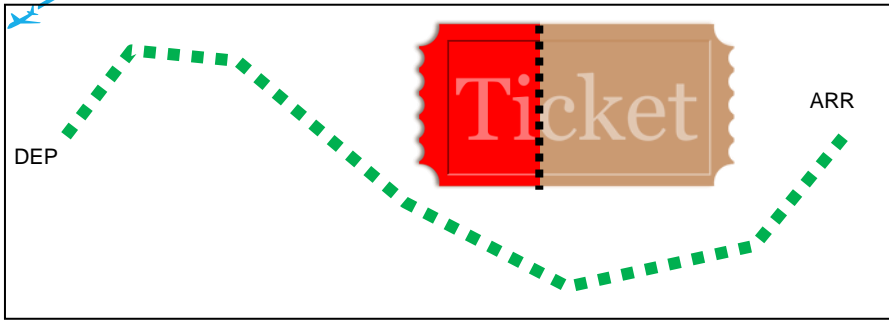




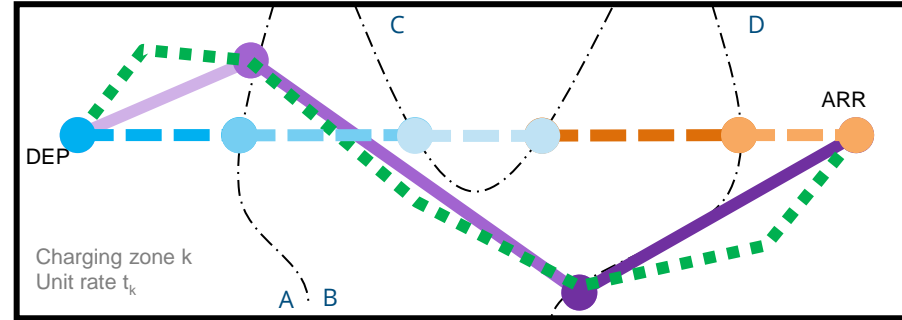
Dedicated to innovation in aerospace

Why aircraft fly more fuel-efficiently on FRIDAY

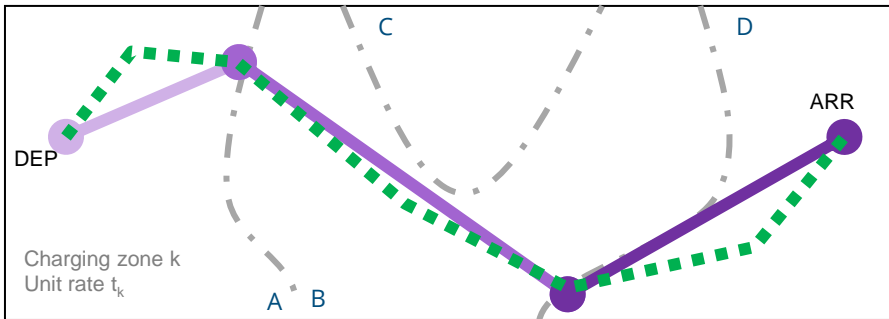
The FRIDAY route charges method **René Verbeek MSc, June 22, 2016**



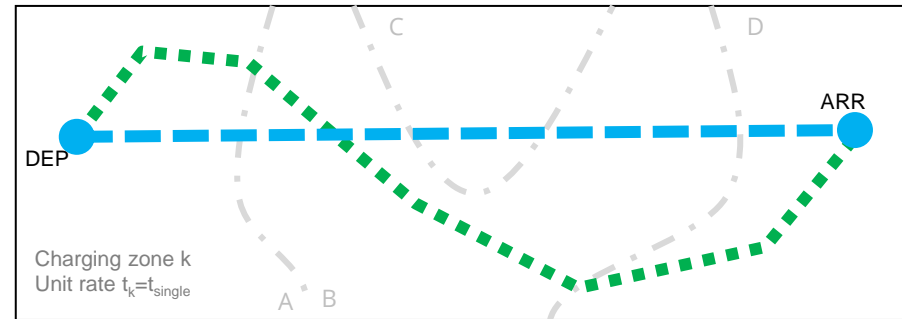
Ticket tax



FRIDAY route charges method

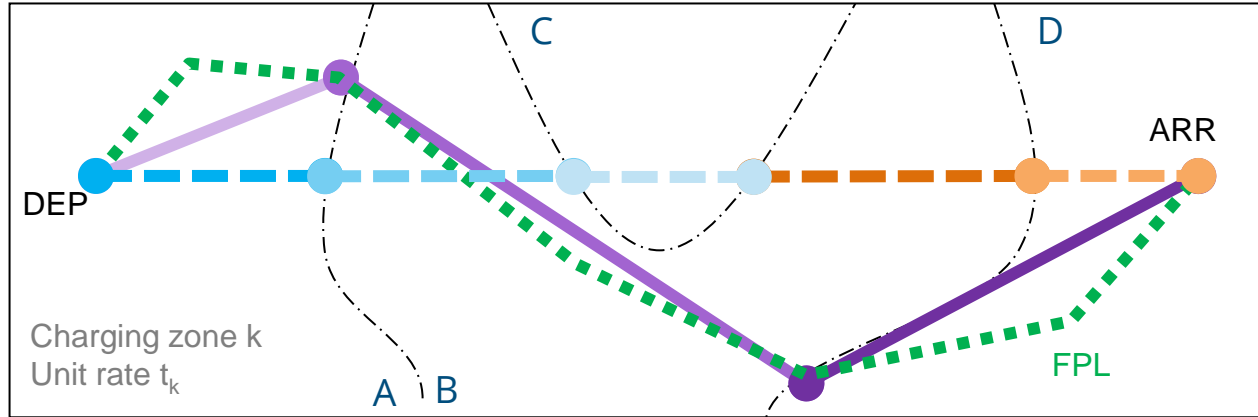


Eurocontrol route charges system



Single unit rate

FRIDAY route charges method

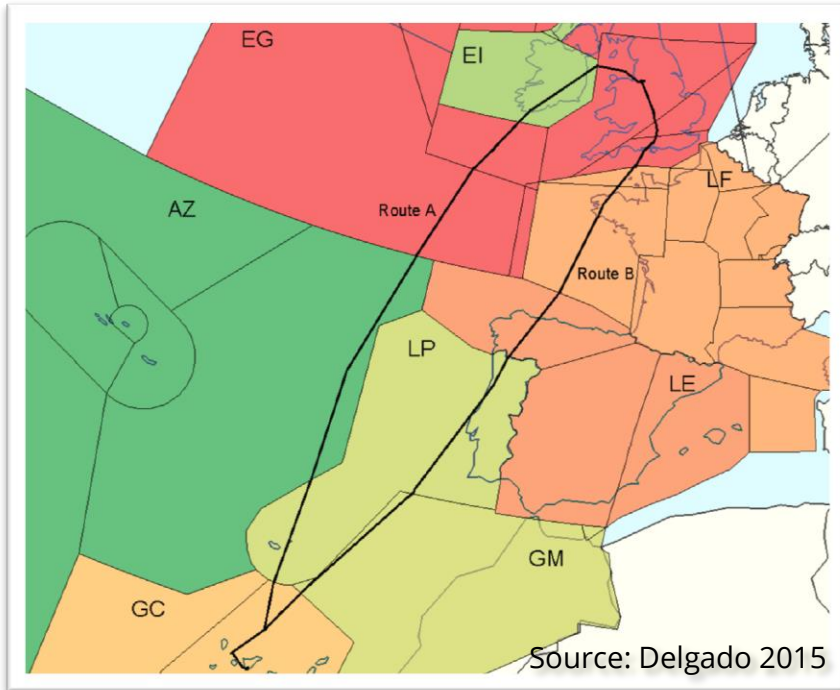


Two step approach:

