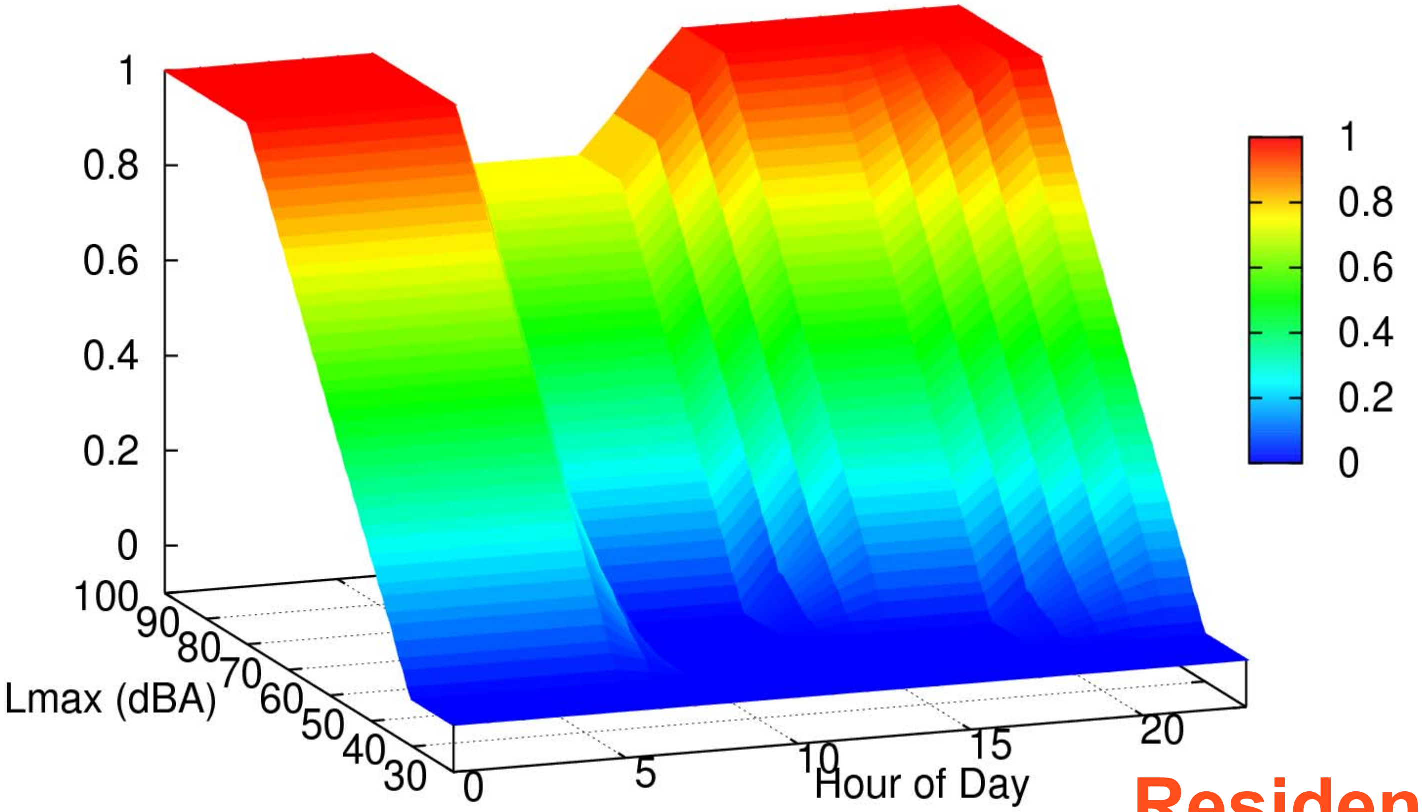
Fuzzy logic annoyance model

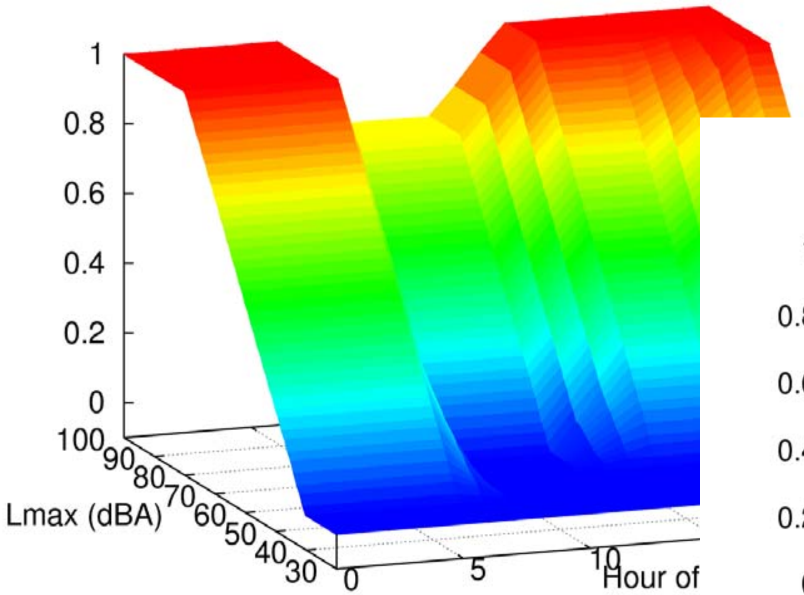
- Defuzzyfication



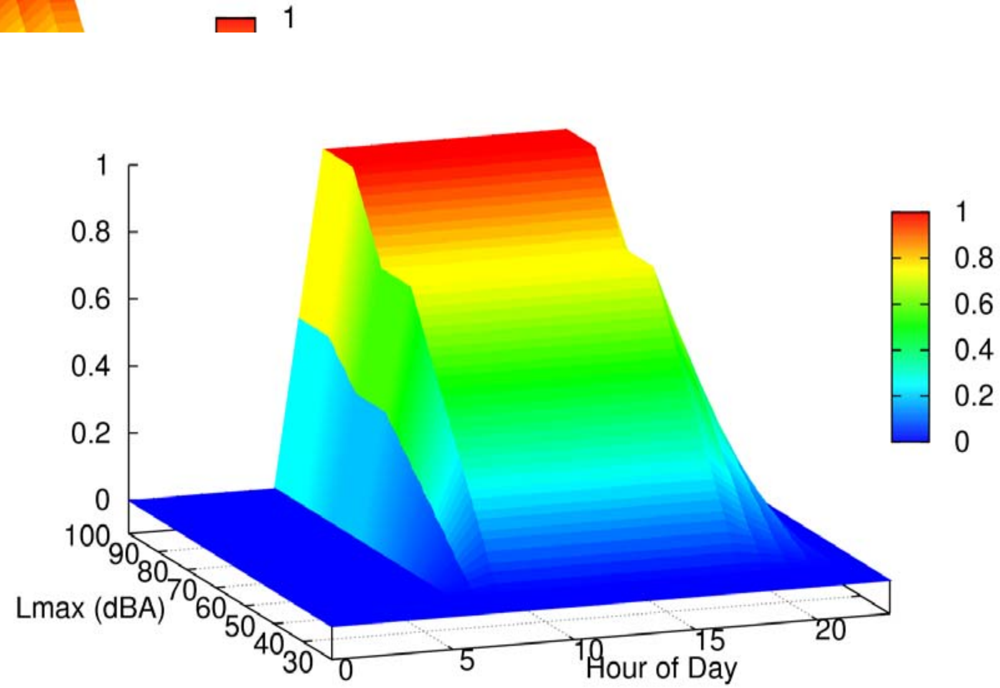
Residential Zone

Fuzzy logic annoyance model

- Defuzzyfication



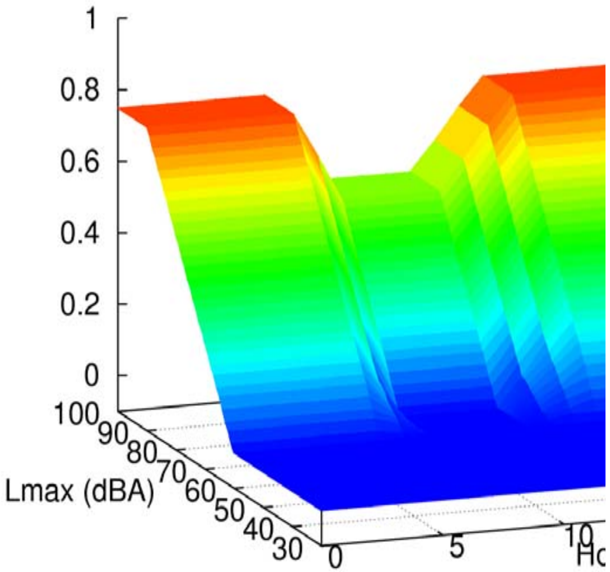
Residential Zone



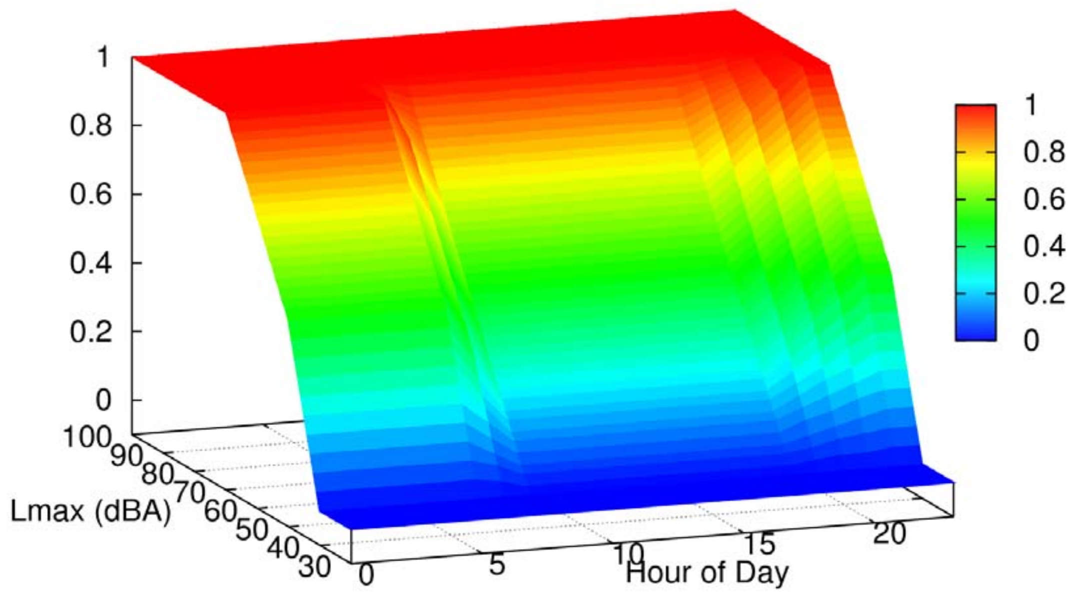
School

Fuzzy logic annoyance model

- Defuzzyfication



Industrial zone



Hospital

Multiobjective optimization

$$\min_{\vec{z}\in\mathcal{Z}} \left[J_1(\vec{z}), J_2(\vec{z}), \cdots, J_{n_j}(\vec{z})\right]$$

Wheighted trajectory

$$\min_{\vec{z}\in\mathcal{Z}} \sum_{i=1}^{n_j} w_i J_i(\vec{z})$$

"Fair" trajectory

$$\min_{\vec{z}\in\mathcal{Z}} \left[\max_i(\Delta_i)\right]$$

$$\Delta_i = J_i - J_i^*$$

Multiobjective optimization

$$\min_{\vec{z}\in\mathcal{Z}} \left[J_1(\vec{z}), J_2(\vec{z}), \cdots, J_{n_j}(\vec{z})\right]$$

Egalitarian principle:

the system is no better-off than its worse-off individual

"Fair" trajectory

$$\min_{\vec{z}\in\mathcal{Z}} \left[\max_i(\Delta_i)\right]$$

$$\Delta_i = J_i - J_i^*$$

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Numerical example

- Airbus A340-600 departure
  - Trajectory optimization from 400ft above RWY
  - Final point: [10 km,20 km] at or above 4000 ft
  - 5 different noise sensitive locations

