Credible HYbrid eLectric Aircraft

CHYLA TECHNICAL MEETING – REGIONAL OPERATIVE SCENARIO

F. MORLUPO, B.F. SANTOS, P. FORSTER, AND M. HOOGREEF

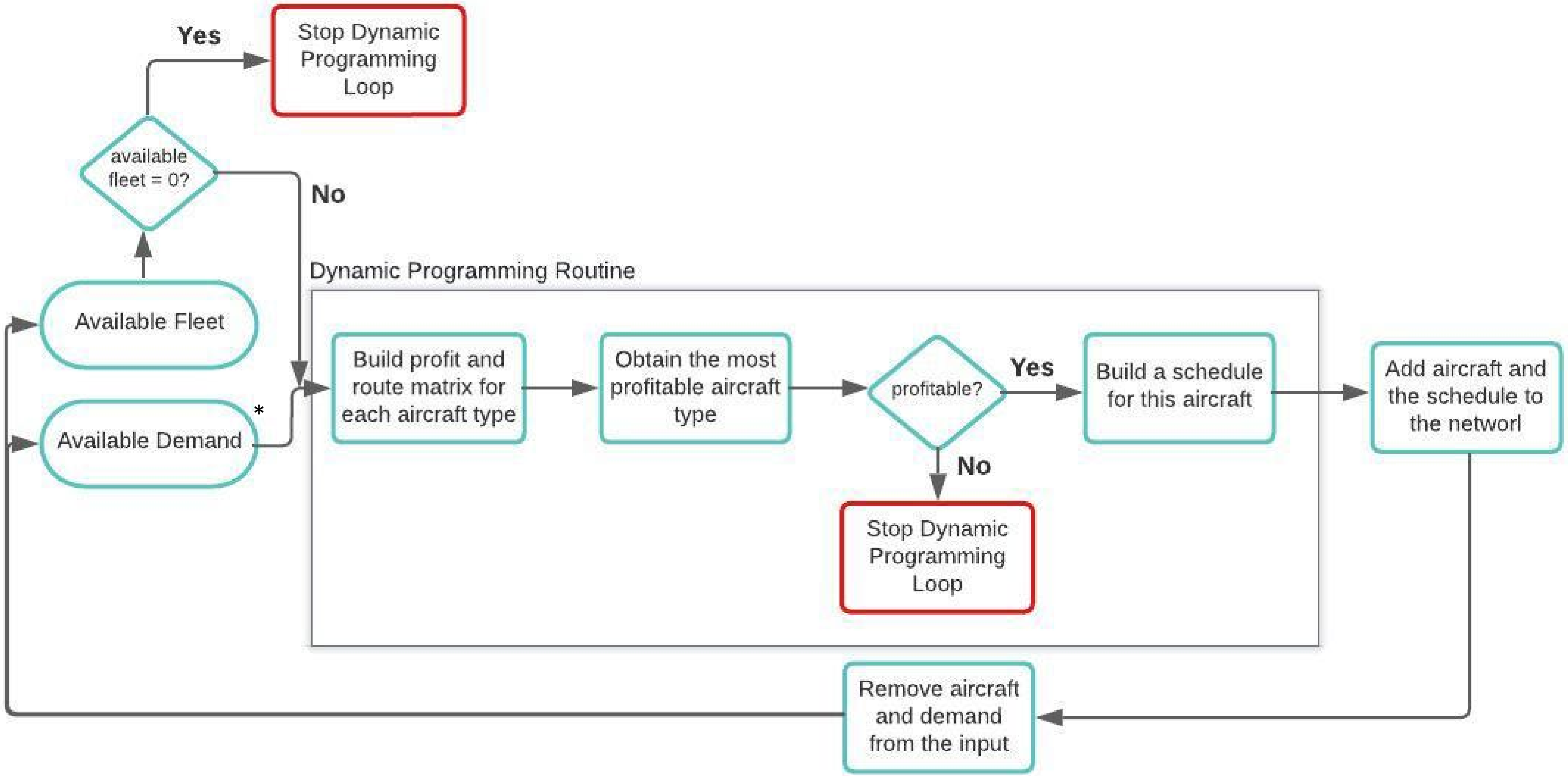
TU Delft | Technische Universität Braunschweig | University of Southampton

CHYLA

CREDIBLE HYBRID ELECTRIC AIRCRAFT

Clean Sky 2

A dynamic programing model for fleet assignment and flight scheduling



*
- Demand known and costant
- Not dependent on service levels
- Competition not considered

