Aircraft Ground Operations: Steps Towards Automation

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ABSTRACT

This paper introduces and analyses the state of the art of aircraft ground handling at airports. The main opportunities for automation of these activities are pointed out. This leads to identify different challenges to be overcome to build safe and efficient automated ground handling operations. Greatest opportunity for automation lies with automated docking of ground support equipment to aircraft in the short term, with further autonomous vehicles moving around the aircraft and automated systems within the aircraft later on. An autonomous fleet management formulation for automated vehicles is also presented.

KEYWORDS: *turnaround time, ground operations, ground handling, automation*

1 INTRODUCTION

Ground handling operations represent the airside activities at airports in charge of processing passengers, cargo, facilities and supplies at and around parked aircraft. Most of these operations are performed by different service providers, using vehicles called Ground Support Equipment (GSE) which are specific to each type of operation.

Ground handling is not considered a prominent activity within the Air Transportation System (ATS), however this activity is an important enabler for efficient airport operation and its management is an important issue. Over the last decades, the complexity of ATS has increased to cope with the worldwide growth of air traffic. Today the operation of this system involves global actors (airports, airlines, Air Traffic Control (ATC), Air Traffic Management (ATM)) as well as local actors (ground handlers, local suppliers…) whose coordination, while pursuing different and sometimes contradictory objectives, is difficult to achieve.

2 AIRCRAFT GROUND HANDLING STATE OF THE ART

The ground handling tasks are usually defined and contracted between the airline and the provider using a service level agreement that defines the scope, price and quality level desired and key performance indicators as well.

The ground handling activities are usually divided in:

- "Over the wing" activities, meaning aircraft passenger cabin related activities: passenger boarding and deplaning, catering galleys, cabin cleaning and preparation, safety and security checks as needed.
- "Under the wing" activities, which are cargo (both containerised and bulk) unloading and loading and other ramp activities: provide electricity (Ground Power Unit (GPU)), condition aircraft cabin temperature (Pre-Conditioned Air unit (PCA)), chocking of landing gears, use of cones, marshalling, refuelling, potable water and toilet servicing, towing/pushback and provide access means to the passengers (via stairs, ramps or Passenger Boarding Bridge (PBB))

The generic sequence of these activities, shown in Fig. 1, is established depending on:

- Those tasks related to aircraft arrival: passenger deplaning, cargo unloading, toilet servicing, removal of catering, cabin cleaning.
- Tasks related to aircraft departure: passenger boarding, cargo loading, refuelling, potable water, provide catering, cabin preparation.
- Safety and security requirements for the overall operation.
- Aircraft accessibility to doors and servicing panels.
- Links and constraints (represented with arrows in Fig. 1). These constraints can be hard or soft. Examples of hard constraints are: need to unload the cargo before loading or to deplane passengers before you enplane them. Examples of soft constraints, which will be highly depending on time pressure (degraded standards as risk mitigation) and operator policies, are: Catering start in some galleys while passengers deplaning has not yet finished. Some ground operators start approaching the PBB even with the aircraft not fully on-chocks.

As a result, the aircraft ramp handling sequence is composed of *mostly independent* chains of tasks for current aircraft from the moment the aircraft is "on-chocks", namely:

- Passenger cabin related: passenger deplaning, catering and cleaning, cabin preparation and checks and passenger boarding
- Cargo and bulk unloading/loading
- Refuelling (it is widely accepted to have refuelling with passenger onboard the aircraft)
- Potable water servicing
- Toilet servicing
- Ground power and air conditioned supply (depending on pilot request, availability and regulations of use for aircraft Auxiliary Power Unit)

