Improvement of Pushback Time Assignment via Stochastic Optimization

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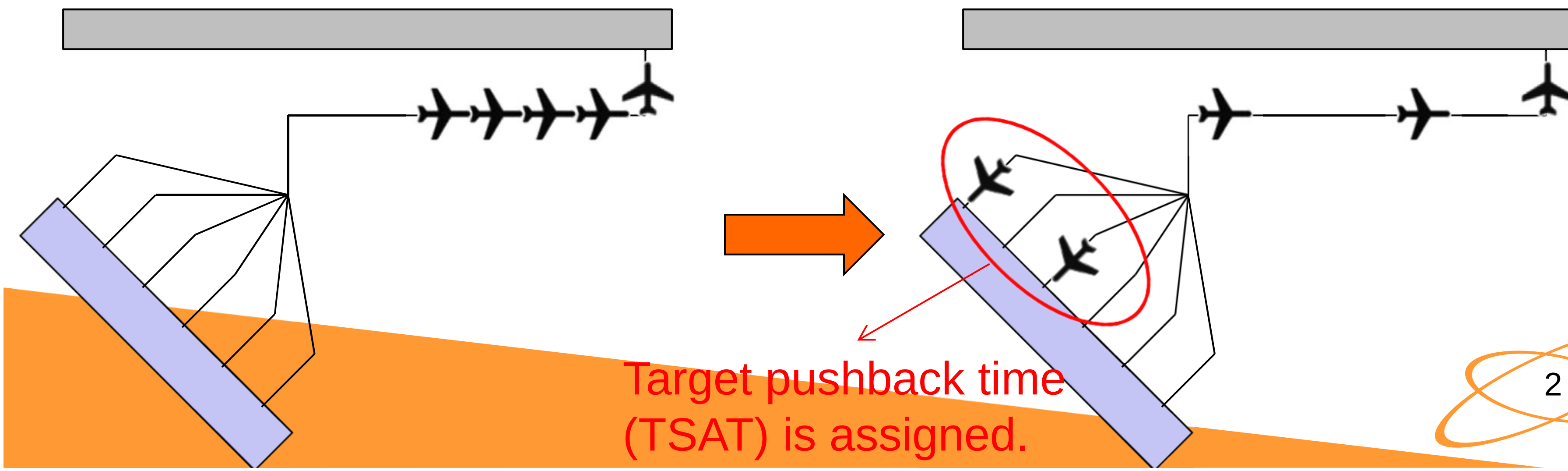
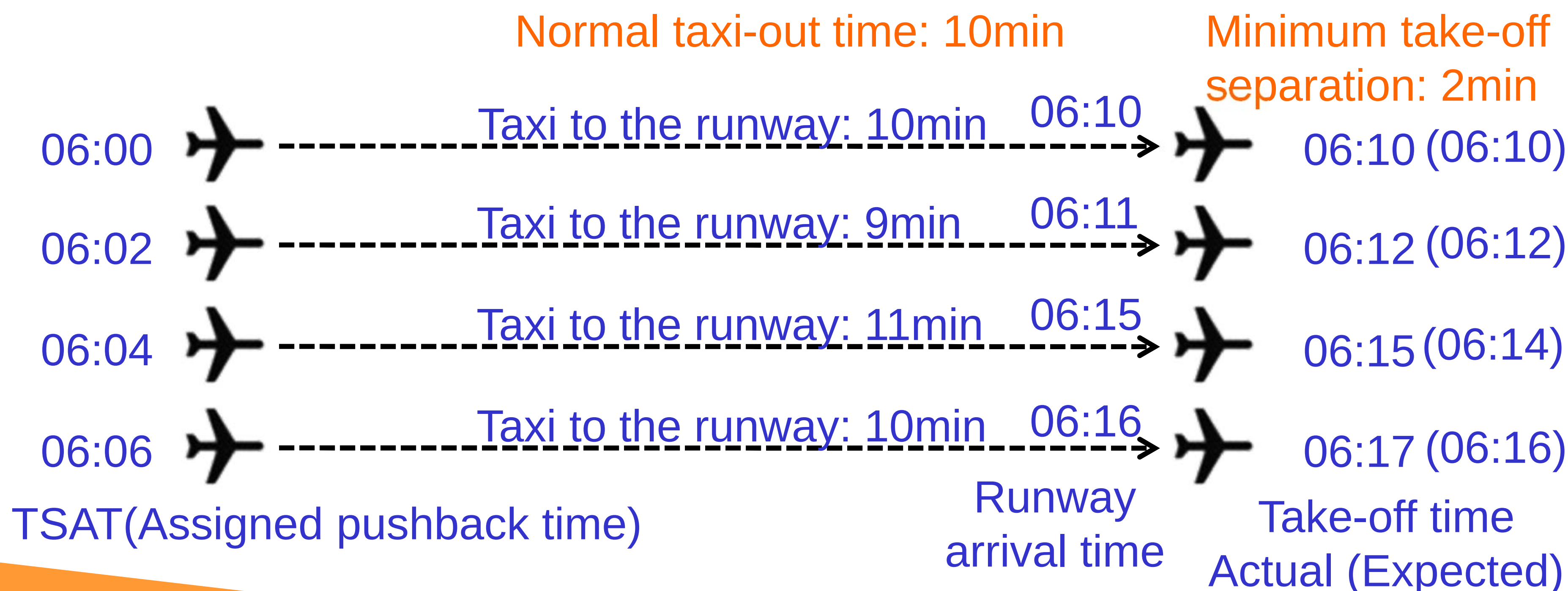
Background (1)

- Aviation growth causes airport congestions.
  - Runways are bottlenecks.
  - Departure and arrival aircraft wait in long queues.
    - A departure aircraft queue is relatively easy to control.
- Pushback time control management (called TSAT operation: Target Start-up Approved Time) is promising.
  - Benefit
    - Reduce taxi-out time (wait at the spot) ➔ save fuel
  - Disadvantage
    - Not investigated and discussed thoroughly yet…



Background (2)

- Possible disadvantage of TSAT operation is…
  - Take-off time delay due to uncertainty



*All aircraft are assumed to be ready for pushback at 06:00.