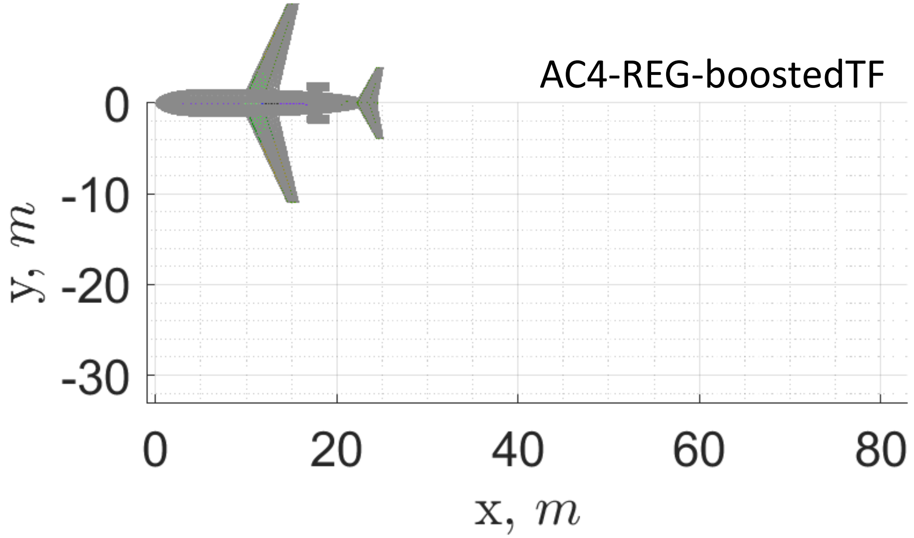
A small case study: The Azores

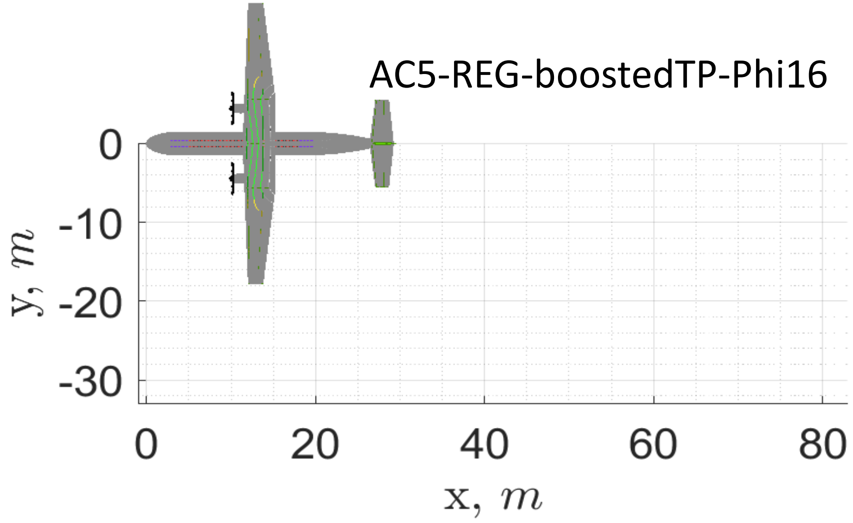
Airport	IATA code
Santa Maria	SMA
Ponta Delgada	**PDL**
Terceira	TER
Graciosa	GRW
Sao Jorge	SJZ
Pico	PIX
Horta	HOR
Flores	FLW
Corvo	CVU

sata Demand and cost data provided by SATA Azores

Fleet composition

Aircraft Name	**Aircraft Type**	**Seats** [-]	**Range** [km]	**MTOM** [tonnes]
Bombardier Dash 8-Q200 (KE80)	KE	80	1839	31
Bombardier Dash 8-Q400 (KE37)	KE	37	2656	45
AC4-REG-boostedTF (RJ50)	HE	50	926	27
AC5-REG-boostedTP-Phi16 (TP72)	HE	72	926	36





Flight scheduling: why is it important for us?

Dep Time	Arr Time	Dep Airport	Arr Airport	AC	Pax	LF
7:40:00	8:20:00	PDL	HOR	TP72	52	0.72
9:40:00	10:20:00	HOR	PDL	TP72	52	0.72
11:40:00	12:20:00	PDL	HOR	TP72	65	0.90
13:40:00	14:20:00	HOR	PDL	TP72	65	0.90
15:40:00	16:20:00	PDL	PIX	TP72	54	0.75
17:40:00	18:20:00	PIX	PDL	TP72	57	0.79
19:40:00	20:00:00	PDL	SMA	TP72	62	0.86
20:40:00	21:00:00	SMA	PDL	TP72	62	0.86
1 day, 7:20:00	1 day, 8:00:00	PDL	HOR	TP72	52	0.72
1 day, 9:20:00	1 day, 10:00:00	HOR	PDL	TP72	47	0.65
1 day, 11:20:00	1 day, 12:00:00	PDL	HOR	TP72	65	0.90
1 day, 13:20:00	1 day, 14:00:00	HOR	PDL	TP72	65	0.90
1 day, 15:20:00	1 day, 16:00:00	PDL	PIX	TP72	65	0.90
1 day, 17:20:00	1 day, 18:00:00	PIX	PDL	TP72	57	0.79
1 day, 19:20:00	1 day, 20:00:00	PDL	PIX	TP72	65	0.90
1 day, 21:20:00	1 day, 22:00:00	PIX	PDL	TP72	29	0.40