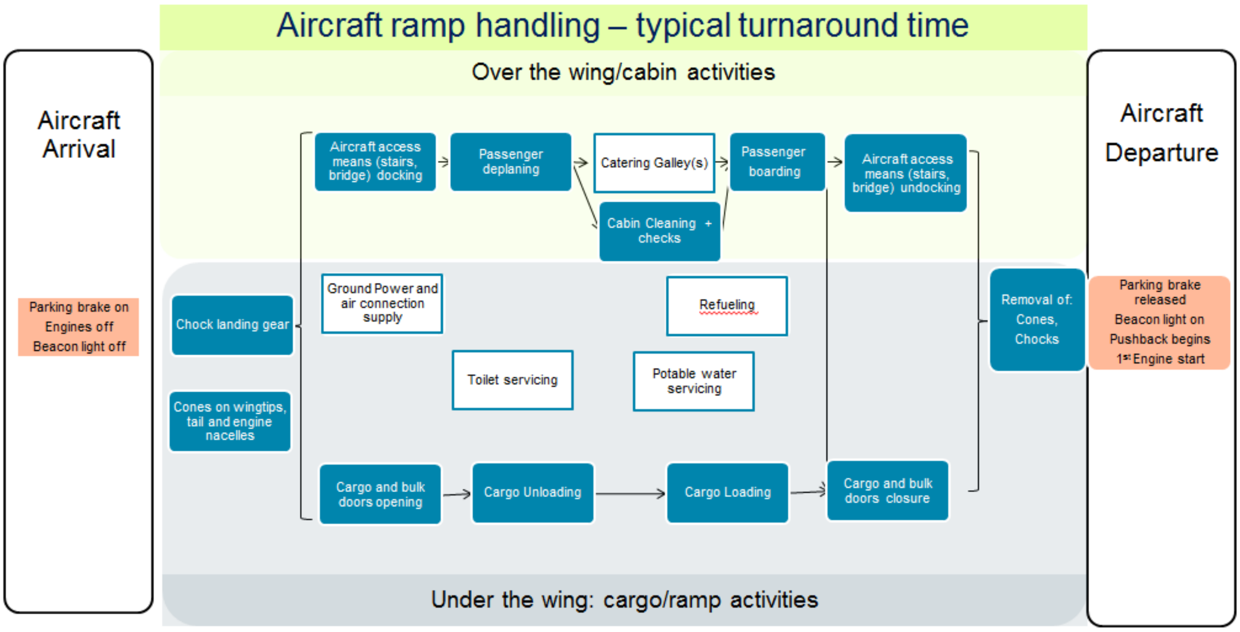

Figure 1: Typical turnaround time. Tasks sequence.

It is worth to be noted that not all of these activities are carried out at each aircraft stop. First and last flight of the day will do only the tasks related to departure and arrival respectively. For the flights in between, some tasks may or may not be done depending on aircraft status, next mission and infrastructure available at the airport (in Fig. 1 these optional tasks are shown with light background). The TurnaRoundTime (TRT) can be defined as the time between the aircraft is on-chocks until it is off-chocks. It can be estimated following a scenario and some assumptions and a set of parameters and rates. The reader is invited to review the different airframe manufacturer's assumptions in their aircraft characteristics or airport planning manuals [1]. An example of TRT result for a given scenario is presented in Fig. 2. The vast majority of the cases, the critical path, the sequence of activities that will determine the duration of TRT, is given by the cabin related activities chain (passenger deplaning, catering, cleaning, cabin preparation and checks and passenger boarding).

Each activity, unless specified differently, comprises the phases of GSE docking or supply connection to the aircraft, the task itself and the GSE removal or disconnection of the utility. Each activity requires a specific GSE, with its own design, shape and constraints (See Fig. 2).
It is important to highlight that even for the same aircraft type, the *turnaround time is not a fix value* and the schedule and the duration of each task and in consequence of the global TRT will vary, because it also depends on aircraft cabin layout, airline operation, infrastructure…
In addition, there are several providers in charge of handling activities for the same aircraft turnaround. Depending on airport size and market regulations[1], the ground handling companies that can typically be found for the same aircraft turnaround are:

- One specialised refuelling company.
- One specialised catering company.
- At least one company dealing with ramp handling activities (could be even more than four).
- One company (usually also dealing with some aspects of ramp handling) dealing with passenger handling.

To complete the list of actors for ground handling, it should be added the airline, the ATC, the airport, the cockpit crew, the cabin crew and the ground handling crew (from five to dozens). The high number of actors involved adds to the complexity and management of the process.

