Creation of Conflict-free Taxi Routes for Aircraft with Evolutionary Algorithms

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DLR

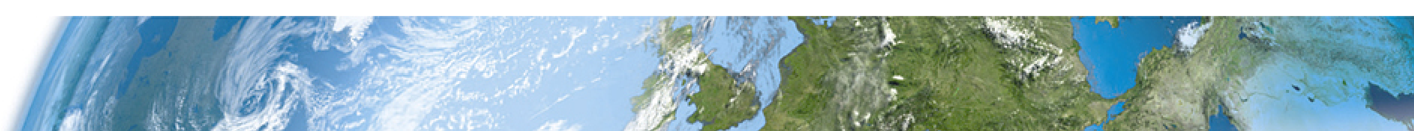
Taxi Routing on Airports: Today's Situation

- Aircraft ground movements are guided and controlled by Air Traffic Controllers (Apron / Ground).
- The controllers issue instructions when to start taxi and which route to take.
- Controllers carry out conflict detection and resolution.
- The mental plan of the controller is nearly nowhere visible to any system.
- Taxi speeds are not determined and on pilot's decision.
- Commands to the pilots are transmitted via radio.
- The speeds vary in different areas of the airport (lower on apron, higher on other taxiways).

Taxi Routing on Airports: Future Vision

TRACC

- All aircraft have pre-planned, conflict free, time-based taxi routes each including a speed profile.
- Conflict detection and resolution is done automatically.
- Route and time conformance is monitored and route/times are adapted for all moving aircraft.
- Controllers are supported by advisories to guide the aircraft as planned.
- Clearances are given by data link.
- Aircraft are able to follow speed advisories with absolute values (“taxi 20 knots” instead of “expedite taxi”).
- Combination of all planning tools like arrival and departure manager (AMAN / DMAN), stand and gate manager (SGMAN) and surface manager (SMAN).



TRACC
Taxi Routes for Aircraft: Creation and Controlling

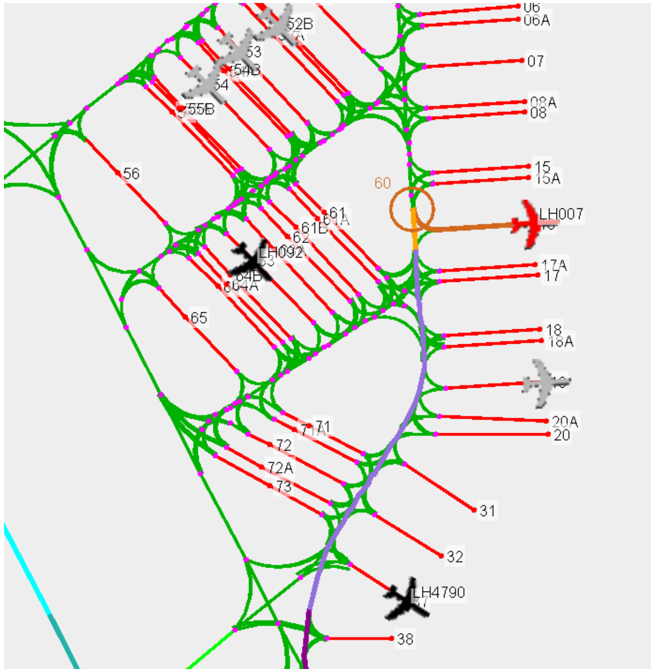
TRACC is a Surface Management System supporting „time-based taxi“.

- Calculates optimized and confict-free taxi routes with speed recommendations.
- Supports the Air Traffic Controller to archieve the proposed time-based routes.
- Adapts planned routes in case of deviations, e.g.
    - Controller wants other route.
    - Pilot deviates accidentally.