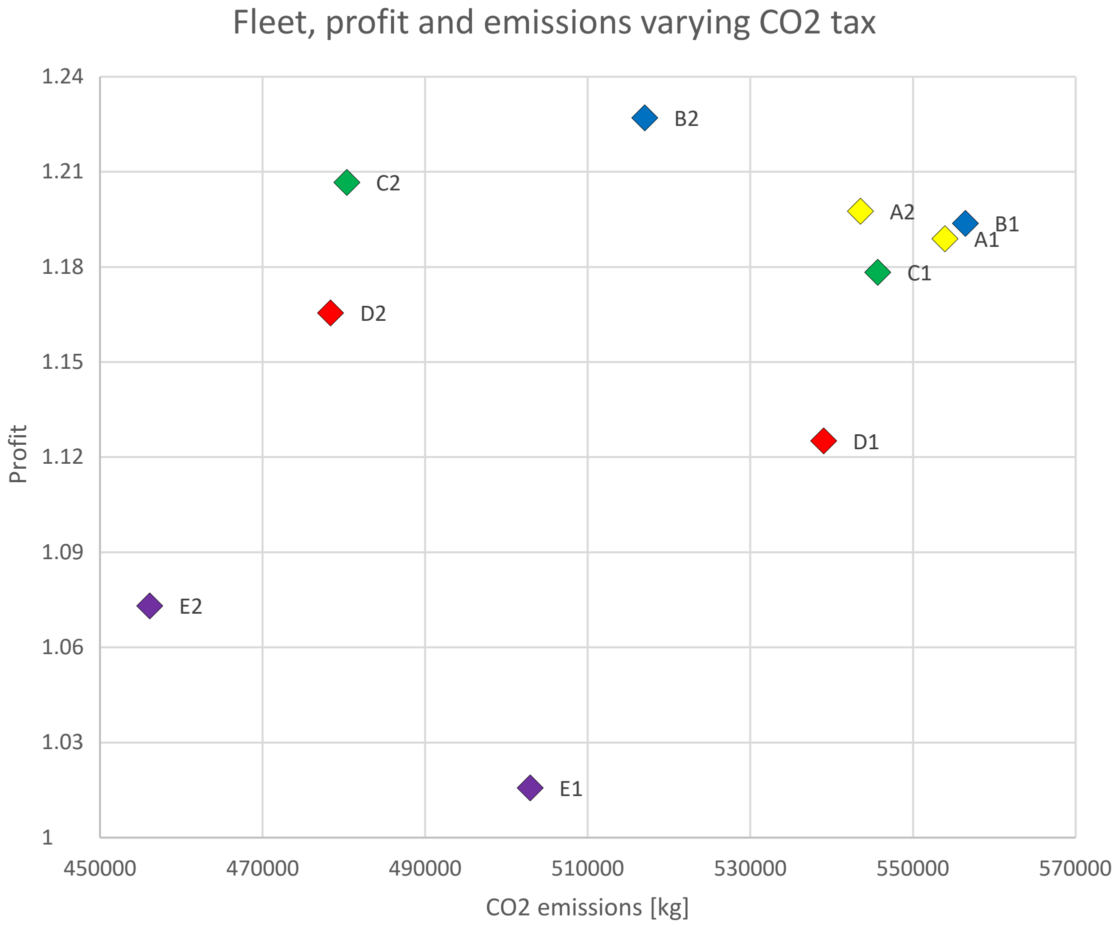
IMPROVED INTEGRATION WITH AIRCRAFT DESIGN!

Aircraft	OD pair	GCD [km]
TP72	PDL-HOR	278
TP72	PDL-PIX	257
TP72	PDL-SMA	97

Aircraft	OD pair	GCD [km]
RJ50	PDL-HOR	278
RJ50	PDL-TER	166
RJ50	PDL-FLW	510
RJ50	FLW-HOR	234
RJ50	HOR-TER	144