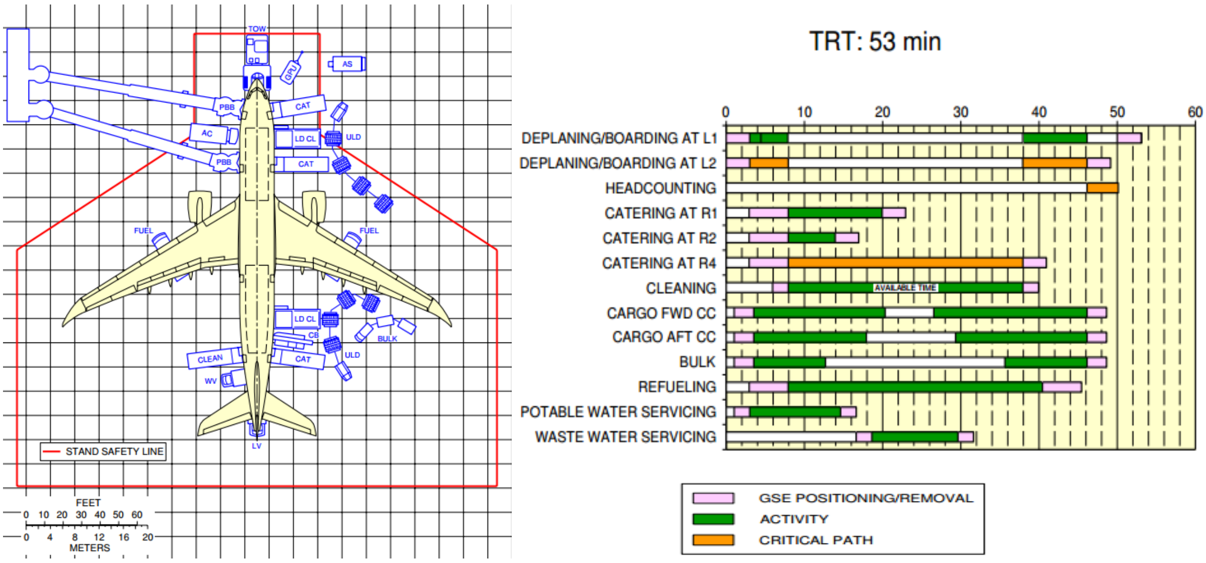

Figure 2: Aircraft typical ramp layout and example of aircraft turnaround time [1].

Further description of the aircraft ground handling and aircraft turnaround process as a whole including the information flows is available [2] and [3].

3 GROUND HANDLING TRAFFIC ANALYSIS

The airport infrastructure will be analysed now. The airport environment will be considered as a linear parking stand layout with two servicing roads at the front and at the back of the aircraft stand. Both servicing roads are connected every 4 to 6 stands (depending on aircraft type as it is wingspan related). See Fig. 3.
When GSE are circulating using service roads, the maximum speed allowed will be typically 25 km/h. When the GSE enters the parking stand, the maximum speed will be 6 km/h [4]. For GSE final position to aircraft contact the maximum docking speed will be 0.8 km/h [4]. See Fig. 4.

[1] E.g. EU ground handling directive: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31996L0067

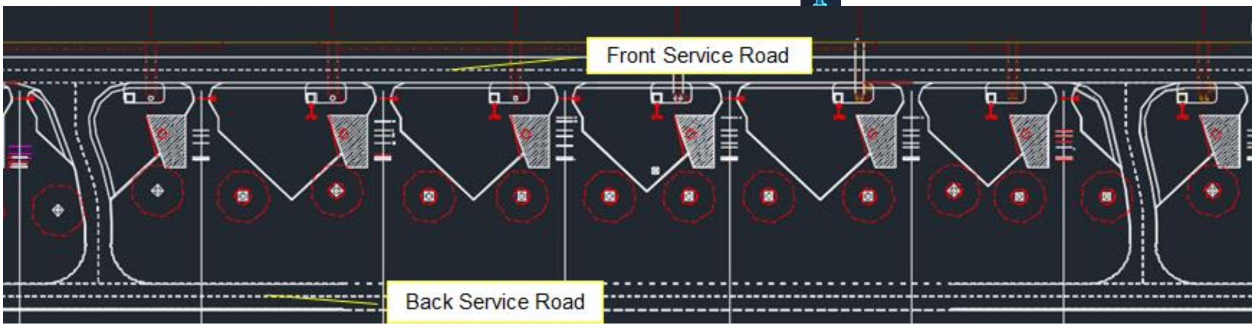

Figure 3: Typical airport parking layout.

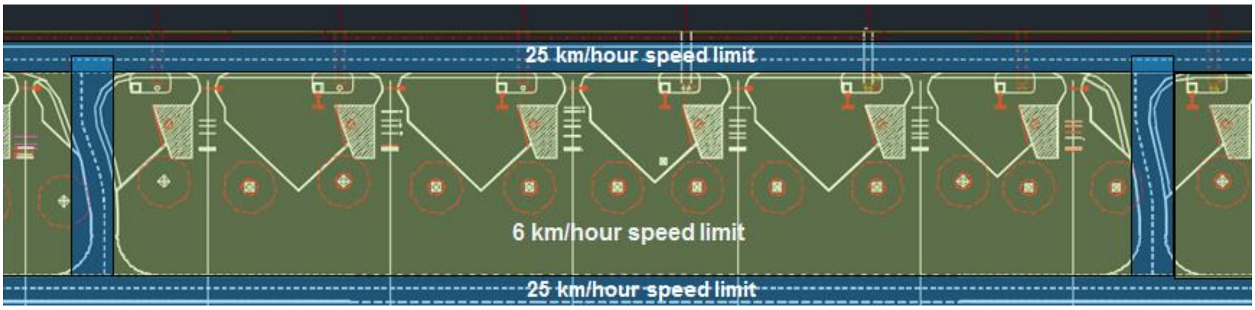

Figure 4: Typical airport parking layout showing speed limits by zones.