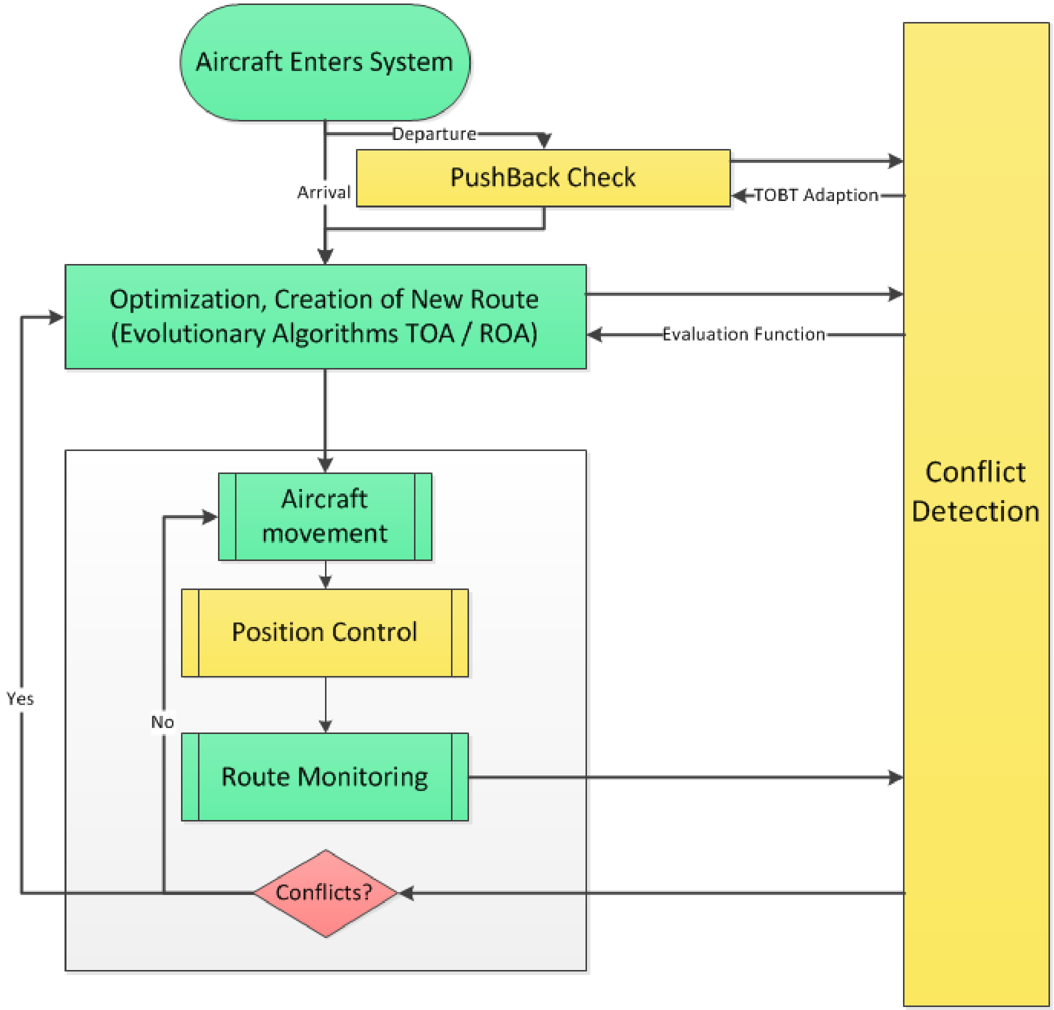
TRACC-Approach: Creation of a Conflict-free and Optimized Taxi Routes

- Based on former work about using evolutionary algorithms for free-routing of aircraft inside the TMA (ROGENA).
- The airport structure is presented as a system of nodes (waypoints) and links (taxiways).
- A waypoint holds information about position of this point and the standard speed.
- Taxi routes are a sequence of waypoints where each waypoint holds additional information (planned speed, holding time and time the waypoint is reached).
- Links can be considered as a vector in space:

$$p = w_i + \lambda(v_i + \Delta v_i t)t\,(w_{i+1} - w_i)$$



Workflow of TRACC



Optimization Concepts

- Implementation of two different optimization Algorithms:
- TOA (Time Optimization Algorithm):
  - Usage of a pre-defined standard taxi route and adaption of taxi speeds and holding times for the creation of a new conflict free route.
  - The probability for inserting a holding time depends on the difficulties to create a conflict-free route (Safe-Node).
- ROA (Route Optimization Algorithm):
  - Modification a the complete taxi route referring to the run of the route, speed profile and holding times.
  - Holding times are created with a predefined probability from the start.

For both algorithm a special operator flats the speed profiles by removing speed changes within a defined distance.