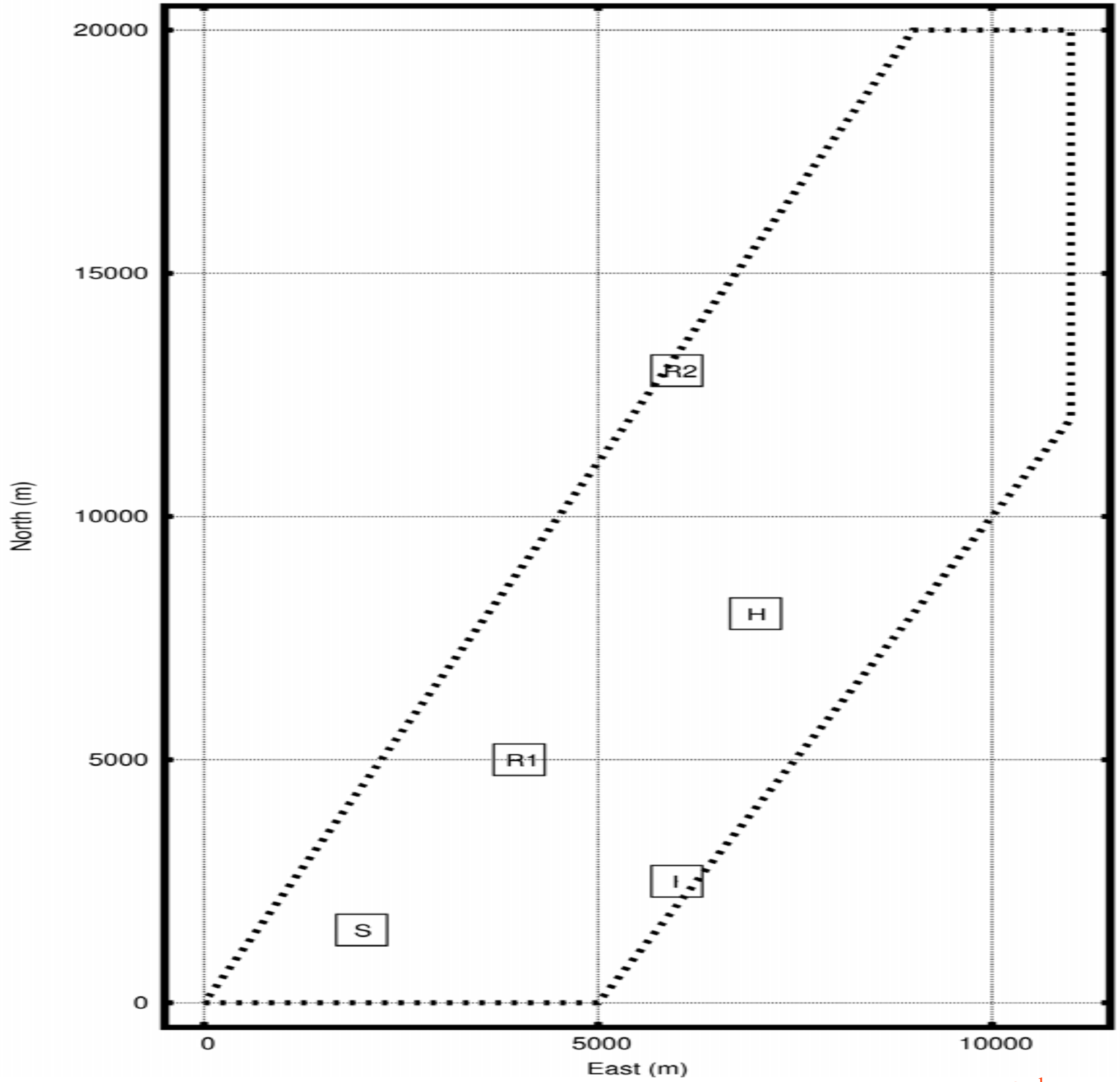
School

Hospital

2 residential zones

Industrial zone

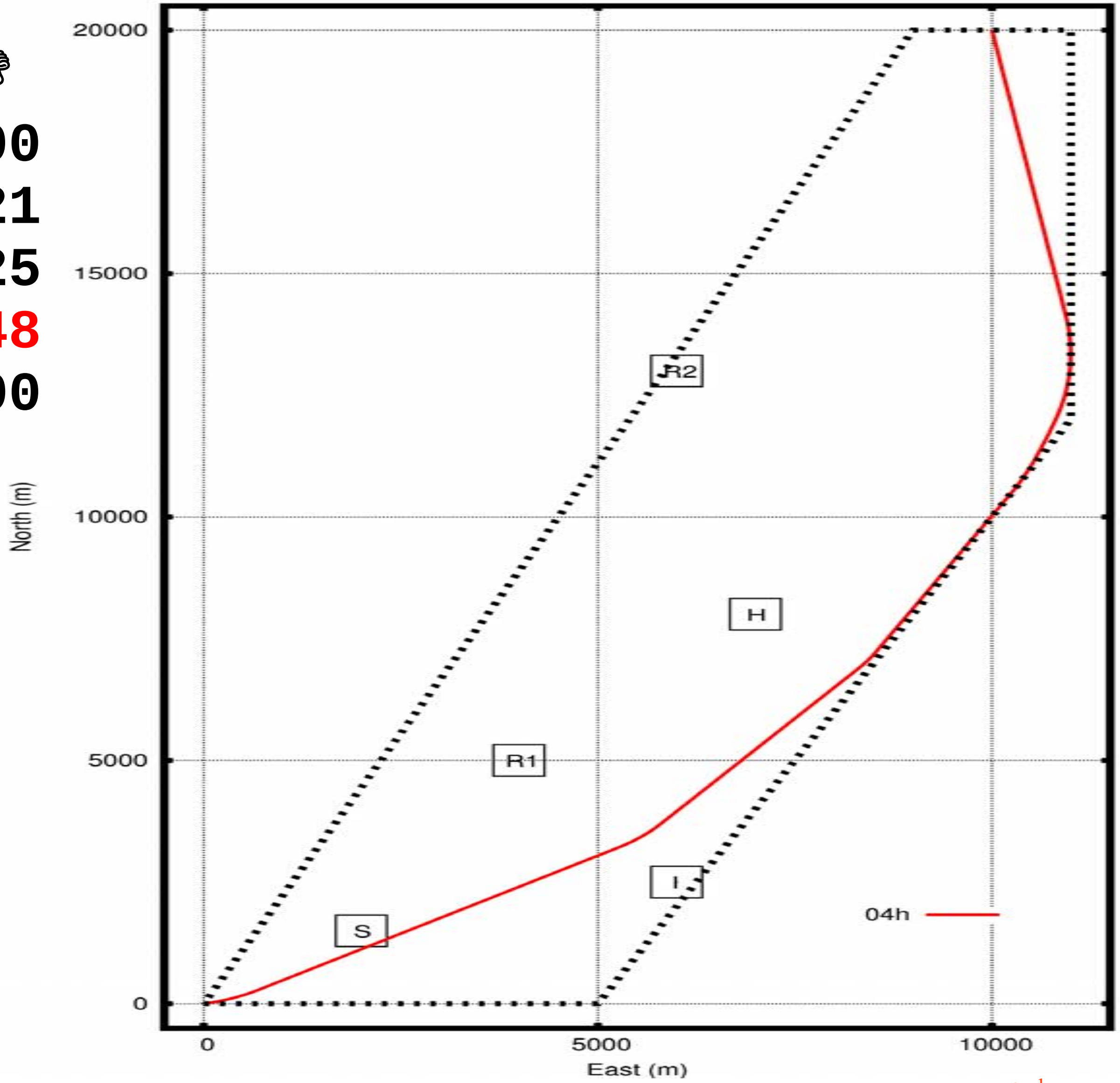
Numerical example



Numerical example

	J	J*	👎
S	.00	.00	.00
I	.21	.00	.21
R1	.38	.13	.25
H	.80	.32	.48
R2	.02	.02	.00

