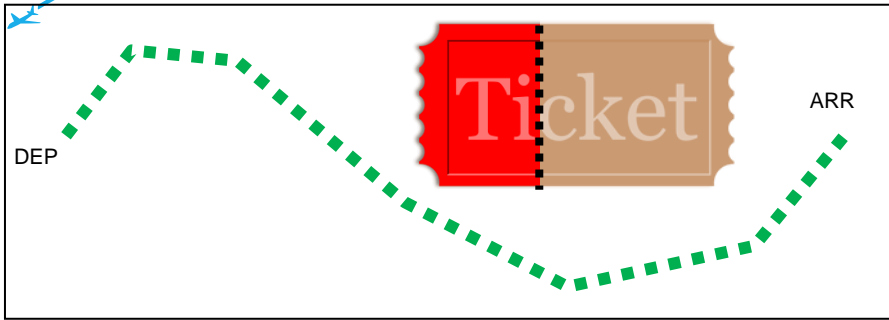




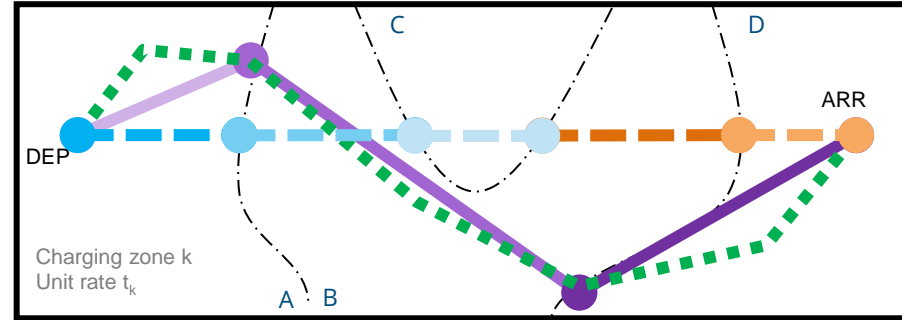
Dedicated to innovation in aerospace

## **Why aircraft fly more fuel-efficiently on FRIDAY**

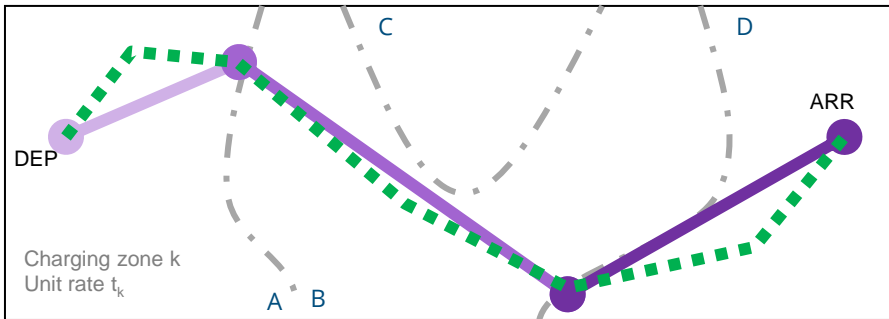
The FRIDAY route charges method **René Verbeek MSc, June 22, 2016**



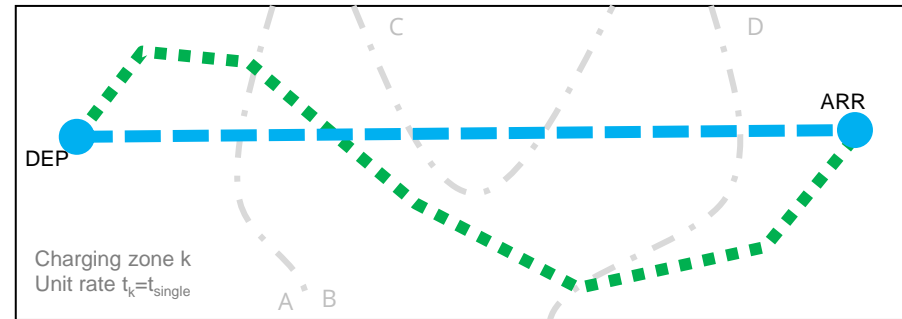
Ticket tax



FRIDAY route charges method

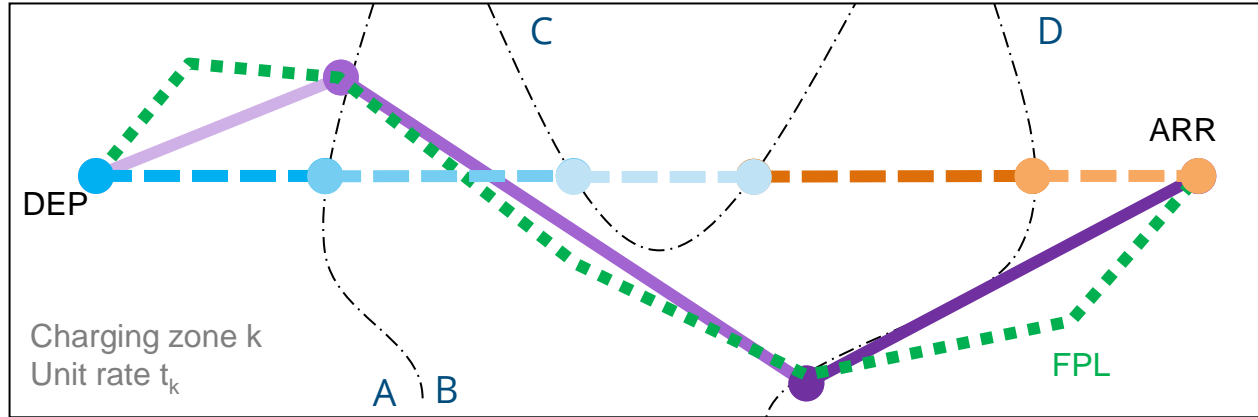


Eurocontrol route charges system



Single unit rate

## FRIDAY route charges method

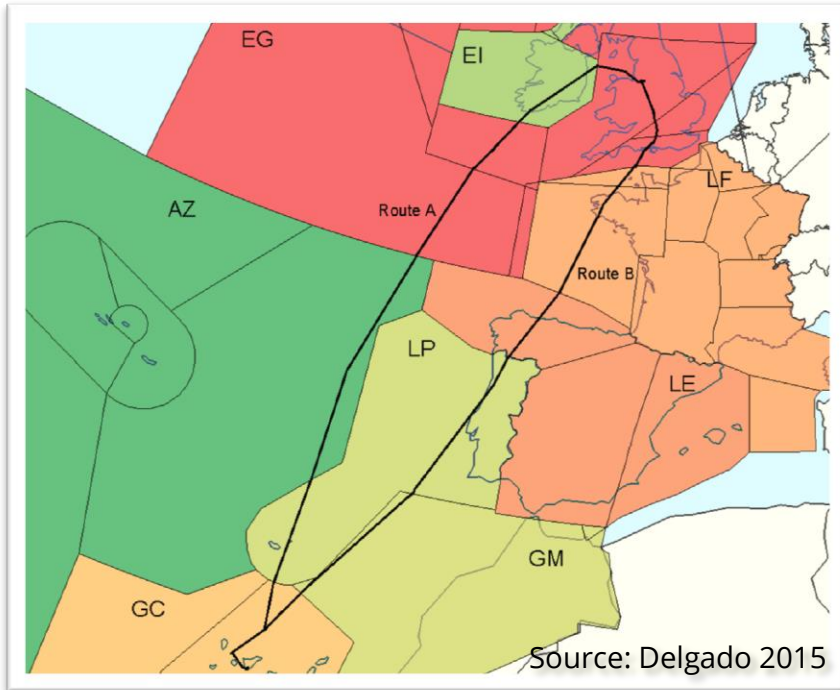


Two step approach:

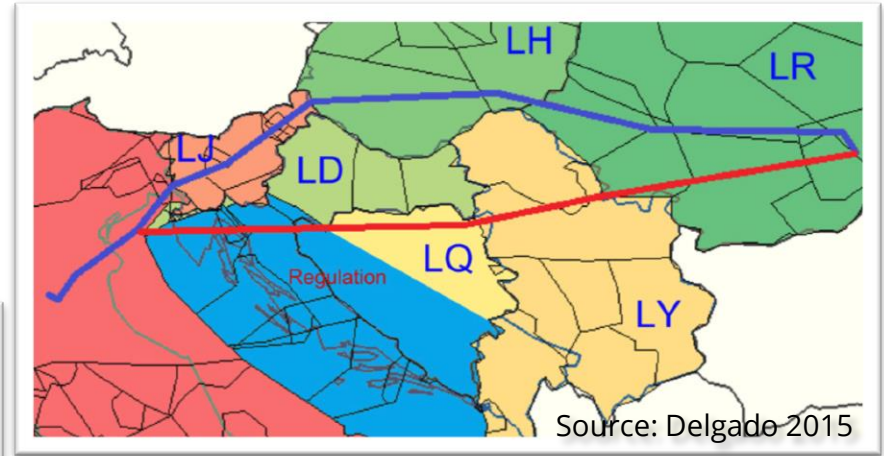
1. Charges are calculated along the great circle line from airport to airport
2. Collected charges are distributed to servicing ANSPs according to CRCO route

Problems with Eurocontrol common route charges system

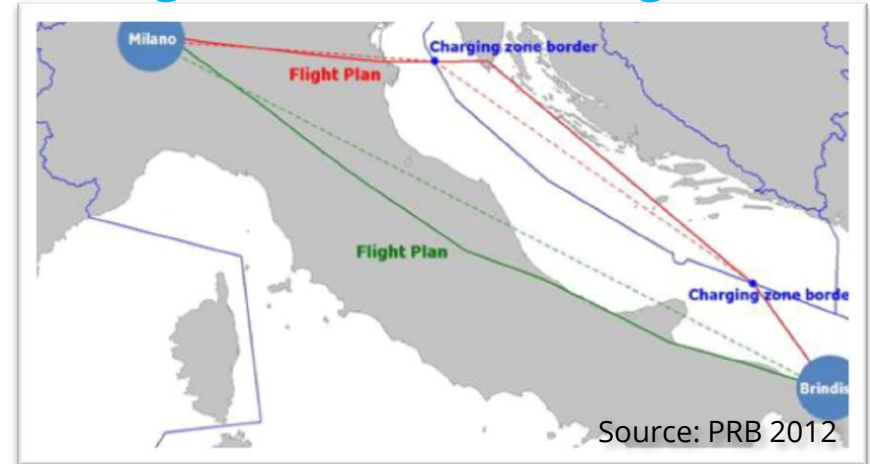
Differences in unit rates result in detours



