PERSPECTIVES FOR AUTOMATION OF GROUND HANDLING

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ABSTRACT

This paper presents 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 overcomed 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.

Keywords: Ground operations, Turnaround time, Automation, Ground Handling

1. INTRODUCTION

The 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 as Ground Support Equipment (GSE) which is 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 OVERVIEW

In this paper, only the aircraft ramp handling activities will be considered. The Airbus A330-200 aircraft is used in the figures for illustration purposes along this paper. The ground handling tasks are usually defined and contracted using a Service Level Agreement (SLA) that defines the scope, price and quality level desired and Key Performance Indicators (KPI) as well. Most of the industry use the IATA AHM 810 Standard Ground Handling Agreement [1] as a template. From overall ground handling operation KPI, the ones that are considered the most important are: On time performance (OTP), Minimize the number of resources (GSE, operators, infrastructure) needed, Predictability for ATM in general and Aircraft Collaborative Decision Making (ACDM)* milestones, Aircraft ramp damage avoidance, Avoid personnel incidents and accidents. The ground handling activities are usually divided into "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, and into "Under the wing" activities, which are cargo unloading and loading and other ramp activities: provide electricity (Ground Power Unit (GPU)), condition aircraft cabin temperature, chocking of landing gears, use of cones, marshalling, refuelling, potable water and toilet servicing, towing/pushback and provide access means to the passengers. 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. The generic sequence of these activities, 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, tafety and security requirements for the overall operation, aircraft accessibility to doors and servicing panels. If the aircraft doors and servicing panels arrangement have been designed correctly, most, if not all, of the activities could be done in parallel (See Fig. 1). There are also 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 it, need to deplane passengers before you enplane them. Operational constraints: e.g. some aircraft to avoid tail tipping need to have unloaded first their aft cargo compartment and load first their forward cargo compartment. 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

* ACDM milestones, mainly the Target Off Block Time (TOBT), see: http://www.eurocontrol.int/articles/airport-collaborative-decision-making-cdm

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, cabin activities (catering and cleaning) and passenger boarding, cargo and bulk unloading/loading, refuelling, potable water servicing, toilet servicing, ground power and air conditioned supply (depending on pilot request, availability and regulations of use for aircraft APU (Auxiliary Power Unit)).

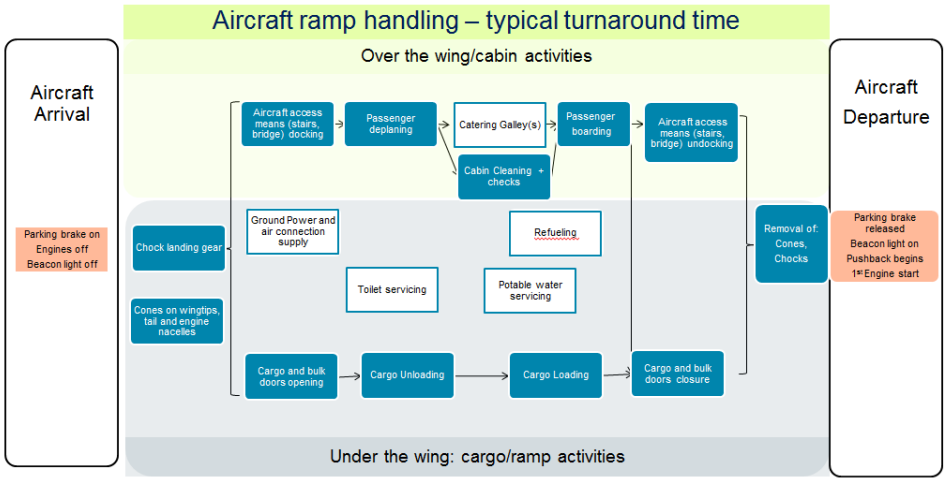


Fig. 1 Typical turnaround time. Tasks sequence.

