Integrating optimization and simulation to gain more efficient airport logistics

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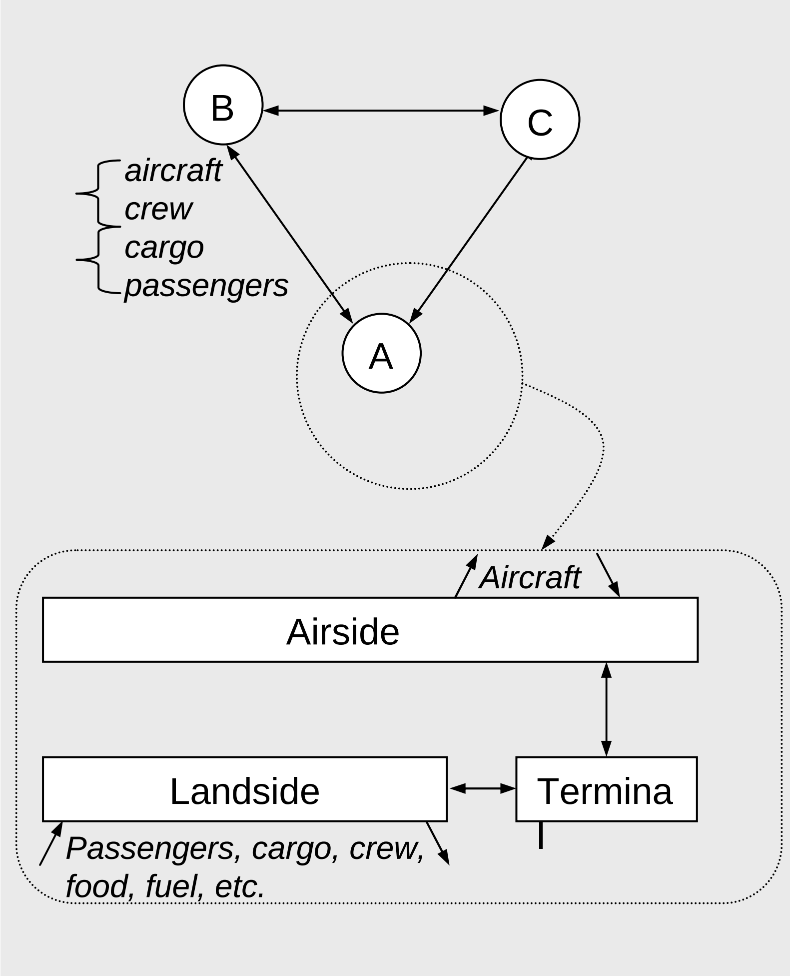
Background

- The air transportation system
  - large and complex
  - time critical processes
  - different actors with contradicting objectives
- The airport is a bottleneck in the air transportation system
- Collaborative decisions making (CDM) creates a common ground for the actors
- CDM gives a growing amount of information that leads to mounting complexity in the decision making process
- Additional support is needed for decision making

