EXPLORATORY RESEARCH

AEON ER Description of the first validation platform

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AEON

ADVANCED ENGINE OFF NAVIGATION

This “Description of first validation platform” deliverable is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 892869 under European Union’s Horizon 2020 research and innovation programme.

Abstract

This document describes the architecture of the simulation platform that will be used for AEON concepts evaluation both on a physical and software point of view.

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1 Introduction

AEON aims at fostering the usage of environmentally friendly ground operations techniques:

- Non autonomous taxiing such as TaxiBots
- Autonomous taxiing like Electric Green Taxi System
- Single Engine Taxiing as last option.

The project aims at defining a concept of operations focusing on engine-off taxiing techniques based on a set of dedicated tools such as fleet management for TaxiBots and supervision interfaces to support the operators and their collaborations.

This document describes the architecture of the simulation platform that will be used for AEON concepts evaluation.

1.1 Structure of the document

The chapter 2 presents the physical facilities whereas chapter 3 presents the software architecture.

1.2 Acronyms and terminology

The following table reports the acronyms used in this deliverable.

Term	Definition
A-CDM	Advanced Collaborative Decision Making
ACHIL	Aeronautical Computer Human Interaction Lab (achil.recherche.enac.fr)
AMAN	Arrival manager
A-SMGCS	Advanced surface management guidance and control system
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air traffic management
CATC	Conflicting ATC clearances
CMAC	Conformance monitoring alerts for controllers
CPDLC	Controller-pilot data link communication
CTOT	Computed Take Off Time
DMAN	Departure manager
D-Taxi	Datalink communication during the taxi phase
DTVETS	Dispatch Towing Vehicle Electrical Taxiing System
ETA	Estimated Time of Arrival
EOBT	Estimated off block time

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FTOT	Forecasted take off times
JSON	Java Script Object Notation
PMP	Project Management Plan
RMAC	Runway monitoring and conflict alerting
RMAN	Runway manger
RWY	Runway
SVG	Scalable Vector Graphics
TCAS	Traffic Collision Avoidance System
TLDTs	Target Landing times
TOBT	Target off block time
TTOTs	Target take off time
TWR	Control Tower

Table 1: List of acronyms used in this document.

1.3 Applicable Reference material

Unless otherwise stated in this **PMP**, the execution of the project **will be fully compliant** with the latest version of the S2020 Project Handbook available in STELLAR Program Library.

AEON Grant Agreement Description of Action - GA-892869-AEON

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2 Simulation facilities

As a reminder, the figure below shows the different working positions the AEON concepts evaluation will need to simulate.