FPL avoiding a congested area may result in higher charges

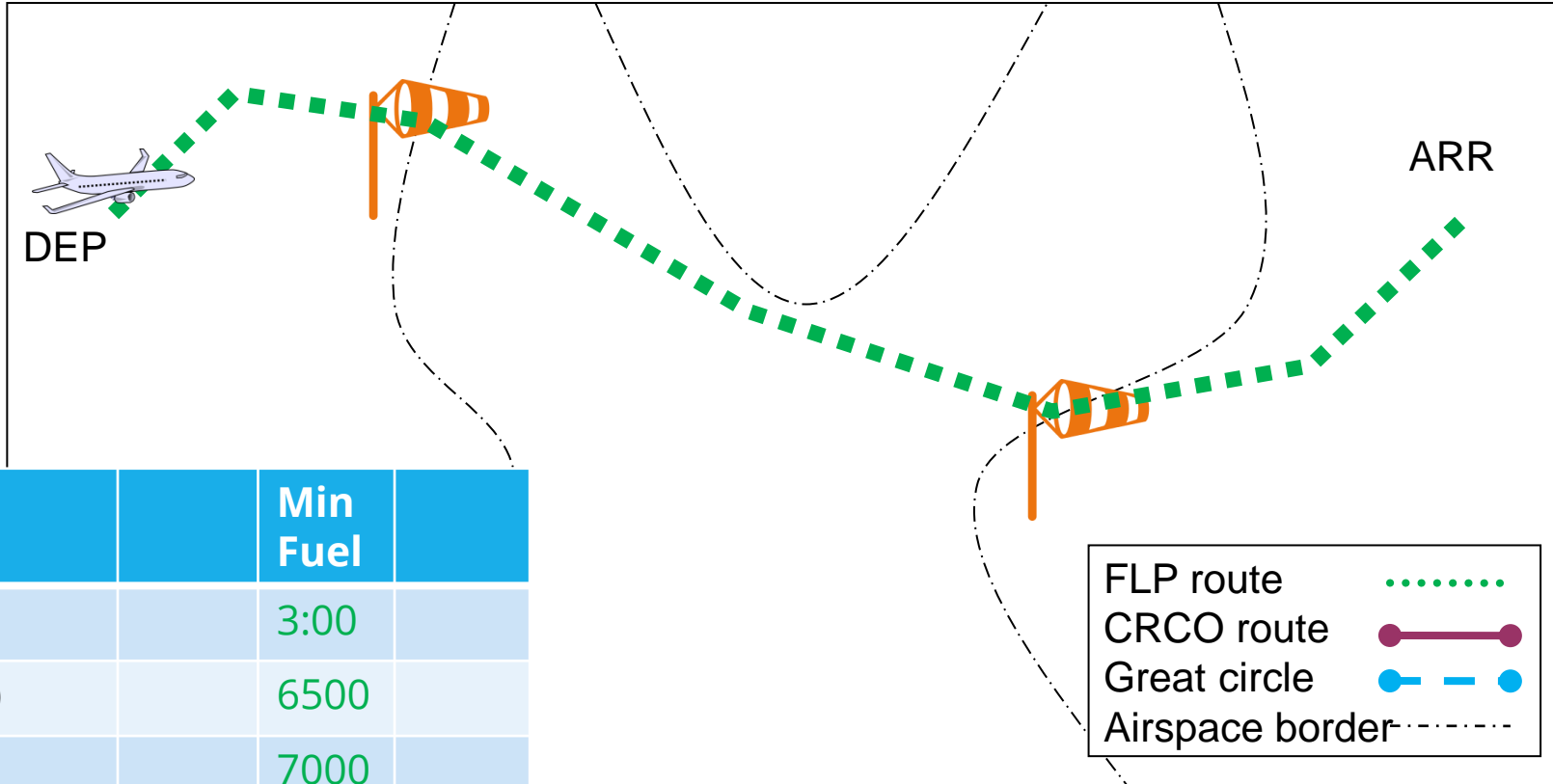


Filing indirect, and asking direct



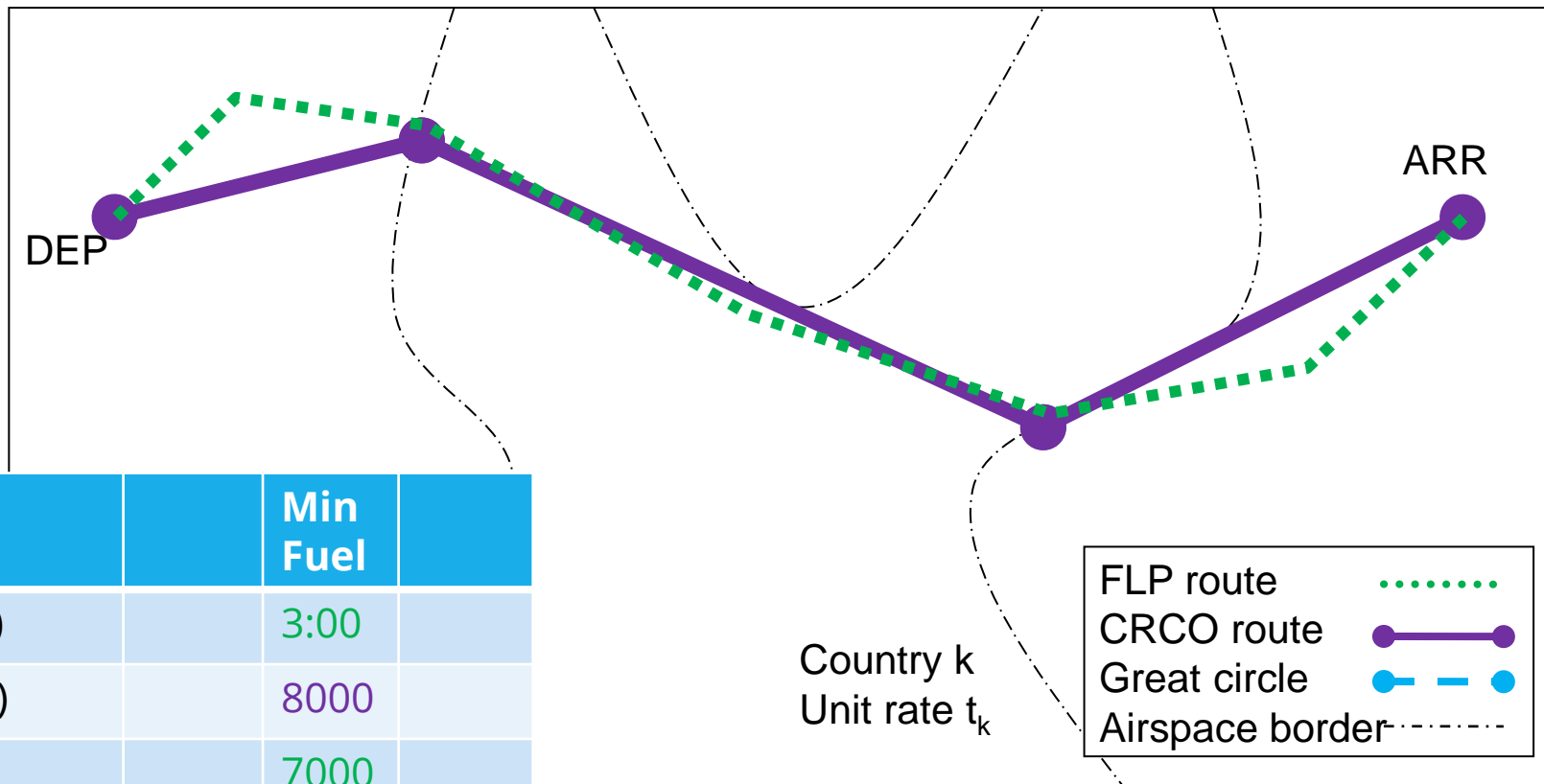
# Underlying mechanism

# Flight plan



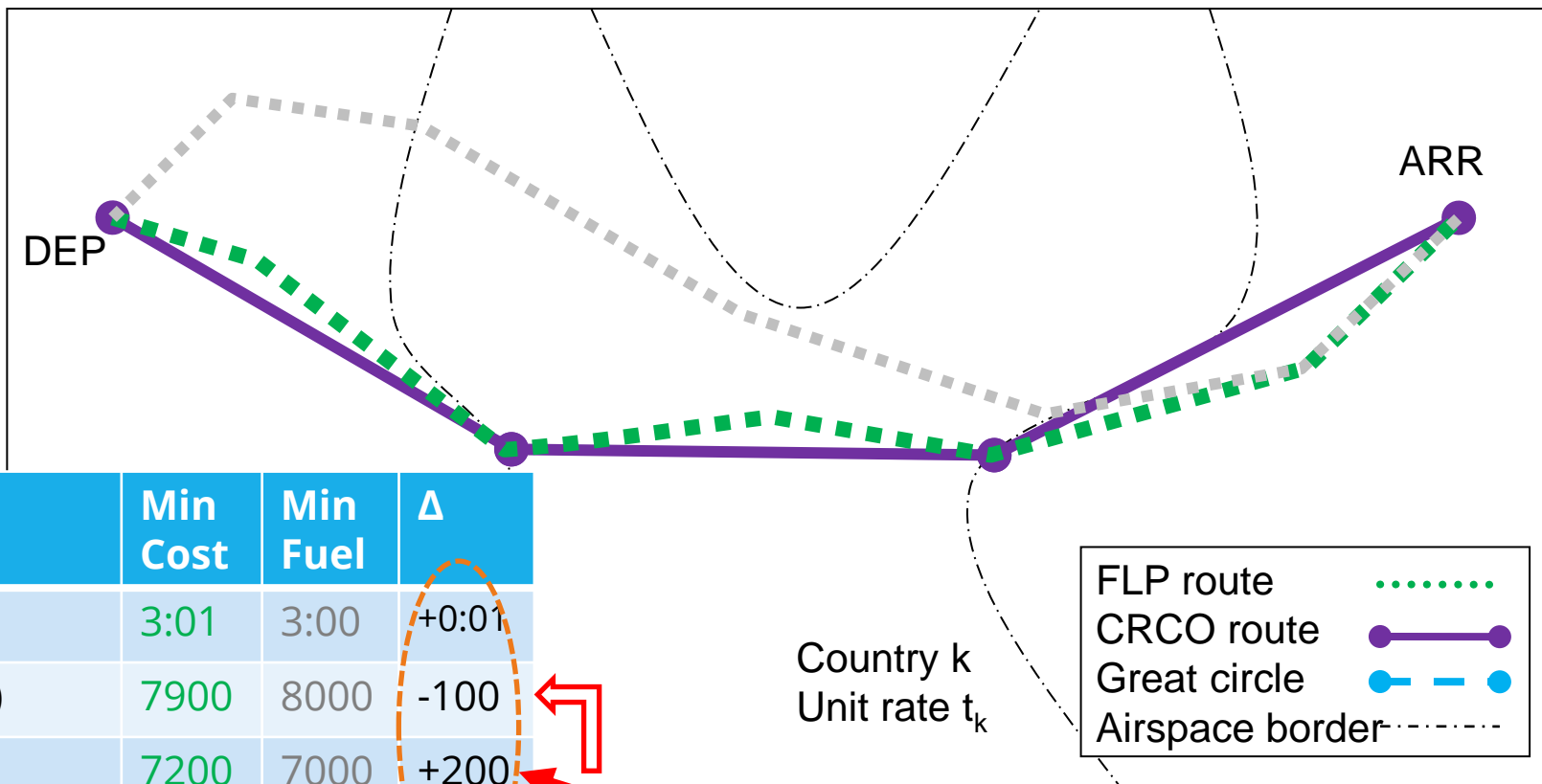
Flight		Min Fuel	
Time (h:mm)		3:00	
Total Cost (€)		6500	
Tripfuel (kg)		7000	