Airport Logistics

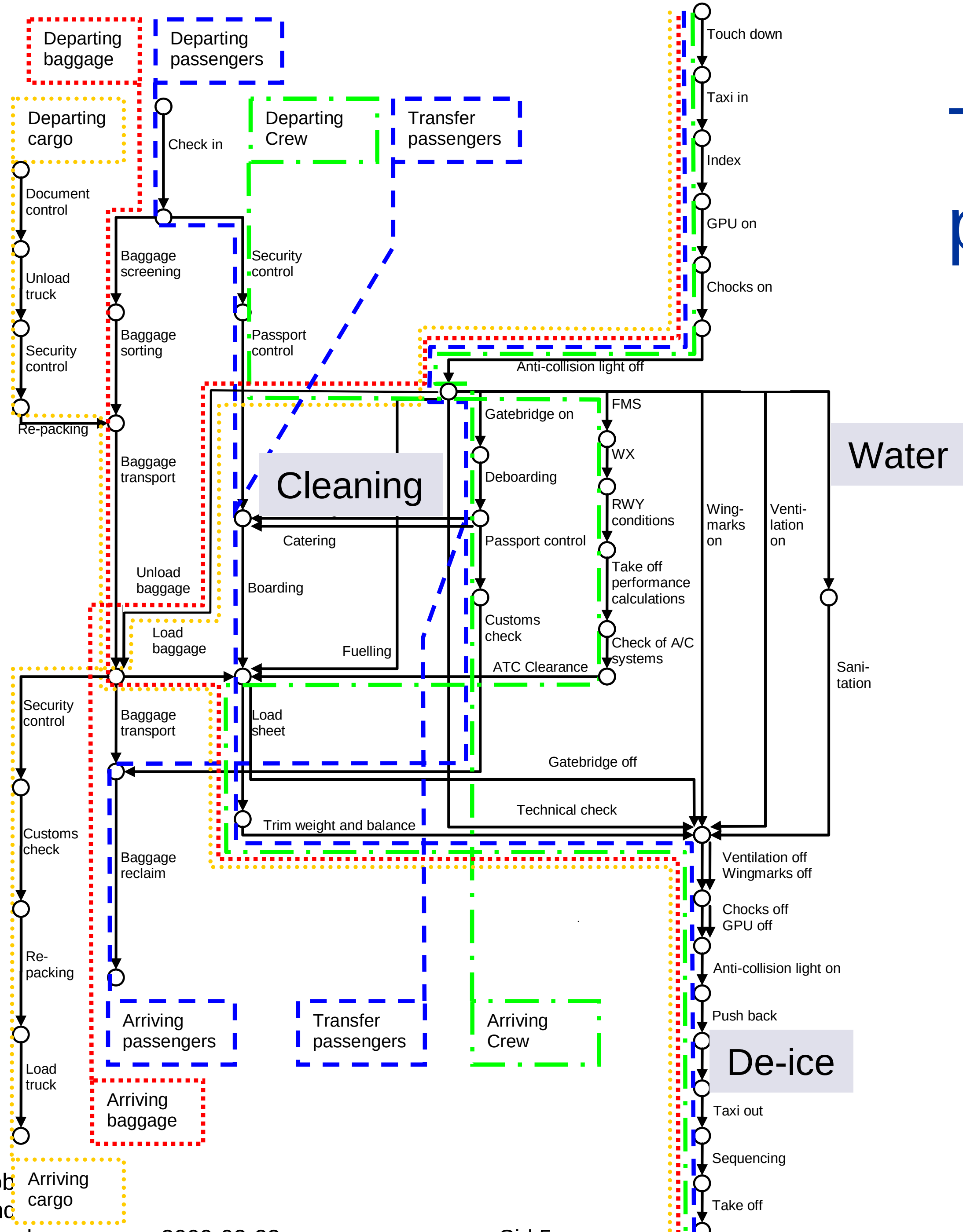
- The vision with airport logistics is to develop a **complete picture** of all processes and activities at and around the airport
  - Interaction and impact
- Analyze **the usage of all resources** at the airport to find solutions optimal for the entire airport, rather than solutions optimized for an individual actor

The air transportation system

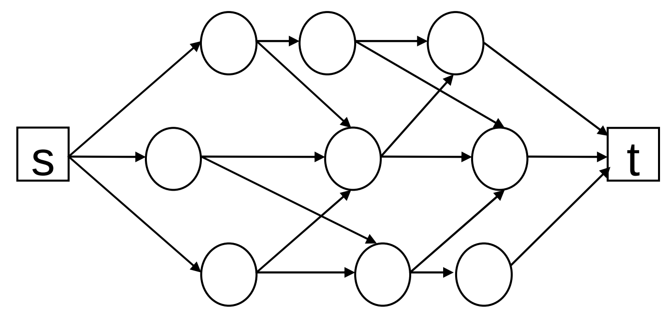


- Value Flows
  - Passengers and baggage
  - Cargo
- Major support flows
  - Aircraft
  - Crew
- Minor support flows
  - Fuel trucks
  - De-icing trucks
  - Cleaning crews
  - Catering
  - Etc.