Background (3)

- Optimal airport operation should be decided considering both pros and cons

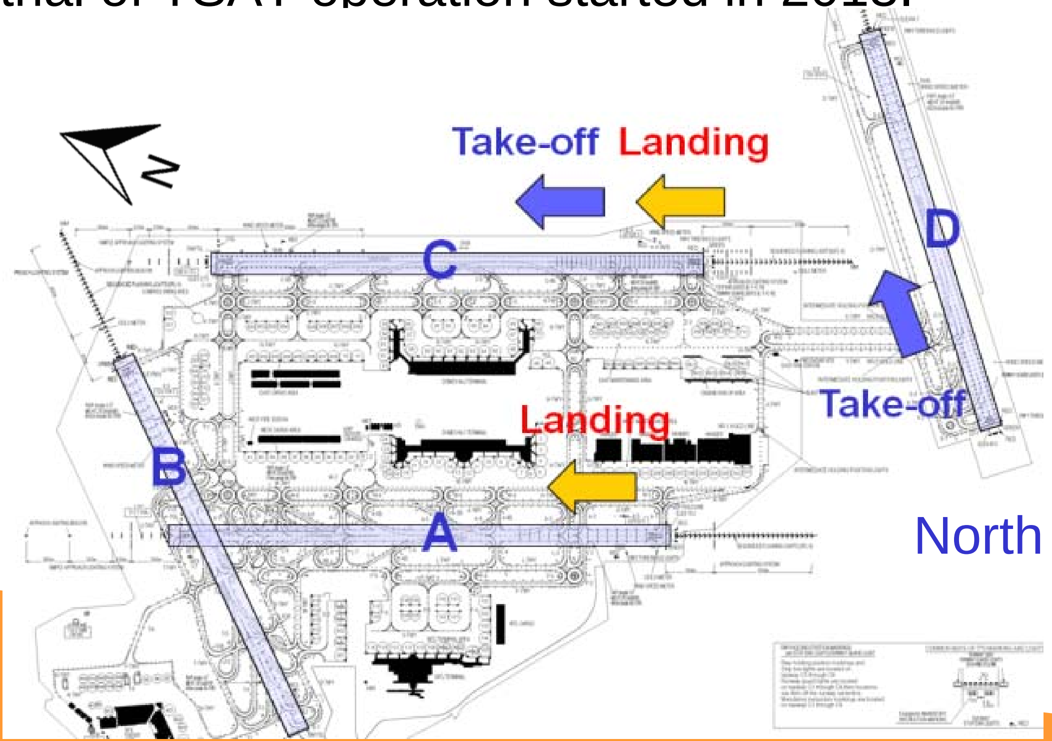
➔ This research focuses on the "real" optimal airport operation.

  - How much delay is caused by uncertainty?

- Evaluation:
  - Stochastic airport operation simulation model is developed.
    - ➔ Previous research (briefly explained later)
  - TSAT assignment algorithm is developed.
    - ➔ Main topic of this presentation

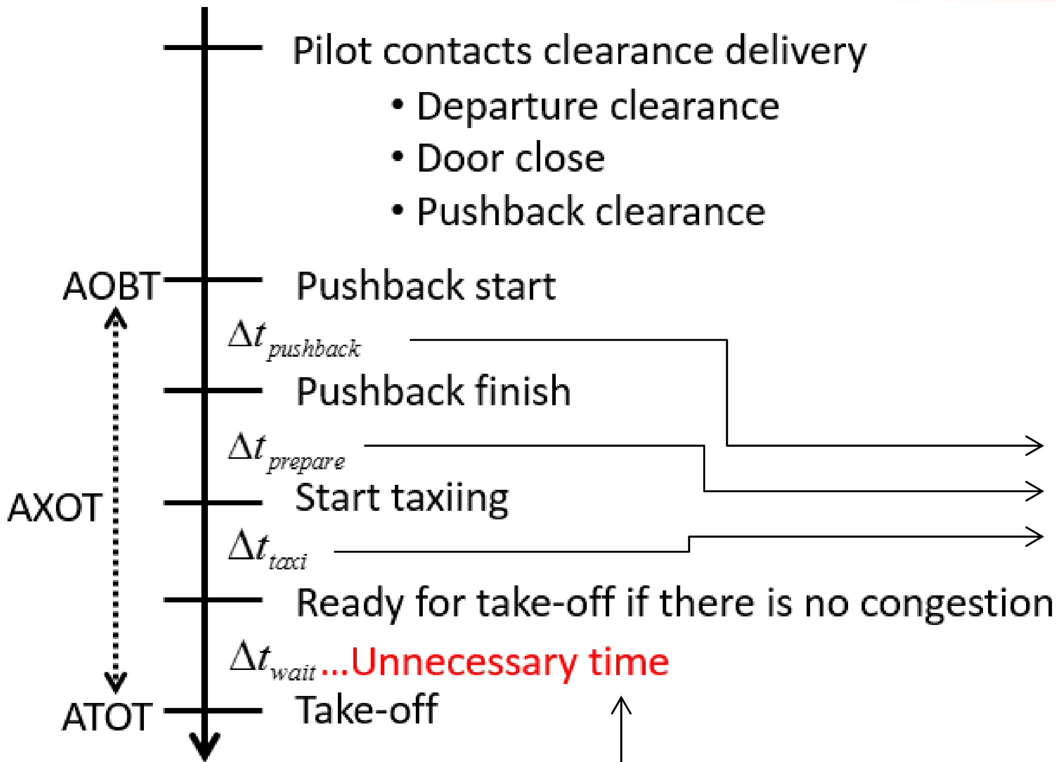
Target Airport

- Tokyo International Airport (Haneda Airport)
  - The busiest airport in Japan with more than 1,000 take-offs and landings per day.
  - 4 intersecting runways.
    - Runway dependencies exist.
  - A trial of TSAT operation started in 2013.