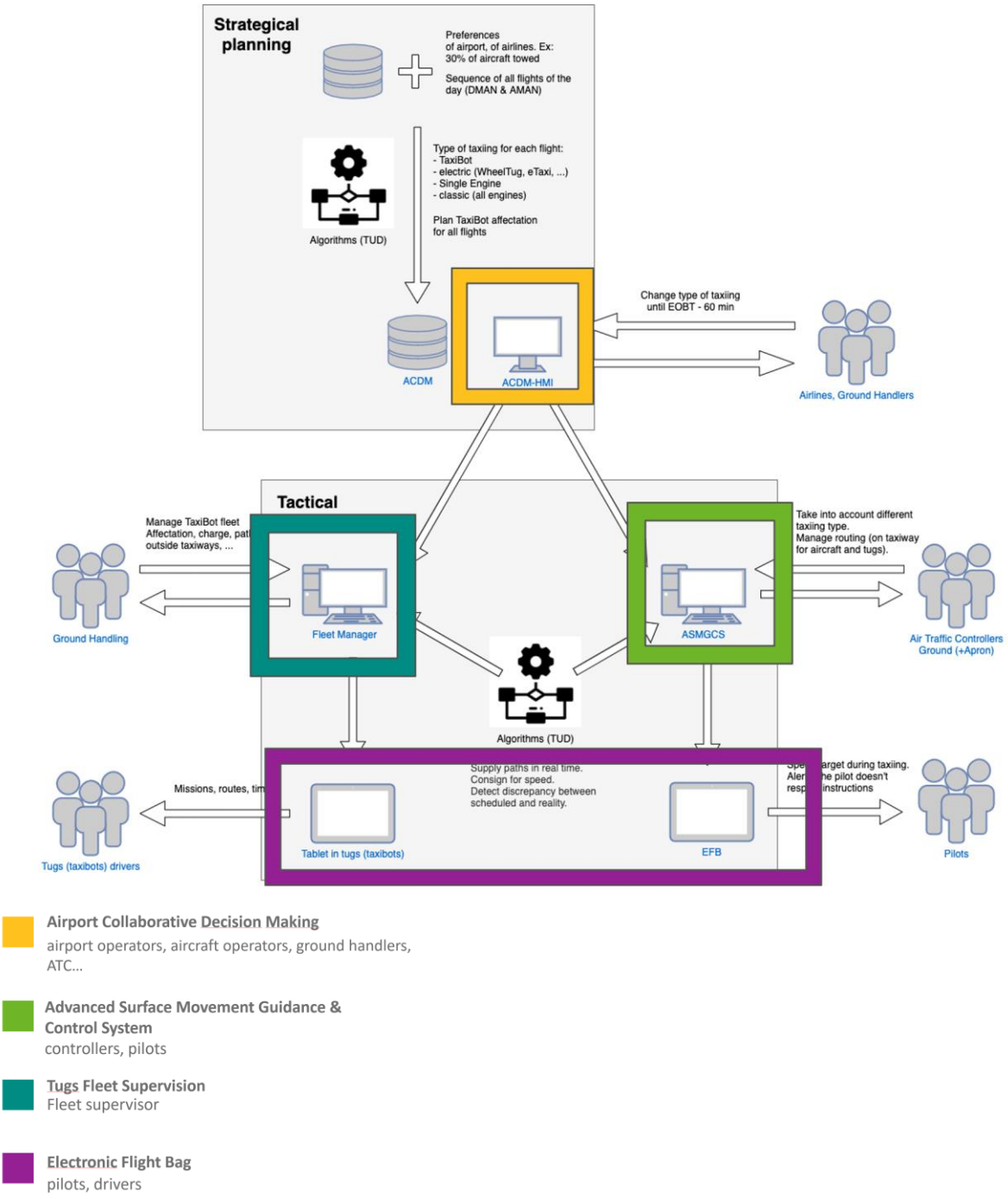

Figure 1: AEON concept

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The following chapters describes the hardware and software solutions put in place to set up the simulation environment that will be used for AEON concepts evaluation.

2.1 ACHIL platform

The ACHIL platform gathers in one place simulators of many working positions of the ATM world: ATC en route, approach and tower positions, cockpit simulators and supervision room. The proximity of air and ground positions makes it possible to focus on air-ground collaboration. The simulation tools employed allow the setup of a very realistic environment for operational experts (AMAN, TCAS, Safety Nets, Aircraft models etc.). Based upon an ad-hoc middleware, the flexibility makes it also compatible with the needs of research and rapid prototyping and offers the possibility to quickly set up a comprehensive operational environment to explore new ideas and concepts.

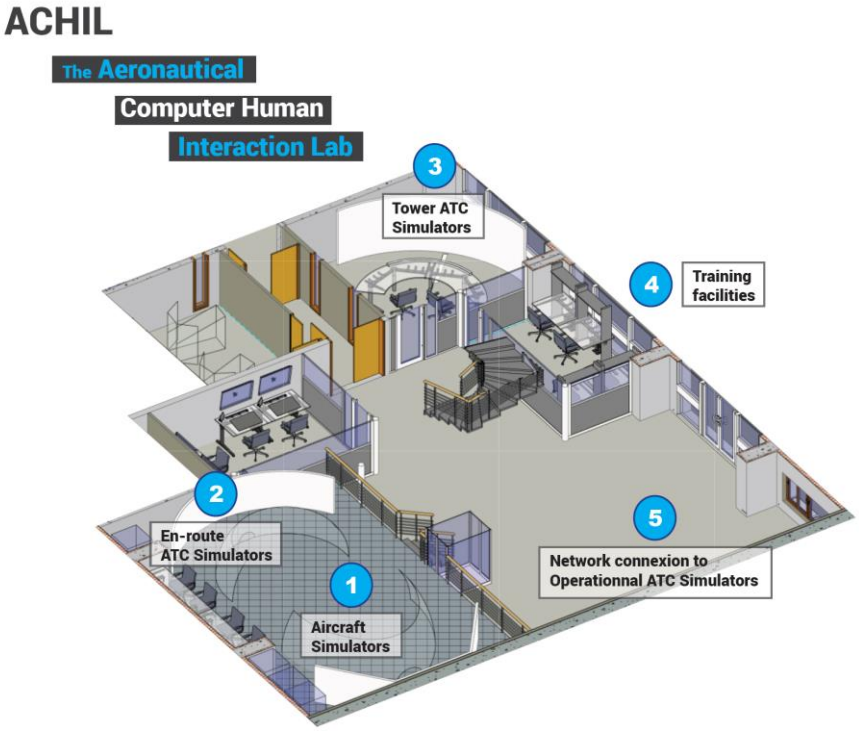

Figure 2: ACHIL simulation facilities

2.2 Working positions

In the frame of AEON project, the foreseen positions to be used are the following:

- Ground tower ATC position

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Figure 3: Ground tower position with RealTwr view

The tower position uses RealTwr [9] for the out of the window view that will also include TaxiBots. In addition, two Wacom tactile displays are available to try different designs for the A-SMGCS interface.

- A320 cockpit simulator

Figure 4: A320 cockpit simulator

The cockpit can be connected to the ATC ground control position in the same simulation and will allow to test the automatic sending of taxi route / speed profile via datalink and validate the design of the HMI to display it to the pilot. The A320 simulator can be driven on ground to try different engine off techniques.

- Dedicated working position for tugs fleet management.
- For now, we suppose that the tug drivers would be provided with the same type of HMI as the aircraft pilots and no specific tool need to be developed for them.

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3 Software description

This section presents the software developed for the simulation platform from its constructions to its operation. Some dedicated tools have been made to produce the input data used during the simulations and other tools are developed for the simulation itself.

3.1 Data sources

The simulation platform has been designed to work on different airports. Hence all the data provisioning has been developed to be generic enough.

3.1.1 Airport maps

The initial source for airport maps, i.e. background image but also routing network with all taxilanes, taxiways and runways defined together with their connections and some geographical information, comes from open source data for the X-Plane flight simulator [5]. The description of ground facilities is available for download [6] and the format is proprietary [7]. AEON team developed a Python program to extract information from these files and generate an SVG file with all the requested information. External data sources such as Open Topo Data [8] have been used to get altitudes of intersections and then compute taxiways slopes.