The turn-around process

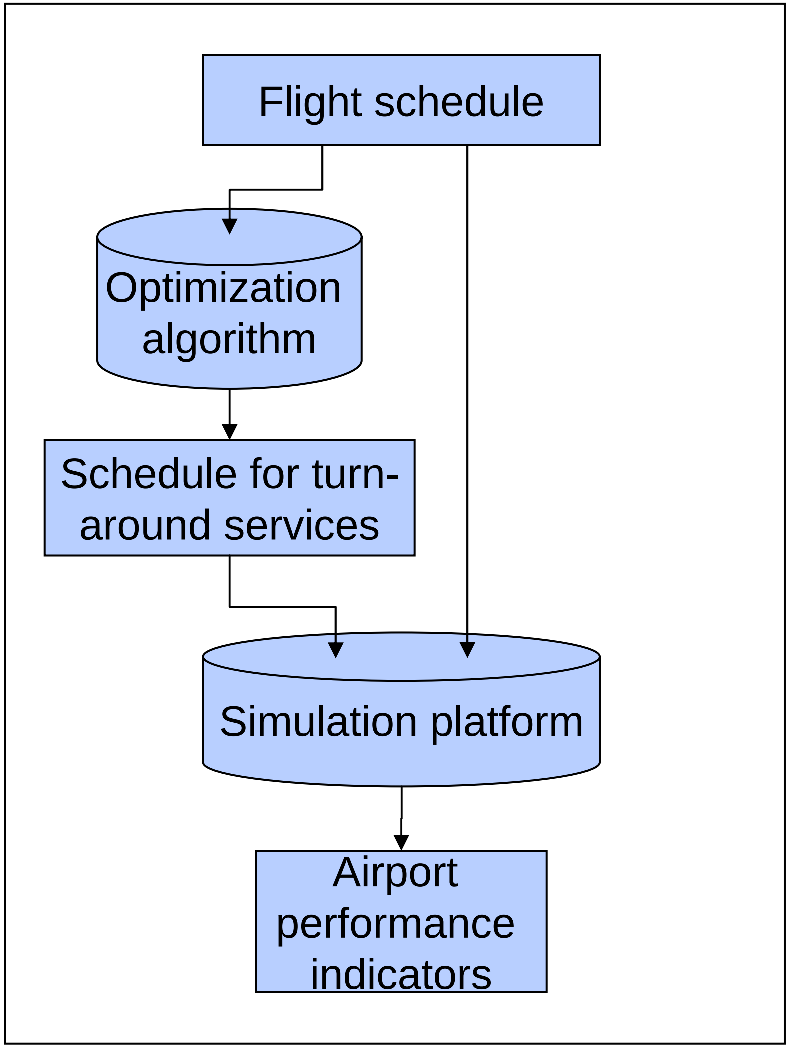


Turn-around services



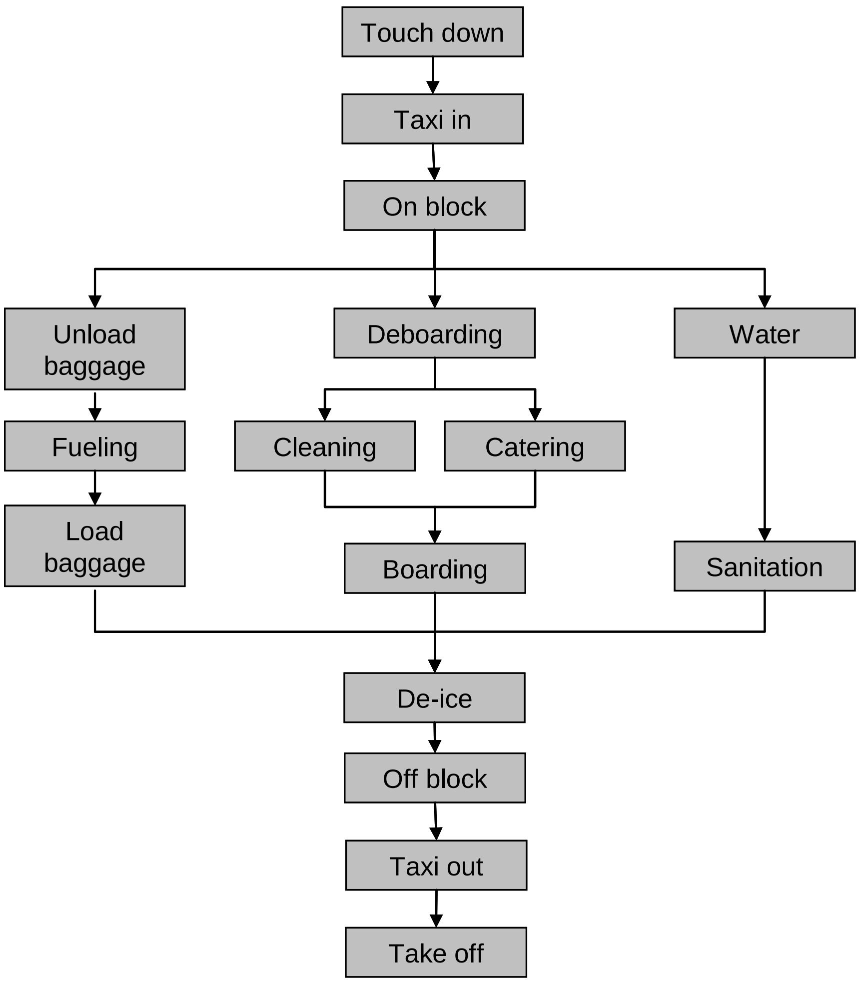
A network flow problem

Integrating optimization and simulation



- A first step to prove the concept
- Simulation model of the turn-around process
- Optimization algorithm for scheduling de-icing trucks