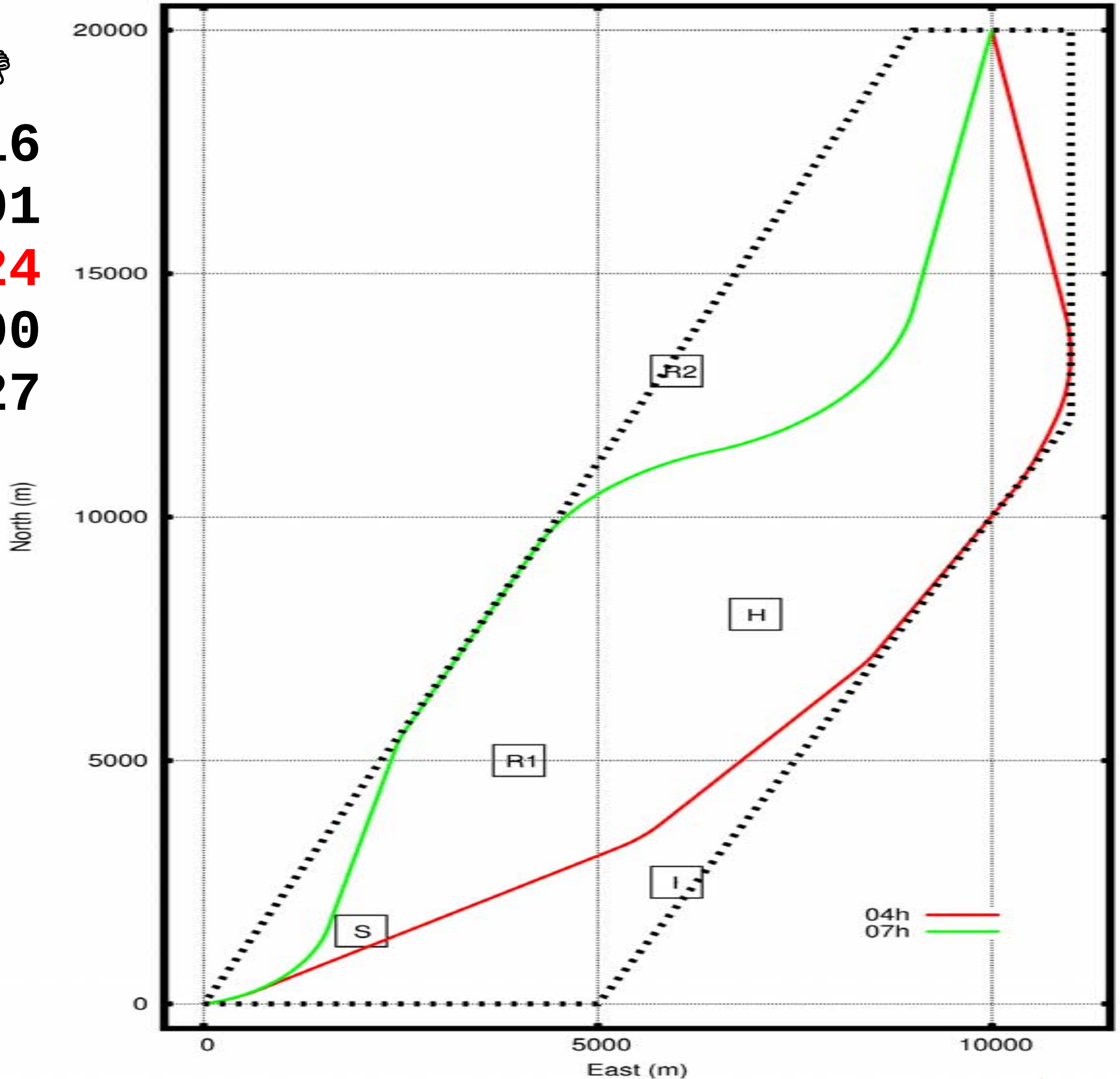
04h



Numerical example

	J	J*	
S	.42	.26	.16
I	.01	.00	.01
R1	.30	.06	.24
H	.24	.24	.00
R2	.28	.01	.27

07h



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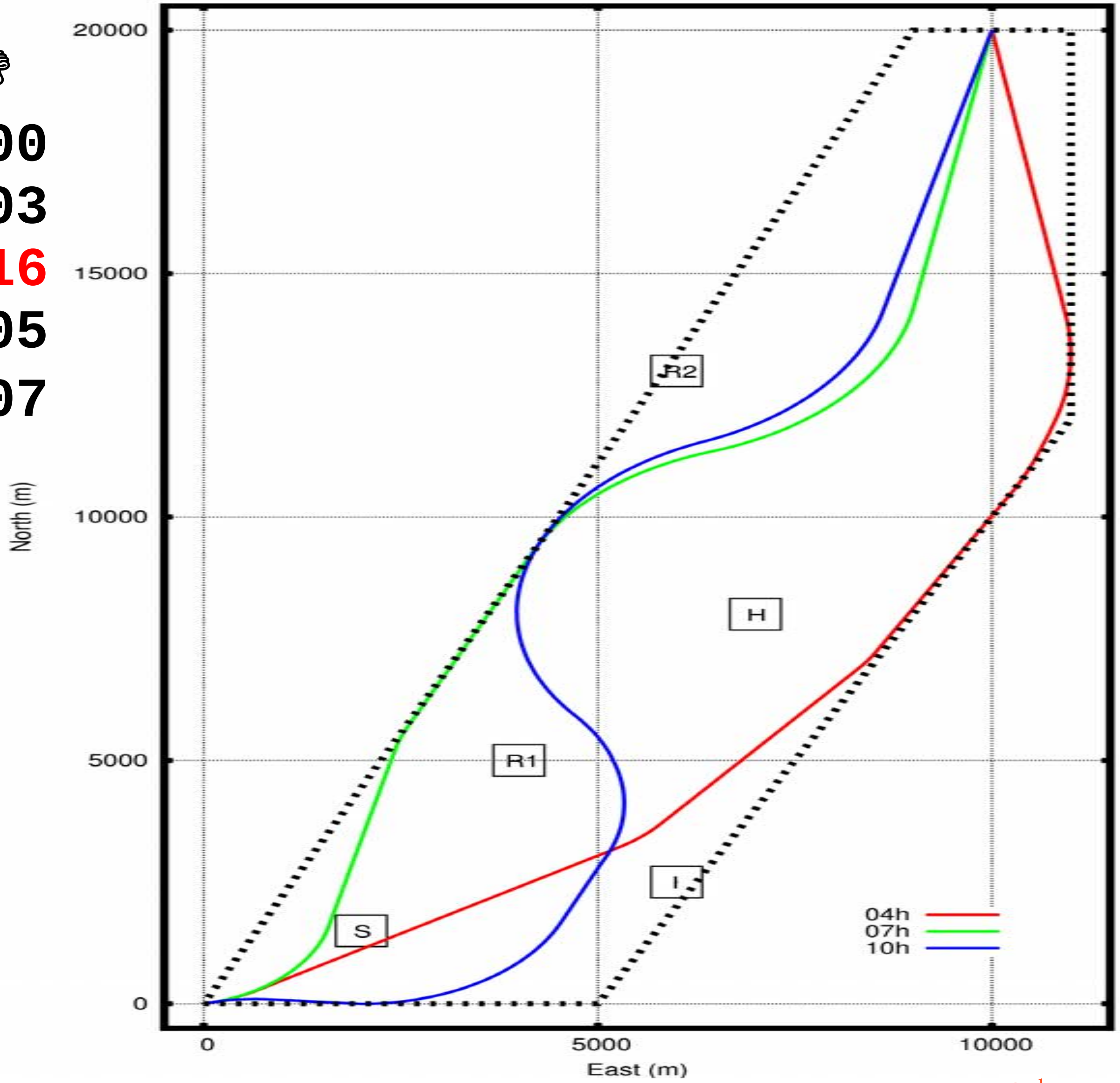
Numerical example