The routing information inside the SVG file is following the structure below:

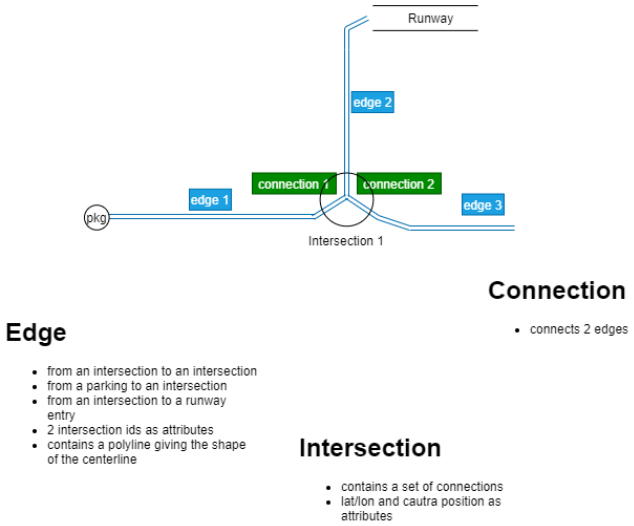

Figure 5: SVG routing data model

An edge defines a portion of taxiway (or taxilane or runway) between 2 intersections and the intersection node gives the information of possible connection between edges. As the shown in the example below, the edge node is actually an SVG path element with additional information, including its length, slope and turn radius:

<path bound1="intersection_node_1208" bound2="intersection_node_1205" d="M 171.7197,302.8247 L 171.7199,302.8247" id="edge_1" pathLength="0.0012" radius="50" slope="0.0"/>

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And the intersection node gives the connection information:

```
<g id="intersection_node_1205" latitude="49.0129" longitude="2.5058"
x="171.7199" y="302.8247">

    <g bound1="edge_1" bound2="edge_480" id="connection_2505"/>

    <g bound1="edge_480" bound2="edge_800" id="connection_2506"/>

</g>
```

The complete structure of the SVG file is the following:

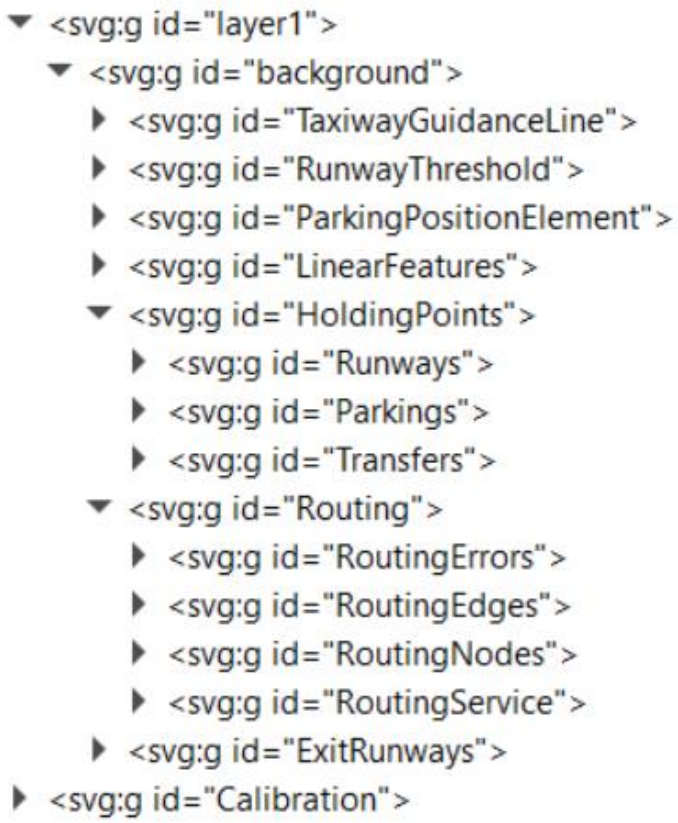

Figure 6: SVG file structure

The first four layers, 'TaxiwayGuidanceLine' 'RunwayThreshold' 'ParkingPositionElement' and 'Linear Features', define the background image whereas the 'HoldingPoints' 'Routing' and 'ExitRunways' layers give the routing information that can be processed by routing algorithms. The last layer, 'Calibration', gives transformation matrices to switch from latitude/longitude coordinates (or Cautra) to SVG coordinates.

The two figures below represents the maps generated for Amsterdam Schiphol and Roissy CDG airports. The SVG can be graphically represented as this but it also contains all the routing information described above.

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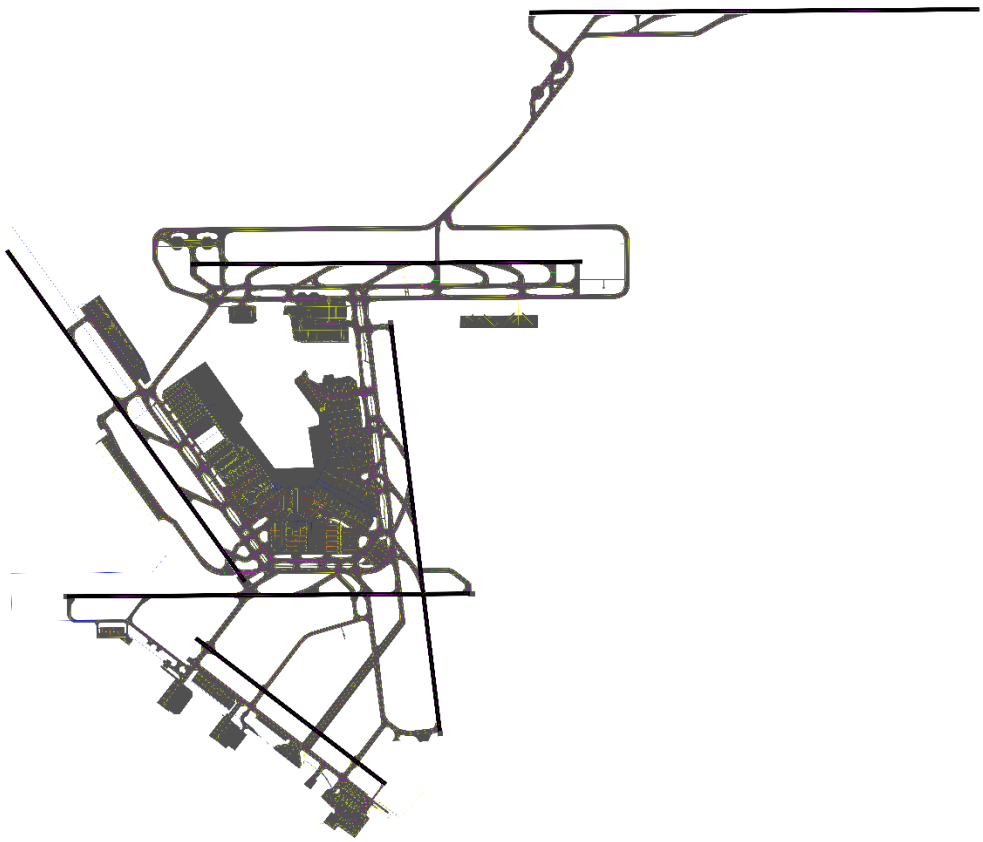