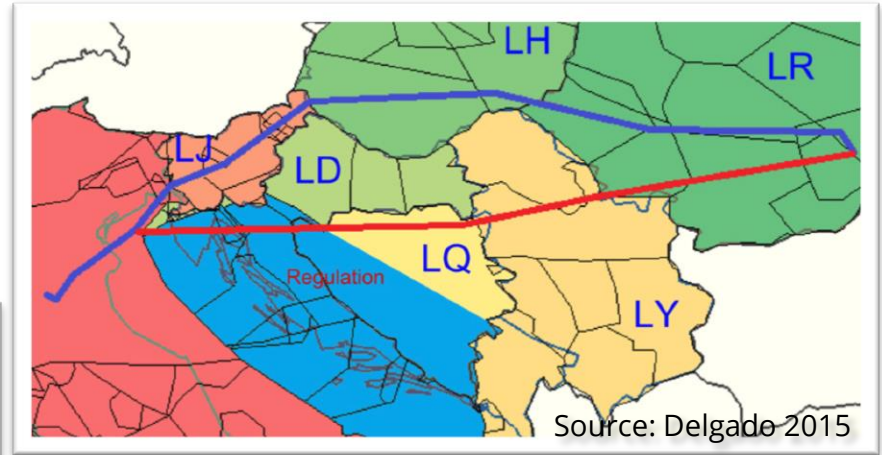
1. Charges are calculated along the great circle line from airport to airport
2. Collected charges are distributed to servicing ANSPs according to CRCO route

Problems with Eurocontrol common route charges system

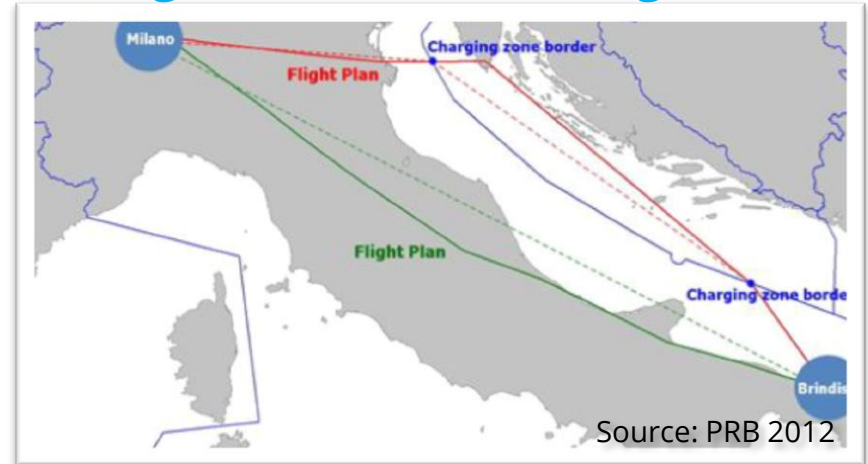
Differences in unit rates result in detours



