UNIVERSIDAD REY JUAN CARLOS

AEROSPACE ENGINEERING

AIR NAVIGATION

Optimization of Future Ground Operations for Aircraft

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ABSTRACT

Inefficient ground operations result in significant increases in taxi times and emissions at major airports. The ensuing research endeavours into the conception of new future implementations within the framework of taxiing procedures. In order to reach the maturity of this issue, a pathway is settled analysing the milestones and needs of the actual system. An optimization is carried out through a further analysis of the industrial developments and deepening on the latest scientific investigations so as to depict a global scenario in which to highlight a path towards new conceptions. The conceived ideas cover the whole air ground operations spectrum, from the infrastructure to the coordination and management of the airport. All this implementations have been developed regarding a philosophy of cost reduction, decreasing environmental footprint, maximizing capacity and overall process efficiency leading to a revolutionary outset of what we believe airports will be.

Keywords - ground operations, surface management, taxiing procedures, automation, airport redesign

Introduction

The aim of this paper is to review, compare and contrast the actual situation through which aviation is undergoing. In order to achieve this synopsis, the different concepts, targets and projects will be dealt within the framework of the transformation of the Air Traffic Management Systems. Undoubtedly highlighting the consistency of the aims and concepts discussed along this report referencing other articles, papers or researches.

Attending ACAREs (Advisory Council for Aeronautics Research in Europe) research: *"Aeronautics and air transport: Beyond vision 2020 (towards 2050)"* it settles the basis to ensure the correct approach and deepening to the issue dealt within this paper, the development of an idea which will improve the future of aviation, independently of the technology required for its implementation and appropriate performance. To reinforce the pillars of this research, the main challenges that aviation industry is facing are stated subsequently, as said priory, to capture the deficiencies and needs of the business so to promote the idea later exposed and object of this research.

- Expansion of airspace capacity.
- Intensification of the safety.
- Cost reduction.
- Diminish of environmental impact.

In a further explanation towards this bullet list of challenges, it is again founded in ACAREs document which formerly cited:

> *The airspace capacity is reaching its limit and there are studies that affirm that the airspace capacity will double by 2050, therefore there is a need to create a system capable to handle this capacity.*

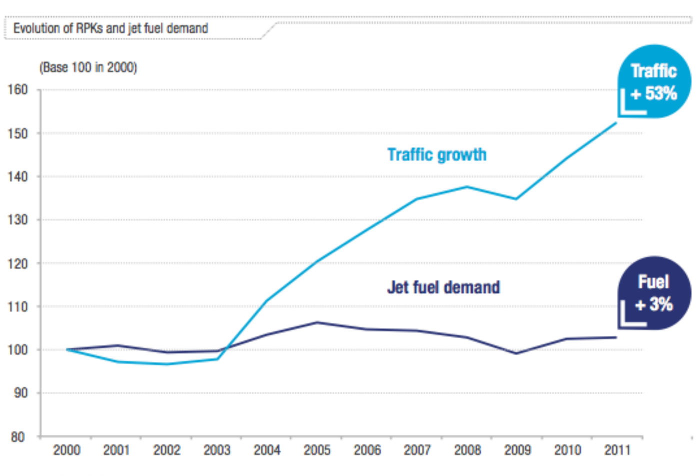

Figure 1: Graph showing the increase in growth of traffic demand and demand in jet fuel.

Aircrafts are already pretty secure, we know that the rate of human decease in airplane accidents is of 0.13 deaths per million of passengers. However, we must never stop improving in this field, which is a continuous challenge.

Cost reduction will be possible due to the increase of the demand as well as the research in management efficiency and the flight efficiency, but we are going to focus our cost reduction investigation upon ground operations.

The reduction in the environmental impact is a very large topic in which there are a lot of investigations going on, such as the reduction of noise, different kinds of emissions (nitrogen, carbon dioxide, etc.) or the research in alternative and sustainable biofuels. Since we will center on the reduction of combustible, this topic will be further analyzed.

None of these schemes or developments can be understood lacking the main platform, the sky. Due to this simple cognitive the first step within the capture of nowadays reigning advances is the unification of this platform. For this purpose, two main projects stand out, NextGen and SESAR. Their implementation is restricted to the United States and European airspace respectively. Both have the same basic aim. This is the conception of a more efficient use of airspace and an improved air safety. Despite this they pursue the same purpose, the implementation frameworks for each of them, are profoundly diverse. The European methodology is founded in a single, multi-stakeholder consortium, rather than the the NextGen ideal, which demands close internal coordination between various government-led programs to guarantee interoperability of the mechanisms delivered by a range of consortia.