# Eurocontrol Route Charges System



Flight	Min Fuel
Time (h:mm)	3:00
Total Cost (€)	8000
Tripfuel (kg)	7000
ATC costs (€)	1500

# Eurocontrol Route Charges System



Flight	Min Cost	Min Fuel	$\Delta$
Time (h:mm)	3:01	3:00	+0:01
Total Cost (€)	7900	8000	-100
Tripfuel (kg)	7200	7000	+200
ATC costs (€)	1300	1500	-200

## Extreme scenario: no route charge

### Airlines



- ~~Route charges~~
- **Fuel/Time** ↓
- Complexity of FPL optimization is reduced

### ANSPs



- ~~Cost recovery~~
- Traffic concentrations ↓
- SESAR: Increased benefits of 4D ops and free routing
- Less need for asking for directs → **Predictability** ↑

### Society



- **Emissions/CO<sub>2</sub>** ↓
- No need for incentive schemes for fuel efficient trajectories



## ~~Extreme scenario: no route charge~~

### Airlines



- **Route charges**
- **Fuel/Time** ↓
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### ANSPs



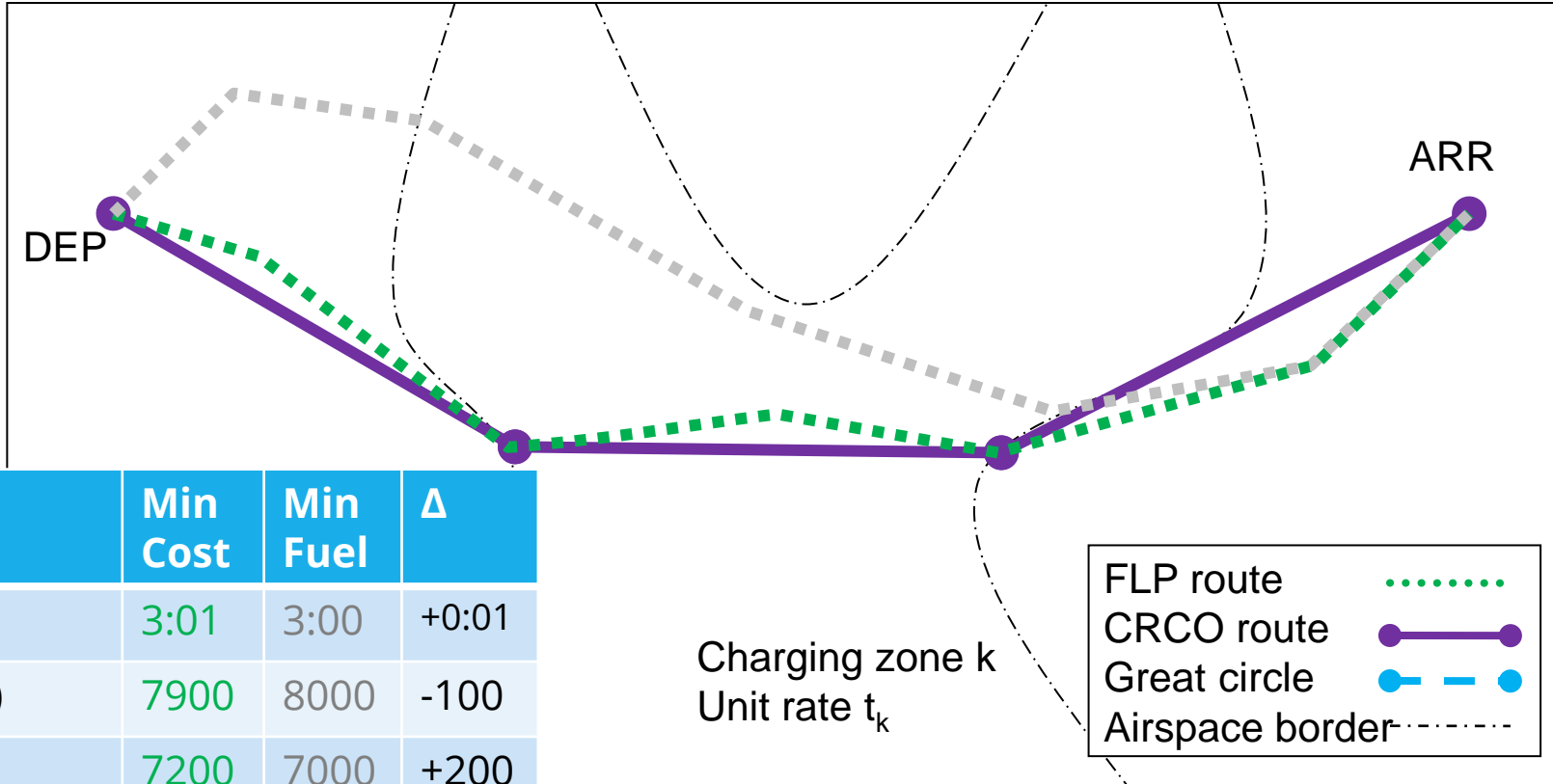
- **Cost recovery**
- Traffic concentrations ↓
- SESAR: Increased benefits of 4D ops and free routing
- Less need for asking for directs →  
**Predictability** ↑