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 [2]. An example of TRT result for a given scenario is presented in Fig. 4. The vast majority of the cases, the critical path, the sequence of activities that will determine the duration of TurnaRoundTime (TRT), is given by the cabin related activities chain (passenger deplaning, catering, cleaning, cabin preparation and checks and passenger boarding).

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 (number of seats and classes), mission

(short vs longer sector), load factor, specificities of some flight/destinations (e.g. some destination have higher baggage loads), airline operation, schedule and slots available (feeder & hub operation at homebase or destination, transit; point-to-point operation), ramp layout (aircraft handled at the gate with fix facilities vs at a remote stand with no fix equipment…), infrastructure related, e.g. availability and number of passenger boarding bridge (PBB), airline and ground handling policy and procedures. E.g. pre-boarding passengers at the terminal as most European low cost airlines do. "H-40 minutes" (being H, the flight departure time) boarding policy for long range aircraft, "H-30 boarding" for short haul aircraft, resources: human (number, qualifications, efficiency) and GSE equipment (number, type and status and availability), ground handler efficiency and environment: weather (wind, rain, ice, high/low temperatures) and visibility (dust, fog, night). In addition, there are several providers in charge of handling activities for the same aircraft turnaround.

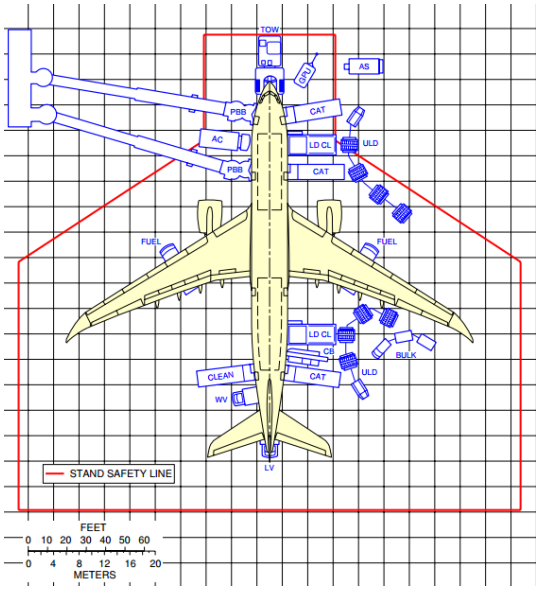


Fig. 2 Aircraft typical ramp layout [2]

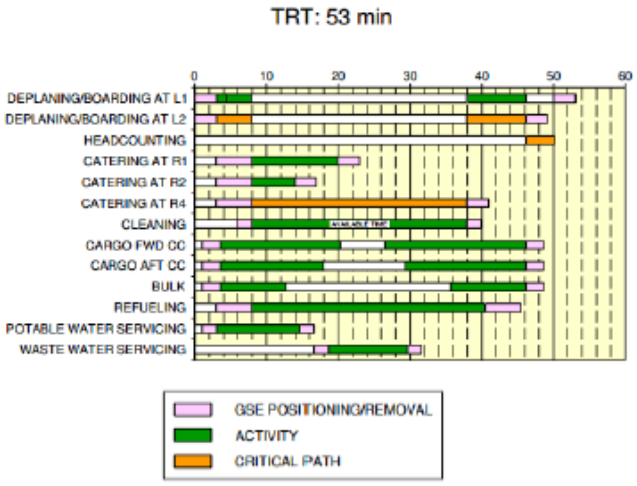


Fig. 3 Example of aircraft turnaround time

Depending on airport size and market regulations[†], the ground handling companies that can typically be found for the same aircraft turnaround are a specialised refuelling company, a specialised catering company at least a company dealing with ramp handling activities (could be even more than four) and a company dealing with passenger handling. To complete the list of

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

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). This high number of actors involved adds to the complexity and management of the process.

3. GROUND HANDLING TRAFFIC ANALYSIS

The airport infrastructure will be analysed now. In this paper 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. 4. 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 for speed zones.