Within both programs, automated tools, data network infrastructures, are contemplated. Each concept relies heavily on the development and fielding of an advanced network and data service architecture assets regardless of the physical location, and enabling continuous data communications between all assets within the system in order to improve surveillance capabilities, weather capabilities, heightened security, safety awareness, and other factors to enable highly efficient, effective, and safe ATM operations.

An expansion in each of the stated concepts is granted through the intensification on their inner configuration:

The Next Generation Air Transportation System, (NextGen), aims to transform Americas air traffic control system from the nowadays ground based system to a satellite based one.

- With these future GPS technologies, air traffic controllers will receive point-to-point locations allowing more planes to share the sky while reducing the risk of error.
- Today crossing an airspace boundary means changing radiofrequency, speeding up, slowing down or changing direction. NextGen aims to unify the airspace in order to create more efficient routes.
- NextGen technologies will integrate weather forecasts in order to avoid delays or cancel flights, creating direct paths accounting for wind, destination, traffic and weather.

Having in account all the implementations mentioned above delays will be reduced a 35%.

- NextGen proposals for runway approximation come to say that pilots will receive taxi instructions and gate information even before landing, cutting down in taxi times, and that using continuing descent approaching carbon will reduce carbon and noise emissions while requiring less fuel.
- In order to reduce taxi time, the STM system (Station Management Manual) will set the order of departure automatically, reducing gridlock and delays.
- Using NextGen will allow reducing fuel consumption by 1.4 billion gallons and reducing carbon emissions by 14 million tons. These figures will save 23 billion dollars in costs through 2020.

With these implementations NextGen will reinvent a safer, faster and *greener* air travel for the future.

Regarding SESAR (Single European Sky ATM Research), this memo states the variety of technical and operational options deployed within the Concept. In the field of figures, amongst other objectives it could be highlighted:

- The redesign of the airspace is performed in order to increase capacity by +73% in 2020 (compared to the 2005 situation) and empowering it 3 times in the longer term.
- An improvement in safety: by a factor of 3 for 2020, and of 10 times in the longer term.
- 10% less environmental impact/flight due to ATM
- 50% less (direct) ATM cost/flight.

In order to reach the objectives for such a giant project it is important to set a number of clear and detailed goals. These will serve as an aid throughout the whole design, development and deployment sequences of the scheme. These aims can be summarized in a number of key features that compose the core and integrity of the venture.

- **Business:** An industry such as aviation is extensively interlinked with corporate themes and in a manner that remains at the core of the concept since without this feature none of this would be possible. Cost efficiency and reduction is of extreme importance ant the ATM services must ensure that the needs are obtained, of course while keeping a level of safety and bearing in mind the environment. It is tremendously essential to avoid any alteration to this concept idea all this achieved through the use of a Collaborative Decision Making system.
- **Trajectory Management:** In the past decade the focus has been set on airspace definitions and the clear division of them. This approach is considered as erroneous or at least inefficient therefore a change is required. The move from this mechanism to a greater focus onto trajectories is compulsory. Users will have the ability to fly preferred routes rather than predefined ones. The latter type of routes will only be activated or put into use in extreme cases such as in airspace congestion where a certain capacity must be reached. Of course military rights will be conserved. Airlines should not suffer any type of segregation from other users in the airspace. Two types of airspaces are required: A managed airspace supported by ANSPs and a unmanaged space where the pilot carries out all navigation operations.
- **Collaborative Planning reflects in the Network Operations Plan (NOP):** All main users in careful planning approach in order to form the NOP of extreme importance in this case. This method allows certain capacity needs to be met easily and reflects an efficient management that permits the use of all available resources by all users. This consequently enables the reduction of holding operations and queuing at ground bases. A priority setting can now be used in the case of maximum capacity issues.
- **Integrated Airport Operations:** Airports now will have access to trajectory management operations in order to reduce environmental impact. This can be achieved through the management of turn around schemes and reducing the impact that low visibility conditions have upon congestion. Moreover this will allow the increase in the overall capacity.
- **Separation Modes:** The gradual implementation of new separations techniques that use the integrated control of the trajectory and a airspace separation system will allow the minimization of potential conflicts and the intervention of the AT controllers. Tools offered by air vehicles themselves and controllers will support these.
- **System Wide Information Management (SWIM):** All data taking into account all actors such as aircraft and ground facilities will form the core of a futuristic ATM concept system. All up to date information will be available to all users and with the deployment of efficient applications will be support CDM processes.
- **Human Roles will be vital:** In order to accept the expected increase in traffic the human role will be a core in all decision-making and the new level of automation. These roles will be altered with time, which requires a large education, selection and competence base in accord with all regulations.