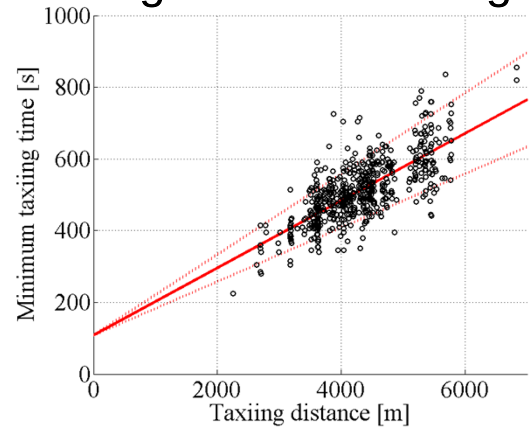


North wind operation

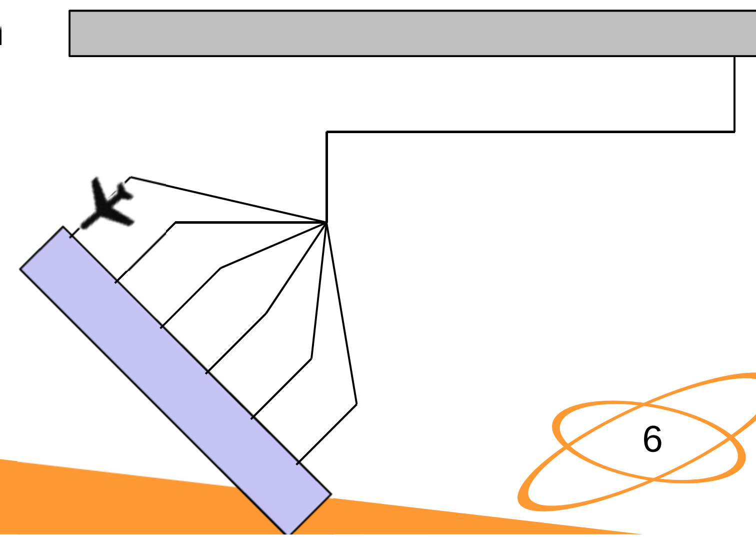
Departure Aircraft Operation Flow



Taxiing time vs. Taxiing distance

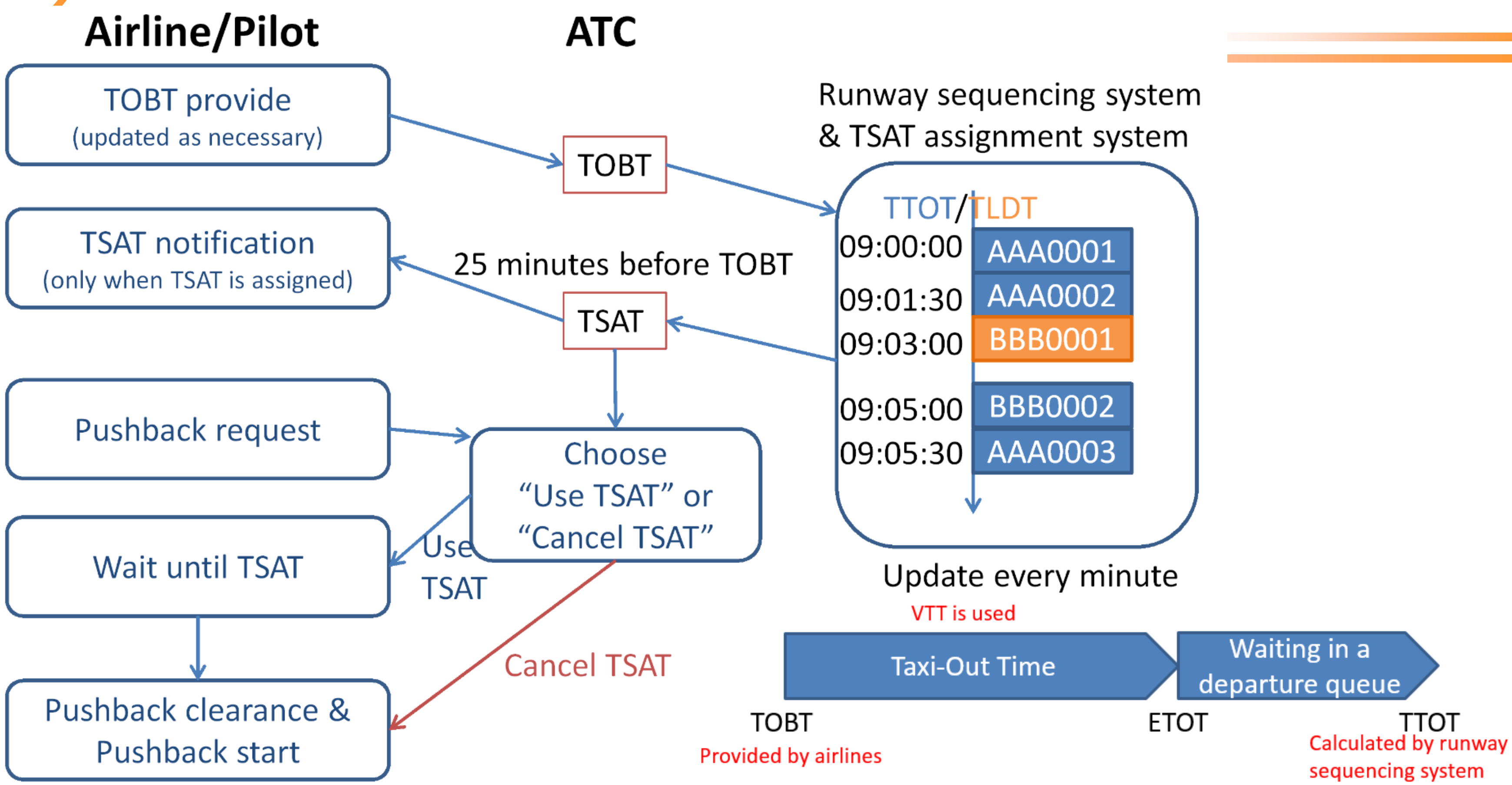


Regression line + normal distribution or Erlang distribution



FCFS basis calculation (take-off & landing separation is stochastically distributed considering wake turbulence category & runway intersection effects)

TSAT Assignment Flow



- Runway sequencing system
  - Take-offs/Landings are sequenced in advance based on the estimated RWY arrival time.
- TSAT assignment system ← Focus of this research
  - TSAT is assigned to each aircraft based on the runway sequence.

Pre-Departure Runway Sequencing System

- Based on ETOT (Estimated Take-Off Time), departure sequence is determined in advance by a virtual queue.