Evolutionary Algorithm of TRACC

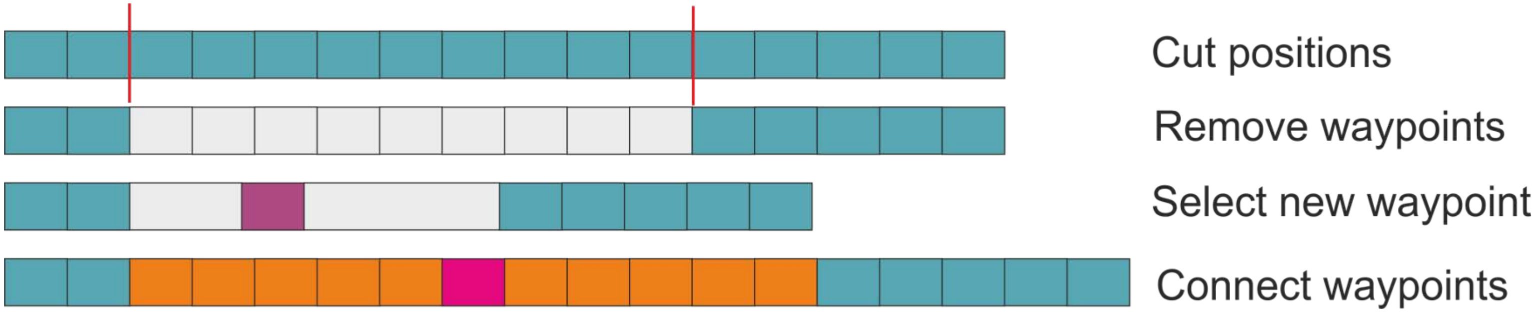
- Based on modGA of Michalewicz.
- Chromosomes are taxi routes with waypoints as genes and additional parameters.
- Trying to prevent super-individuals from overtaking the population.
- Population selected for the next generation is divided in 3 different groups:
  - Group of unchanged routes (including a fixed number of best and different chromosomes)
  - Group of chromosomes which will undergo mutation.
  - Group of chromosomes which will undergo crossover.
- Evaluation function depends on the number of conflicts with other aircraft, number of speed changes, difference to expected time at route destination (target time) and length of route.
- Selection probability depends on the evaluation value of the chromosome.

Problem Dependent Operators: TOA

- Mutation of speeds:
  - Small probability for each waypoint (gene) for a speed change.
- Crossover of speeds:
  - Selection of a pair of chromosomes.
  - Selection of two indices as crossover-points.
  - Exchange of speeds between selected pairs of chromosomes.

Problem Dependent Operators: ROA

- Mutation of speeds:
  - Small probability for each waypoint (gene) for a speed change.
- Mutation of routes:
  - One mutation for each route.
  - Random selection of two indices of the waypoints of the route.
  - Removing the part of the route between the selected indices.
  - Random selection of a new waypoint and inserting the route from the start point of the selection via the new waypoint to the end of the selected part of route.

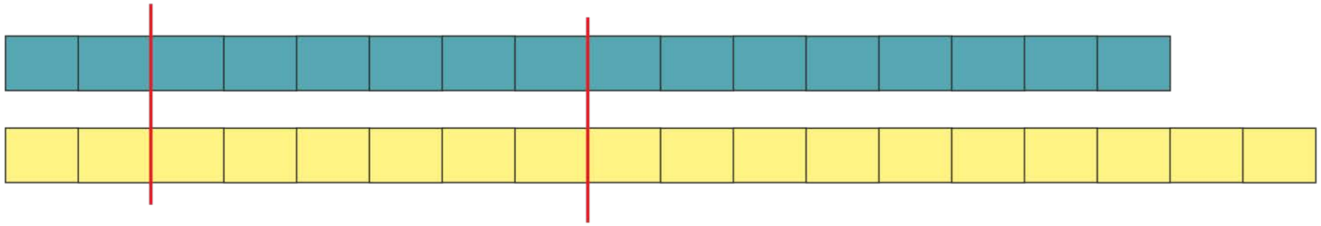


Problem Dependent Operators: ROA

- Crossover of taxi routes:
  - Selection of a pair of chromosomes.
  - Selection of two indices for crossover.
  - Exchanging the parts of the routes between the selected indices.
  - Insert connections (taxi route) between the last point of the first remaining part of original route to the start of the exchanged part and from the last point of the exchanged part to the beginning of the second remaining part.