	J	J*	👎
S	.53	.53	.00
I	.03	.00	.03
R1	.16	.00	.16
H	.21	.16	.05
R2	.07	.00	.07

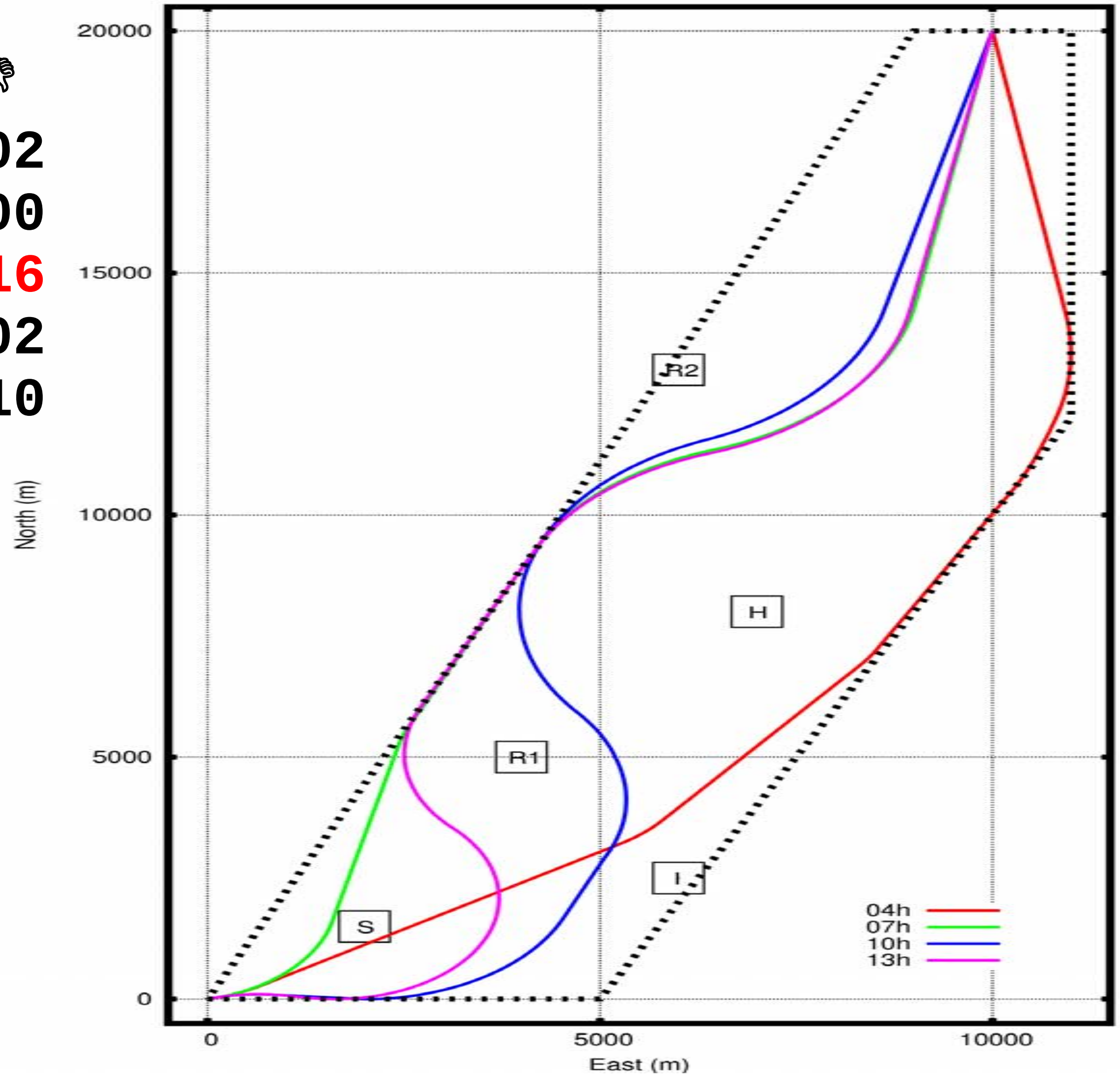
10h



Numerical example

	J	J*	👎
S	.55	.53	.02
I	.00	.00	.00
R1	.16	.00	.16
H	.18	.16	.02
R2	.10	.00	.10

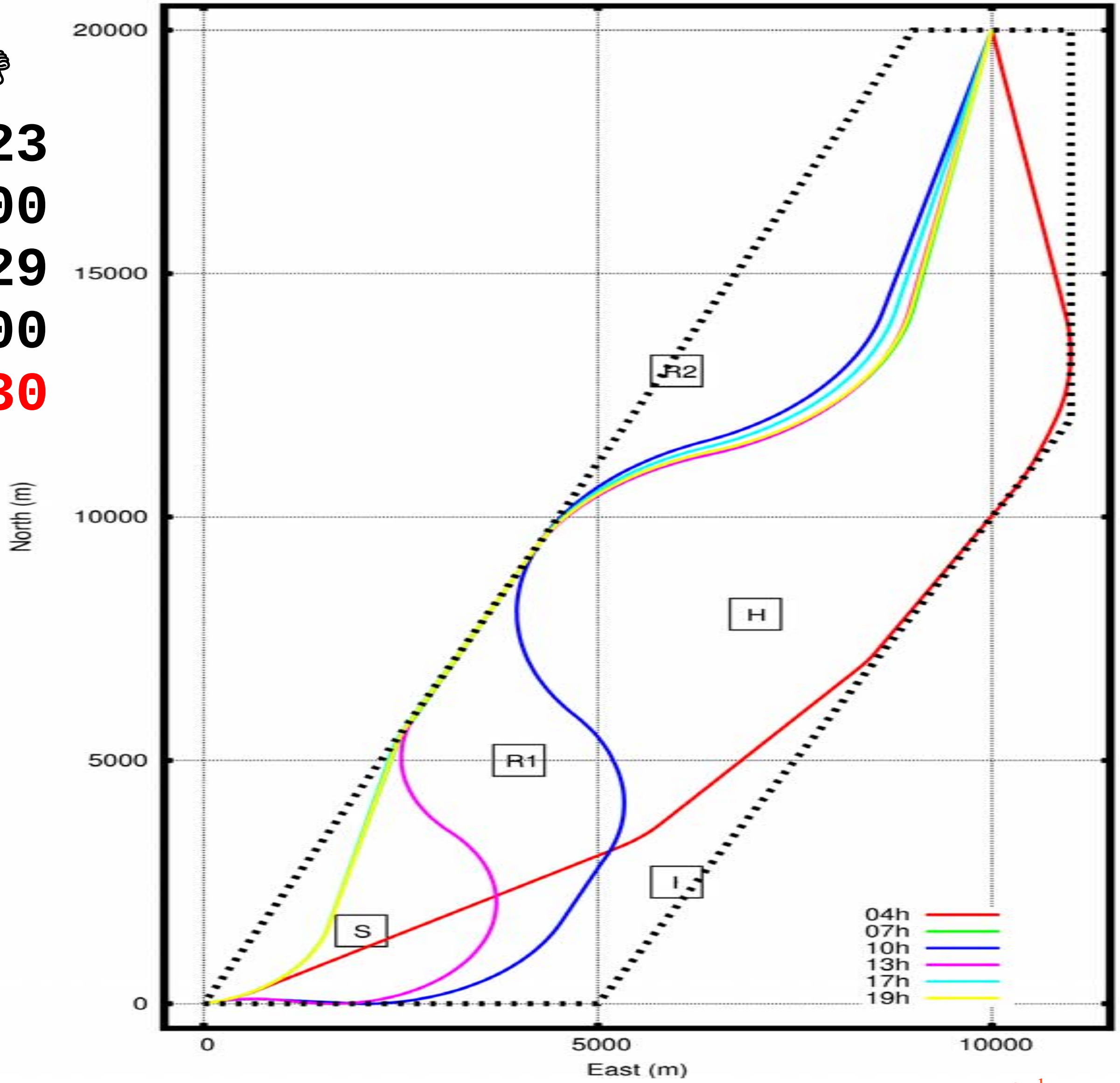
13h



Numerical example

	J	J*	👎
S	.62	.39	.23
I	.00	.00	.00
R1	.33	.04	.29
H	.20	.20	.00
R2	.30	.00	.30

17h 19h



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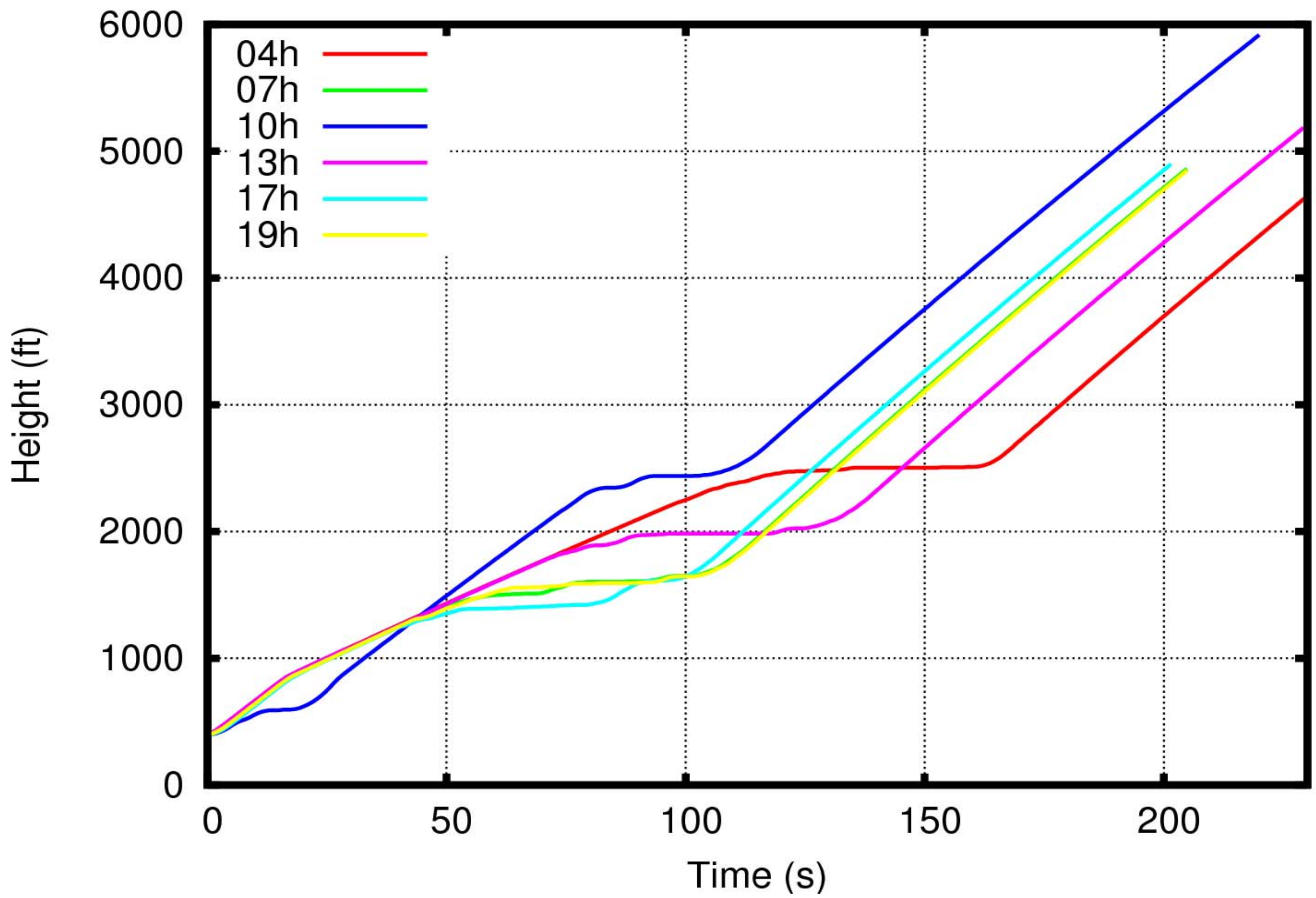
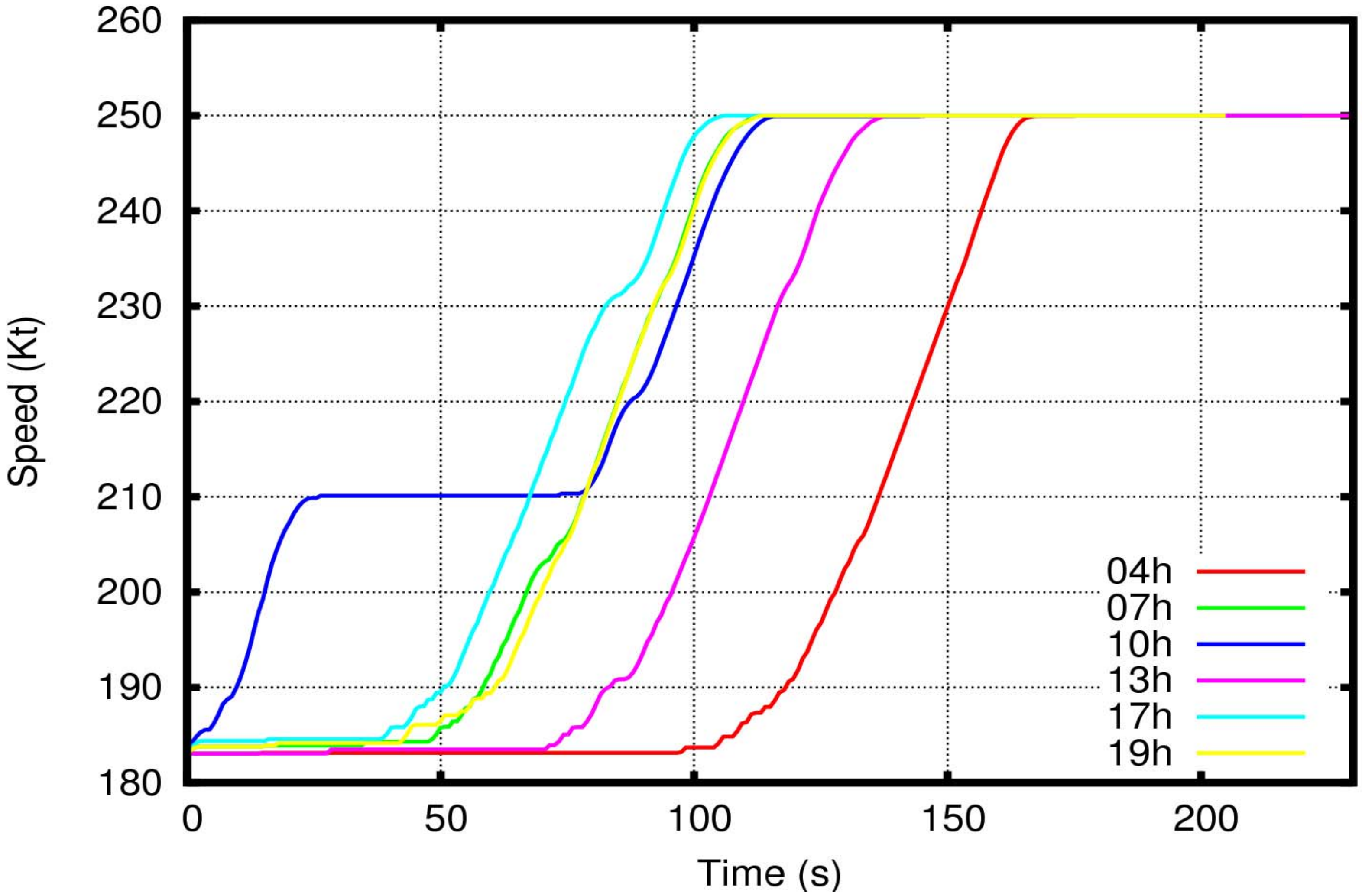
Preliminar numerical example



Preliminar numerical example



Conclusions

- A framework for noise abatement optimum procedures is presented
- Noise annoyance can be taken into account by using a fuzzy logic model
- Egalitarian principle for noise abatement multi criteria optimisation
- Good tool for airport or airspace planners

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Thank you!

Introduction

- Increasing air traffic demand
- Increasing population around airports

Aircraft noise reduction:

- Source (aircraft)