### Society



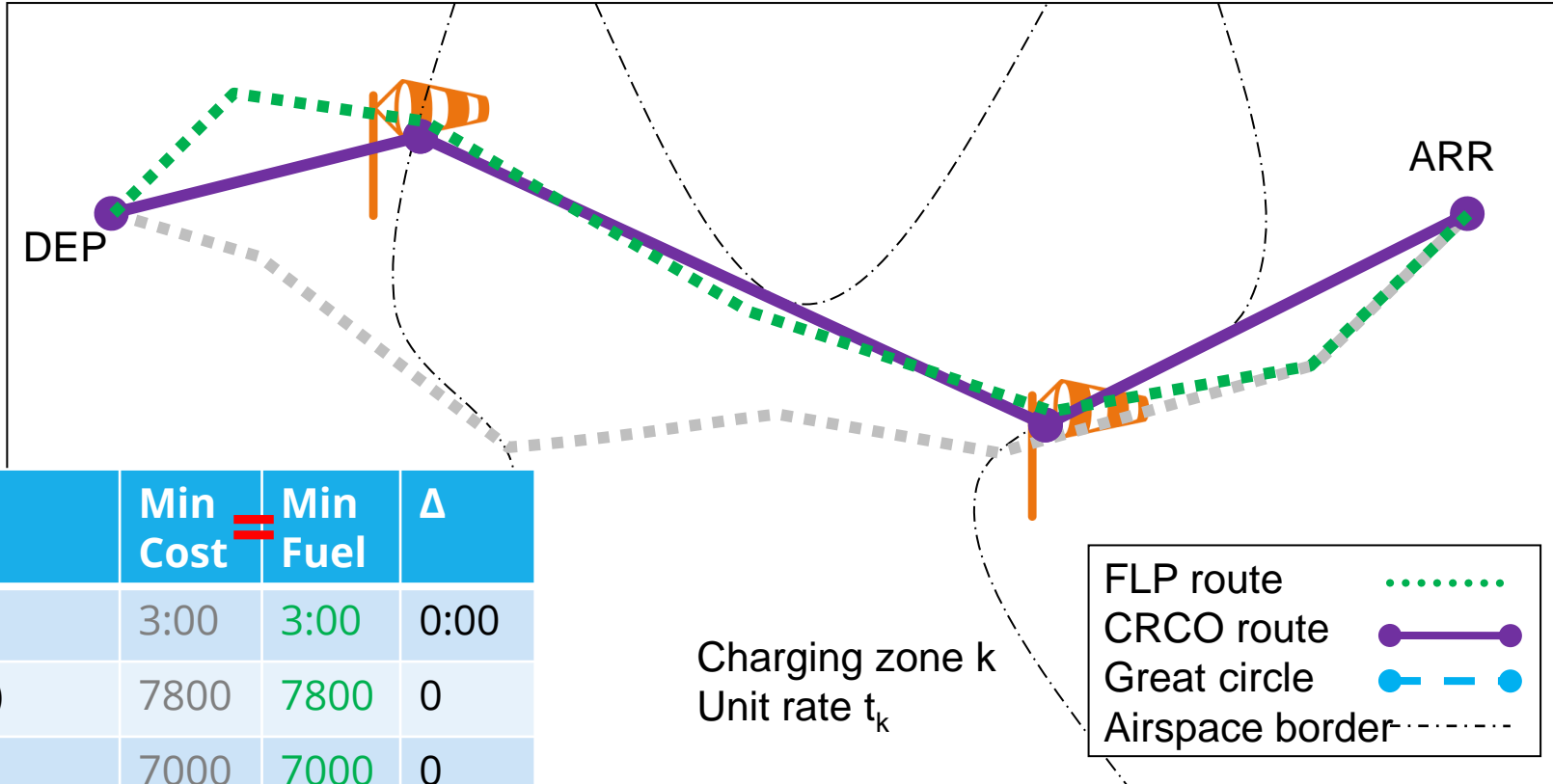
- **Emissions/CO<sub>2</sub>** ↓
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# Eurocontrol Route Charges System



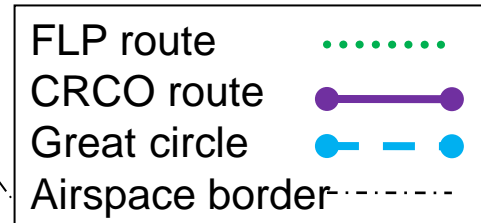
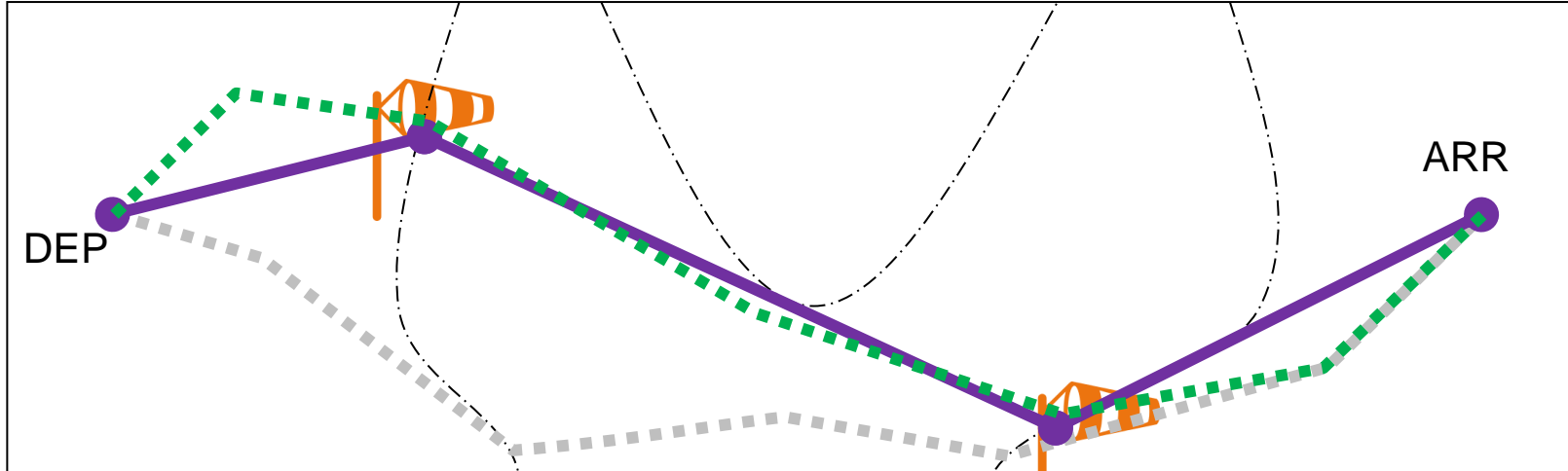
Flight	Min Cost	Min Fuel	$\Delta$
Time (h:mm)	3:01	3:00	+0:01
Total Cost (€)	7900	8000	-100
Tripfuel (kg)	7200	7000	+200
ATC costs (€)	1300	1500	-200

# Desired outcome



Flight	Min Cost	Min Fuel	$\Delta$
Time (h:mm)	3:00	3:00	0:00
Total Cost (€)	7800	7800	0
Tripfuel (kg)	7000	7000	0
ATC costs (€)	1300	1300	0

# Desired outcome



Flight*	Min Cost =	Min Fuel	Δ	Min Cost ERCS	Savings
Time (h:mm)	3:00	3:00	0:00	3:01	<b>-0:01</b>
Total Cost (€)	7800	7800	0	7900	<b>-100</b>
Tripfuel (kg)	7000	7000	0	7200	<b>-200</b>
ATC costs (€)	1300	1300	0	1300	<b>0</b>