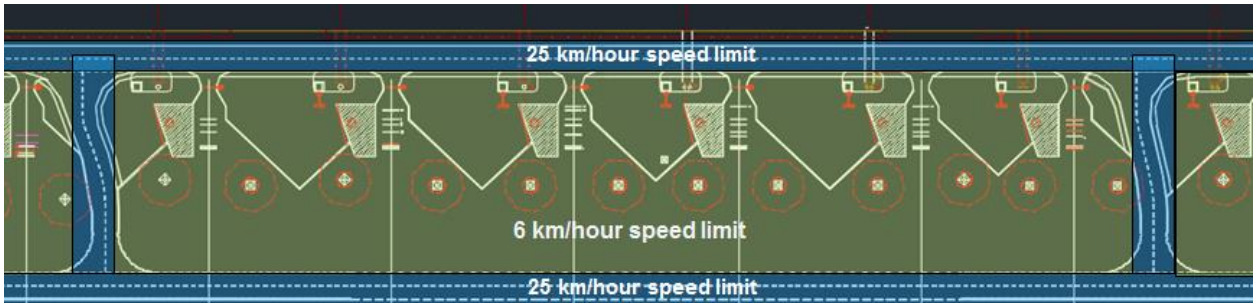


Fig. 4 Typical airport parking layout showing speed limits by zones.

The number of GSE typically needed for a long range aircraft is presented in Figure 2. It is to be noted that these resources are usually assigned in the airport environment between aircraft parking stands with a given criteria: 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.

GSE resources for a long range aircraft are: Passenger boarding bridge (PBB), Fix GPU attached to PBB, Fix PCA attached to PBB, Passenger Stairs, Cargo Loaders, Belt loaders, Catering trucks, Cleaning trucks, Refuelling/hydrant vehicle, GPU mobile, PCA mobile, Air Start Unit (Engine start) mobile, Potable water truck, Toilet servicing truck, Towtractor, Baggage tractors, Container / Pallet dollies, Bulk dollies, Loose and static GSE: cones, chocks, towbars…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.

We can assume GSE circulation rules to be: 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. For GSE docking or approaching the aircraft, only the toilet servicing vehicle 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. Adopting these circulation rules, all the trajectories are plotted 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.

As per all the above description and using the conclusions of other projects (INTERACTION EU project) [3], 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 and aircraft ramp damage.

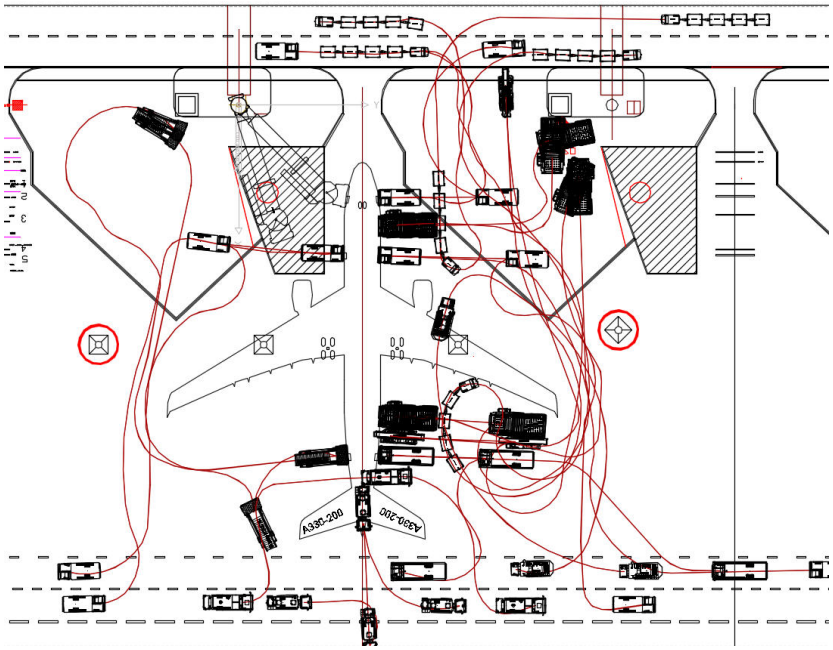


Fig. 5 GSE trajectories for the full aircraft turnaround.