The number of GSE typically needed to handle a long range aircraft is presented in Table 1. It is also shown how these resources are usually assigned in the airport environment between aircraft parking stands: linked to parking stand, shared between some stands typically 2 to 4, some zones (e.g. east of passenger terminal) or for the full airport.
On top of all this GSE, there are a number of other vehicles for transport of people (airport staff, airline crew, ground handling crew) that mix and are around the airport stands.
Regarding GSE circulation rules, we will assume:

- Driving on the right lane.
- GSE cannot go under the wing (except for refuelling vehicles) and have to go around the wingtip.
- Any point in the service road can be an entry or exit point to the aircraft parking stands area.
    - The front service road for GSE-truck based will be privileged for access to aircraft most forward door and for the train of dollies.
    - GSE linked to stand or shared between several adjacent stands will depart from and arrive to its parking position in the defined staging area.
    - Rest of GSE vehicles will use the back service road from departure and arrival
- For GSE docking or approaching the aircraft, only the toilet servicing vehicle (due to its most frequent typology with the servicing platform at the rear) will use reverse gear.
- For the cargo dolly's train, which is the most complicated trajectory, as a rule it will always leave the aircraft on the left.

With all these assumptions, we can finally proceed to simulate and plot the GSE trajectories for docking to the aircraft doors and positioning to aircraft servicing panels as shown in Fig. 5, where crossings and common tracks represent potential conflicts areas. In these spots, conflicts are avoided by time separation of vehicles. This can generate traffic congestion when queues build up.
The trajectories in the same stand and with the same aircraft type, airline and the same turnaround type will vary largely between turnarounds as they depend on GSE vehicle turning radius and steering characteristics, start position (for parked GSE) the current environment status when GSE actually move and the most important and variable factor: the human driver.

Table 1: GSE resources for a long range aircraft TRT and GSE sharing strategy.

Ground Support Equipment (GSE)	Number	Shared Resources Strategy
Passenger boarding bridge (PBB)	1 or 2	Specific to parking stand
Fix GPU attached to PBB	1 or 2	Specific to parking stand
Fix PCA attached to PBB	1 or 2	Specific to parking stand
Passenger Stairs	1 to 2	Shared with adjacent stands
Cargo Loaders	2	Shared with adjacent stands/zones
Belt loaders	1	Shared with adjacent stands/zones
Catering trucks	2 to 3	Shared with all the airport
Cleaning trucks	0 or 1	Shared with all the airport
Refuelling/hydrant vehicle	1	Shared with all the airport
GPU mobile	1	Shared with adjacent stands/zones
PCA mobile	1	Shared with adjacent stands/zones
Air Start Unit (Engine start) mobile	0 or 1	Shared with all the airport
Potable water truck	1	Shared with all the airport
Toilet servicing truck	1	Shared with all the airport
Towtractor	1	Shared with all the airport
Baggage tractors	2 to 3	Shared with all the airport
Container / Pallet dollies	8 to 26	Shared with all the airport
Bulk dollies	2 to 3	Shared with all the airport
Loose and static GSE: cones, chocks, towbars…	Variable	Shared with adjacent stands/zones