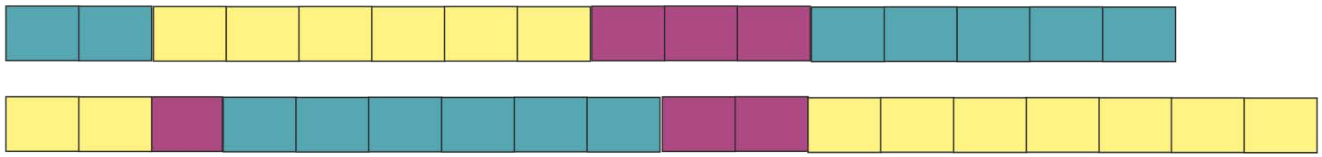
Visualization of Crossover

Select crossover points:



Exchange route parts:

Repair taxi route



Problem Dependent Operators: Other

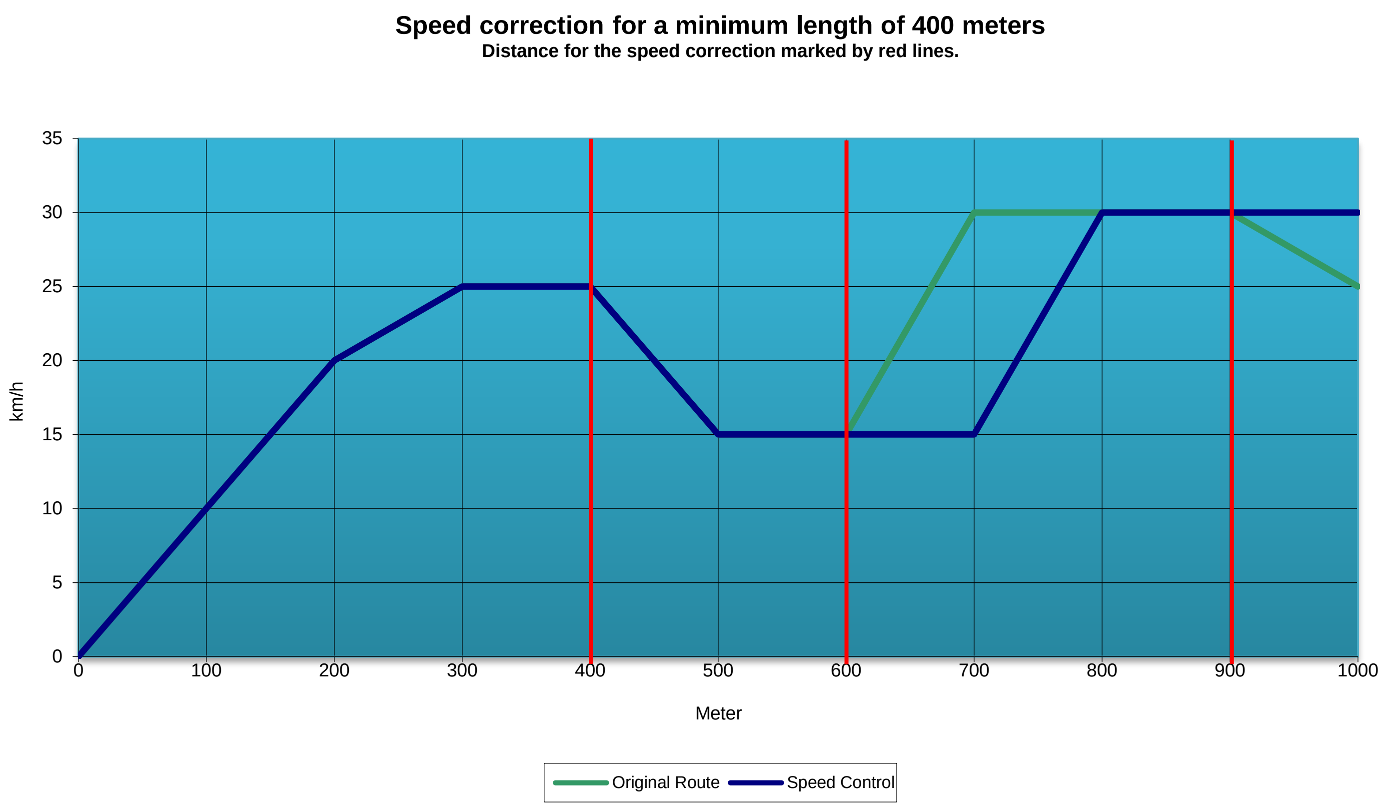
Add holdings on waypoints:

- Insertion of holdings in a taxi route in dependence of the success of optimization.
- Probability to be selected as holding point depends on the "Safe Node" of a route (last safe holding position in case of conflicts) and the type of the nodes (already holding point, stop bar exists for this node, no runway node).
- Random selection of node.