example calculated loadfactors

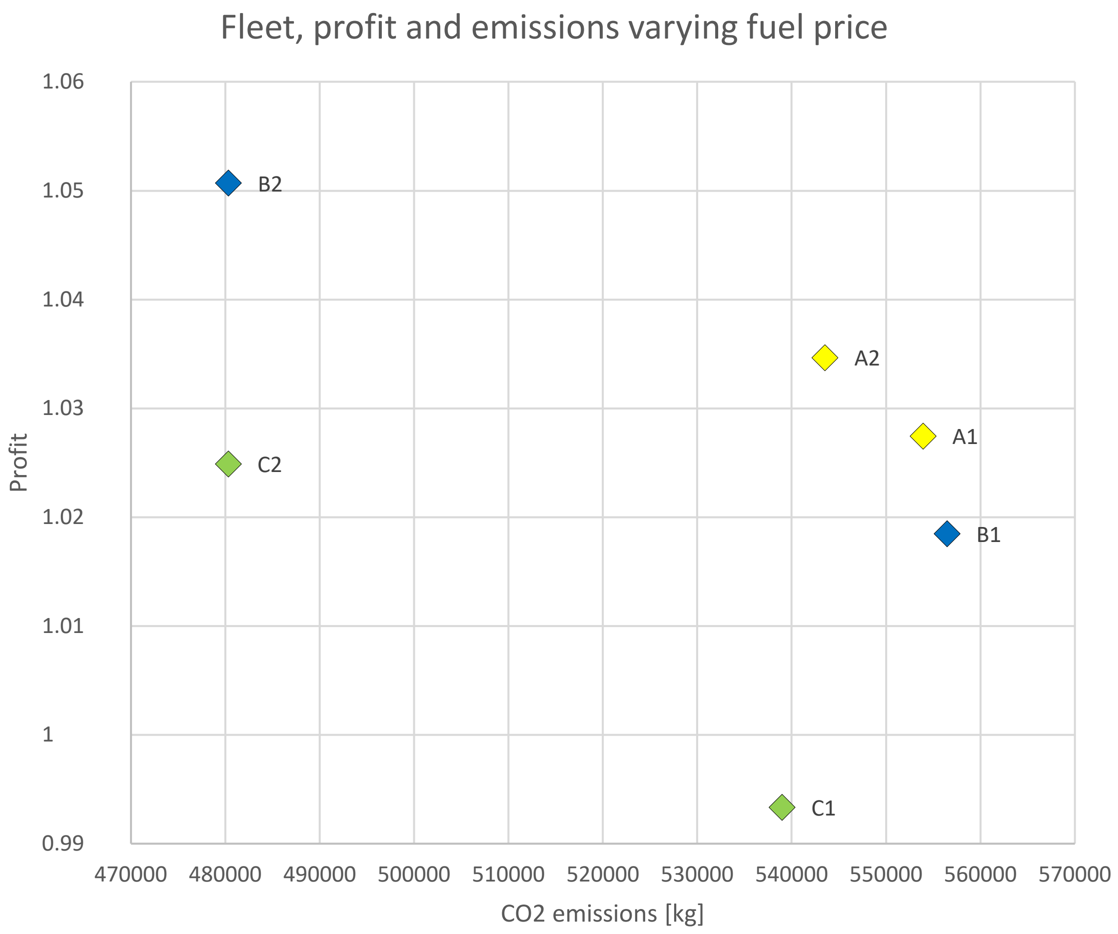
Best solution varying CO2 tax



Scen	CO2 Tax [€/kg]	Best fleet	% prof	% ems
A1	0	KE80 (3), KE37 (4)	-	-
A2	0	KE80 (3), KE37 (3), **RJ50 (1)**	+1%	-2%
B1	0.082	KE80 (3), KE37 (4)	-	-
B2	0.082	KE80 (3), KE37 (3), **RJ50 (1)**	+3%	-7%
C1	0.164	KE80 (3), KE37 (4)	-	-
C2	0.164	KE80 (2), KE37 (3), **RJ50 (1), TP72 (1)**	+2%	-12%
D1	0.328	KE80 (3), KE37 (4)	-	-
D2	0.328	KE80 (2), KE37 (3), **RJ50 (2), TP72 (1)**	+3%	-11%
E1	0.656	KE80 (3), KE37 (3)	-	-
E2	0.656	KE80 (2), KE37 (3), **RJ50 (2), TP72 (1)**	+5%	-9%