4. OPPORTUNITIES AND CHALLENGES FOR AUTOMATION

4.1 Opportunities

The aircraft handling operation at an airport as described in the previous section details the current situation, but is not significantly different to the way it was 10, 20, 30 or even 50 years ago. 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 or 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.

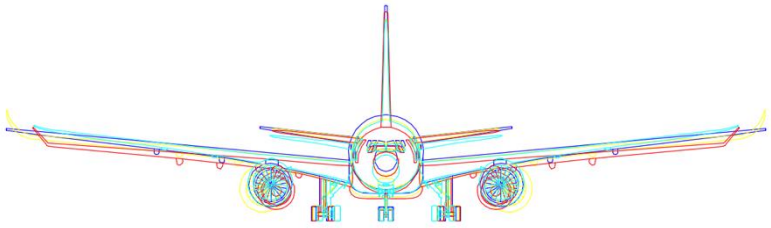


Fig. 6 Aircraft front view comparison.

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 left and/or right hand 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 and with a limited number of potential events of known actors and vehicles. Furthermore, the technology now is available and also affordable. Operator ergonomic (health and safety) requirements are becoming more stringent. 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).

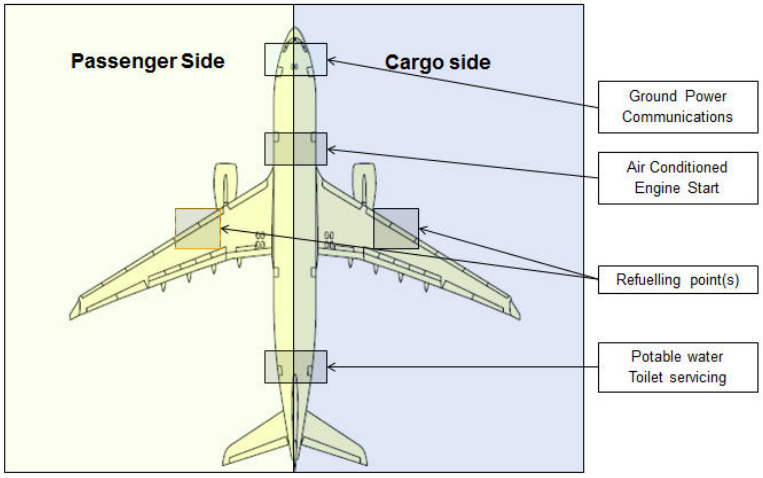


Fig. 7 Aircraft servicing points location.

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, aircraft pushback (e.g. e-taxi [‡]), aircraft towing or dispatch towing (e.g. Taxibot [§])) and in aircraft ground handling (docking of GSE vehicles to aircraft passenger and cargo doors, movement of GSE vehicles around the aircraft and 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.

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 Unilt Load Devices (ULD) like containers and

[‡] 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/

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

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. Failure is not an option. 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.

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 (SAE AS 6896 [8]), aircraft door identification and autoleveling function when GSE is in docked position. In the mid term: robotising of aircraft systems: remote opening of doors and access panels, automatic connection of systems and utilities. (Physical and information exchange) and 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[**] could be flyable.

Around the aircraft parking area, in the short-mid term, a new automated system compared to the current state of the art, would be*:*

- The same circulation rules and speed applied as explained in previous section.

- 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. 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 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.

[**] https://flytranspose.com/

As a natural consequence, all GSE vehicles will have straight movement trajectories.

- To set the priority in case of movement conflict for our case of GSE automated systems

Adopting priority rules, the trajectories shown in Fig. 9 will be much simplified. Congestion will be managed more easily with the automated GSE system. This idea of simplifying trajectories is not new: for example, for the train of dollies, some operators use transporter vehicles wich conmute between the cargo loader docked in position to the aircraft and the dolly train aligned to the aircraft fuselage beyond the wingtip. These transporters take one ULD at a time from one point to the other. The same modus operandi could be used for an automated system.