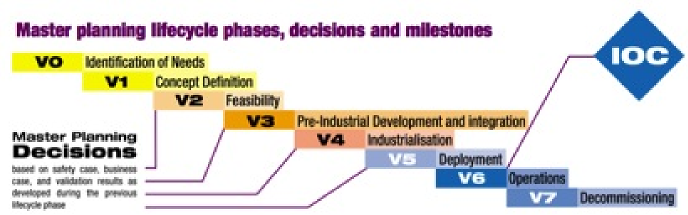

Figure 2: Diagram displaying the master plan process followed by the SESAR project.

The previous background research delivers a clear view of the current needs in the aviation industry such as: the reduction of the environmental impact and their corresponding emissions, an improvement in sequencing which in turn diminishes overall delays along the traveling process and increases capacity and throughput, improve safety specifically during airport surface movements. As ACARE has mentioned numerous times throughout its publications the goal to achieve a fully emission-less taxi procedure.

These goals can be channelled into a unique idea, which has the aim to revolutionize the current aviation condition and encourage scientific research into the subject. Having thoroughly studied a wide scope of the industry a clear need arises among the current issues, more specifically a sequenced airport surface management system which permits the reduction in aircraft taxi time, emissions into the atmosphere and a fundamental increase in safety when dealing with the signaling organisms. This topic has been chosen since the implementation of complex algorithms due to the actual computational limitations that leads the industry to focus the research on other subjects such as continuous ascent/descent procedures that are not as restrictive. Despite this deviation, the field of surface management remains relatively empty and in need for further development. This lack of focus persists since it is of extreme importance to comprehend the concept that every flight starts on the ground and the implementation of such systems is vital.

State of the Art

Once the conception phase and the formulation of the research problem stage have been conceptualized, the immersion in both, the industrial and theoretical platform enclosing our unknown, turn up to be indispensable in order to empower and construct a correct approach to the desired issue of the research, the deployment of the innovative idea. This immersion will be performed due to the support of previous papers and the contemporary concerns and projects of the aircraft industry. In order to have a clearer image of the different ideas circulating within the taxi concept, these ideas will be grouped according to specific criteria and subsequently developed with the back-up of scientific papers and current industrial projects.

Before the scanning of the industry, the overall airport situation will be depicted for a further knowledge of the current needs.

During the past years elaborated studies showed an increasing demand but not a corresponding fast capacity expansion. The predictions derived from this held an annual traffic growth of the 4.8% up to 2030. Straightforward and based on this increasing demand, 1390 aircrafts per year were expected to be required within the period of time 2011-2030. Hence, the correct management of this air traffic flow will lead to a significant cost drop. Delays, per every minute of wait will cost the company 102$. Forecasts aside, fuel consumption within surface operations, represents the 10% of the overall air transport. Additionally airports need to achieve CO2 emissions reduction by 50% and noise abatement. Moreover SESARs deployment reduces the ATC cost by 50% for doubled traffic.

In the wake of the above, it is tangible that when dealing with airport operations some issues prevail amongst others. They stand as a demand so as to create a basis within which the development of distant future airport operations can be gazed at.

- A-CDM (Airport Collaborative Decision Making)
- Unambiguous communications
- Runway entrance control
- No confusing lights
- Less stop and go
- Continuous taxi speed
- Improved controller efficiency
- Optimizing the use of available infrastructure
- A-SMGCS (Advance Surface Movement Guidance and Control Systems)

The subsequent fragment covers the problems previously stated relapsing in the support of the industry projects and in the scientific papers so as to approach a suitable path, which will make visible the gaps surrounding ground operations.

Industrial Approach

Along the ensuing issue, the most relevant and considered remarkable endeavors of engineering so as to empower ground operations will be considered, even though there are projects of interest but not scope of our background research.

The industrial lane covering ground operations is majorly cornered by the enterprise ATRiCS, as it will be seen throughout the different sections.

Regarding Airport Collaborative Decision Making procedures, ATRiCS launched **Pre-Departure Sequencing (PDS)** [14]. It regulates the outbound demand by calculating Target Start-Up Approval Times (TSAT) to provide the most efficient fit to available runway capacity. Especially during peak traffic times, the resulting sequence reduces the negative impact of the traditional first-come-first-served off-block approach.