1 = only kerosene aircraft; 2 = mixed fleet
Note that profit is anonymized

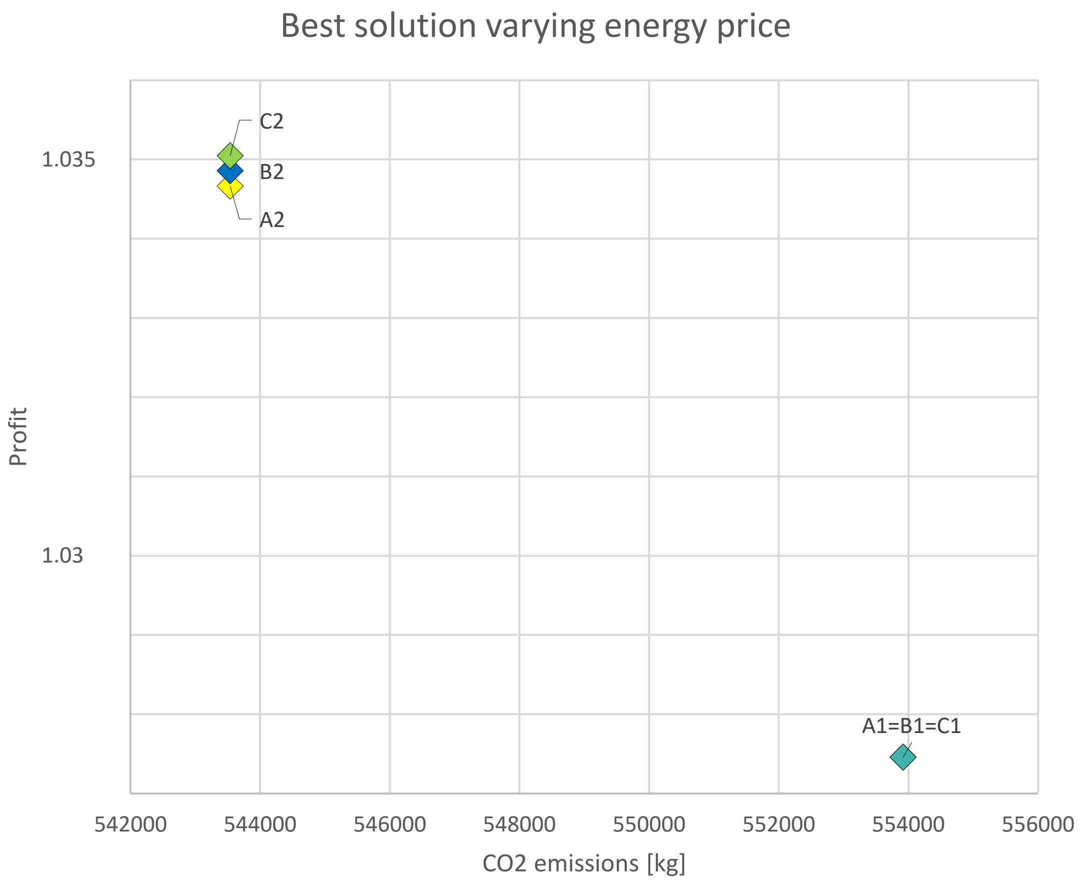
Best solution varying fuel price



Scen	Fuel price [€/kg]	Best fleet	% prof	% ems
A1	0.8	KE80 (3), KE37 (4)	-	-
A2	0.8	KE80 (3), KE37 (3), **RJ50 (1)**	+1%	-2%
B1	1.2	KE80 (3), KE37 (4)	-	-
B2	1.2	KE80 (2), KE37 (3), **RJ50 (1), TP72 (1)**	+3%	-14%
C1	1.6	KE80 (3), KE37 (4)	-	-
C2	1.6	KE80 (2), KE37 (3), **RJ50 (2), TP72 (1)**	+3%	-11%