Conceptual simulation model



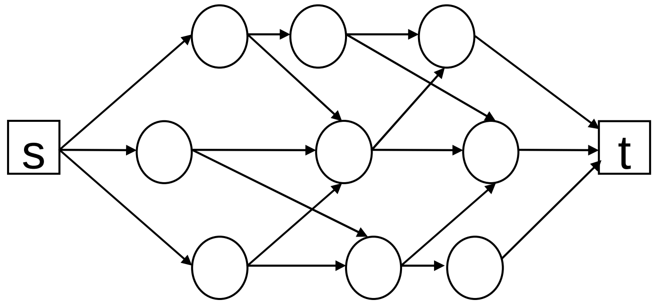
- TA-resources in service pools
- Simplifications
  - Cleaning and catering can always be performed simultaneously
  - Fuelling can always be performed after boarding
  - Fuelling can not be performed simultaneously as baggage handling
  - Water is *not* always performed before sanitation in the simulation

De-icing

- At Stockholm Arlanda, between October and April
- Step 1: De-ice with Type 1 fluid
- Step 2: Anti-ice with Type 2 fluid
- Hold-over time: from anti-ice to take-off
  - Gives a tight time window for service
- Planning today
  - Tactical based on weather and flight schedule
  - Operational based on pilot request

Scheduling de-icing trucks

- A schedule is constructed before the day of operations
  - Truck schedule based on a flight schedule
  - Each truck will get a number of departing flights to serve
- Multiobjective
  - Minimize the departure **delay** that the de-icing trucks are causing
  - Minimize the **distance** travelled by the de-icing trucks



$$\text{Min} \quad \sum_{i=0}^{N} \sum_{j=0, j\neq i}^{N} \sum_{k=1}^{K} \sum_{r=1}^{R} (a * l_i + b * w_{ij} x_{ij}^{kr})$$

a = 1, b = 0.5

s.t. $\sum_{i=1}^{N} x_{ih}^{kr} - \sum_{j=1}^{N} x_{hj}^{kr} = 0$ $\quad h \in \{0,\ldots,N\},\ k \in \{1,\ldots,K\},\ r \in \{1,\ldots,R\}$

$\sum_{j=0}^{N} \sum_{k=1}^{K} \sum_{r=1}^{R} x_{ij}^{kr} = 1$ $\quad i \in \{0,\ldots,N\}$

$\sum_{i=1}^{N} \sum_{j=1}^{N} d_i x_{ij}^{kr} \le q^k$ $\quad k \in \{1,\ldots,K\},\ r \in \{1,\ldots,R\}$

$t_i + s + f_i + w_{ij} - M(1 - x_{ij}^{kr}) \le t_j$ $\quad i, j \in \{1,\ldots,N\},\ k \in \{1,\ldots,K\},\ r \in \{1,\ldots,R\}$

$p_i \ge t_i + s + f_i$ $\quad i \in \{1,\ldots,N\}$

$p_i \ge STD_i$ $\quad i \in \{1,\ldots,N\}$

$l_i \ge t_i + s + f_i - STD_i$ $\quad i \in \{1,\ldots,N\}$

$t_m^{stop} + f_0 - M(1 - z_{mn}^{k}) \le t_n^{start}$ $\quad m, n \in \{1,\ldots,R\},\ k \in \{1,\ldots,K\}$

$z_{mn}^{k} \ge x_{i0}^{km} + x_{0j}^{kn} - 1$ $\quad m, n \in \{1,\ldots,R\},\ n > m,\ k \in \{1,\ldots,K\},\ i, j \in \{0,\ldots,N\}$

$t_r^{stop} \ge p_j + w_{j0} - M(1 - x_{j0}^{kr})$ $\quad j \in \{1,\ldots,N\},\ k \in \{1,\ldots,K\},\ r \in \{1,\ldots,R\}$

$0 \le t_r^{start} \le t_i - w_{0i} + M(1 - x_{0i}^{kr})$ $\quad i \in \{1,\ldots,N\},\ k \in \{1,\ldots,K\},\ r \in \{1,\ldots,R\}$