Figure 7: Schiphol (EHAM) SVG map

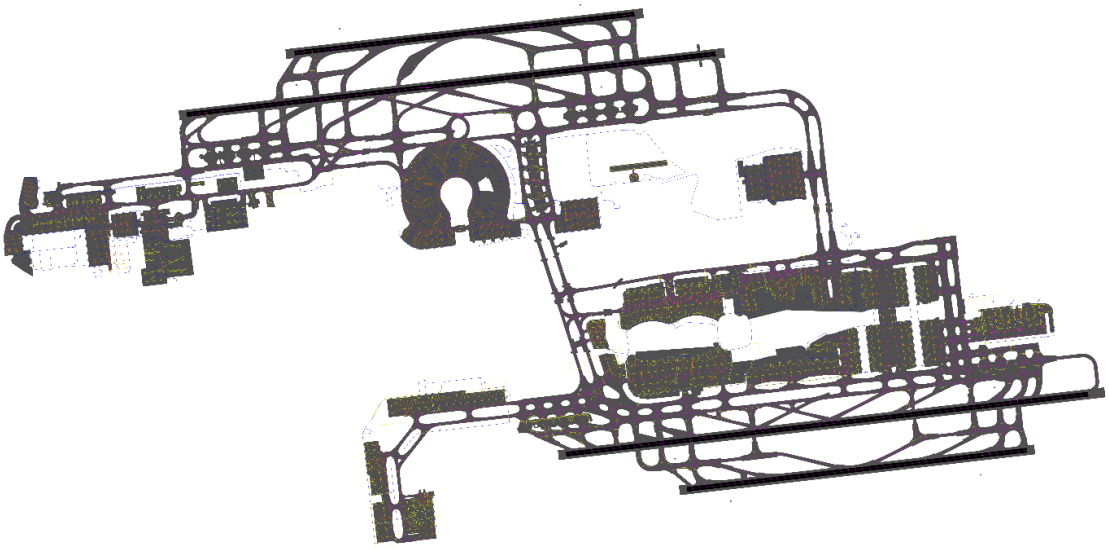

Figure 8: Roissy CDG (LFPG) SVG map

3.1.2 Traffic rules

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In order for the routing algorithms to work properly and propose solution that are in line with the operational practices, a definition of the standard procedure is required on top of the topological routing network definition from the SVG file.

For instance, a specific turn can be forbidden to a/c with a wingspan greater than 65m:

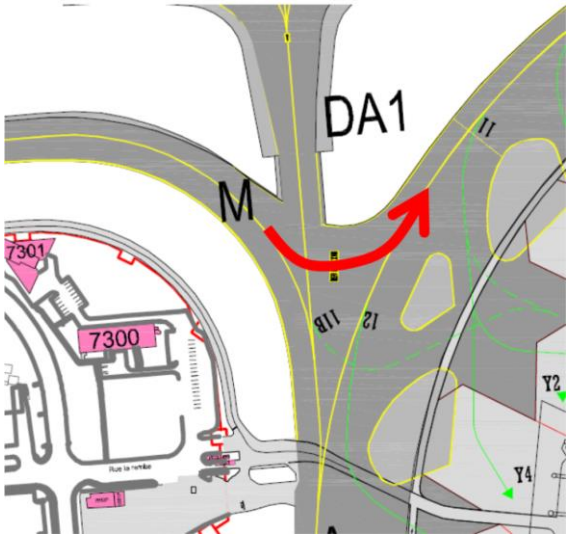

Figure 9: Operational traffic rule example

This information is described in an external JSON file.

There are two JSON parts:

- a first block to define paths that must respect the airport circulation rules, it constitutes a mapping of a path identification and the names of edges that constitute this path;
- a second block to define rules corresponding to previously defined paths.