Considering that in the near future part of the ground handling activities will still remain manually operated, ground handling automation will have to be gradually implemented.

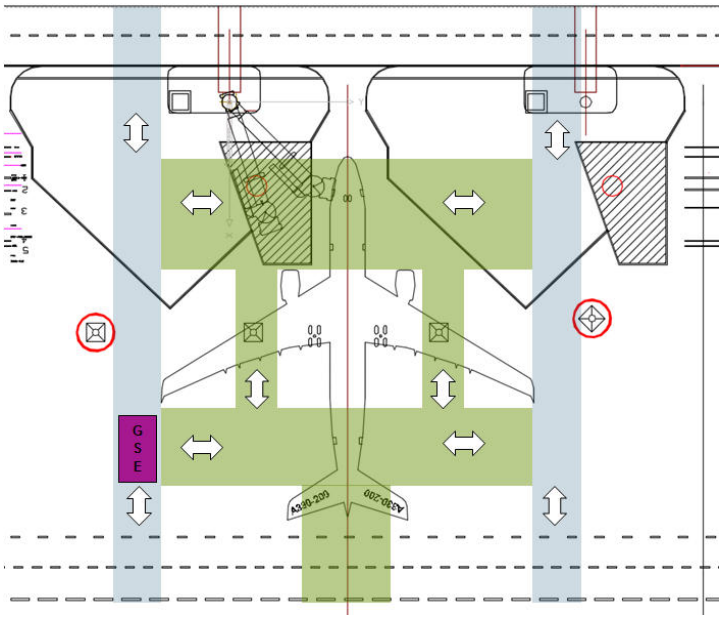


Fig. 13: Proposed zoning and directions for GSE automated solution.

The first generation of automated ground handling should be relative to the operation of a fleet of specialized autonomous vehicles. These 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) and automated docking to aircraft using visual targets. Already available four orientable wheel vehicles should allow to follow 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 to replace the used one 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.

5 TOWARDS AUTOMATED GSEs FLEETS MANAGEMENT

The whole ground handling fleet could be managed from an operations centre. This management should be performed in accordance with the Collaborative Decision Making (CDM) scheme adopted in the considered airport. This operations centre will 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 [9-13], 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:

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

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

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

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

where T is a receeding assignment horizon considering m tasks to be performed by the n GSEs of the same category. Here x_{ij} is the binary decision variable indicating if vehicle i is assigned to task j ($x_{ij} = 1$) or not ($x_{ij} = 0$), d_{ij} is the distance travelled by vehicle i to perform task j. The above criterium is 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 (2) indicate that each ground handling activity is performed using a single GSE. To each task *j* is attached the set of tasks $\overline{F}_j$ whose realization by the same vehicle is unfeasible (time overlapping tasks, distance between activity locations, round trip duration, etc). Then constraints (3) indicate that when task *j* is performed by vehicle *i*, the tasks belonging to $\overline{F}_j$ cannot be performed by this same vehicle. Finally constraints (4) where T_{ij} 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 [13] to produce a feasible solution with acceptable performance.

6 CONCLUSION

The perspective 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 expected benefits:

Costs reduction: resource optimization for humans since 80% of ground handling cost is manpower related, improved qualification of handling staff: from a very low-minimum wage profile with high turnover to a technical/maintenance people skill profile, elimination of ergonomic constraints in airport GSE (e.g. loading heights), increased security (the less people around the aircraft the less opportunities for threats), enhanced benefit (most incidents and accidents are human related), reduced incidence of human induced errors, automate reporting (key point for ground handling damage in composite aircraft), increased awareness of the aircraft status on ground 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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SAE ARP 4084B – Aircraft Ground service connections – Locations and type

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ISO 7718-2 Interface requirements in vicinity of passenger doors (upper deck doors)

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