FPL avoiding a congested area may result in higher charges



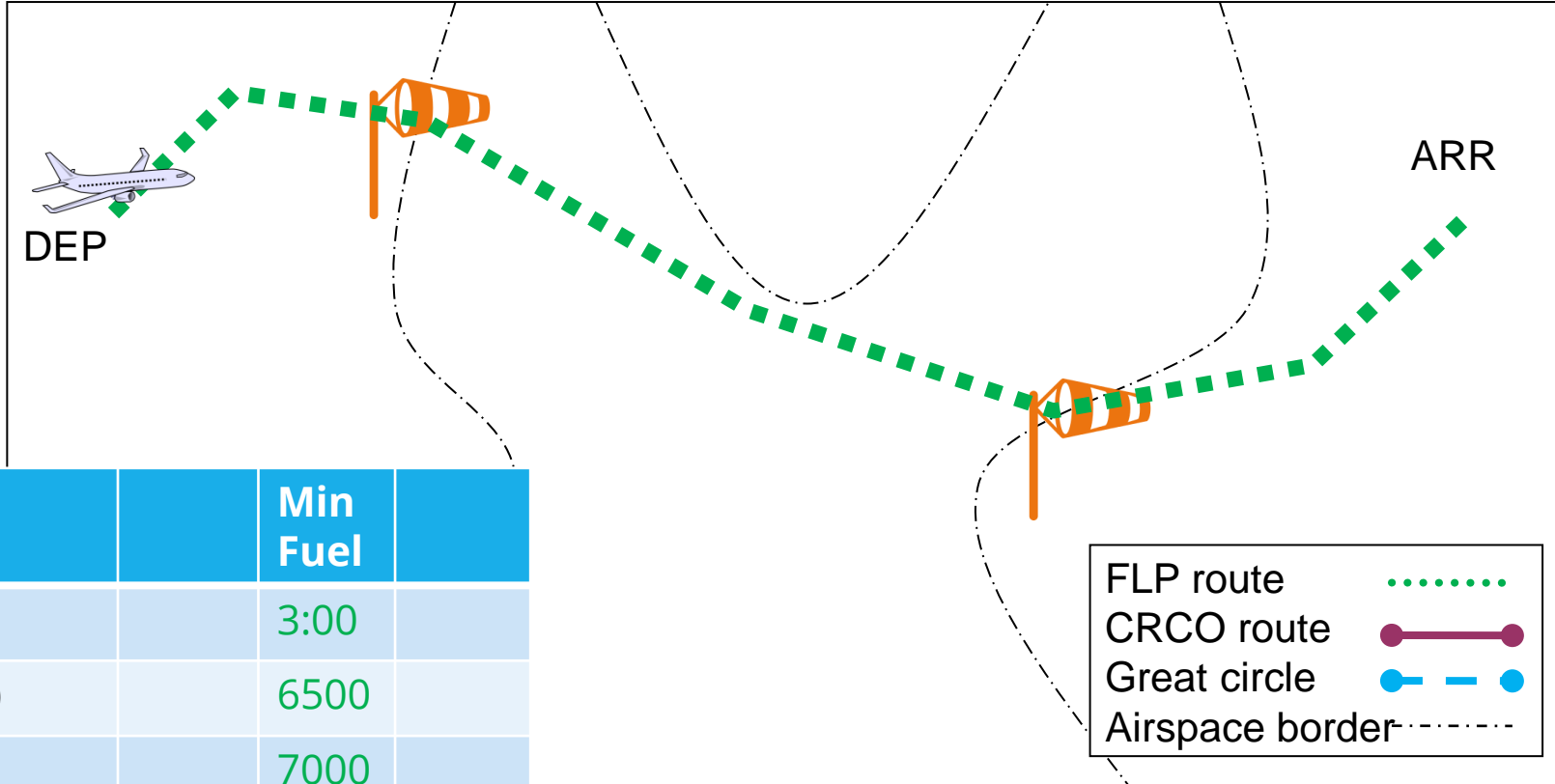
Filing indirect, and asking direct



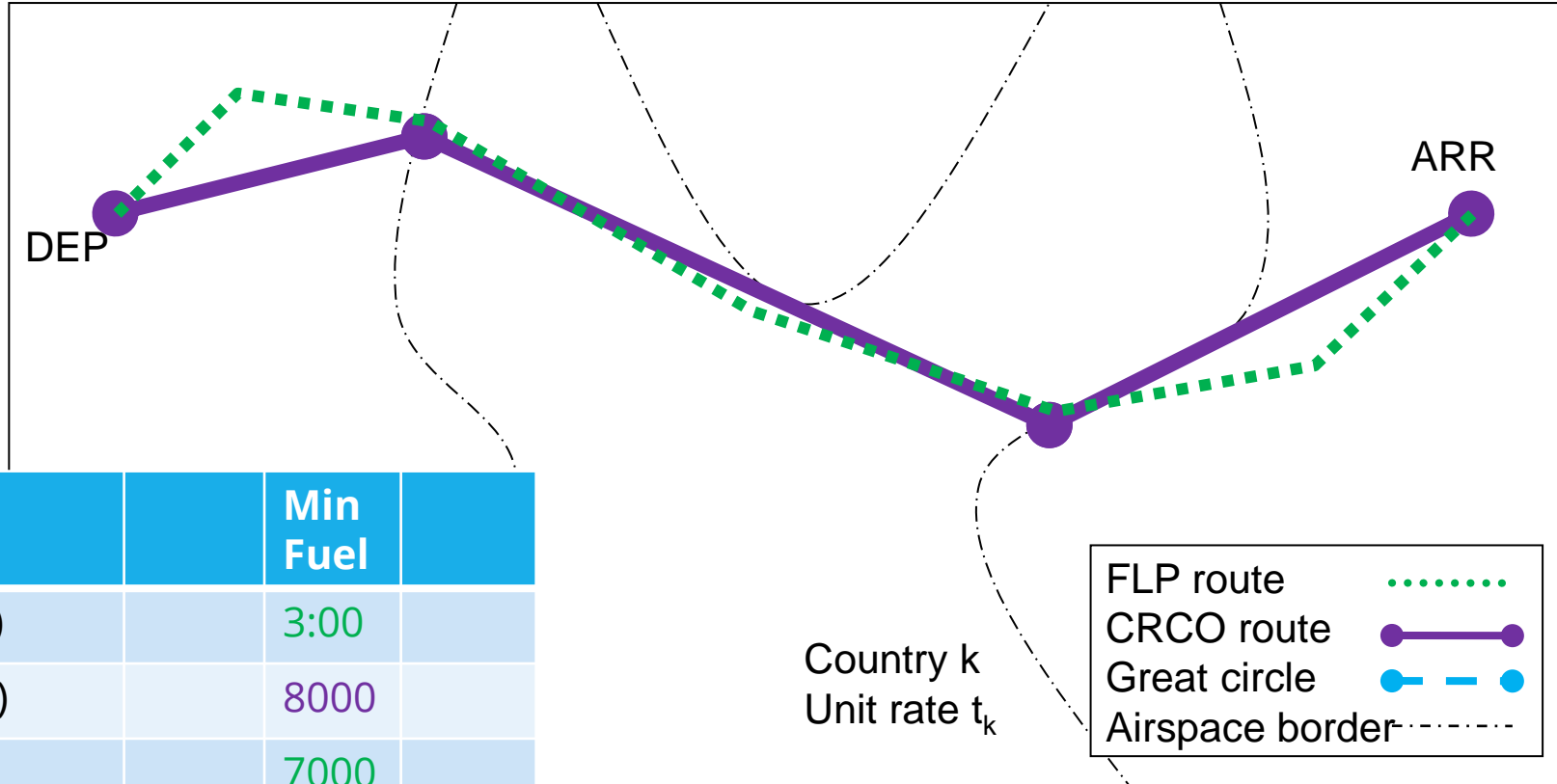


Underlying mechanism

Flight plan

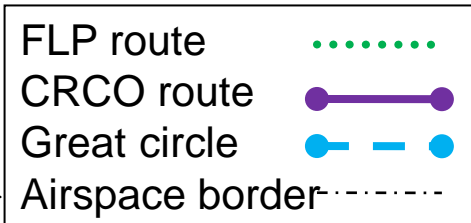
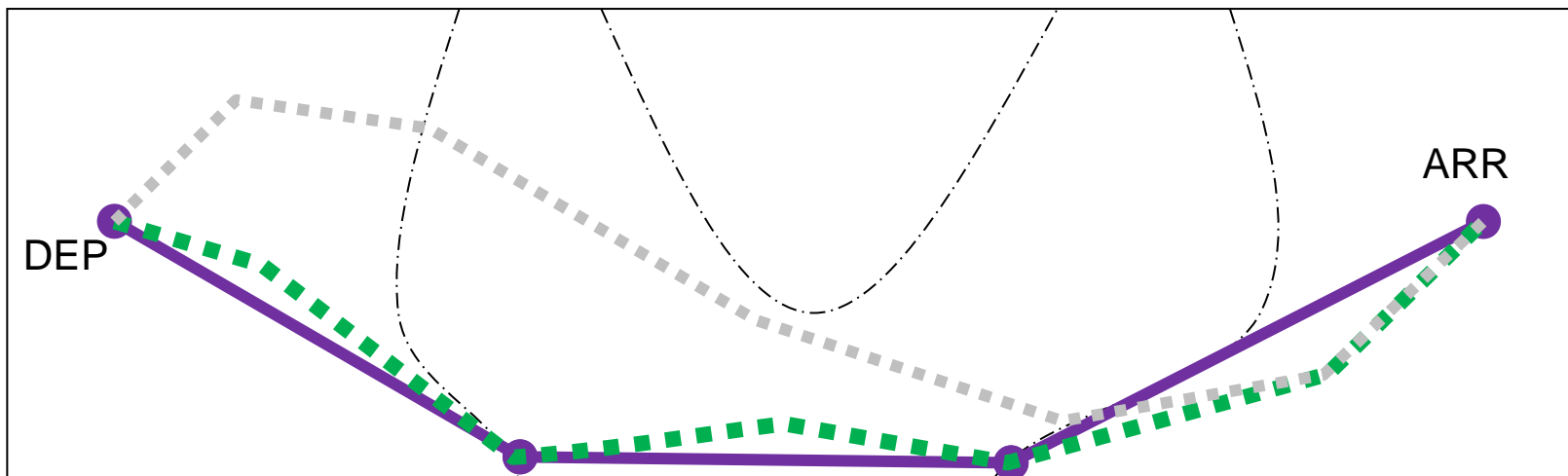