It corresponds to the structure of this class diagram:

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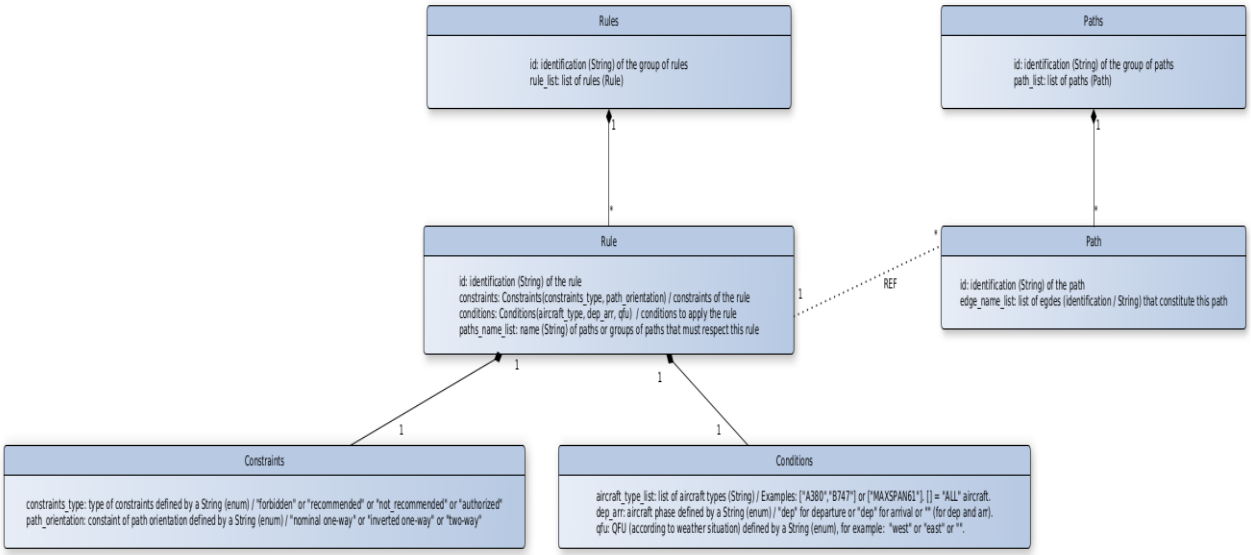

Figure 10: JSON traffic rules structure

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```
{
    "id": "Paths_Def",
    "path_list": [
        {
            "edge_name_list": [
                "edge_idJ1-J41-1797",
                "edge_idJ1-J41-1807"
            ],
            "id": "J1"
        },
        {
            "edge_name_list": [
                "edge_idG-GE11-906",
                "edge_idE4-891",
                "edge_idE4-893",
                "edge_idE4-895",
                "edge_idE4-897",
                "edge_idE4-898"
            ],
            "id": "E4"
        },
        {
            "edge_name_list": [
                "edge_idGE12-917",
                "edge_idE5-919",
                "edge_idE5-935",
                "edge_idE5-944",
                "edge_idE5-959",
                "edge_idE5-947",
                "edge_idE5-945"
            ],
            "id": "E5"
        }
    ]
}
```


Figure 11: JSON block that defines rules

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```
{
    "id": "Rules",
    "rule_list": [
        {
            "conditions": {
                "aircraft_type_list": [],
                "dep_arr": "dep",
                "qfu": "west"
            },
            "constraints": {
                "constraints_type": "recommended",
                "path_orientation": "inverted one-way"
            },
            "id": "departure_west",
            "paths_name_list": [
                "FR"
            ]
        },
        {
            "conditions": {
                "aircraft_type_list": [],
                "dep_arr": "",
                "qfu": "west"
            },
            "constraints": {
                "constraints_type": "recommended",
                "path_orientation": "inverted one-way"
            },
            "id": "manex_west",
            "paths_name_list": [
                "J1",
                "E4",
                "E5",
                "E12",
                "G12",
                "T",
                "RP",
                "RT",
                "R",
                "P",
                "W10",
                "Q",
                "B",
                "U",
                "Middle",
                "C"
            ]
        }
    ]
}
```


Figure 12: JSON block that defines paths

Details about constraints:

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- constraints_type ("authorized" by default):
    - "forbidden" / "authorized”: hard constraint (mandatory / the rule cannot be violated)
    - "not-recommended" / "recommended": soft constraint (preferably / the rule can be violated)
- path-orientation ("two-way" by default):
    - "nominal one-way" (-->): only in one direction whose orientation is the same compared to that in the JSON description of paths
    - "inverted one-way" (<--): only in one direction whose orientation is inversed compared to that in the JSON description of paths
    - "two-way" (<-->): in two directions

Details about conditions:

- aircraft_type_list / several possibilities ("" = "ALL" by default):
    - Directly a list of aircraft type, for example: ["A230","B777"]
    - Or a list of categories of aircraft: like maximal span ("MAXSPAN61"...), ICAO aircraft classification ("A", "B"...), maximal take-off weight ("MTOW80"...) or other aircraft characteristics
- dep_arr ("" = dep and arr by default): aircraft phase
- qfu: configuration of ways defined by the airport (according to weather situation)

3.1.3 Traffic rules editor

To facilitate the definition of the traffic rules, especially the list of paths, a dedicated visual editor is being developed.