  - The aircraft is ordered by ETOT.
  - Priority to landing aircraft based on ELDT (Estimated Landing Time).
  - Runway sequence is updated every minute.

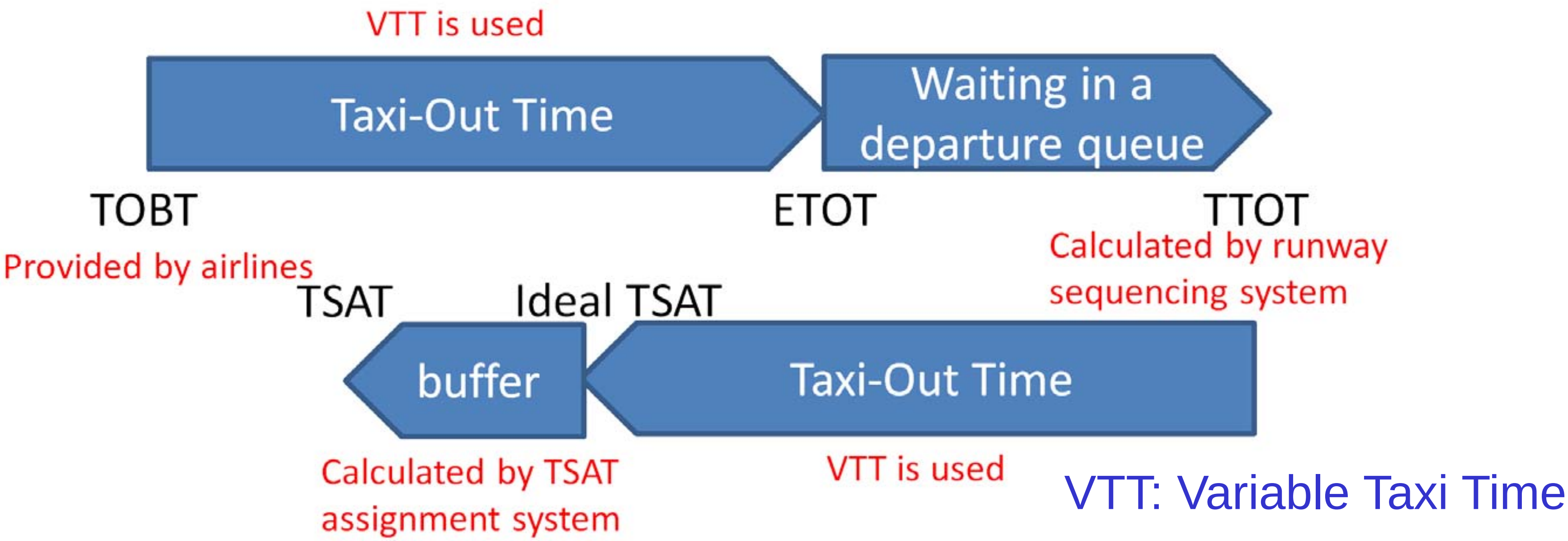
Virtual runway queue

Time	Callsign (ETOT)
06:00	XXX1 (06:00) ⟹ XXX1 (06:03)
06:02	YYY1 (06:02)
06:04	XXX2 (06:02)
06:06	XXX1 (06:03)
06:08	
06:10	
06:12	

Departure aircraft

Landing aircraft

TSAT Assignment Strategy



- TSAT assignment is the same as the buffer assignment to each aircraft.
- The straightforward buffer assignment is "constant buffer" strategy.
  - The assigned constant "buffer" corresponds to the maximum uncertainty considered.

Problem Formulation

- The best buffer should be obtained under the current situation.
  - The best strategy should maximize the following objective function.