Eurocontrol Route Charges System

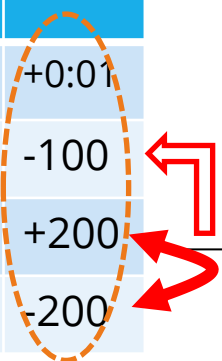


Flight	Min Fuel
Time (h:mm)	3:00
Total Cost (€)	8000
Tripfuel (kg)	7000
ATC costs (€)	1500

Eurocontrol Route Charges System



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



Country k
Unit rate t_k

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/CO₂** ↓
- No need for incentive schemes for fuel efficient trajectories

~~Extreme scenario: no route charge~~

Airlines



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

ANSPs



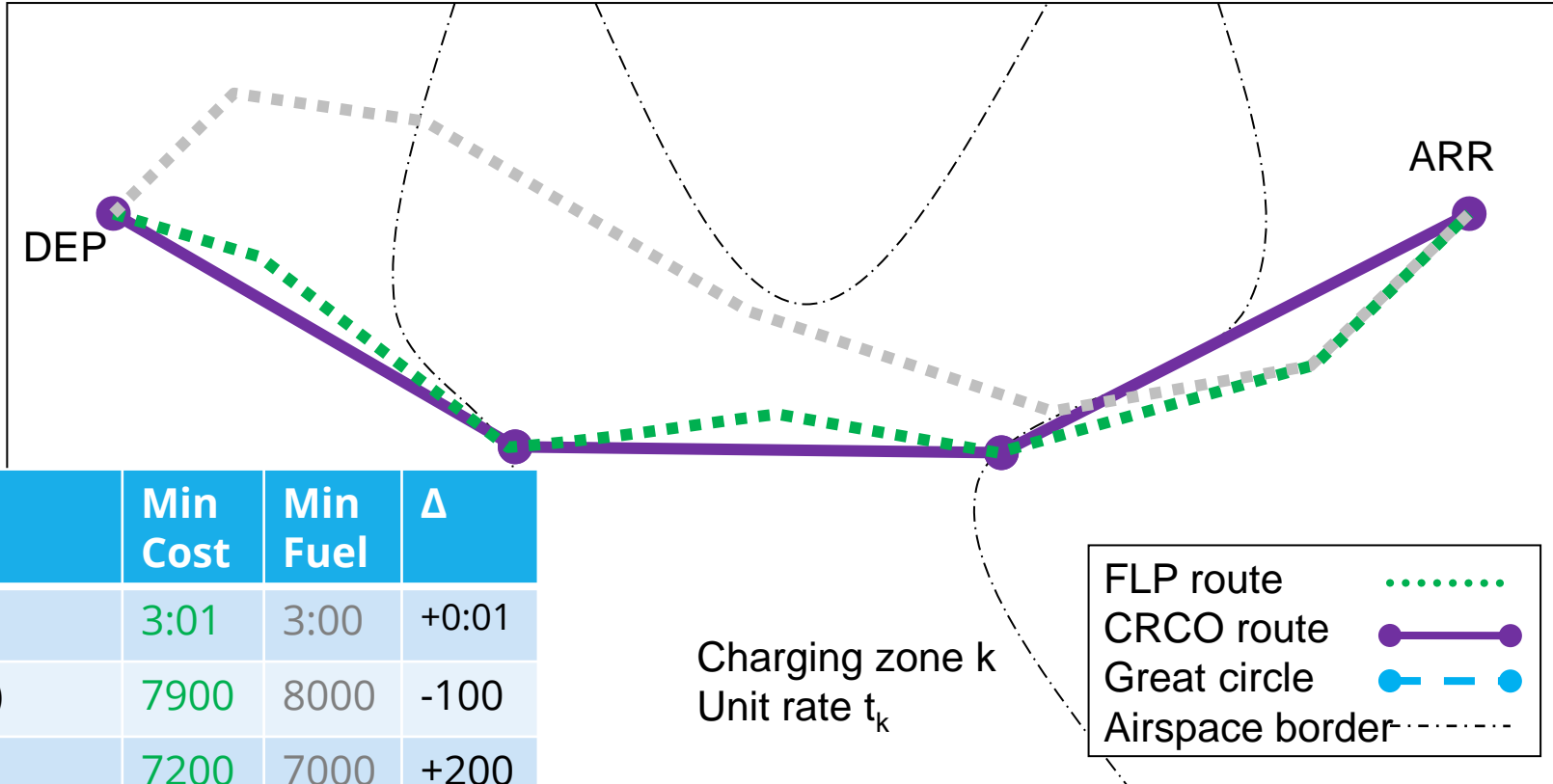
- **Cost recovery**
- Traffic concentrations ↓
- SESAR: Increased benefits of 4D ops and free routing
- Less need for asking for directs →
Predictability ↑