Benefits:

- **Capacity:** improves slot allocation to minimize delays caused by air traffic flow management restrictions
- **Efficiency and Environment:** reduces stop and go traffic as well as holding times at the departure runways to save delays, fuel and CO_2 emissions
- **Predictability:** minimizes variability of taxi times to support airline network operations and to reduce buffer times in the flight schedules

PDS is currently the only system of its kind that is in operational use at several airports, including Frankfurt and Dusseldorf.

Surveillance Technology is linked to SEARIDGE technologies concerning surface management, which developed Intelligent Video systems, in order to be integrated with ATM systems so to improve situational awareness, safety and security and helping with this evaluation Air Navigation Providers (ANSPs) and airports. According to their products and services, their key benefits for both ANSPs and Airports will be portrayed. SEARIDGE deployed ATC-Grade Video to continuously monitor and present real-time feeds to a one-look. It can also leverage feeds from existing CCTV cameras, making it cost-effective enhancement to safety and throughput in airside operations. Mainly, it increases safety and airport capacity, deals with hot-spot and runway incursion monitoring, shares video data across all stakeholders and manages multiple operations from a single location. Combining these surveillance technologies with an integrated tower platform can unlock the benefits of CDM at airports. This integration with ATM provides more efficient airport management on the surface and in the local airspace. Efficiency of the airport is also achieved through the integration of the surveillance data to Airport Operational Database.

A combination of A-CDM and Surveillance data leads to the ensuing project **Aerobahn** [13] ascertained to improve efficiency and reduce costs along a wide range of fields. Developed by Saab SENSIS, it is portrayed followingly.

The project is considered as a browser, based on surface management systems available for airlines and airports, as mentioned priory, in order to improve efficiency and reduce costs along a wide range of fields. It is aimed at airside operations, which by combining operational information with surveillance data from a different number of sources, provides a clear view of the current state of the airfield. This feature allows users to manage everything from gate conflicts to pre-departures sequencing and taxi routing. All stakeholders receive a wide set of data represented along various methods and thus relating to the Collaborative Decision Making system enabled throughout the whole process.

Through its TaxiView tools, it grants users an outlook of the location of all vehicles along the ground, and permits process improvements as well as post operational system analysis.

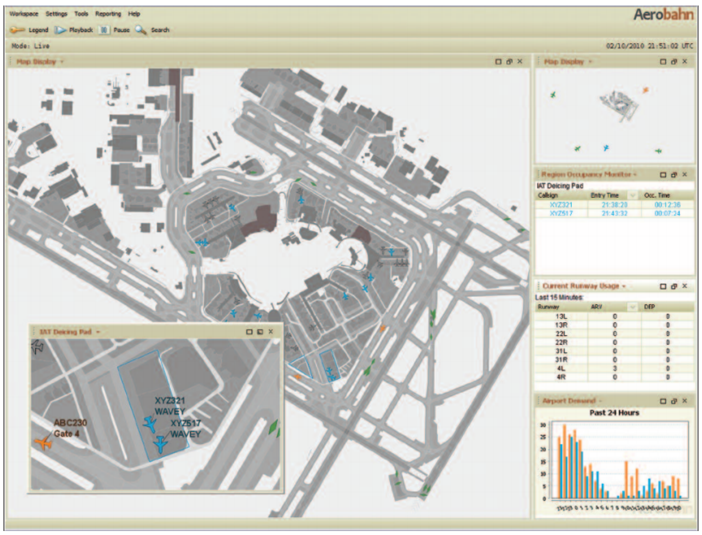

Figure 3: A screenshot from the TaxiView application, displaying aircraft while taxiing.

Over a wide range of benefits stand out the following features:

- **Efficiency and Environment:** This project increases schedule efficiencies. Efficiency is directly related to environment and then this increase turns into a reduction of pollution emissions. Also considering efficiency, an analysis of airport resource usage can be performed leading to better its distribution.
- **Capacity and Resilience:** Maximize runway, taxiway and gate usage. During irregular situations it allows a flowing performance while reducing delays.
- **Safety:**Trend and operational conflict detection and analysis.
- **Predictability:** Forecasting of future events. Easy long-term planning.