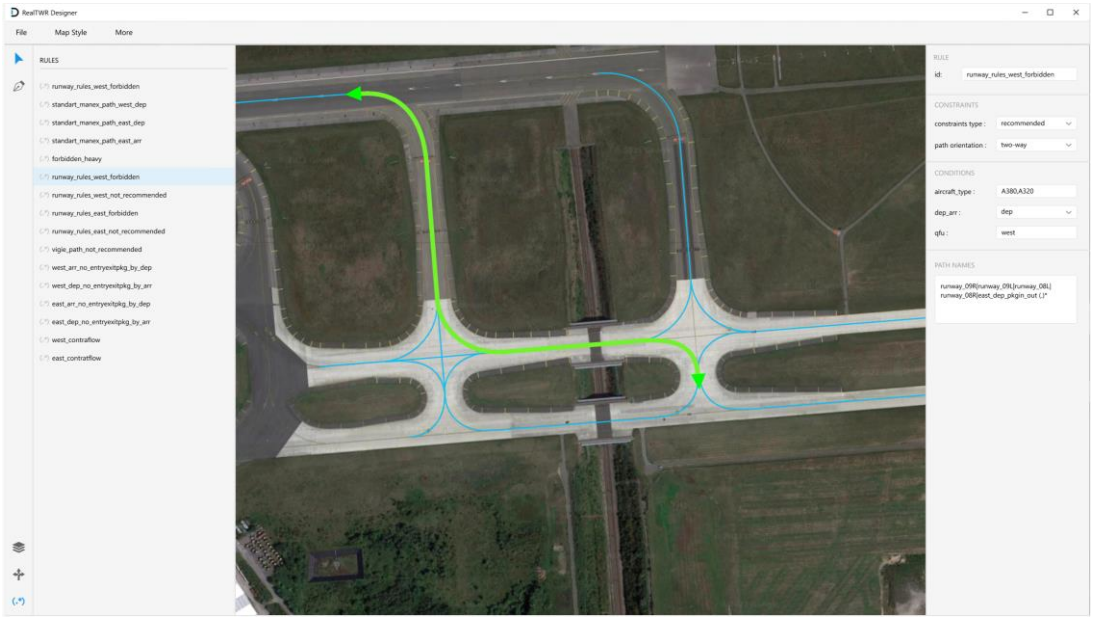

Figure 13: Traffic rules editor

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The tool will simplify the selection of connected edges of the routing network in order to specify the rule to be applied.

3.2 Distributed architecture

3.2.1 IVY middleware

Ivy[1] is a simple protocol and a set of libraries and programs that allow applications to communicate with each other through text messages. Each connected application is called an agent. The background mechanism uses subscription based on regular expressions. Ivy libraries are available under an open-source licence (LGPL) in C, C++, Java, Python and Perl, on Windows, Unix and Macs. Several Ivy utilities and hardware drivers are also available. It has been used on several research projects and proved to be effective even when a large number of agents are involved, in addition it is simple to use and easy to set up.

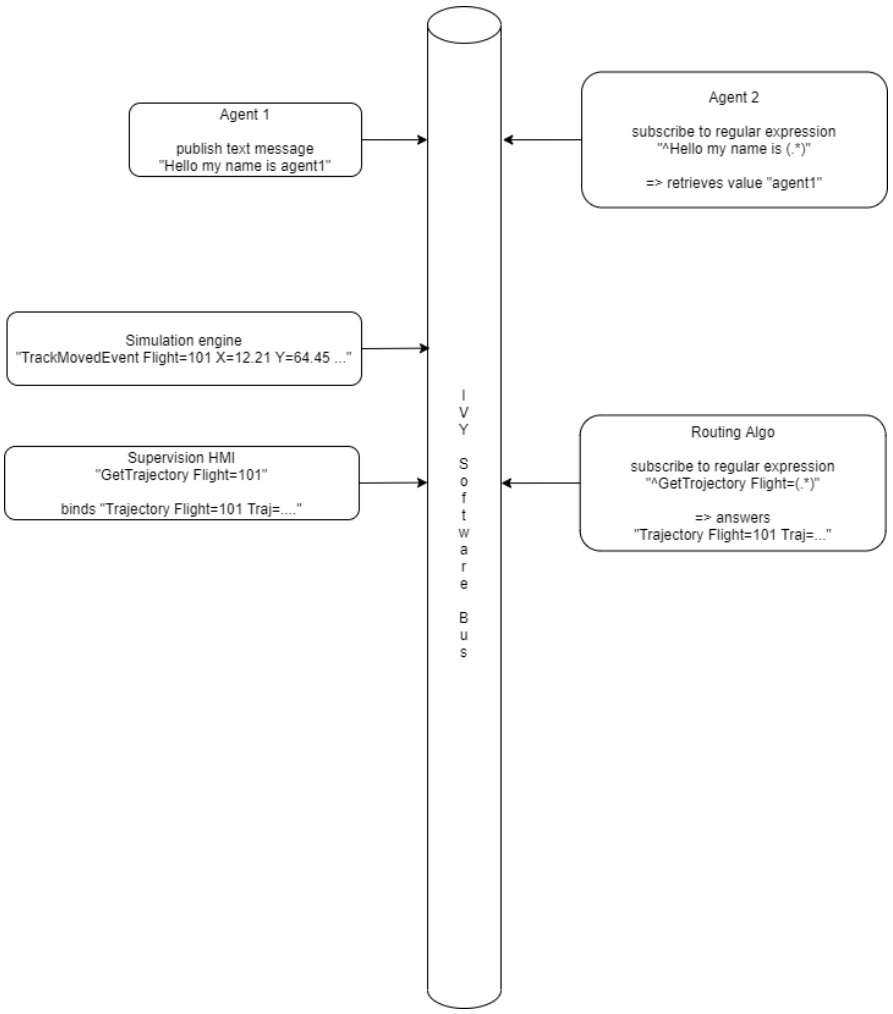

Figure 14: IVY principles

Ivy is currently used in research projects in the air traffic control and human-computer interaction research communities as well as in commercial products.

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Actually, the IVY protocol is easy to use, and the data exchanged are human readable, which will facilitate the debugging. In addition, IVY has already proven to be capable to handle a heavy traffic, it is widely used at ENAC in ATC simulation with high traffic load.

3.2.2 Architecture overview

The diagram below presents the main data flows between the different part of the AEON simulation.