Society



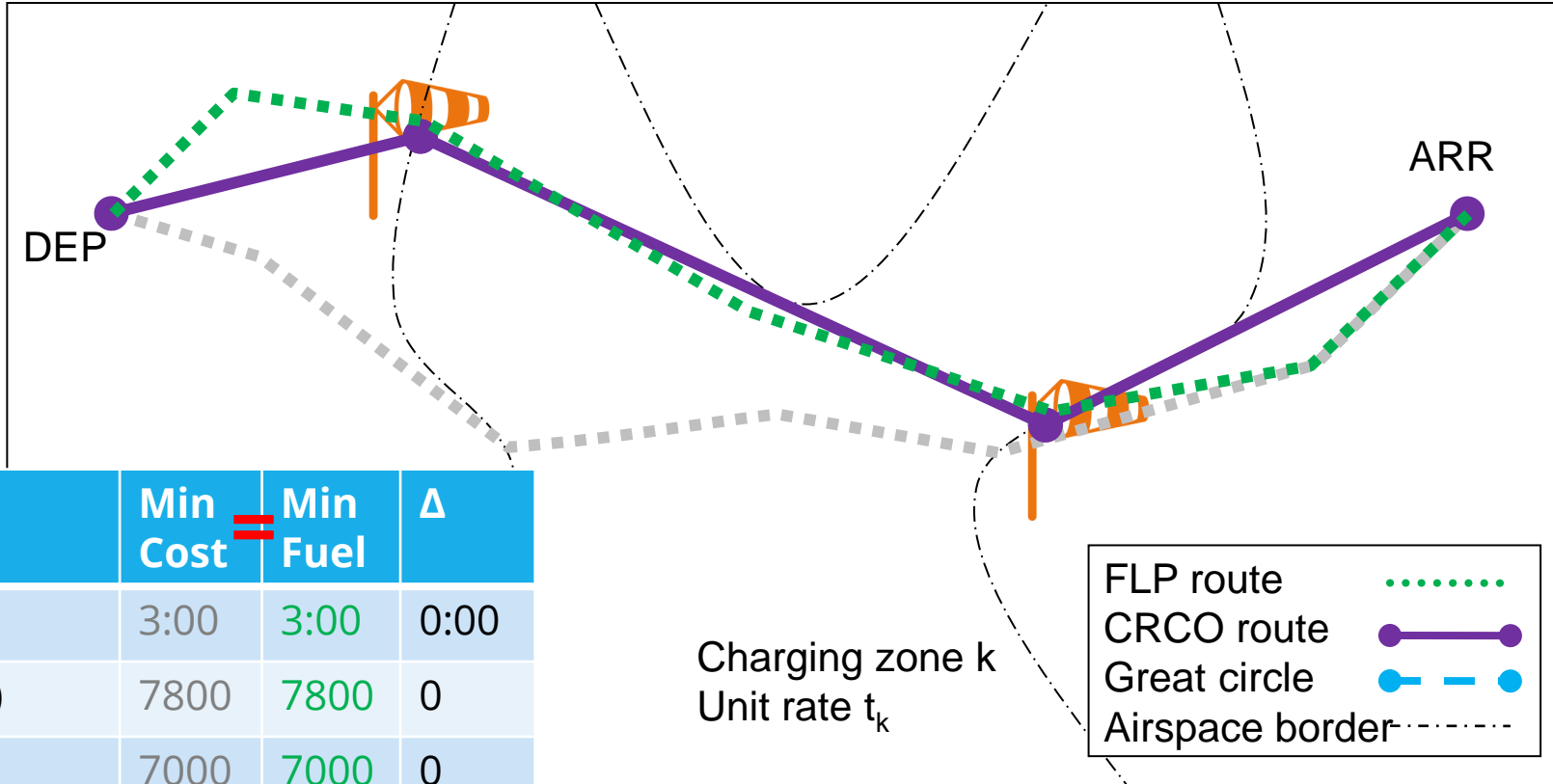
- **Emissions/CO₂** ↓
- No need for incentive schemes for fuel efficient trajectories

Eurocontrol Route Charges System



Flight	Min Cost	Min Fuel	Δ
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

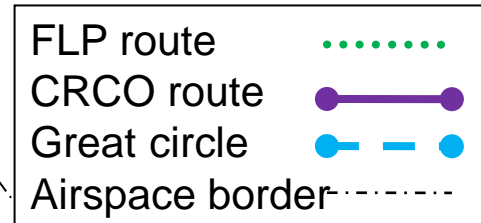
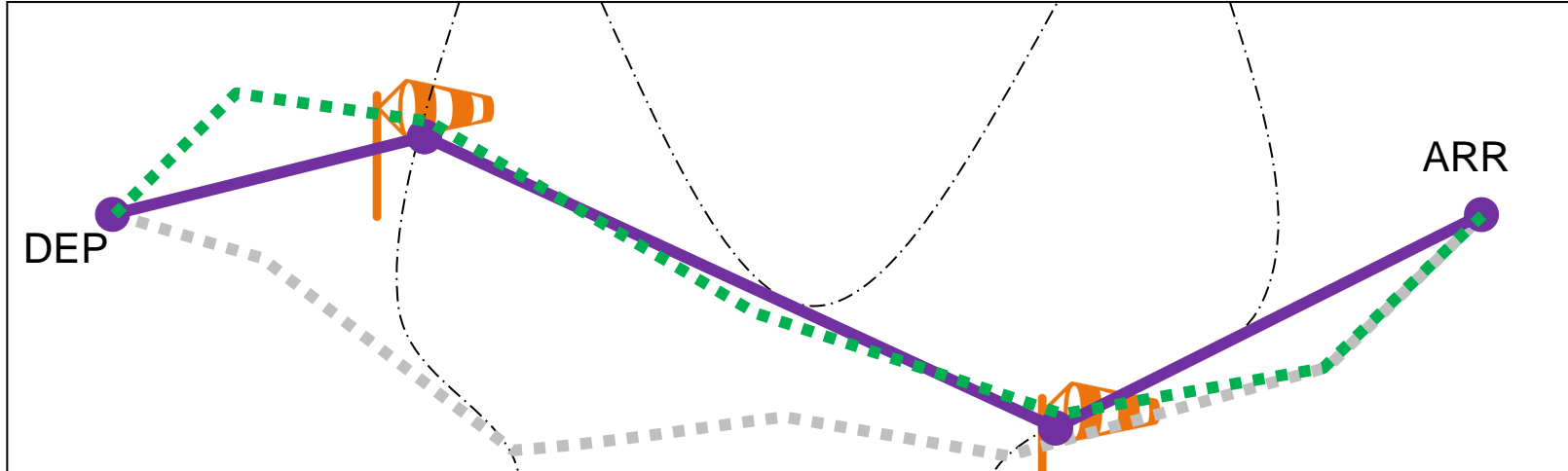


Flight	Min Cost	Min Fuel	Δ
Time (h:mm)	3:00	3:00	0:00
Total Cost (€)	7800	7800	0
Tripfuel (kg)	7000	7000	0
ATC costs (€)	1300	1300	0

Charging zone k
Unit rate t_k

- FLP route
- CRCO route ——●——●——
- Great circle - - - ● - - - ● - - -
- Airspace border - - - - -