1 = only kerosene aircraft; 2 = mixed fleet; CO2 tax is assumed equal to 0

Best solution varying energy price

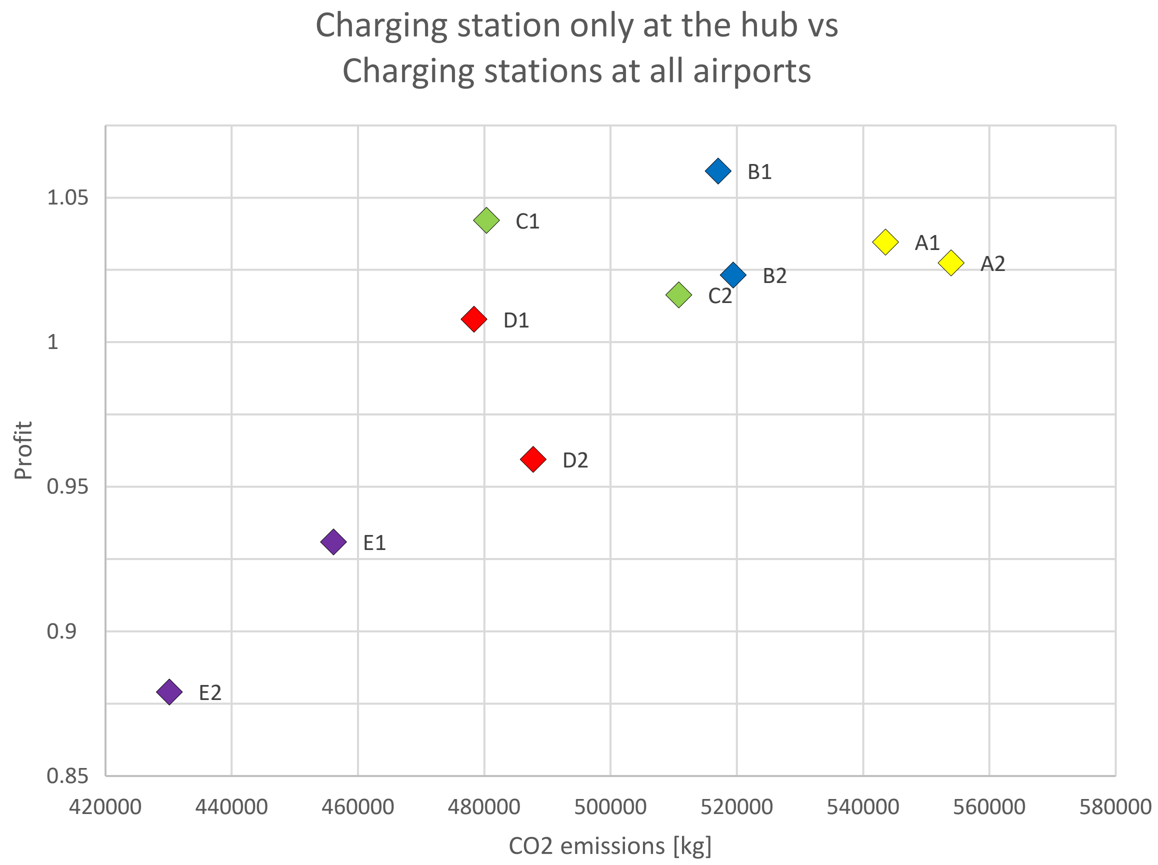


Scen	En.gy price [€/kWh]	Best fleet	% prof	% ems
A1	0.1445	KE80 (3), KE37 (4)	-	-
A2	0.1445	KE80 (3), KE37 (3), **RJ50 (1)**	+1%	-2%
B1	0.1084	KE80 (3), KE37 (4)	-	-
B2	0.1084	KE80 (3), KE37 (3), **RJ50 (1)**	+1%	-2%
C1	0.0723	KE80 (3), KE37 (4)	-	-
C2	0.0723	KE80 (3), KE37 (3), **RJ50 (1)**	+1%	-2%

1 = only kerosene aircraft; 2 = mixed fleet; CO_2 tax is assumed equal to 0

What if we have only one charging station?

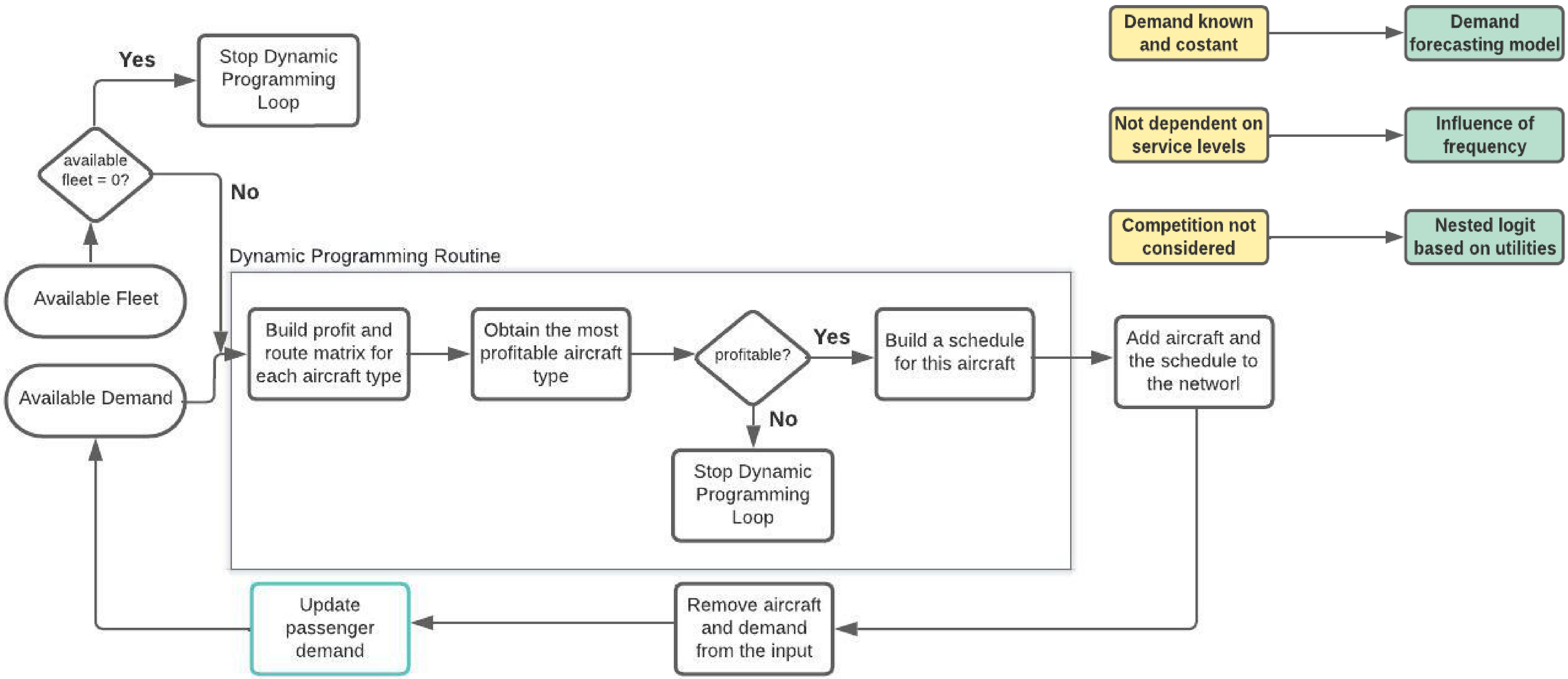
It will be important that all airports are equipped with charging stations!