- Propagation (trajectory)
- Receiver (population)

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State of the Art

- Noise abatement procedures
  - ICAO (NADP-1, NADP-2)
  - SOURDINE EU projects
  - LPLD, CDA, TDDA,...

Generic procedures
Effects on population?
Optimality??

  - *Visser et al.*
  - *Clarke et al.*

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Multiobjective optimization

Optimisation criteria

$$\vec{J}(\vec{z}) = [J_1(\vec{z}), J_2(\vec{z}), \cdots, J_{n_j}(\vec{z})]$$

- **Noise nuisances**
- **Airliner costs (fuel, time, final altitude)**

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Multiobjective optimization

Optimisation criteria

$$\vec{J}(\vec{z}) = [J_1(\vec{z}), J_2(\vec{z}), \cdots, J_{n_j}(\vec{z})]$$

- Noise nuisances
- Airliner costs (fuel, time, final altitude)

Decision Variables

$$\vec{z} = [\vec{x}(t), \vec{u}(t), \vec{p}, t_f]^T,$$

- State, Control
- Parameters, Final Time

$$\vec{x} = [v\ \chi\ \gamma\ n\ e\ h]^T$$

$$\vec{u} = [n_z\ \mu]^T$$

$$\vec{p} = [h_c]$$

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Multiobjective optimization

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$\vec{z}), \cdots, J_{n_j}(\vec{z})]$

$\vec{p}, t_f]^T,$

$- D(v, n_z) - mg \sin\gamma]$

Constrained continuous multiobjective optimal control problem

Optimisati

Dynamic c
Event con
Path cons
Box const

- **Calculus of variations**
- **Discretisation + NLP optimisation**
- **Dinamical programing**
- **Evolutionary algorithms**
- **…**

Trajectory optimization

- Several noise annoyance values:
  - Hospital ⟶ A_H
  - Industrial Zone ⟶ A_I
  - Residential Zone ⟶ A_R
  - School ⟶ A

Minimize A_H, A_I, A_R, A_S ??

Multiobjective optimization

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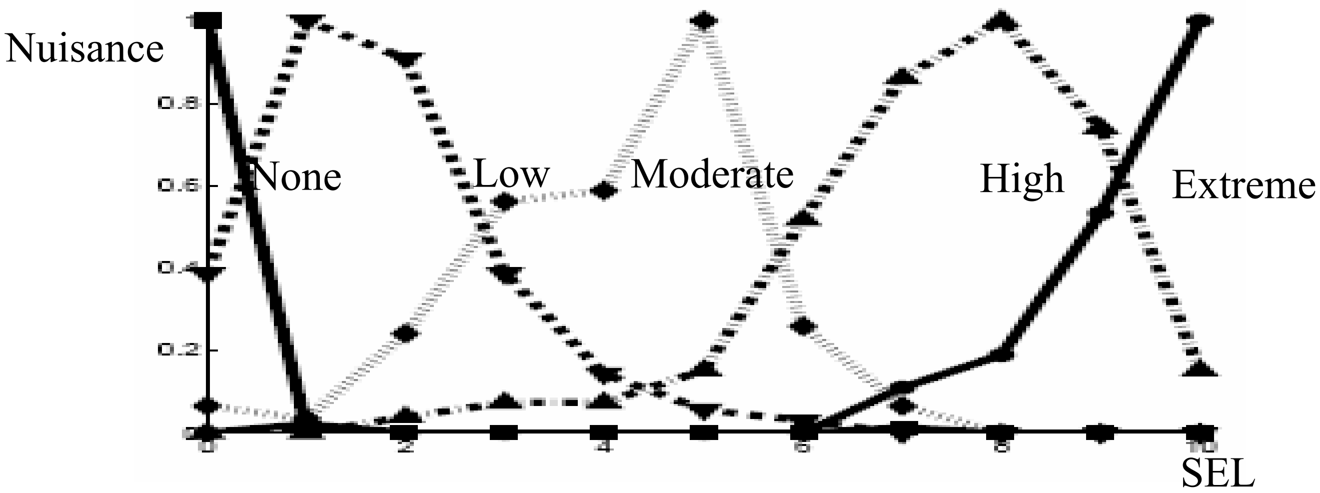
Perceived noise nuisances

- Received amount of noise
  - Lmax, Leq, Lden, SEL, DNL, ...
- Population reaction to noise
  - Type of activity undertaken during noise
  - Time of day and day of week
  - Periodicity of repeated noise events
  - Type of population (age, health, social environment...)
  - etc!