Desired outcome



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

Alternative route charges systems

WIN-LOSE-SOLUTIONS



Single unit rate

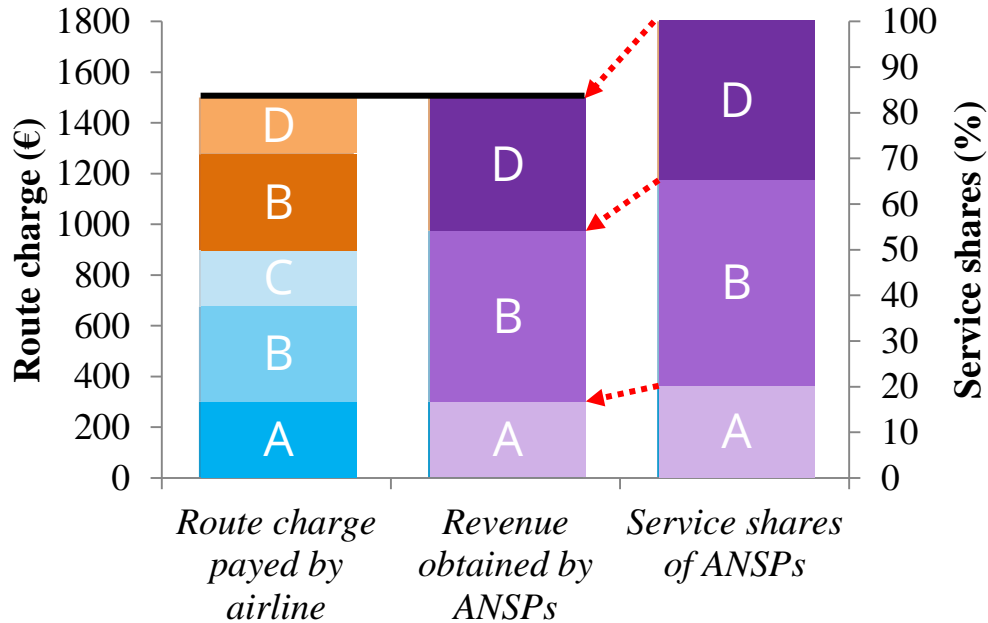
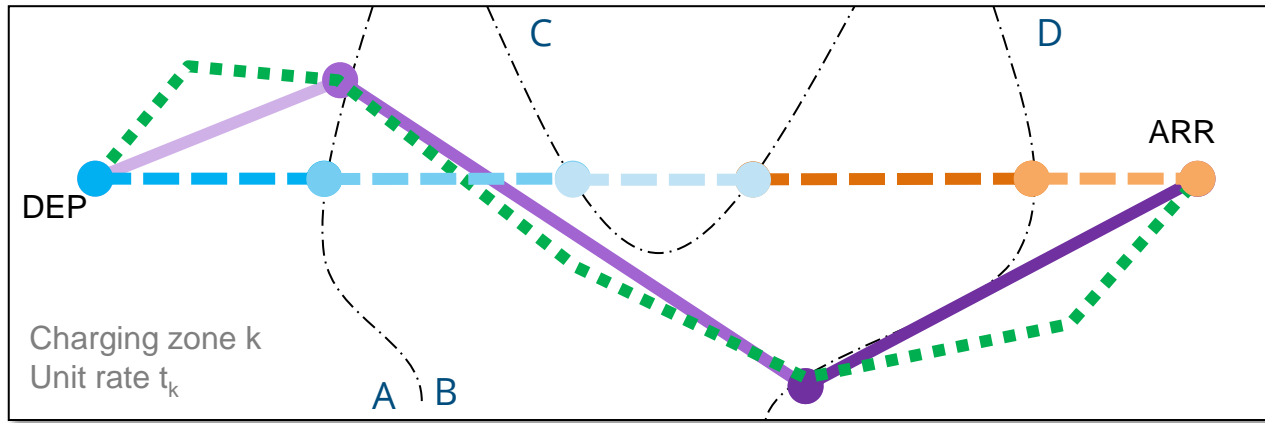
- Has desired outcome, but
 - **Some** airlines will pay **higher charges**
 - Revenues have to be **redistributed**
 - ANSPs need to **agree** on the single unit rate
 - ANSPs need to agree on what to do with **deviations** from expected revenues
 - Considered for **single FAB**, but not for multiple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

Eurocontrol Route Charges System

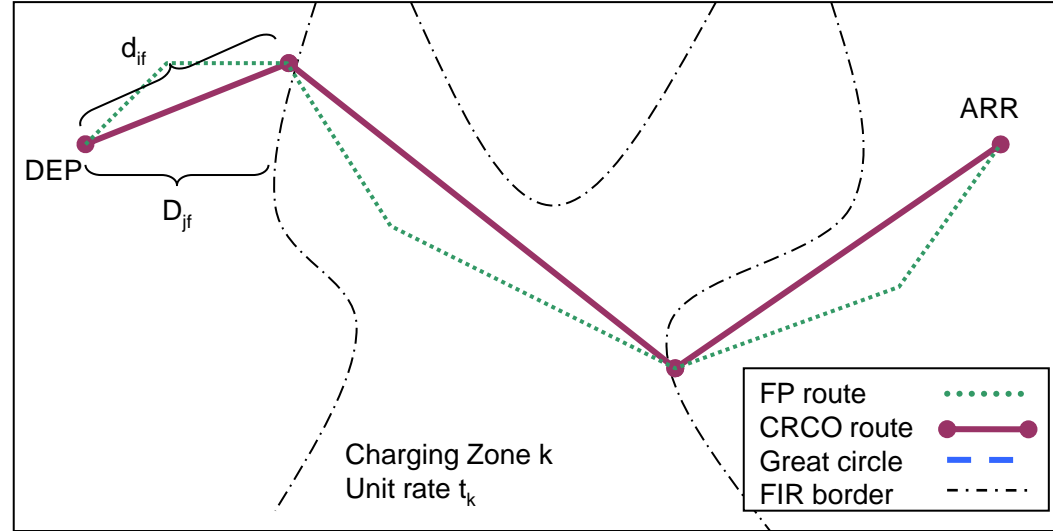
Central Route Charges Office
Service central des redevances de route

Please find hereunder the unit rates of route charges (monthly average of the "Closing Cross Rates") for 2016 flights, as well as the exchange rates used for their calculation, i.e. the rate of December 2015

Adjusted unit rates applicable to January 2016 flights

Zone 1 - United Kingdom

Portugal / Santa Helena	67.00
Belg-Luxemburg	29.76
Allemagne / Luxembourg	61.75
Finlande / Suède	40.36
Royaume-Uni	34.00
Playa-Estados Unidos	62.70
Islande / Danemark	
Norvège	
Pologne / Grèce	
Lettonie / Lituanie	
Liban / Espagne / Gibraltar	
Albanie / Albanie	
Bulgarie / Bulgarie	
Cyprus / Chypre	
Croatie / Croatie	
Espagne / Espagne - Comores	
France	
Grèce / Grèce	
Hongrie / Hongrie	
Italie / Italie	
Slovénie / Slovénie	
République Tchèque / République Tchèque	
Malte / Malte	
Autriche / Autriche	
Portugal / Liban	
Bosnie Herz / Bosnie Herzégovine	
Roumanie / Roumanie	
Suisse / Suisse	
Turquie / Turquie	
Moldavie / Moldavie	
ARYM / FYROM	
Serbie/Monténégro/KFOR	
République Slovaque / Slovaquie	
Arménie / Arménie	
Géorgie / Géorgie	