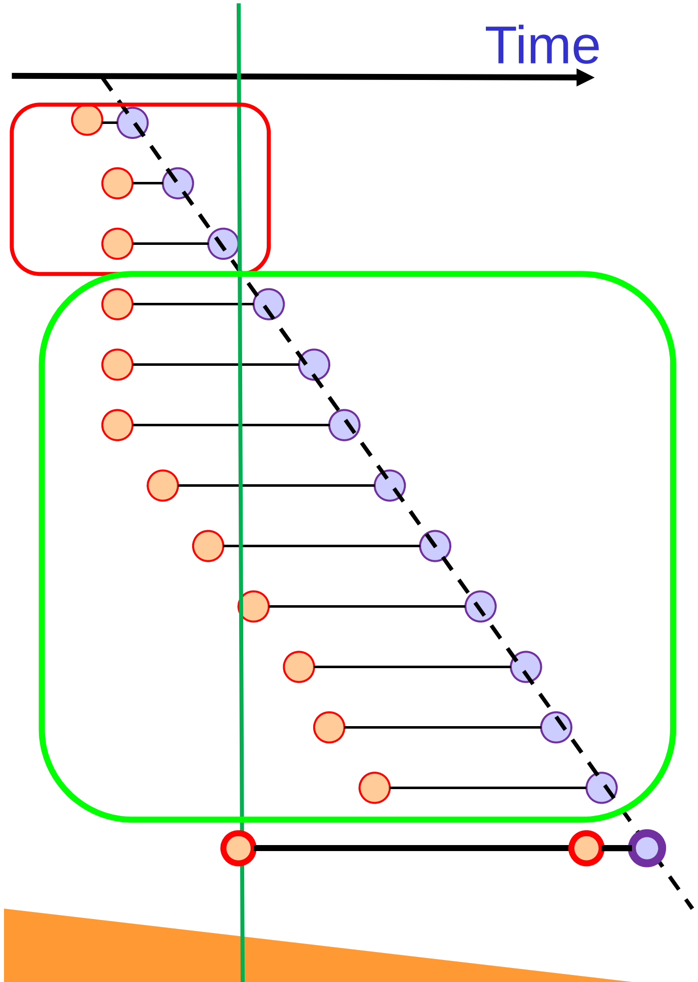
$$r = \Delta t_{save} - \beta \Delta t_{delay}$$

  - Directions to solve the problem:
    - Small buffer should be set when delay is hardly expected.
    - Large buffer should be set when delay is expected with high chance.

➔ How do you predict the expected delay?

→Several kinds of information are available to estimate the delay.

How to reduce delay? (1)



○ : ETOT (Expected time at the runway)

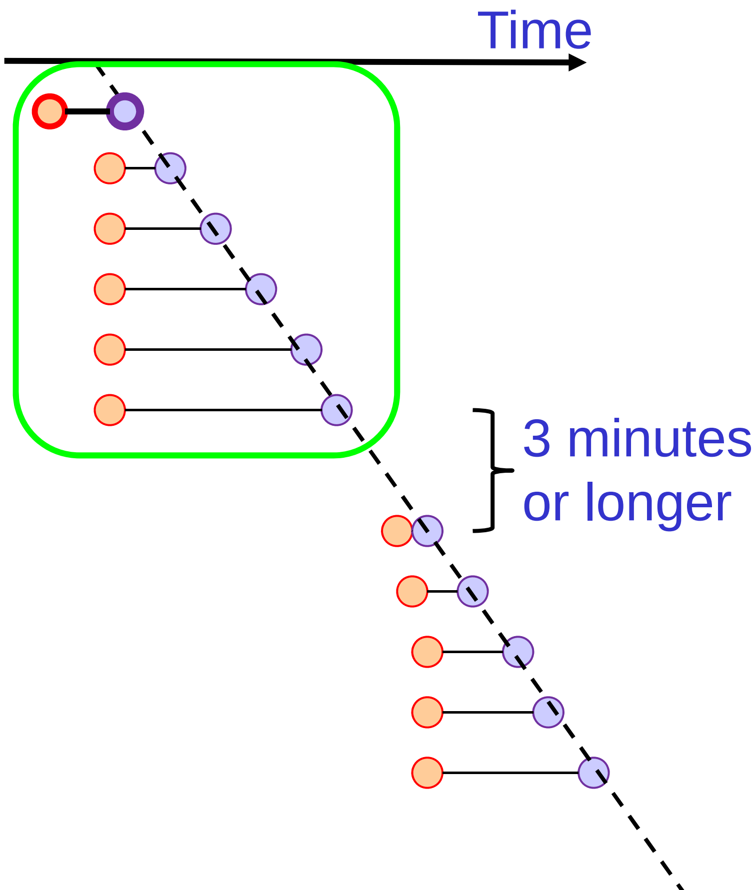
○ : TTOT (Assigned take-off time)

Line length: Actual buffer

- The best buffer is changed based on x_1 (=average buffer of the preceding aircraft).
  - If the average buffer is small, large buffer should be set to absorb the uncertainty of the preceding aircraft.

x_1 : E(TTOT – ETOT)

How to reduce delay? (2)



- If the considered aircraft is delayed, the delay will propagate to the following consecutive aircraft.
  - If x_2 is large, the total delay will increase.

x_2 : number of the following consecutive aircraft

Optimal Strategy

- The buffer (b) is set based on the following rule:

$$b = b_0 + f(x_1) + g(x_2)$$

$$f(x_1), g(x_2) \in \{-2, -1, 0, 1, 2, 99\} \quad [\text{min}]$$

$$x_1 \in \{>1, 2, 3, \ldots, 8, 9, 10<\} \quad [\text{min}]$$ …average buffer of the preceding aircraft

$$x_2 \in \{0, 1, 2, 3, \ldots, 17, 18, 19<\}$$ …number of the following consecutive aircraft

- The optimal strategy ($F(\mathbf{x})$) should be found.

$$F(\mathbf{x}) = (f(>1), f(2), \ldots, f(10<), g(0), g(1), \ldots, g(18), g(19<))^T$$

  – The possible combination of solutions is 6^{30} (=2.2E23).

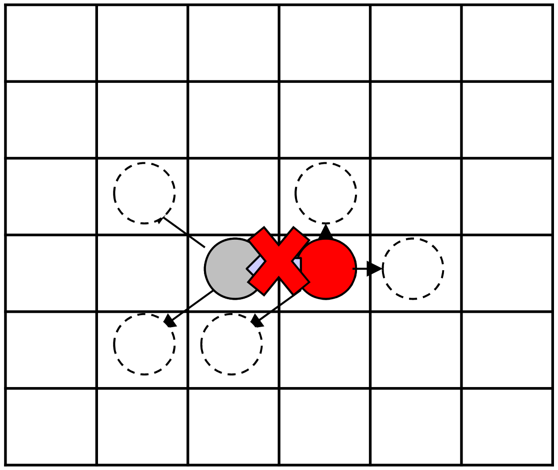
  → Tabu search is used to find the optimal solution.