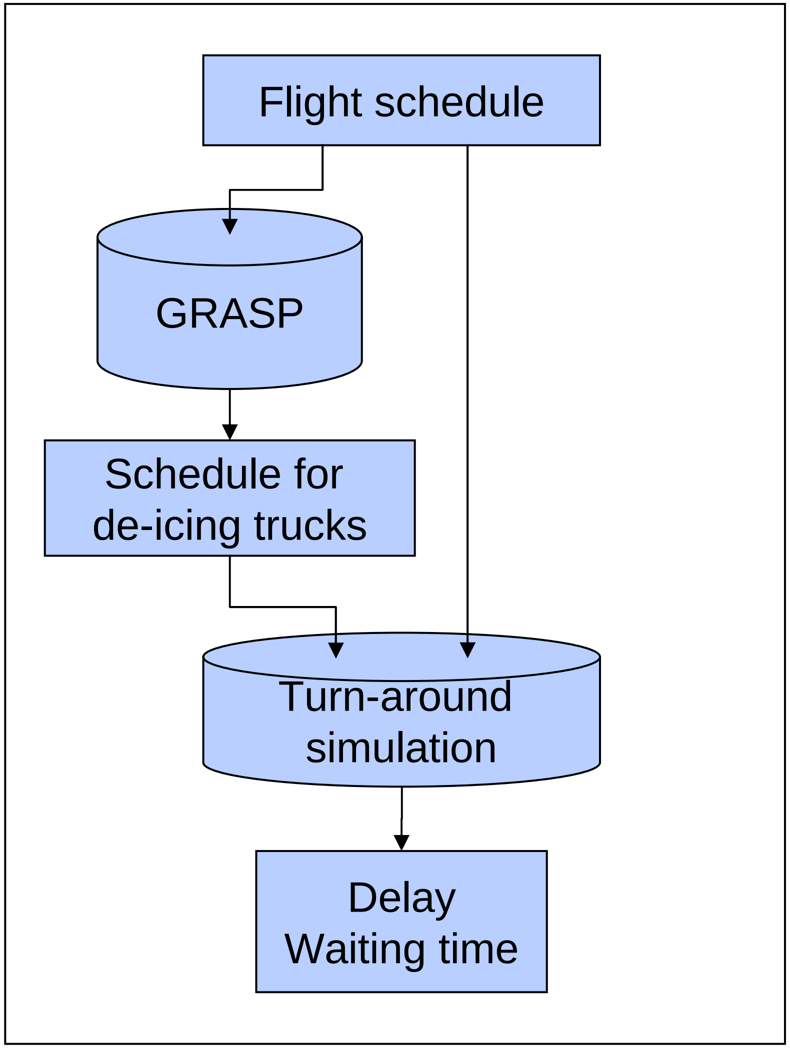
$t_i \ge 0, \quad p_i \ge 0, \quad l_i \ge 0$ $\quad i \in \{1,\ldots,N\}$

Computational results

- The de-icing scheduling problem is solved using a GRASP heuristic

Solution	Traveling time [minutes]	Delay [minutes]
GWOAC	842	340 270
GRASP 1	1020	295
GRASP 2	1066	207

Integrating de-icing schedules in the turn-around simulation model



- Schedule conditions
  - Additional delays due to other services, arrival time delay etc.
  - Other process times and fluid requirements
- Simulation scenarios
  1. No de-icing
  2. De-icing based on first-go-first-served
  3. De-icing based on GRASP1
  4. De-icing based on GRASP2

Computational results

	Touch down			Stand			Off block		
	Percentage delay	Max delay	Average delay	Percentage delay	Max delay	Average delay	Percentage delay	Max delay	Average delay
Scenario 1	19%	3 min	44 sec	1%	7 min	4 min	8%	14 min	5 min
Scenario 2	19%	3 min	42 sec	2%	10 min	5 min	27%	32 min	8 min
Scenario 3	19%	3 min	42 sec	1%	7 min	3 min	26%	43 min	7 min
Scenario 4	19%	3 min	42 sec	1%	7 min	3 min	24%	20 min	6 min

	De-icing			
	Percentage waiting	Max waiting time	Average waiting time	Total waiting time
Scenario 1	-	-	-	-
Scenario 2	23%	40 min	13 min	1181 min
Scenario 3	21%	47 min	10 min	808 min
Scenario 4	18%	33 min	9 min	646 min

Future Research

- Optimization and integration of other turn-around services
- Extend and refine the simulation model
  - Final approach, taxiing and take-off
- Make the decision support tools useful for operational planning and control