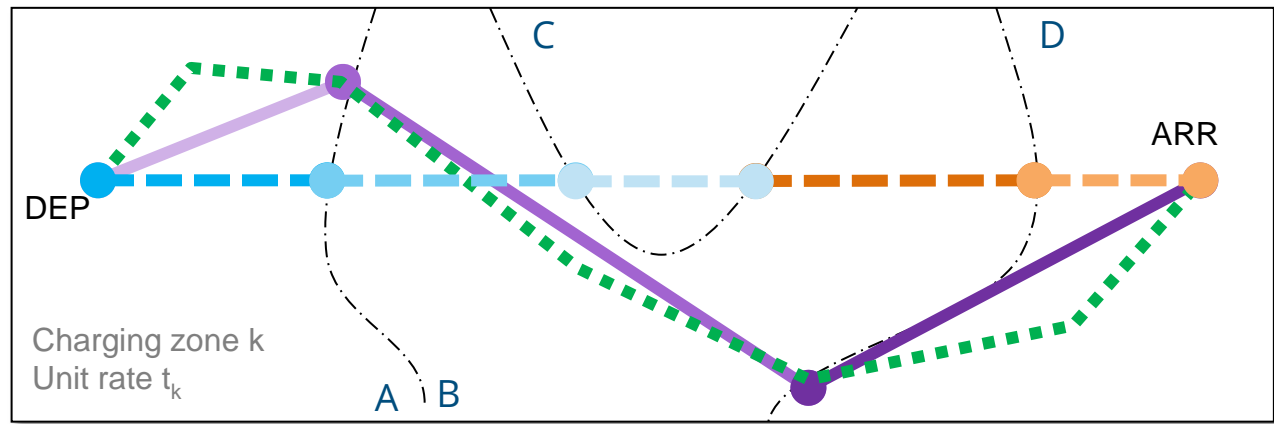


$$R_{CRCO} = \sum_i d_i \times p \times t_i$$

Route charge = f(airspace, distance, weight factor, unit rate)



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:

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

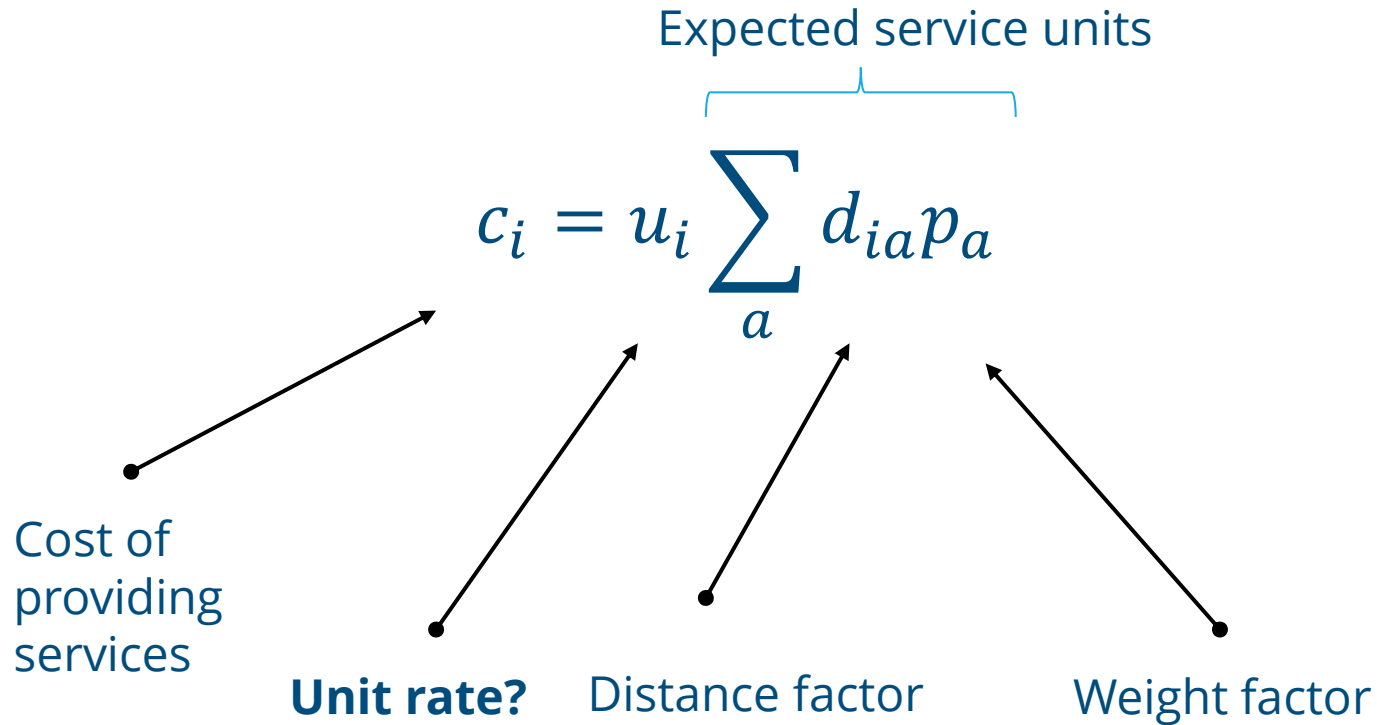
Flight time

Fuel cost coefficient

Route charges

Time cost coefficient

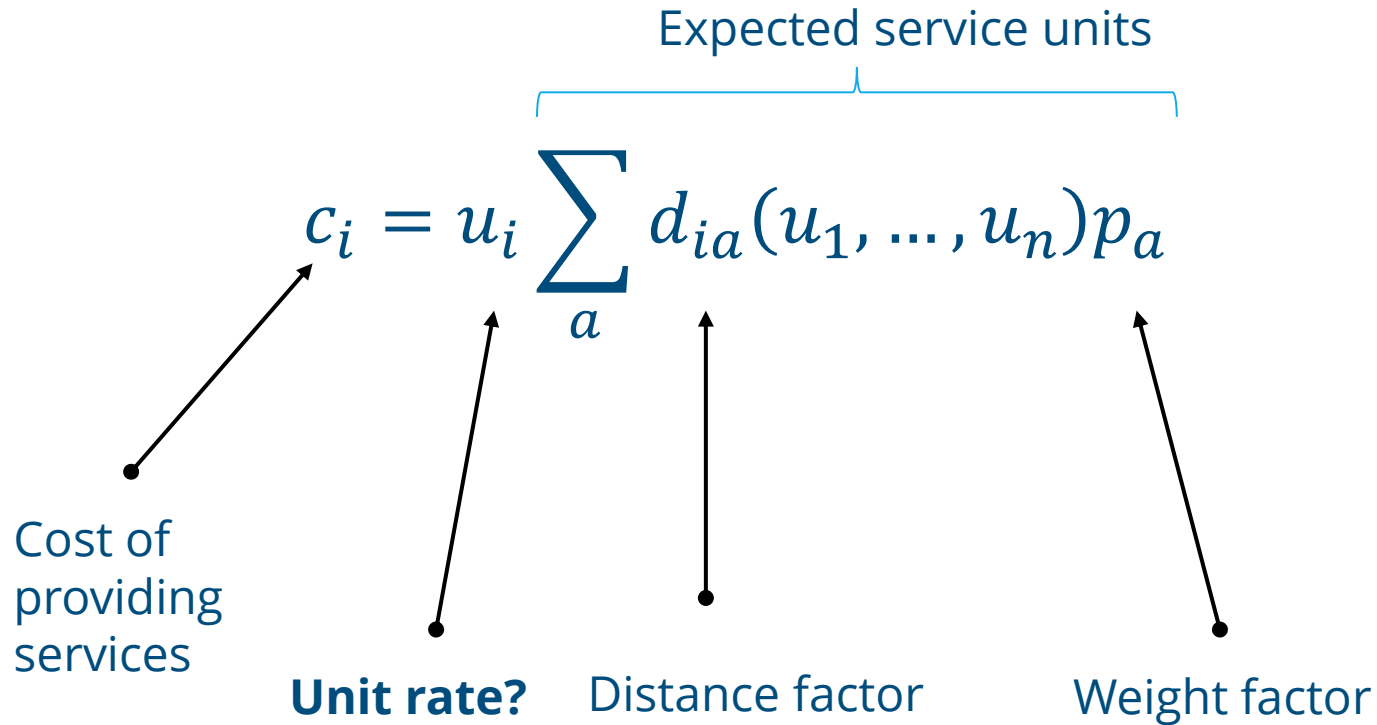
Setting unit rates (Eurocontrol Route Charges System)