Scen	CO_2 Tax [€/kg]	Best fleet	% prof *	% ems *
A1	0	KE80 (3), KE37 (3), **RJ50 (1)**	-	-
A2	0	KE80 (3), KE37 (4)	-1%	+2%
B1	0.082	KE80 (3), KE37 (3), **RJ50 (1)**	-	-
B2	0.082	KE80 (3), KE37 (3), (-)	-3%	0%
C1	0.164	KE80 (2), KE37 (3), **RJ50 (1)**, TP72 (1)	-	-
C2	0.164	KE80 (2), KE37 (4), TP72 (1)	-2%	+6%
D1	0.328	KE80 (2), KE37 (3), **RJ50 (2)**, TP72 (1)	-	-
D2	0.328	KE80 (2), KE37 (4), (-), TP72 (1)	-5%	+2%

* Percentage difference compared to the same scenario but with charging stations in all airports

Next steps – Introduction of passenger demand update



A new case study: European regional network

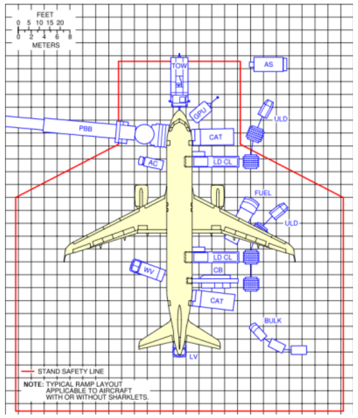
- Assessing the scalability of the model
- Possible case study:
  - HOP!
  - KLM CityHopper
  - Air Nostrum
- Integration with ground operations (airport side)

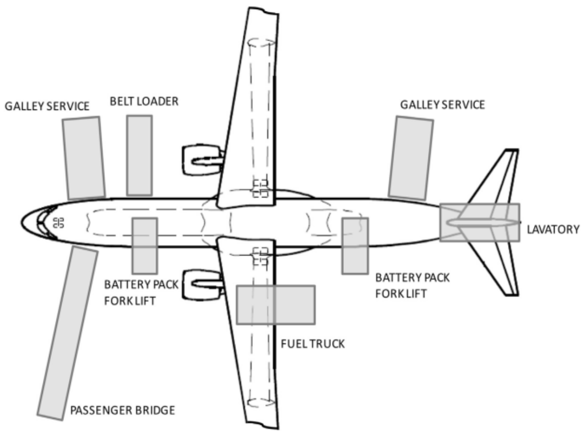
Airport operations

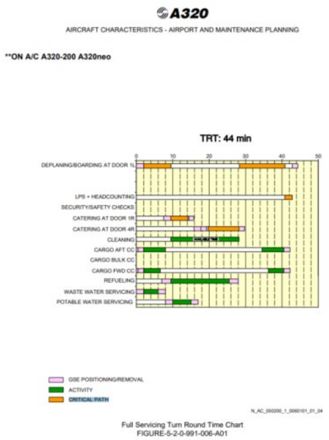
Upcoming extension towards hybrid aircraft integration in airport operations

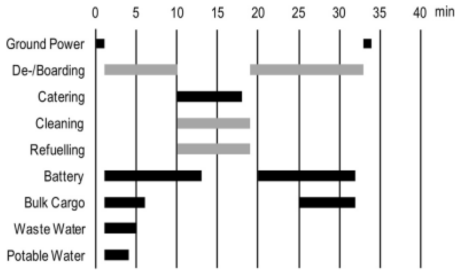
Effects of hybrid aircraft on operations

- Investigation into procedures
  - Adapt ground processes to enable turnaround times which are comparable with current operations
- Investigation into infrastructure
  - Determine requirements for airport ground architecture
- Assessing operational viability by means of simulation
  - Discrete Event Simulation as modeling approach
  - Definition of a reference scenario
  - Sensitivity studies to reveal interdependencies