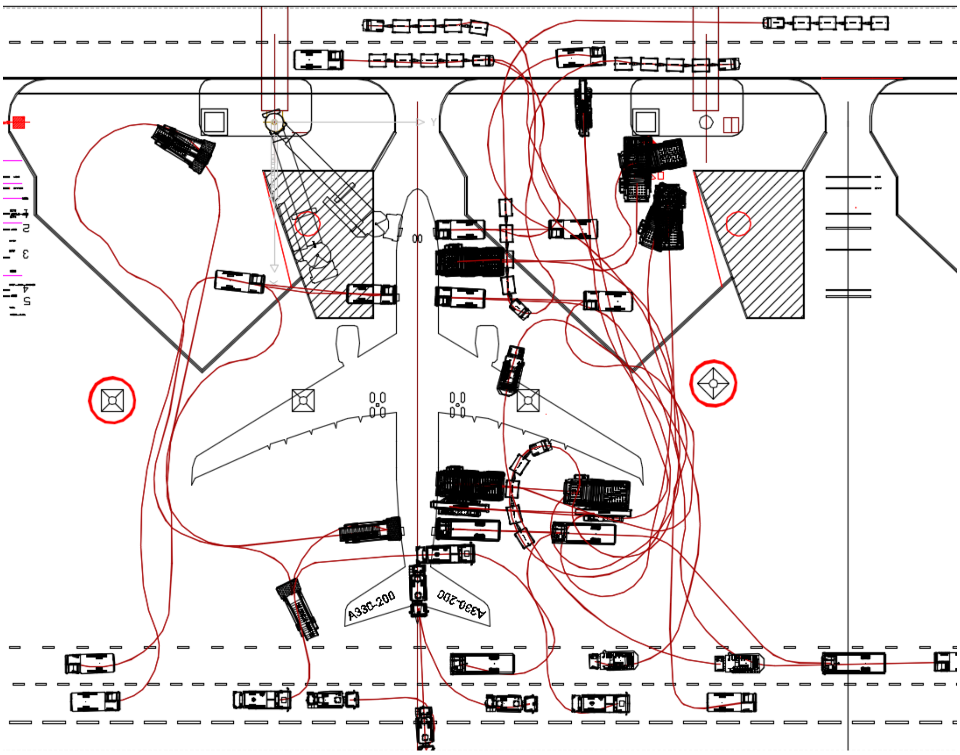

Figure 5: GSE trajectories for a full aircraft turnaround for a long range aircraft.

4 OPPORTUNITIES AND CHALLENGES FOR AUTOMATION

The aircraft handling operation at an airport as described in the previous sections details the current situation, but is not significantly different to the way it was 10, 20, 30 or even 50 years ago. Considering what has been exposed and using the conclusions of other projects [2], we can summarize the main inefficiencies related to the aircraft ramp handling as:

- Availability (free and on working state) of airport infrastructure.
- Availability (free and on working state) of GSE.
- Ramp congestion.
- Coordination of actors and resources to perform the tasks.
- Aircraft ramp damage

4.1 Opportunities

There have been no major changes in the operation since the beginning of aircraft commercial operation. However, the technology and its cost have evolved tremendously, making possible options that could not be envisaged before. There are some general favourable conditions and enablers for aircraft ground handling automation:

- All current and future civil passenger aircraft of more than one hundred seats are very similar from ground handling perspective. For this purpose an aircraft is a fuselage tube with at least two separated decks for passenger cabin and cargo. The fuselage has attached a low wing with positive swept angle where the 2 (or 4) engines are hanging; the landing gear has a tricycle configuration with one nose landing gear and 2 (or more) main landing gears. As an illustration, in Fig. 6 is shown a front view comparison of some long range aircraft: A350-900, A330-200, 777-300ER and 787-10.

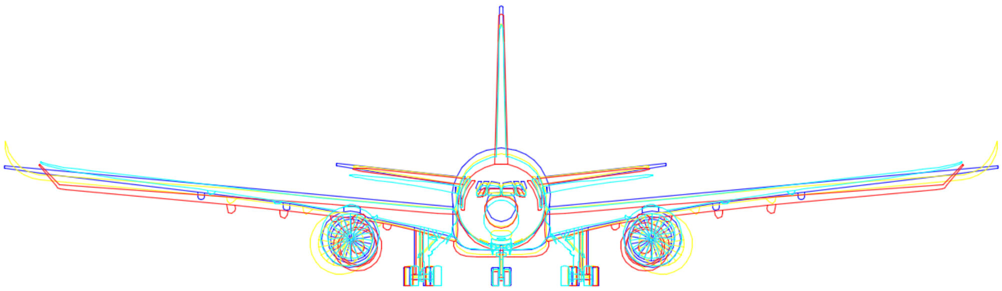

Figure 6: Aircraft front view comparison.

- The aircraft doors and its usage are standardized: passenger doors on the forward port side for passenger boarding/deplaning, on the starboard side and aft port side for catering and cleaning activities. Forward and after the wing, are the cargo doors (available only on the aircraft starboard side) for cargo activities. The bulk door for bulk items only, always the at the aircraft rear part (on short range aircraft always on starboard side; for long range aircraft may be on the port or on starboard side).
- The aircraft servicing points locations and the aircraft – GSE interface follow standards [5,6] and are at common areas, see Fig. 7: electricity always at the front, fuel under the wing half way to the fuselage (depending on airframers and options on port and/or starboard side) low pressure and high pressure air in front of the wing, potable water (either front or most commonly back in the aircraft) and toilet servicing at the aircraft fuselage end.
- The aircraft couplings for GSE connection are standardized [7].
- Robotics and autonomous vehicle technology is available, tested and operated in indoor and outdoor environments. The airport ramp is an outdoor environment, subject to weather conditions, but is also a quite homogeneous and controllable environment, mostly flat (slopes not going typically beyond 3%) and with a limited number of potential events of known actors and vehicles. Furthermore, the technology now is available and also affordable.