Perceived noise nuisances

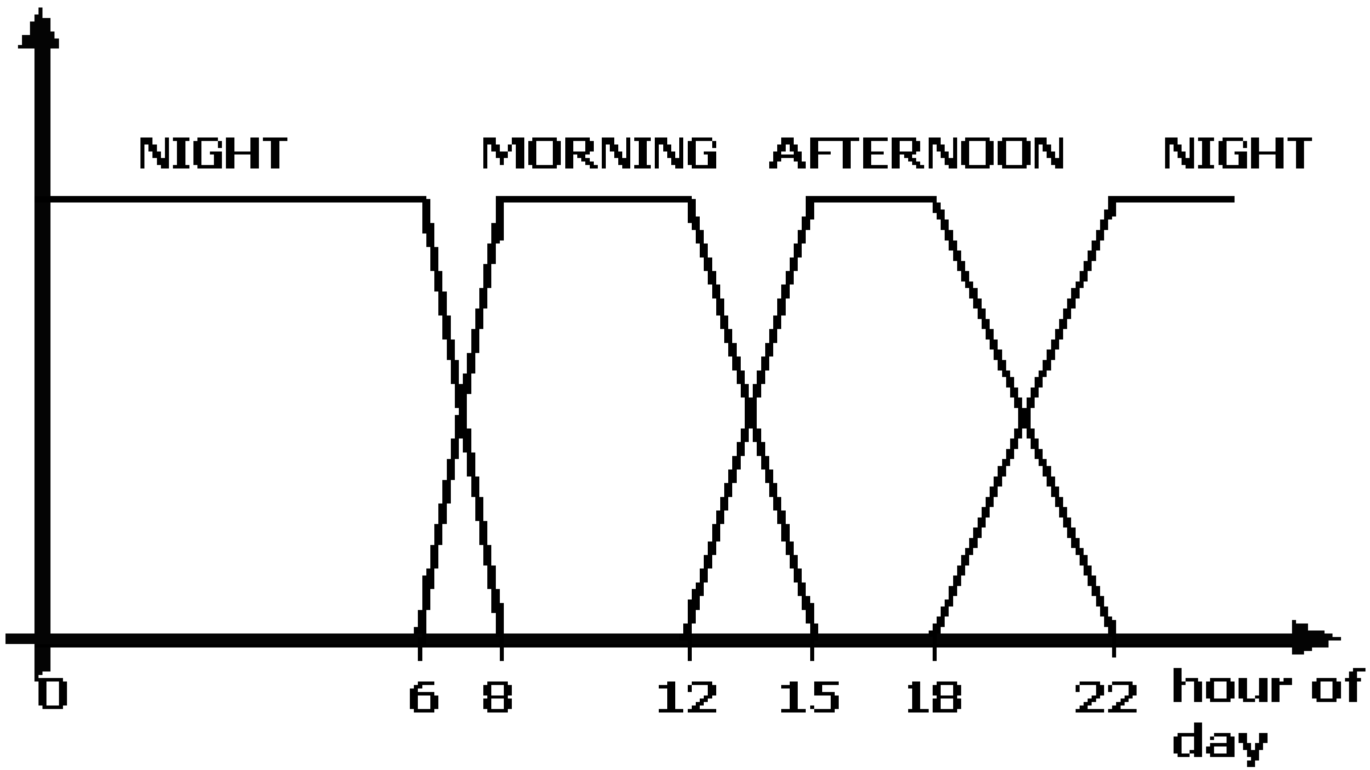
- Population reaction to noise
  - Quantitative methods
  - Fuzzy logic / Neural Networks

Fuzzy model for noise nuisances (A.Verkeyn)



Fuzzy logic nuisance model

- Fuzzyfication (membership functions)



Fuzzy logic nuisance model

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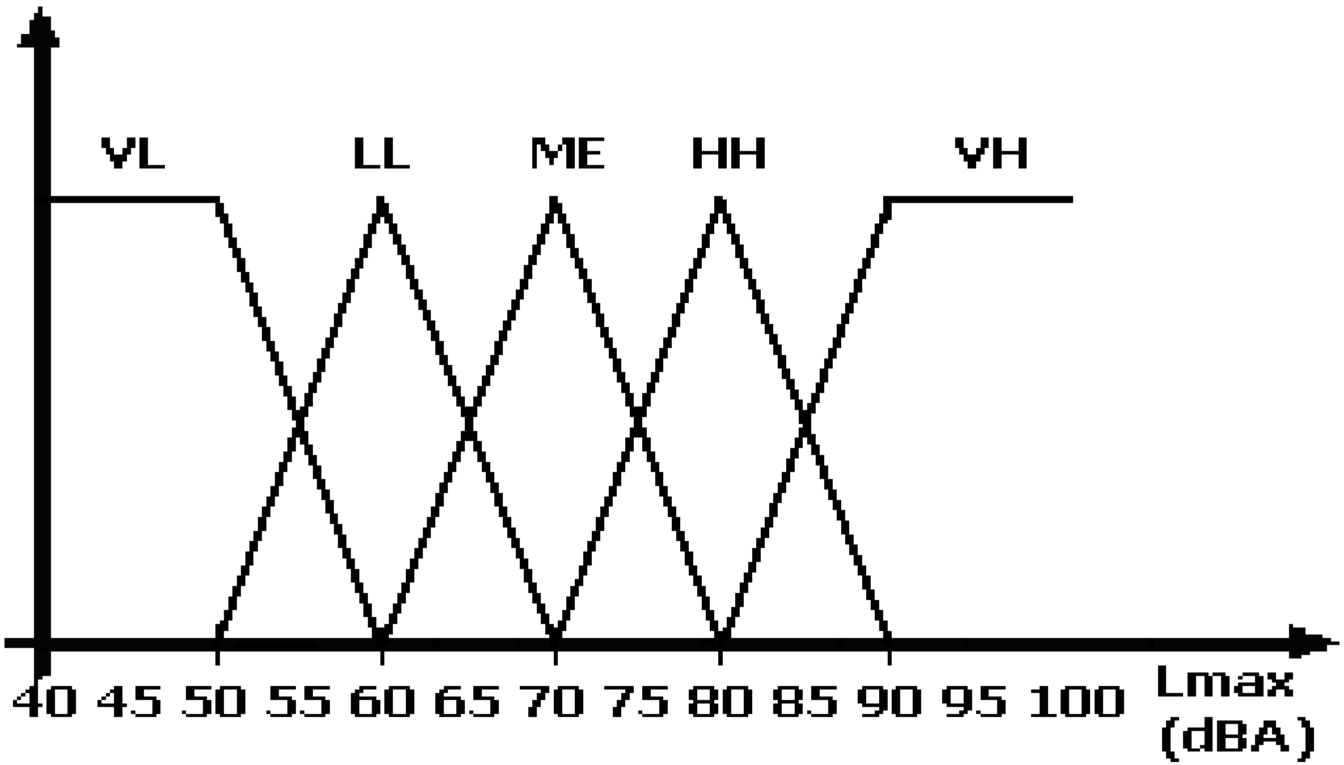