\*for illustrative purposes

## Alternative route charges systems

# WIN-LOSE-SOLUTIONS



### Single unit rate

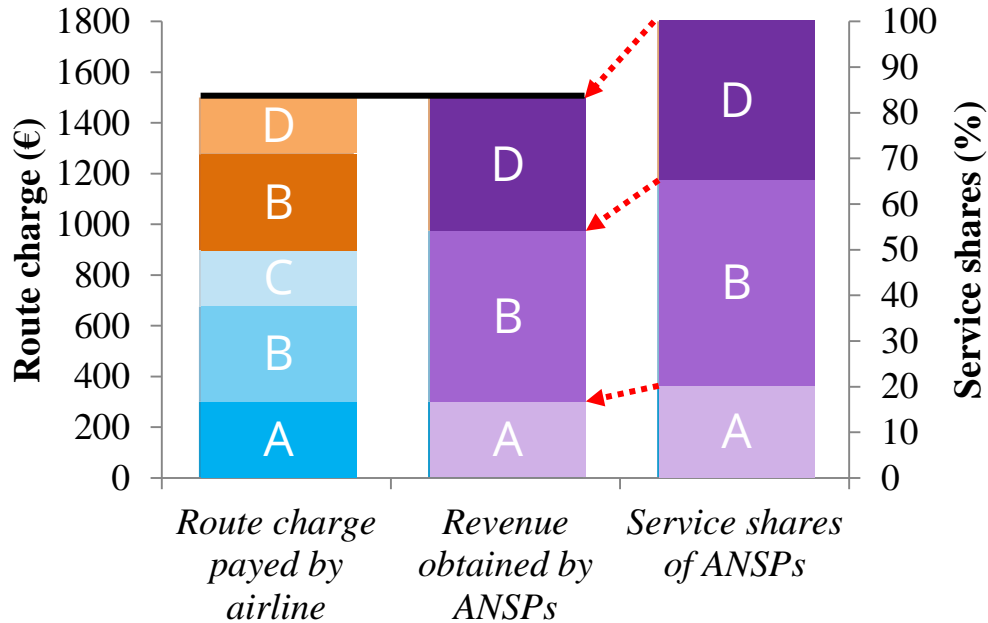
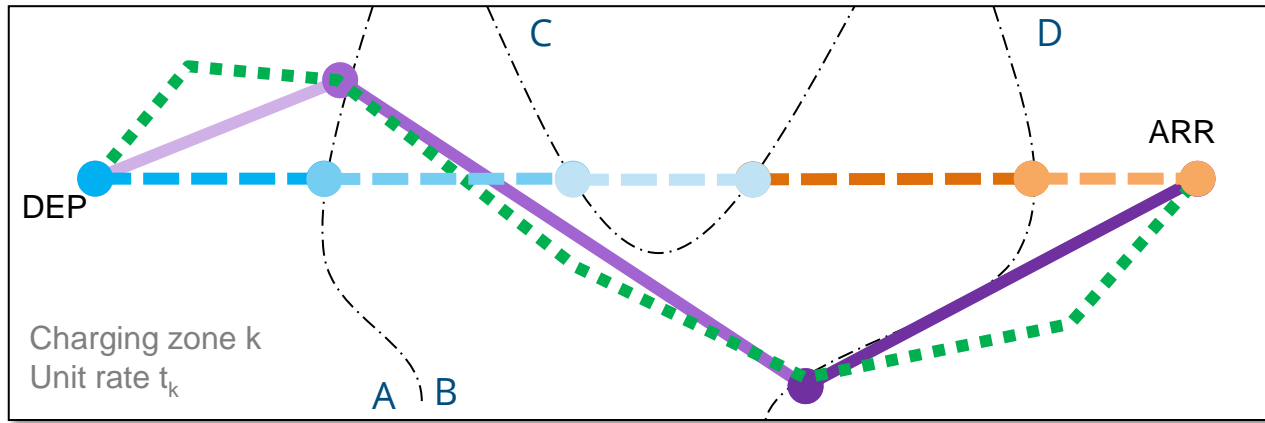
- Has desired outcome, but
  - **Some** airlines will pay **higher charges**
  - Revenues have to be **redistributed**
  - ANSPs need to **agree** on the single unit rate
  - ANSPs need to agree on what to do with **deviations** from expected revenues
  - Considered for **single FAB**, but not for multiple FABs.

### Ticket tax

- Has desired outcome, but
  - Revenues have to be **redistributed**
  - ANSPs need to **agree** on the tax rate
  - ANSPs need to agree on what to do with **deviations** from expected revenues
  - How to handle flights that end or start **outside European airspace?**



# FRIDAY route charges method



- Two step approach:**
- Charges are calculated along the great circle line from airport to airport
  - Collected charges are distributed to servicing ANSPs according to CRCO route



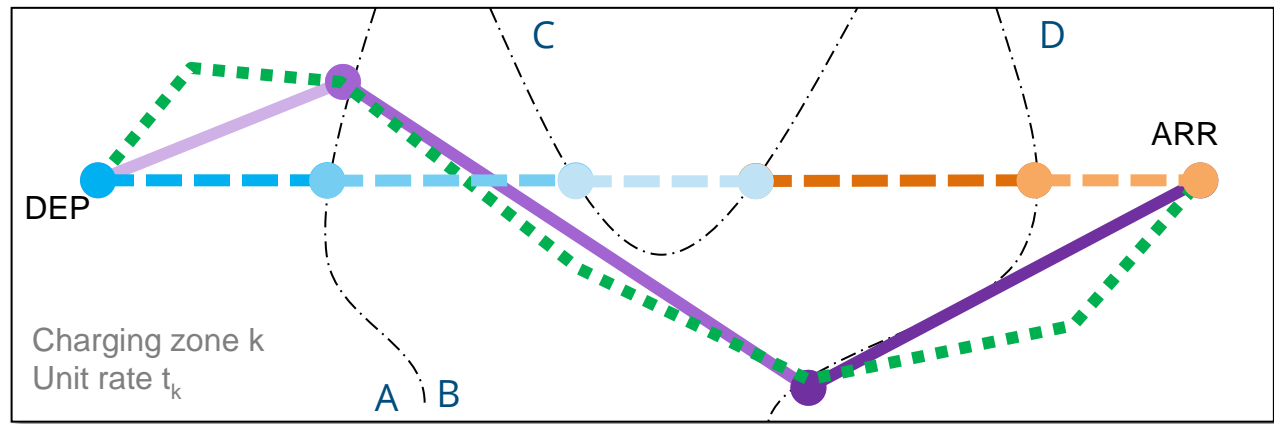
# Mathematics behind FRIDAY







# FRIDAY route charges method



## 1. What the airline pays:

$$R_{great\ circle} = \sum_j D_j \times p \times t_j$$

Route Charge =  $f(\text{airspace, great circle dist., weight factor, unit rate})$

## 3. What the ANSP gets payed:

$$r_i = \frac{R_{great\ circle}}{R_{CRCO}} d_i \times p \times t_i$$

## 2. What the airline would pay according to CRCO:

$$R_{CRCO} = \sum_i d_i \times p \times t_i$$

Route charge =  $f(\text{airspace, distance, weight factor, unit rate})$

# Influence of route charges on Flight Planning

**MAKE  
INDEPENDENT**

Objective function for flight planning:

$$J_a = \int_{t_{0a}}^{t_{1a}} [C_{ta} + C_{fa}g(h, m, v)] dt + \sum_i d_{ia}p_{ia}u_i$$