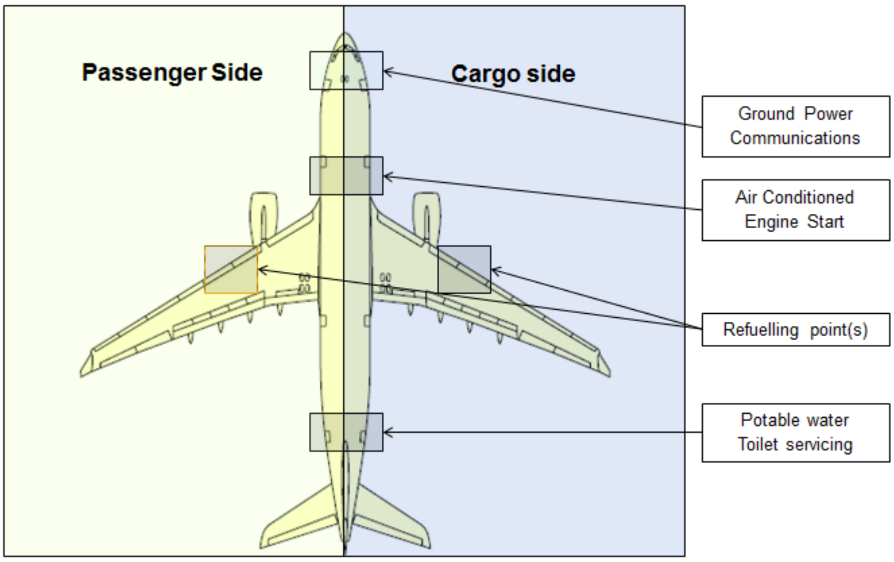

Figure 7: Aircraft servicing points location.

- Operator ergonomic requirements (health and safety) becoming more stringent. It started with load lifting limits in Scandinavia and is slowly but steadily spreading out.
- Availability of manpower. In certain cities where the living expenses are high with low airport ramp wages, finding manpower willing to work on an airport is very difficult.
- Momentum for automation exists at the airports, mainly for the terminal buildings and related to self-service passengers service (self-check-in, baggage drop-off, passport e-gate…).
- Security challenges. The less people around the aircraft, the less potential threats.
- Airport/aircraft safety challenges: mainly aircraft ramp damage. A more controlled aircraft environment will help to control the evolution of vehicles around the aircraft and remove the human error factor (e.g. speeding, no respect of procedures) and enforce procedures (e.g. report damage).

As a result, we see that automation can take a bigger role in the aircraft handling environment in:

- Aircraft movement:
  - Aircraft last turn into parking stand [8]
  - Aircraft pushback (e.g. e-taxi[2])
  - Aircraft towing or dispatch towing (e.g. Taxibot[3])
- Aircraft ground handling:
  - Docking of GSE vehicles to aircraft passenger and cargo doors
  - Movement of GSE vehicles around the aircraft
  - Movement of vehicles on the airport area

The automated supply of utilities to aircraft (electricity, air, water) beyond the conveyance of the servicing unit to the aircraft panel point location is not feasible in the short to mid-term future. Since the aircraft servicing panels (with manual latches) have not been conceived to be opened remotely or operated by a robot in any way. Also, all aircraft couplings or connectors that are standard cannot be easily connected and disconnected with a simple and affordable robot. Therefore, they will continue to be operated manually in the immediate future.

As solutions exist for aircraft movement, the focus of this paper is in the aircraft ground handling part and to the points which are specific to this environment, the docking of GSE vehicles to the aircraft doors and the movement of GSE vehicles around the aircraft.

[2] See: http://www.airbus.com/presscentre/pressreleases/press-release-detail/detail/airbus-signs-mou-with-honeywell-and-safran-to-develop-electric-taxiing-solution-for-the-a320-family/

[3] http://www.taxibot-international.com/

4.2 Challenges

The main challenges for implementing automation into the aircraft ground handling system can be classified as:

- Aircraft related:
  - No palletised cargo hold for many aircraft yet (for some aircraft, e.g. B737 the cargo hold volume is not enough for receiving Unit Load Devices (ULD) like containers and pallets that can be treated by a conveyance system), making mandatory manual processing.
  - Certification rules. Even remote door opening which is perfectly technically feasible as of today and one of the enablers for further automation is not envisaged in current certification rules.
- Operational:
  - Airport "environment": weather conditions, number of stakeholders with lots of potential conflicts and diverging interests.
  - Mix mode: manual and automate mode coexisting on airports. Cannot go to full automation overnight; both will need to co-exist, which is the most complicated environment.
  - Government rules, that currently prevent fully automated vehicle on the airport ramp (case of Germany, for example).
  - Conservative industry mindset. Systems need to be "bullet-proof" to have the buy-in from the industry with no second opportunities.
  - Cost and affordability of the solution. No GSE manufacturers research available, only limited development or adaptation are carried out.
- Scientific:
  - Real time control of heterogeneous fleet of vehicles.
  - Use of nonlinear and hybrid control theory to design of 2D+T and 3D+T ultra-accurate guidance laws for autonomous service vehicles.
  - Planning of 2D+T conflict free trajectories between GSE using heuristic and semi-heuristic methods.
  - Responsivity to incidents and disruptions.
  - Modelling of the ground handling process as a hybrid dynamical system (continuous time-event driven).
  - Design of coordination and communication schemes for monitoring the different sub-processes.
  - Introduce new hybridization schemes between sensors to improve positioning of GSE.