- The strategy is optimized to maximize r.

$$r = \Delta t_{save} - \beta \Delta t_{delay}$$

Tabu Search

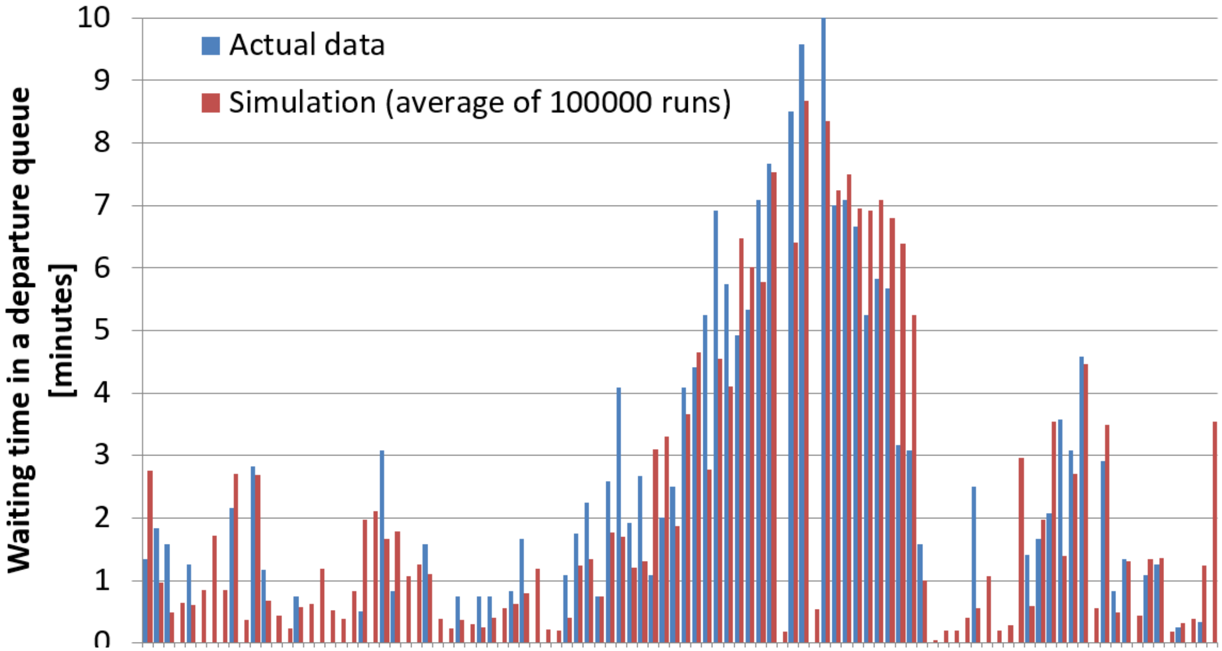
- Tabu search is a metaheuristic search method and proceeds with the following steps:
  - Several neighbors around the current solution are searched, and the best neighbor becomes the new current solution.
    - The solution becomes worse if all neighbors are worse than the current solution.
  - The current solution is put into the tabulist, and the solution within the solution list cannot be a neighbor.
    - To avoid the convergence to local minima.
  - The best neighbor is obtained after a sufficient number of steps.
- SAA (Sample Average Approximation) is used to obtain the objective function under stochastic environment.
  - 1000 ~ 50000 simulation runs are conducted.



Simulation Environment

- To consider uncertainty effect,
  - Simulations are conducted multiple times in each scenario.
    - The average taxiing time saving and average take-off delay are considered.
- To obtain a general rule,
  - 5 scenarios based on 5 days are used. (Day1-Day5)
    - "Scenario" includes the initial condition. (the pushback ready time of departure aircraft or the landing time of arrival aircraft, spot position, used runway, taxiing route)
    - Traffic density in each time range is set the same as the actual.
  - Data between 6pm and 9pm are used.
    - This time range includes both "congested time" and "non-congested time".
- Two patterns (with & without TSAT allocation) are calculated.
  - The difference of average taxiing time → Saved taxiing time by TSAT
  - The difference of average take-off time → Take-off delay caused by TSAT