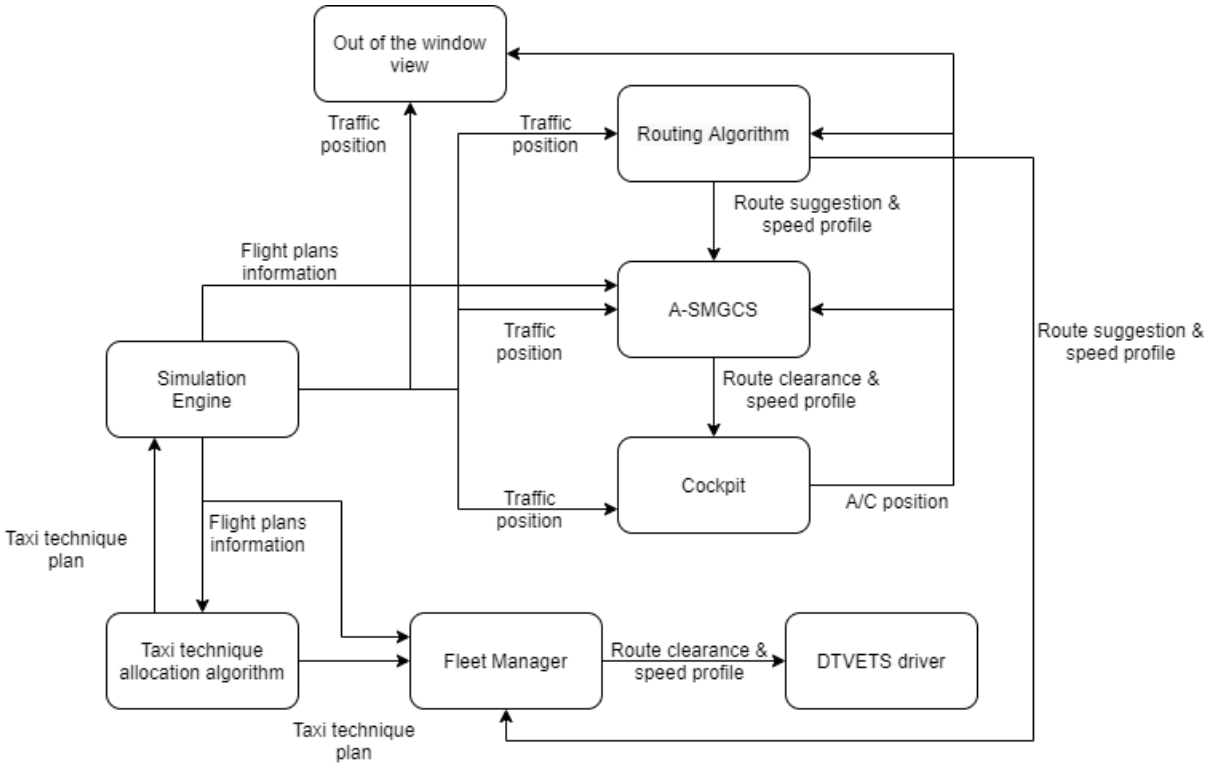

Figure 15: Architecture overview

The diagram above gives an overview of the main information flows between the different agents of the simulation.

3.2.3 Simulation engine

The simulation engine is an IVY agent that basically sends messages for every radar tracks of a scenario with the position information every seconds and answers requests for flight plans data.

3.2.3.1 Traffic generation

The creation of scenario is based on a flight schedule of arriving and parking flights. The simulation engine can receive orders to generate the corresponding data in the radar tracks database.

For an inbound flight, the simulation engine will compute the radar tracks from 10 miles out in air until the aircraft has vacated the runway. After that the pseudo pilot will take the aircraft in charge and coordinate with ATCo to continue the taxiing until the parking (see 3.2.3.3 Pilot orders).

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Concerning a departing flight, the simulation engine will generate radar tracks at the parking position for 1 hour. When the flight is ready to taxi, the pseudo pilot will give the push back and taxiing orders in accordance with ATC clearances (see 3.2.3.3 Pilot orders).

3.2.3.2 Flights database

The simulation stores flight plan for each aircraft in the simulation, the important data are:

- Departure and arrival airport
- Aircraft Type
- Equipment: CPDLC, e-Taxi
- Runway for landing or take-off
- Parking position
- Timings: EOBT TOBT CTOT ETA

In addition to these 'static' information, the database also stores the current status of each flight. For instance, for an aircraft equipped with e-Taxi the database also stores the current status of the electrical engines (on / off) and sends an update to all other agents whenever this status changes. It also stores flight status (can be planned / scheduled / routed / taxiing or finished).

3.2.3.3 Pilot orders

In addition, the simulation engine will compute new trajectories upon reception of pilot orders such as a turn or an acceleration order or a trajectory to taxi. Then the newly computed positions for the given aircraft are stored in database and replace the old ones in the periodically emitted track position update message.

The computations consider the taxiing techniques in use for the given aircraft. The performances will be different for a single engine taxi or an aircraft towed by a TaxiBot.

3.2.4 Routing agent

The routing agent gives the best routing options for a given vehicle upon request together with a speed profile that would smooth the circulation by avoiding stop and goes at intersections. It will use the current position of the vehicle, its destination and potentially waypoints (whenever the ATCo has manually set them in the HMI to force a specific path). The routing suggestion must follow the traffic rules defined for the airport. These rules are not absolute but are weighted, i.e. the routing algorithm will not basically suggests a route that does not follow the traffic rules, so that an ATCo can always set a route as he wants even if it does not follow the standard procedure.

A basic version of the routing agent has been implemented using Dijkstra algorithm for integration purpose, in order to pave the way for the multi agent version developed for AEON.