5 TOWARDS AUTOMATED GSES FLEET MANAGEMENT

The set of solutions for the aircraft ground handling automation, on existing aircraft can be:

- In the short term: Targets around aircraft doors as enabler for assisted and automated docking of GSE to aircraft. See SAE AS 6896 [9]. This is the most promising solution.
- In the midterm: Robotising of aircraft systems: remote opening of doors and access panels, automatic connection of systems and utilities. (Physical and information exchange); Automated cargo loading system within the aircraft.
- On the longer term: Aircraft cabin supplies changes, easier for automation and servicing, e.g. catering load supplies more modular with full galley exchange instead of individual trolleys. A more modular aircraft cabin concept[4] could be flyable.

Some elements of a new automated system compared to the current state of the art would be:

- The same circulation rules and speed applied as explained in section 3.
- Further to aircraft arrival and with the exact stopped position known the automatic definition of a zoning to be used by the GSE vehicles for their trajectories, see Fig. 8: Up-down corridors: Connecting front and back service roads on both sides of the aircraft (shadowed light) and allowing movement in both directions. Side corridors (shadowed

[4] https://flytranspose.com/

dark): Connecting the up-down with the aircraft servicing areas. Specific corridor for refuelling vehicles going under the wing that will join the side corridors

To set the priority in case of movement conflict for our case of GSE automated systems, we can use the Table 1 clarifying the priority rules for all GSE involved in the turnaround.

With this proposed solution, the trajectories shown in Fig. 5 will be much simplified as all GSE vehicles will have straight movement trajectories. Congestion will be managed more easily with the automated GSE system.

Considering that in the near future part of the ground handling activities will remain manually operated, ground handling automation will have to be gradually implemented. The first generation of automated ground handling should be relative to the operation of a fleet of specialized autonomous vehicles.

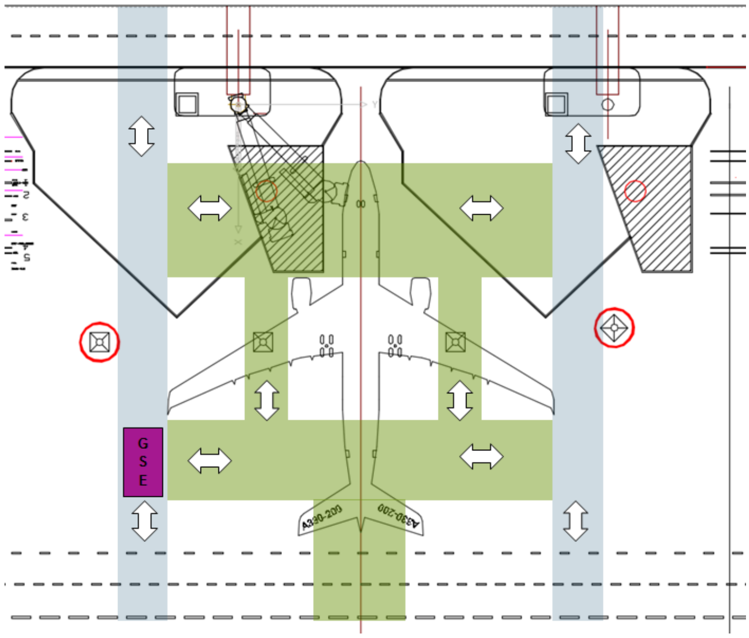

Figure 8: Proposed zoning and directions for GSE automated solution.

These autonomous vehicles will be equipped with sensors useful for:

- Navigation in the ground handling area and access paths
- Guidance along the service access ways
- Collision threat detection with people, other vehicles and fixed obstacles (aircraft and airport installations)
- Automated docking to aircraft using visual targets.

Already available four orientable wheel vehicles should allow following standard tracks composed of straight lines and sharp turns materialized in the ground handling manoeuvre area allowing lateral and direct approaches to the body of the aircraft. Adoption of electrical propulsion supposes accessibility to electrical stations either to charge an on-board battery or to replace the used battery by a charged one. With the momentum the electrical GSE has nowadays, this can be assumed as granted in the near future.