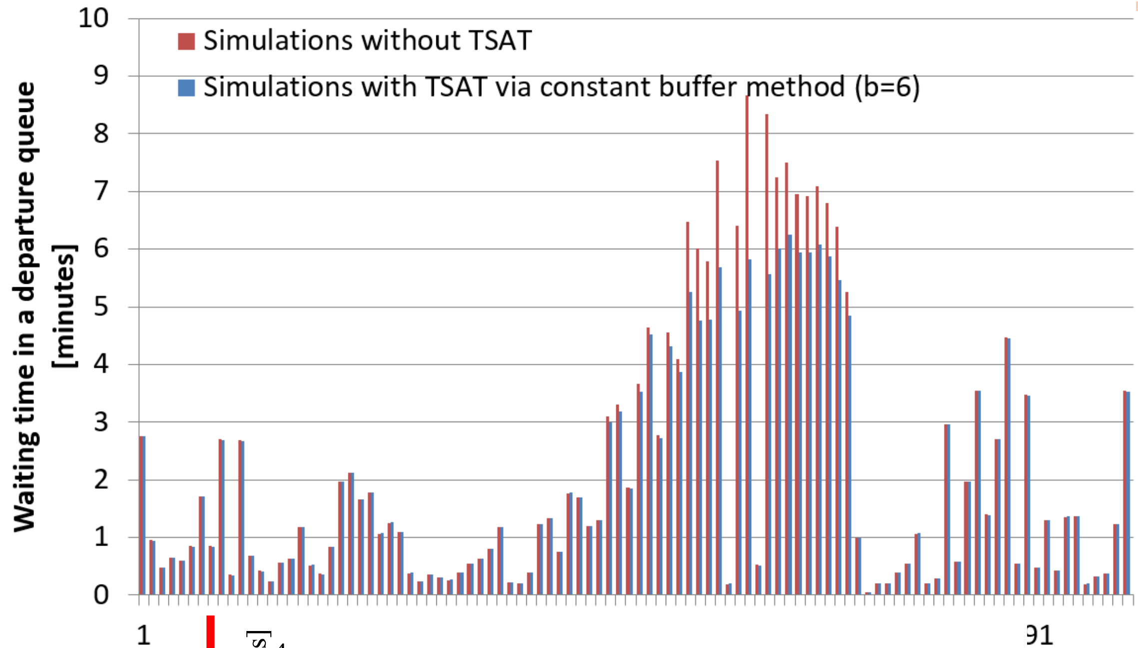
Simulation Accuracy

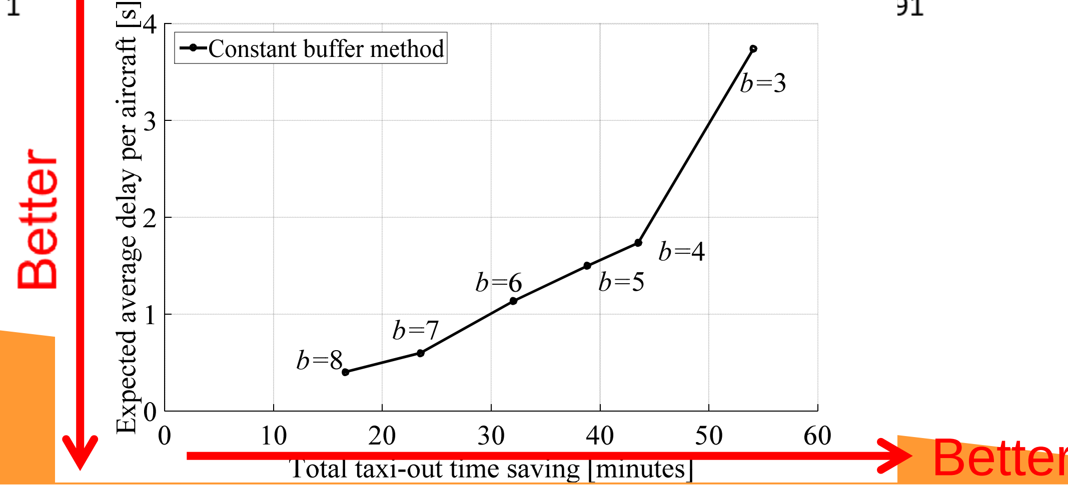


Waiting time of each aircraft in a departure queue on Day3

	Actual total waiting time [minutes]	Average total waiting time in simulations [minutes]
Day1	257.7	230.4
Day2	257.3	237.4
Day3	199.9	214.8
Day4	479.0	453.0
Day5	214.6	282.8

Simulation Results
Constant Buffer Method





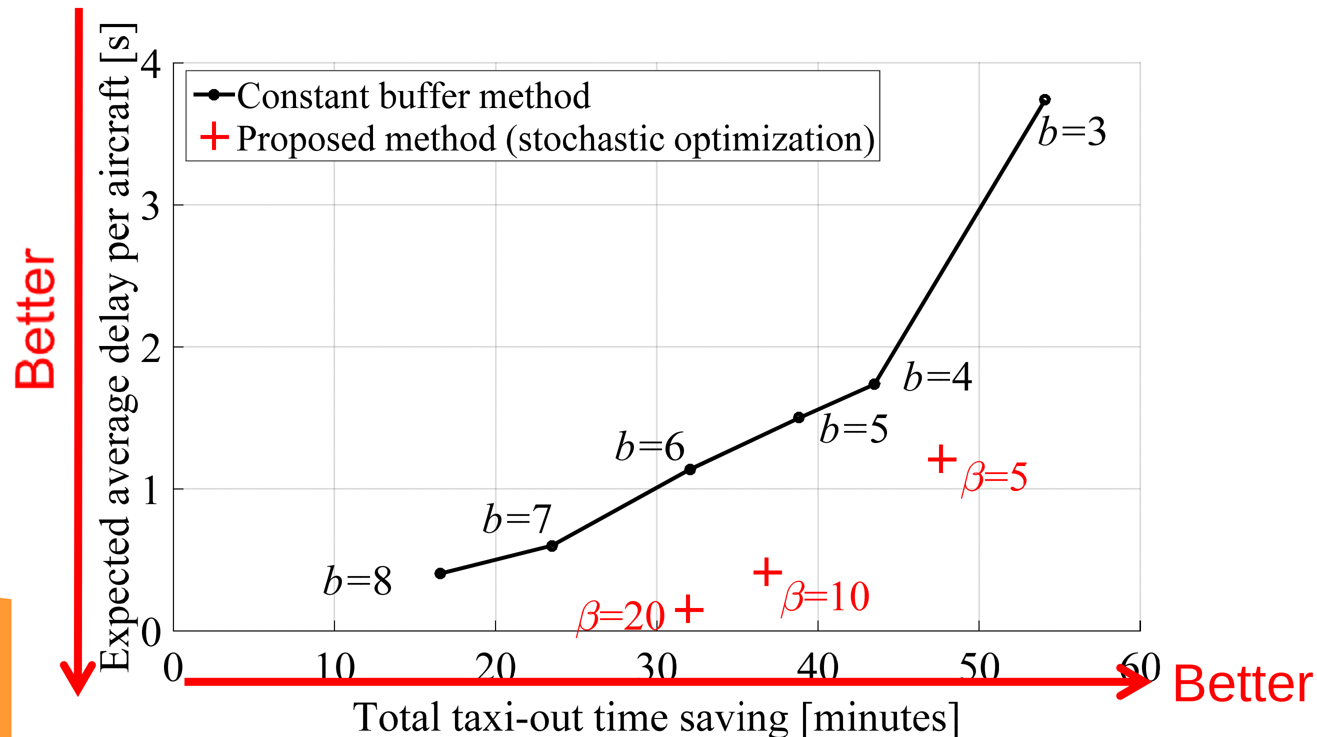
Simulation Results
Optimal Strategy (1)