Referring to the no confusing lights topic, ATRiCS enabled the so called: **Tower Surface Management System (TSMS)**. It consists of a software system for automated routing, guidance and control of aircraft movements on the ground. TSMS processes the input from the ground surveillance system and automatically controls the airfield lights while continuously scanning the traffic situation for conflicts. The surface management system helps pilots manoeuvering on the ground by creating an ad hoc light path towards the parking area or the runway in use. It intelligently controls airfield ground lights, achieving a level of automated guidance and control proven to reduce controller workload and improve common situational awareness for pilots. The high performance system supports: Surveillance Data Management, Airfield Lighting Management, Individual Routing, and Automatic Guidance Control.

Benefits:

- **Safety:** Avoids up to 75% of all runway incursions by eliminating the main causal factors such as disorientation of pilots, incorrect use of phraseology, misunderstandings and misleading information signs
- **Capacity and Resilience:** Increases the movement rate in adverse conditions and reduces the longitudinal spacing required for safe separation during low visibility.
- **Controller Productivity:** Reduces the controller workload and helps to improve the controller-movement ratio.
- **Efficiency and Environment:** Reduces taxi time by avoiding delays and interruptions in the flow of traffic, maintaining throughput, a continuous taxi speed leading also to a decrease in fuel consumption. As a direct result, fuel burn and CO_2 emissions are reduced proportionally.

TSMS is currently used at several airports, Berlin, Dubai, Kuala Lumpur and Seoul.

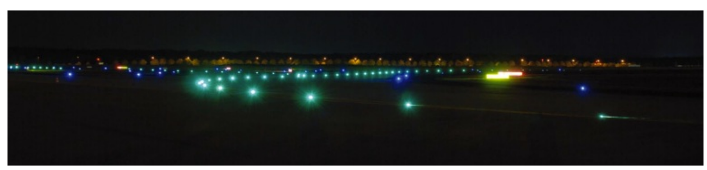

Figure 4: View from the cockpit, with a view to the taxiway. Notice the path illuminated with green LED lights

Fuel consumption drop is noticeably the pursuit of all airliners. In order to achieve this diminution **Honeywell** launched its **Electric Green Taxiing System**. This project employs APU, the planes Auxiliary Power Unit, to provide power to specialized motors near the main landing gear wheels. Unique power electronics and system controllers allow the pilot to control the speed, brakes and direction of the aircraft throughout ground transportation.

Moreover, **TaxiBot** [6] is a system developed by the Israel Space Industries Ltd. It is a semi-robotic designed with the purpose of towing the selected aircraft to its assigned runway and vice-versa with an external engine to the airplane. This system eliminates the need of aircraft fuel consumption due to engine use during taxi-in and taxi-off operations. An ordinary PTS-1 tow truck is attached to the aircraft nose landing gear, and transferring the control of this extension to the on-board crew. Vehicle electronics allow the towing operations to be managed while in pilot control mode. During the process a command, control and communications centre monitors its behaviour and the mission execution. Data links, video and audio are transferred over an advanced, flexible, wireless communication system equipped within. The pilot is able to remain at all time connected to ground traffic controllers, pushback and return drivers in the vehicle. The system offers no radical changes to the crew, since all control remains using existing controls on-board providing a transparent taxiing feeling. Taxiing speed with a fully loaded aircraft is remains as current, up to 40 km/h.

The main difference of permitting taxi while aircraft engines are disabled results in a number of advantages:

- **Efficiency and Environment:** Reduction in CO2, NOx and other emissions, dropping from 18,000,000 tons per year to only 2,000,000 tons. Reduced noise pollution. Lower fuel consumption on general gate-to-gate period reducing from 126 gallons to 7-15 gallons of fuel consumed. The system is able to reduce costs of global fuel consumption from $7,000,000,000 to only $750,000,000 per year, considering more than 81000 per year. Fewer jet engine hours.
- **Safety:** Increased safety. Fewer runway incursions. Reduced levels of Foreign Object Damage (FOD), saving a total of $350,000,000 per year.

Initially tested at the Toulouse (France) airport with a variety of Airbus aircraft, and is being executed at the Frankfurt (Germany) international airport during a trial period of six months starting in mid-2013 with Boeing 737 operations, while certification is in process.

Figure 5: A TaxiBot from IAI operating at the Toulouse Airport with a Airbus A340-600

Optimizing the use of available infrastructure

GECIs **Q-MITS Airport (Quick Modular Integration Terminal Solutions)** initiative so as to modify airports infrastructure according to the given demand, grants the flexibility to expand or down size dependent on your requirements, reducing the risk of sudden changes occur.