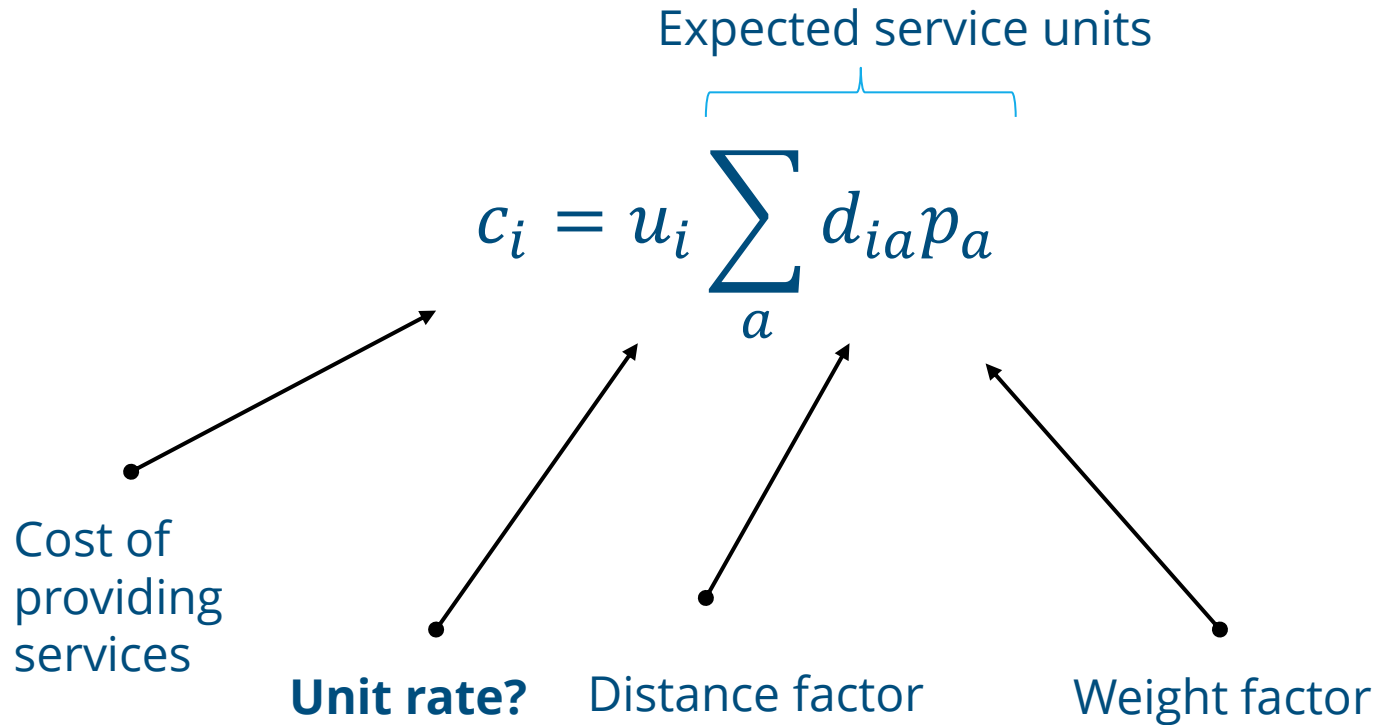
Flight time

Fuel cost coefficient

Route charges

Time cost coefficient

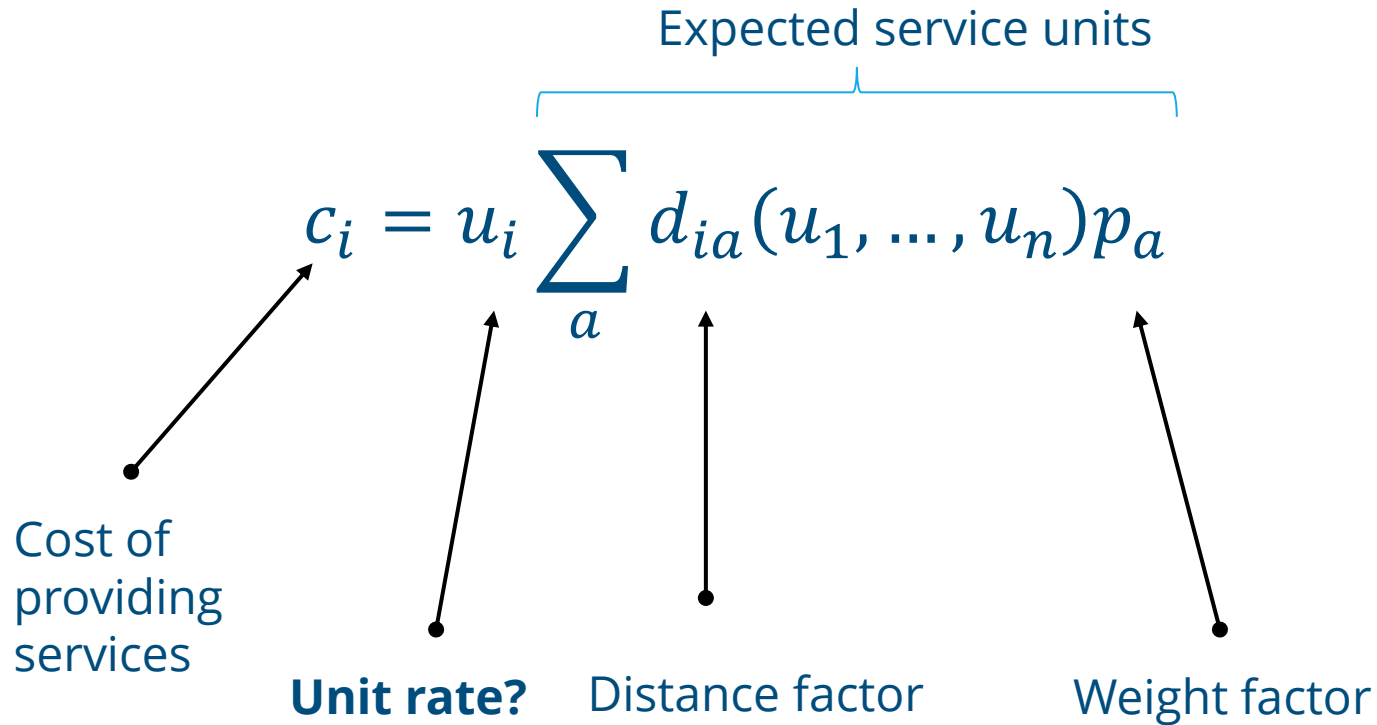
# Setting unit rates (Eurocontrol Route Charges System)