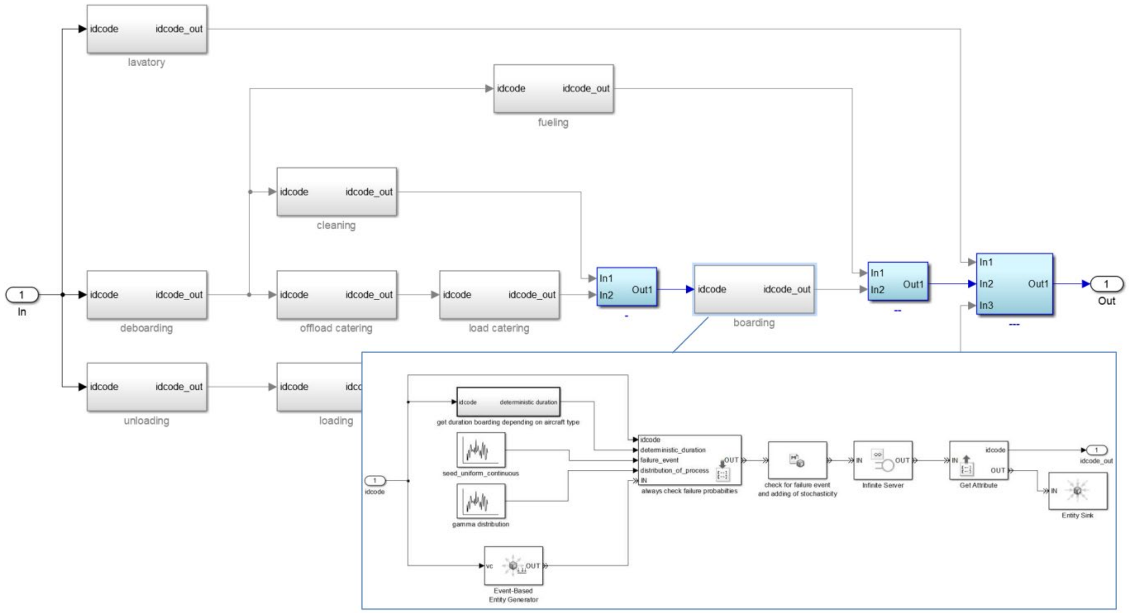




Ramp layout for an A320-200 at gate and according Gantt chart
Ground service equipment for SUGAR Volt concept [Bradley and Droney, 2011] and according Gantt chart [Schmidt, Paul, Cole, & Ploetner, 2016]

Modeling approach

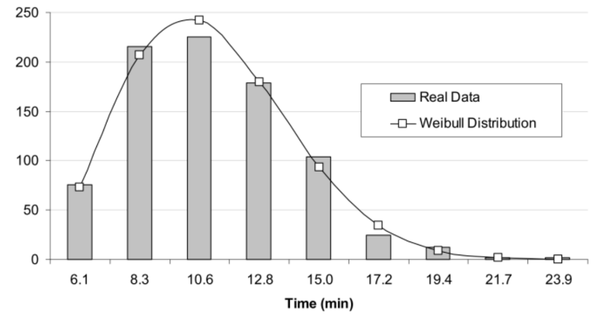
- Discrete Event Simulation
  - Various processes such as networks, logistics, manufacturing systems or traffic show time discrete behavior - time driven vs. event driven, „events drive the clock“
  - Fast implementation of synchronization, choice, sequence and concurrency of processes and actions
  - Hierarchical and modular, allows simulation of particular (sub)processes at higher detail and to extend the scope
  - Incorporation of stochastic influences, such as of process durations or to reflect probability of failures rates
  - Abstraction of the model via building blocks such as servers, queues, entities, attributes, gates, etc.
  - Unlimited entities and according attributes allow for example to reflect multiple airports



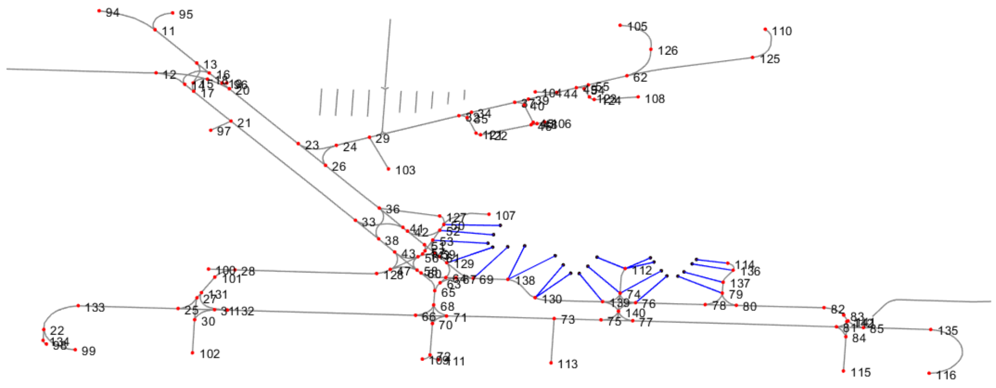
Implementation of a turnaround model in the discrete event simulation environment
with insight into the boarding process

Modeling assumptions

- Deterministic aspects
  - Manufacturer based process durations of 43 aircraft types
  - Standard ground operations from manufacturer to assess feasibility of adapted processes in current operations
  - Activity diagrams of all turnaround processes to reflect dependencies of stakeholders
- Stochastic aspects
  - Distribution of particular turnaround-process durations
  - Model of disruptions on the airport, based on real operational data
- Topological aspects
  - Representation of airports in the form of graphs, to enable for example the taxiing process



Example of fit for cleaning process with Weibull distribution



Section of the graph model of the topology of Hanover airport

Operational challenges

Requirements, Certification, Risks and Operational Challenges – Where do we stand?

OPERATIONAL CHALLENGES
- Charging time (and its effect on turnaround time)

AIRPORT CHALLENGES
- Additional space for battery storage
- Additional space for charging stations
- New equipment

CERTIFICATION SPECIFICATIONS

RISKS/HAZARDS
- Battery thermal runway
- Firefighting of infrastructures
- Ramp safety

OTHER
- Battery life
- Utilities requirements in terms of electricity demand
- Possibilty of parallelizing battery swapping and passenger (de-)boarding