- Optimal strategy ($\beta = 20$): $r = \Delta t_{save} - \beta \Delta t_{delay}$

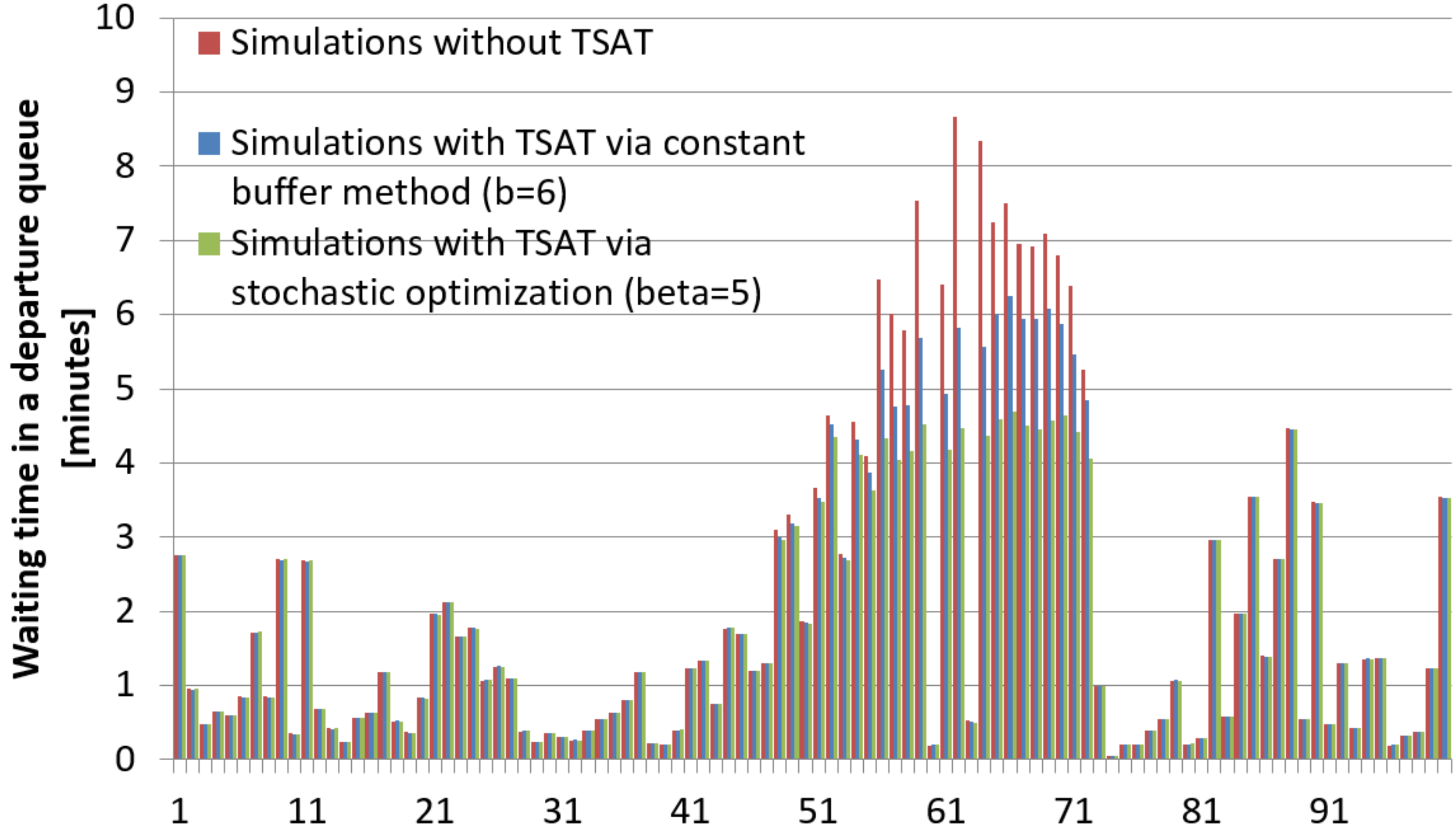
$F(\mathbf{x}) = \{99, 1, 99, 1, 99, 99, -2, -2, -1, -1,$ …Average buffer of preceding aircraft

$1, 1, 1, 0, 0, -1, 2, 2, 99, 1, -1, -2, 99, 99, 99, 99, 1, 99, 1, 99\}$

…Number of following consecutive aircraft



Simulation Results
Optimal Strategy (2)



- Both methods show a similar delay, but the optimal strategy reduces taxiing time more.

Summary and Future Works

- A new TSAT assignment algorithm was evaluated via stochastic optimization.
  - Statistical airport simulation model was developed.
  - TSAT was evaluated in respect to both taxiing time saved and take-off delay.
    - Two informative variables are found to reduce take-off delay.
  - Optimal strategy was found via Tabu search.
    - Optimal strategy shows a better performance than a “constant buffer method”.
- Future works
  - Algorithm update to improve the performance.
    - Optimization technique will be improved.
    - Additional useful information might be available.
  - Proceed discussions with stakeholders about optimal operations.
    - How long a delay is acceptable for airlines?

Thank you for your attention!

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