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Fuzzy logic annoyance model

Fuzzyfication

Defuzzyfication

Input variables

Linguistic rule base

Output variables

Multiobjective optimization

- Wheighting methods

$$\min_{x} \sum_{i=1}^{r} w_i f_i(x)$$

$$subject\ to: x \in \chi$$

fi: objective functions

wi: wheights

Difficulty in choosing weights (a *posteriori* method)

Multiobjective optimization

- Lexicographic method

1: $J_1^* = \min_{\vec{z} \in Z} [J_1(\vec{z})]$

2: **for** $i = 2$ to n_j **do**

3: $\quad J_i^* = \min_{\vec{z} \in Z} \left[J_i(\vec{z}) | J_j(\vec{z}) \le J_j^*,\ j = 1, ..., i-1 \right]$

4: **end for**

5: Determine the lexicographic minimiser set as:

$\vec{z}^* = \arg(J_{n_j}^*)$

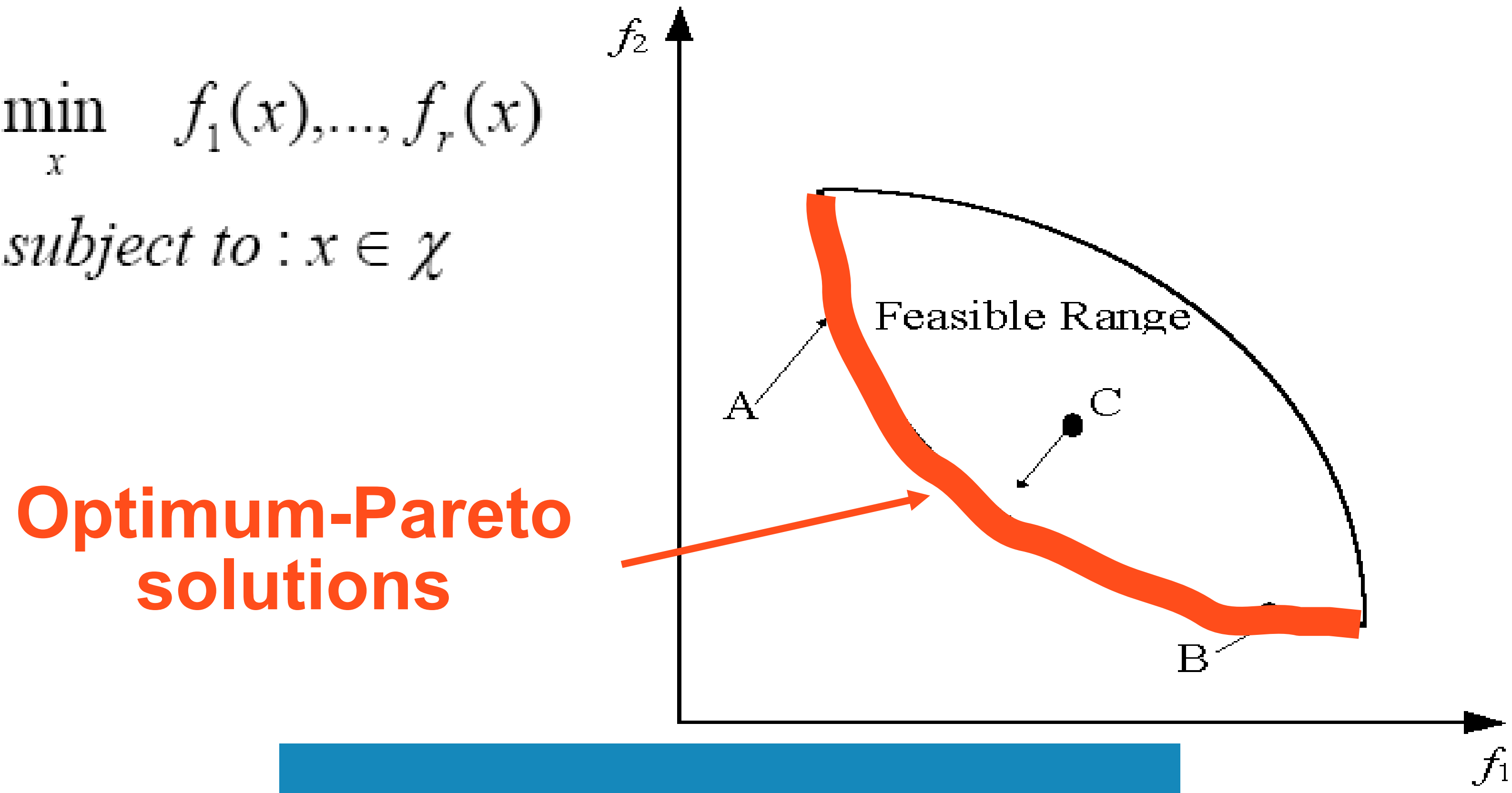
Calculate all prioritisations

Multiobjective optimization

- Introduction

$$\min_{x} \quad f_1(x), \ldots, f_r(x)$$

$$subject\ to: x \in \chi$$



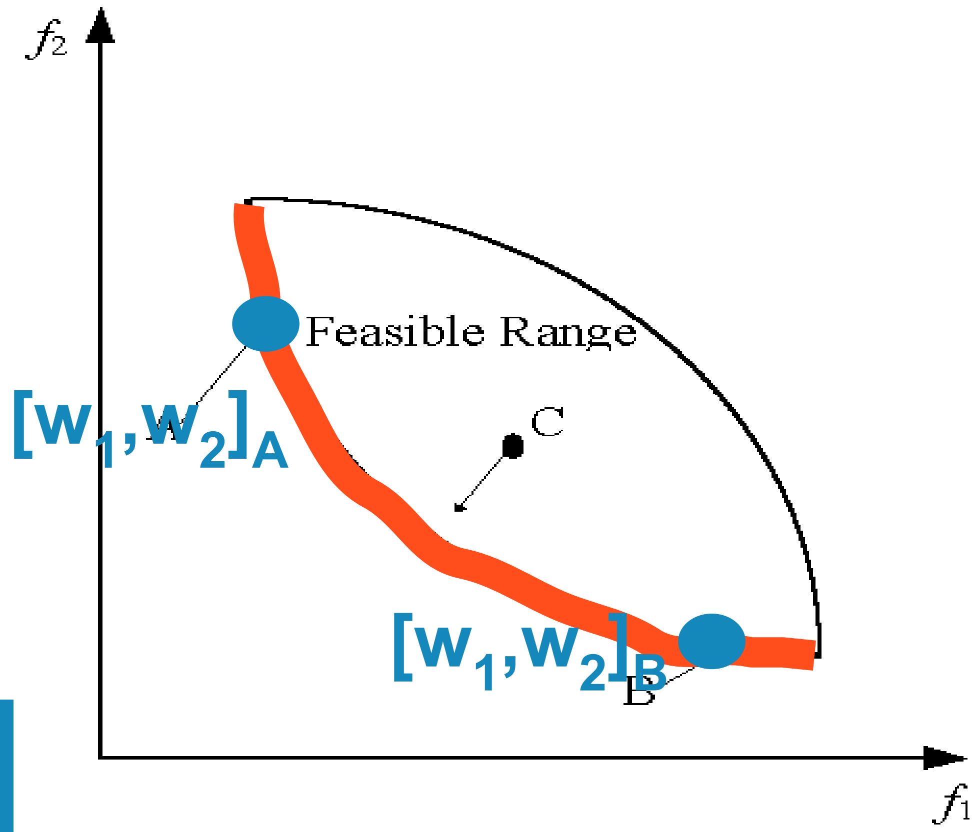
Decision Making is needed

Multiobjective optimization

- Weighing methods

$$\min_{x} \sum_{i=1}^{r} w_i f_i(x)$$

$$subject\ to : x \in \chi$$



Difficulty in choosing weights (a *posteriori* method)

Future work

- Improve fuzzy nuisance model
- Take into account residential areas and population
- Study a real scenario