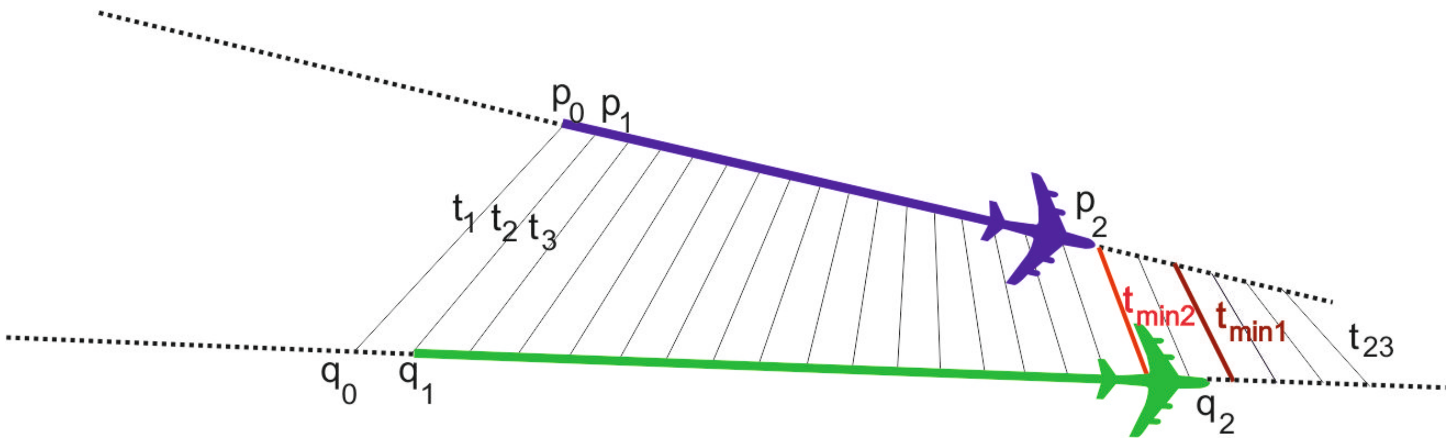
Adapt speed changes:

- In case of more than one speed change within a certain distance the second speed change is moved behind the prescribed distance.

Example for Adaptation of Speed Changes



Core Element: Conflict Detection



Position p on the link W:

$$p = w_i + \lambda_i \cdot (v_i + \Delta v_i \cdot t) \cdot t \cdot (w_{(i+1)} - w_i)$$

Minimum distance between two links U and W (Calculation of extreme values):

$$dis^2 = \sum_{j=1}^{2} (w_{i,j} - u_{k,j} + (v_1 t + \Delta v_1 t^2) \lambda_1 (w_{i+1,j} - w_{i,j}) - (v_2 t + \Delta v_2 t^2) \lambda_2 (u_{k+1,j} - u_{k,j}))^2$$

Monitoring and Adaption of Actual Position:

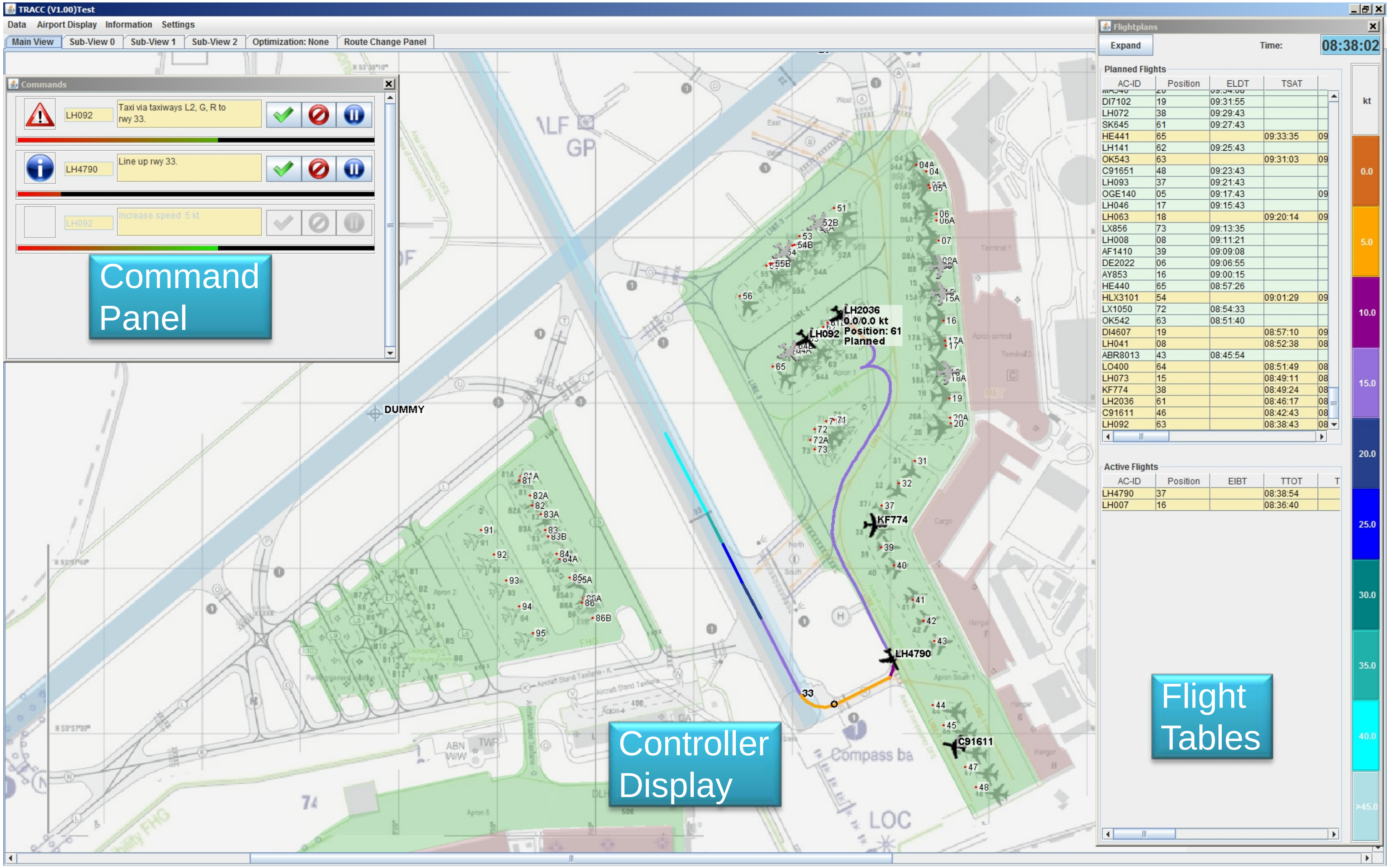
Possible deviation types:

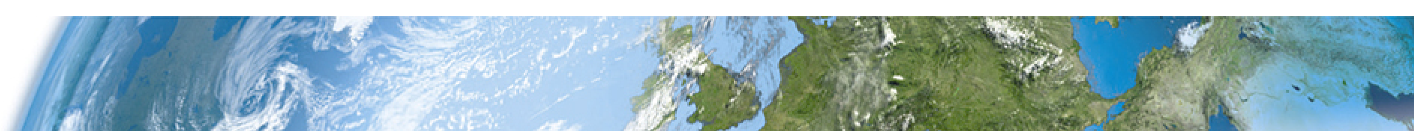
- Correct taxi route, no conflicts and a negligible difference to target time.
- Correct taxi route, no conflict and the difference to target time is to high.
- Wrong route
- Conflict

All: Adaption to actual position and speed.

- Nothing
- New optimization for a smaller difference to target time.
- New route including the actual position.
- New optimization.

Reality Check: 1st Workshop at DLR


TRACC (V1.00)Test
Data
Airport Display
Information
Settings
Main View
Sub-View 0
Sub-View 1
Sub-View 2
Optimization: None
Route Change Panel
Commands
LH092
Taxi via taxiways L2, G, R to rwy 33.
LH4790
Line up rwy 33.
LH092
Increase speed 5 kt
Command Panel
DUMMY
LH2036
0.0/0.0 kt
Position: 61
Planned
LH092
KF774
LH4790
C91611
Controller Display
Flightplans
Expand
Time:
08:38:02
Planned Flights
Active Flights
Flight Tables



Summary

- Introduction of conflict-free time based taxi routes.
- Problem solution done with evolutionary algorithms.
- 1st Workshop gave „go“ for further development.

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Thank you for your interest.

Questions?

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