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



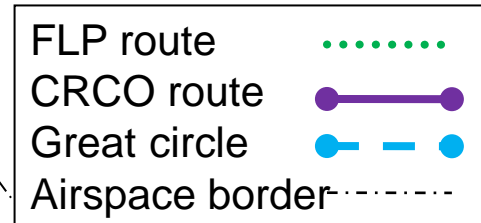
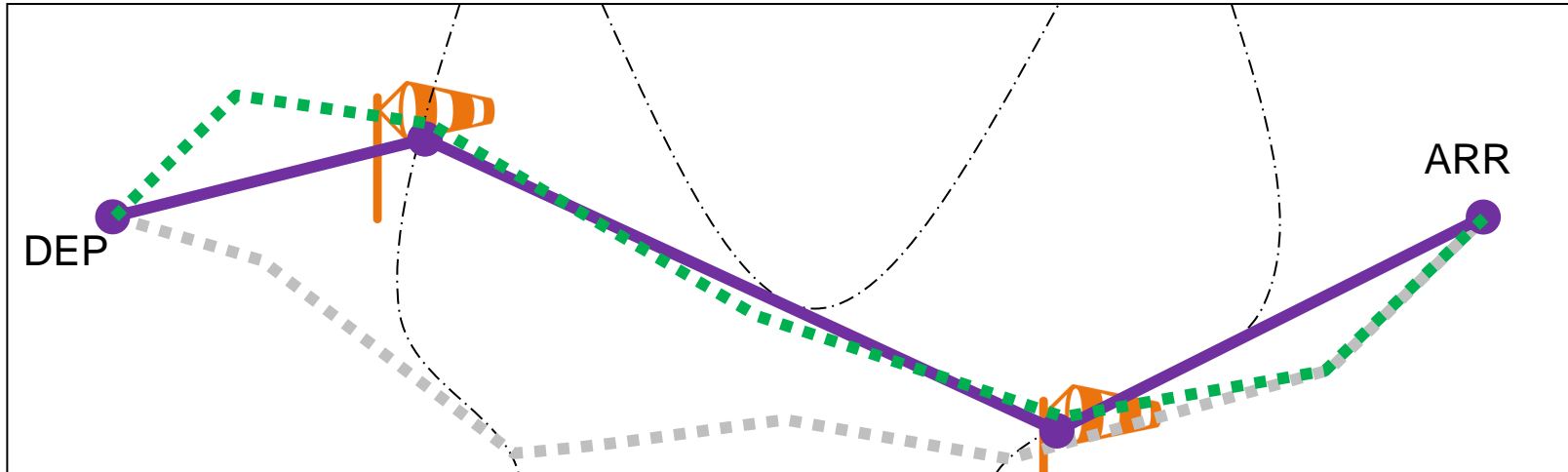
Setting unit rates (FRIDAY)

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	-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

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 Δ 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/CO₂** ↓
- 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

Airlines



- **Cost/Fuel/Time** ↓
- Route Charges the same on average
- Route Charges stay close to current
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ANSPs



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Society



- **Emissions/CO₂** ↓
- No need for incentive schemes for fuel efficient trajectories
- ANSPs can attract more traffic when they provide more efficient routes

Next steps?

Research questions

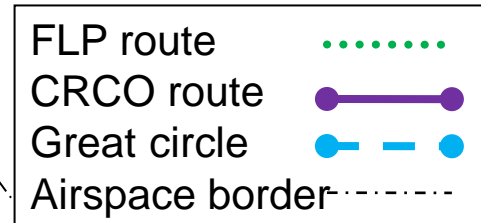
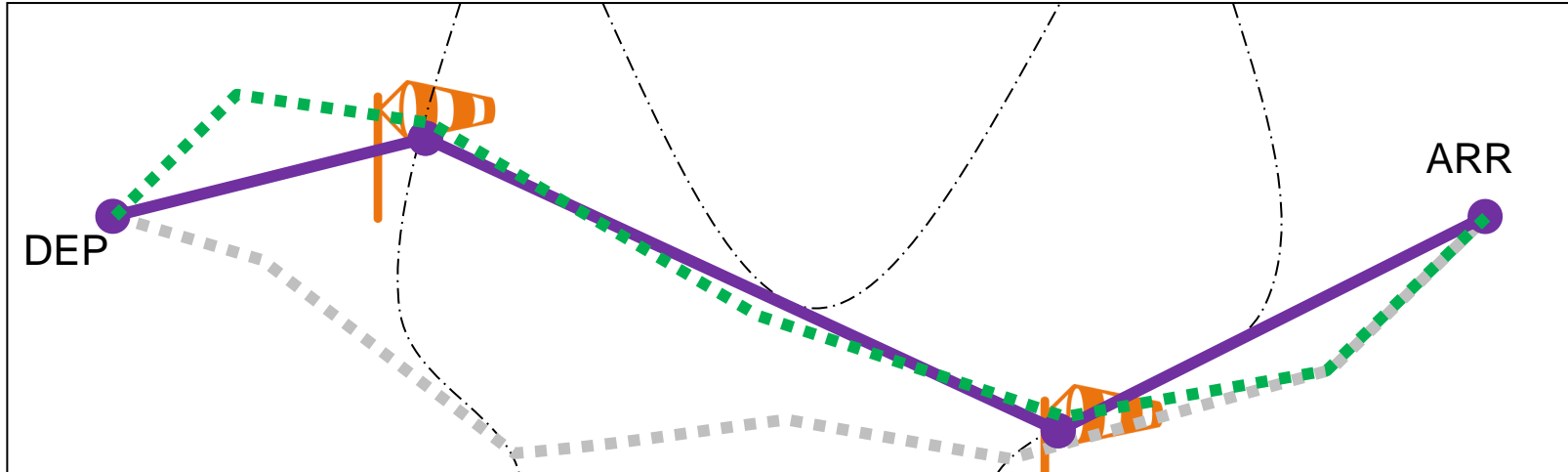
- What is the difference in performance between FRIDAY/ERCS/Single Unit Rate?
- What is the effect of uncertainties (weather/traffic numbers/...)?
- Is unit rate estimation method giving correct results?



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



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Fully engaged

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