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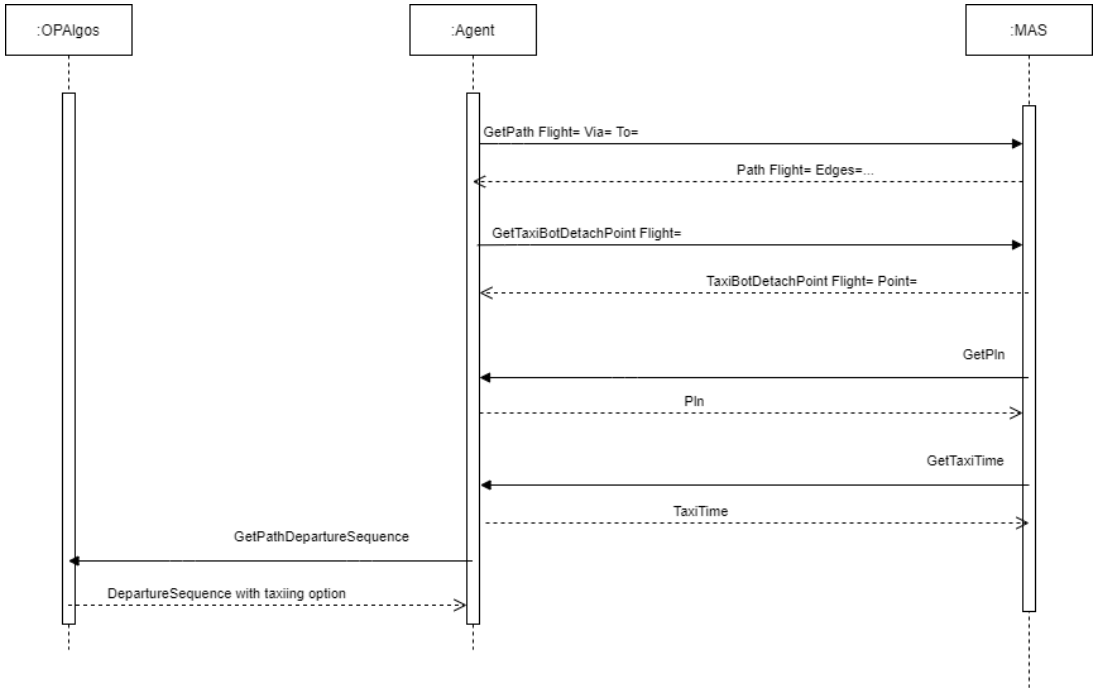

Figure 16: IVY API for routing

3.2.5 Taxi techniques allocation agent

This agent is in charge of computing the best taxi technique, based on an ecological indicator, for each aircraft in the simulation and sharing it with the HMIs agent such as the fleet manager.

3.2.6 HMI agents

3.2.6.1 A-SMGCS working position

The A-SMGCS working position will be built upon the prototype developed during previous SESAR project MoTa (WP-E grant E.02.024 [2]) and TaCo (SESAR grant No 699382 [3]).

The core of the prototype is an interactive radar image where the ATCo can input the taxiing clearances. It cannot be rated at a single A-SMGCS level since it meets different levels depending on the functions:

- Surveillance: Level 2. The radar image represents aircraft and tugs on the airport layout (apron and manoeuvring area) with their identity.
- Control: Level 2. Control function can detect any conflict concerning mobiles on the movement area. The alarms are provided to the controller.
- Route Planning: Level 4. The route planning function determines the best route for an aircraft on the ATCo's request. The calculated route considers the ground rules and other traffic. The validated route can then be electronically sent to the pilot if the aircraft is equipped with datalink.

It also provides additional monitoring:

- Clearance conformance.

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- Aircraft arriving at the end of clearance.
- Aircraft responsibility status (assumed, transferred…)

More information can be found in project MoTa deliverable [2].

3.2.6.2 Fleet Manager working position

For now, the fleet manager working positions is in the design phase. Its goal is to send missions and trajectories to tugs drivers (datalink communications will be simulated via IVY messages) and potentially update timings (EOBT) in the flight plan information database of the simulation engine.

3.2.6.3 Electronic Flight Bag

For now, the electronic is in the design phase. Its goal is to display missions and trajectories to aircraft pilots and tugs drivers (datalink communications will be simulated via IVY messages) together with a speed profile suggestion in order to smooth the traffic.

3.3 Radio communications

The simulation platform uses an existing IVY agent developed at ENAC that implements the AudioLAN protocol and adds live voice modifications to the streamed voice so that each a/c is emitted with a different voice although only 2 or 3 pseudo pilots are actually in charge.

3.4 Data logging

For the evaluation process an additional IVY agent will be connected for data logging. Actually, everything can be logged, the main advantage of the platform architecture is that every information will be timestamped in real time with the real and the simulated time. This will facilitate the analysis of the record.

Once the interesting indicators are defined, the relevant agent simply needs to send a log message with the IVY bus with the value to be recorded in real time, while the simulation runs.

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4 References

[1] IVY Software bus - https://www.eei.cena.fr/products/ivy/

[2] Modern Taxiing project final report - https://www.sesarju.eu/sites/default/files/E.02.24_MOTA_D0.9_D06_final_report_v2.pdf

[3] TaCo project results - https://cordis.europa.eu/project/id/699382

[4] Smala website – http://smala.io

[5] X-Plane filght simulator - https://www.x-plane.com/

[6] X-Plane Scenery Gateway - https://gateway.x-plane.com/

[7] X-Plane APT file specification - https://developer.x-plane.com/article/airport-data-apt-dat-file-format-specification/

[8] Open Topo Data - https://www.opentopodata.org/

[9] RealTwr - https://realtwr.fr/

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