# Setting unit rates (Eurocontrol Route Charges System)

$$c_i = u_i \sum_a d_{ia}(u_1, \dots, u_n) p_a$$

}
Expected service units



Cost of providing services

**Unit rate?**      Distance factor      Weight factor



# Setting unit rates (FRIDAY)

$$c_i = U_i \sum_a \frac{\sum_k D_{ka} U_k}{\sum_j d_{ja} U_j} d_{ia} p_a$$

Expected shares

Cost of providing services

**Unit rate?**

Share in distance factor

Weight factor



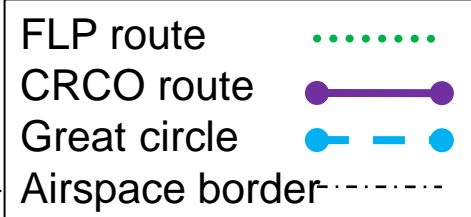
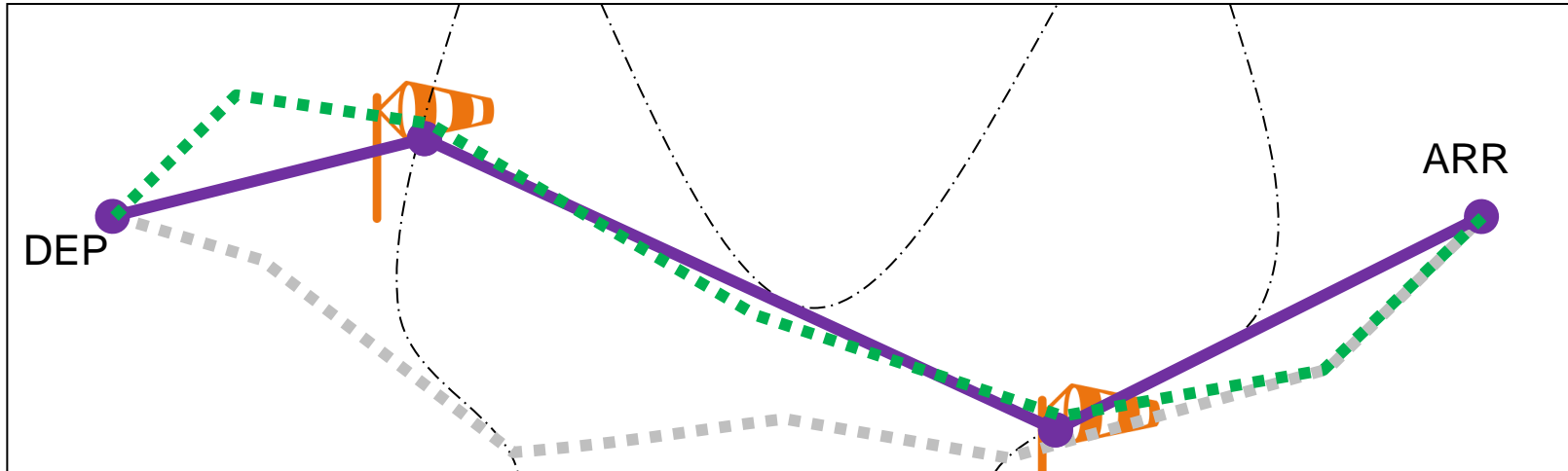
## Setting unit rates (FRIDAY)

*System of non-linear equations:*

$$c_i = f_i(U_1, \dots, U_n)$$

- Solve this using a generic numerical method for systems of nonlinear equations
- Routes need to be calculated only once

# FRIDAY route charges method



Flight*	Min Cost =	Min Fuel	Δ	Min Cost ERCS	Savings
Time (h:mm)	3:00	3:00	0:00	3:01	<b>-0:01</b>
Total Cost (€)	7800	7800	0	7900	<b>-100</b>
Tripfuel (kg)	7000	7000	0	7200	<b>-200</b>
ATC costs (€)	1300	1300	0	1300	<b>0</b>

\*for illustrative purposes

# Expected impact

## Airlines



- **Cost/Fuel/Time** ↓
- Route Charges the same on average
- Route Charges stay close to current
- Complexity of FPL optimization is reduced
- No  $\Delta$ route charges when evading restriction/congestion

## ANSPs



- **Cost recovery**
- **Traffic risks** ↓
- Unit rates need to be tuned
- Less need for asking for directs → **Predictability** ↑
- Traffic concentrations ↓
- SESAR: Increased benefits of 4D ops and free routing

## Society



- **Emissions/CO<sub>2</sub>** ↓
- No need for incentive schemes for fuel efficient trajectories
- ANSPs can attract more traffic when they provide more efficient routes



# WIN-WIN-WIN-SOLUTION



## Expected impact

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## Next steps?

### Research questions

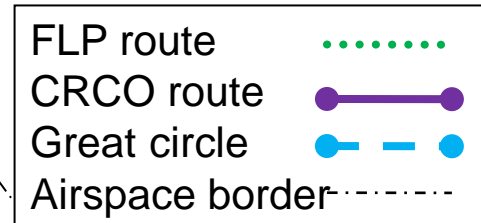
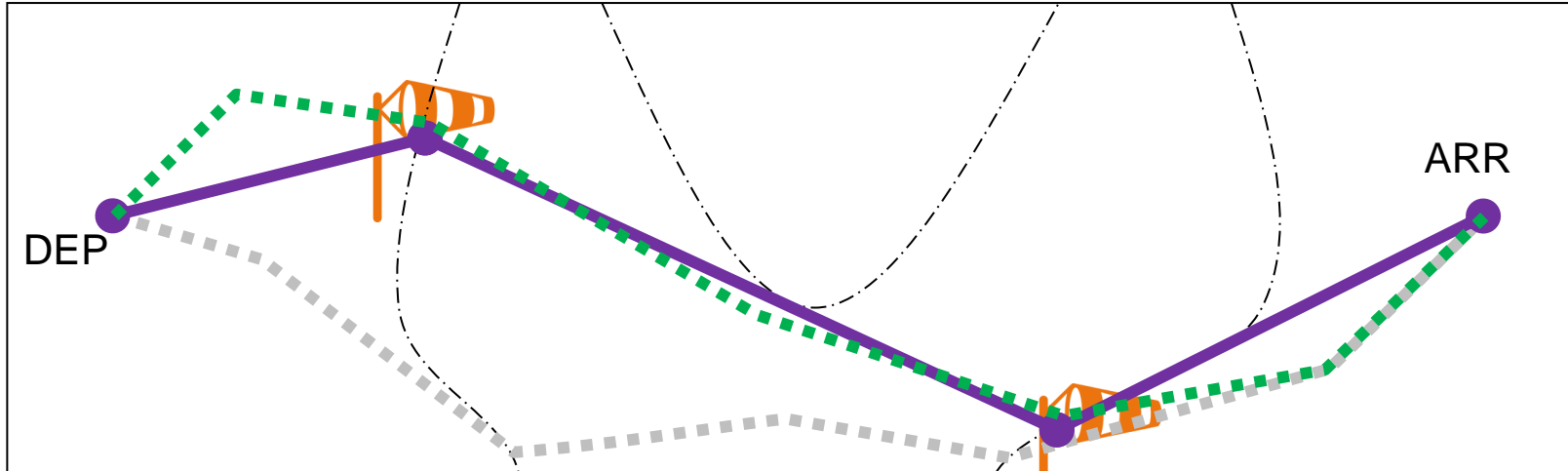
- What is the difference in performance between FRIDAY/ERCS/Single Unit Rate?
- What is the effect of uncertainties (weather/traffic numbers/...)?
- Is unit rate estimation method giving correct results?



### Feasibility study applied to European airspace case

- Proof of concept
- Major questions:
  - Fuel/time performance
  - Traffic risks
  - Cost recovery
  - Route charge effects on individual airspace users
  - Unit rates
  - Traffic concentrations
- Unidentified issues

## FRIDAY route charges method



Flight*	Min Cost =	Min Fuel	Δ	Min Cost ERCS	Savings
Time (h:mm)	3:00	3:00	0:00	3:01	-0:01
Total Cost (€)	7800	7800	0	7900	-100
Tripfuel (kg)	7000	7000	0	7200	-200
ATC costs (€)	1300	1300	0	1300	0

\*for illustrative purposes



Dedicated to innovation in aerospace

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