Each automated vehicle will follow an operations cycle composed of several stages (idle park, maintenance, energy charge, charge/discharge operations at aircraft) taking place at specific locations linked by nominal paths.

The whole ground handling fleet could be managed from an operations centre. This management will be performed in accordance with the Collaborative Decision Making (CDM) scheme adopted in the considered airport. This operations centre would be responsible for:

- Assigning vehicles to specific arrival and departure flights according to availability and proximity.
- Generating a time schedule for each activity performed by the GSEs assigned to each particular ground handling operation. For that, an extension of PERT technique to include as activities the motion of the GSEs within the ground handling area and take into account priority rules between them will allow to establish nominal time tables for each GSEs during

its assignment to a given ground handling operation, so that time constraints generated by the airport CDM will be ensured. These nominal timings should correspond to conflict free trajectories for the GSEs.

- On-line follow up of each ground handling operation, however, considering the characteristics of vehicles and planned trajectories, automated conflict resolution schemes [10-14], such as those resulting from the edge reversal technique, could be implemented.
- Management of fleet incidents (vehicle failure) by implementing greedy approaches to restart as soon as possible the corrupted tasks of the ground handling operation.

This will result for each GSEs fleet in a set of decision problems to be solved on-line to face all possible perturbations. For instance, a fleet to task assignment problem can be formulated as:

$$\min \sum_{i=1}^{n}\sum_{j=1}^{m} d_{ij} x_{ij} \quad (1)$$

$$\sum_{i=1}^{n} x_{ij} = 1 \quad j = 1 \; to \; m \quad (2)$$

$$x_{ij} + \sum_{j' \in \bar{F}_j} x_{ij'} \leq 1 \quad i = 1 \; to \; n, \; j = 1 \; to \; m \quad (3)$$

$$\sum_{j=1}^{m} T_{ij} x_{ij} \leq T \quad i = 1 \; to \; n \quad (4)$$

Where T is a receding assignment horizon considering m tasks to be performed by the n GSEs of the same category. In Eq. 1, xij is the binary decision variable indicating if vehicle i is assigned to task j (xij = 1) or not (xij = 0); dij is the distance travelled by vehicle i to perform task j. The above criteria are related with energy and environmental issues by minimizing the total distance travelled to perform the whole set of activities for the considered ground handling function. Other optimization criteria could be considered, however since it is expected that ground handling activities will suffer in permanence perturbations, the optimization criteria is used here as a guideline towards global efficiency rather than as a mathematical measure of the optimality of the solution of a problem which is in permanence resettled in the considered on-line environment.
Constraints in Eq. 2 indicate that each ground handling activity is performed using a single GSE. To each task j is attached the set of tasks not belonging to F_j whose realization by the same vehicle is unfeasible (time overlapping tasks, distance between activity locations, round trip duration, etc). Then constraints in Eq. 3 indicate that when task j is performed by vehicle i, the tasks not belonging to F_j cannot be performed by this same vehicle. Finally constraints in Eq. 4 where Tij is the time needed for vehicle i to perform task j, are relative to the maximum occupancy of each of the GSEs.
From the point of view of mathematical programming, this leads to consider a large combinatorial optimization problem with many constraints. Here, the exact solution from the mathematical point of view is not essential; feasibility is here a critical issue. Then different heuristics, in general of the greedy class, can be considered [14] to produce a feasible solution with acceptable performance.

6 CONCLUSION

The perspectives of the automation of aircraft operations inside the airport parking area will provide opportunities for reducing fuel consumption, reducing cockpit crew workload, improving the predictability of parking and ground handling delays, improving the protection of people, materials and equipment. This new operational concept may lead naturally to the redesign of aircraft ground facilities in terms of layout, interfaces, dimensions and equipment.
More specifically, enabling automated handling of the aircraft as we remove some of the tasks that are currently done by humans would have the following benefits:

- Costs reduction: resource optimization for humans since 80% of ground handling cost is manpower related.

- Rise of profile for handling staff: from very low-minimum wage profile with high turnover to technical/maintenance people skill profile.
- Get rid of ergonomic constraints in airport GSE (e.g. loading heights).
- Security benefit: the less people around the aircraft the lesser opportunities for threats.
- Safety benefit: most incidents and accidents are human related. Reduce human induced errors, automate reporting
- Aircraft status on ground awareness increase with early detection of performance issues.
- "Industrialisation" of the aircraft operation on ground, improving predictability, with more robust rotations less subject to disruption and less spread in times when aircraft are processed (to be noted, not necessarily further reducing the TRT).

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