Scientific Research Approach

No industrial project is performed lacking the prior scanning research step. Hence this section encompasses all the needed background required for any project. The scientific research is comprehended within the academic level and is intended to further advance the progress of science. The researches covered subsequently stand for the studies performed within airport congestion, runway optimization, pre-departure sequencing and various Taxi systems, which will empower airports efficiency and that will settle the path in order to perform the correct approach to harbor the outstanding idea dealing with ground operations.

The scheme of this concern will start from overall ideas funneling the subject first to the conception of airports, airport surface management and runway scheduling and conclusively dealing with Taxi systems uprising various researches focused on the aim of this project, Taxi-boats.

Airport conception

In order to understand how does the implementation of improvements evolve within airports ground operations, regarding different countries, two airports will be compared. Each of them will be relying below different Airspace systems, NextGen (USA) and SESAR (Europe). These are EWR (Newark airport) and FRA (Frankfurt airport) respectively.

These two airports were selected because both have mainly the same characteristics; by the time this research was being developed, both had two parallels runways and a third one. The difference between these airports relied in the display of this third runway.

In FRA the third runway remains independent from the parallels, making easy the capability and reducing taxi time, rather than in EWR, where the third runway was dependent on the other two.

From the analysis of the aircraft movements and the number of ground operations two conclusions were achieved. Due to the number of gates, movements within FRA turned to be limited to the number of slots, resulting in few delays, the largest was of ten minutes, but the airport did not cover the real demand that was able to shelter. In the other hand, regarding EWR airport, the airlines scheduled movements referring to the VFR, which predicted the number of movements. Hence, it covered all the demand but it had long-range delays between 30 to 60 minutes.

Before intending the scientific approach to diverse papers so as to depict a global scenario of the current researches taking place within the matter of ground operations, it is extremely important to internalize the close bond concerning fuel consumption and taxi time. This relationship is granted through the following paper **"The trade-of between taxi time and fuel consumption in airport ground movement**[11]. This paper presents a new development multi-objective approach to analyze the balance between the running time and Fuel consumption during taxiing. The approach is a combination of a graph-based routing algorithm and a population adaptive immune algorithm to discover different velocity profiles of aircraft.

The results showed that the integrated procedure is able to tackle this hard problem in a comparatively efficient way. Furthermore, results seemed to be consistent over several days, although more research is needed in order to upgrade the system.

The ensuing section embodies Airport Congestion subject. Within the expansion of this topic, two perspectives will be granted: Pre-departure sequencing and surface management and runway scheduling. Prior to the maturity of this matter, it stands as major relevance the comprehension of **Analysis of Surface Congestion Management Technique** [8]. This paper reads Airport congestion as the main cause for significant increases in taxi times, fuel burn and emissions. For this reason various surface congestion techniques as the push back rate control or the Collaborative Departure Queue Management (CDQM), tested at Memphis airport (MEM) are being developed. This paper describes the development of one of such techniques at the JFK. Through the analysis of operational data, the study has calculated that by implementing this system we could save the amount of 5.0 million US gallons of fuel and 48,000 metric tons of carbon dioxide emissions per year by reducing taxi time (14,800 hours).

Every airport has a limit of aircrafts, which can be efficiently handled. This number relies strictly dependent to the airport characteristics such as runway configurations, meteorological conditions this study aims to work with this limit instead of exceed it, so as to continue being efficient. For doing this we need to hold the aircraft or relocate it with off-engines until they can be released to the departure runway. What this research intends is to move the excess congestion flights to new time departures so that they will always manage the appropriate number of flights departures. The thresh of this paper will be granted by other researches with similar scopes. This section will encompass pre-departure sequencing and Airport surface management and Runway scheduling respectively.

Regarding Pre-departure sequencing, **Demonstration of Reduced Airport Congestion Through Pushback Rate Control** [12], for the occasion of the Ninth USA/Europe Air Traffic Management Research and Development Seminar otherwise known as the ATM2011, a team of leading engineers from the Massachusetts Institute of Technology published its winning case study titled *Demonstration of Reduced Airport Through Pushback Rate Control*. This scientific paper had as an aim to discover a manner or at least lead into a mechanism to reduce a significant number of taxi times in order to diminish fuel burn and emissions at major airports. The flied tests were carried at the Boston Logan International Airport between August and September 2010.

Trends in Europe have signalled that up to 10 to 30% of the flight time is wasted during taxiing. As a matter of fact 5 to 10% of the fuel consumption from an average short to medium flight on an A320 is lost on the ground. Moreover domestic flights in the United States account for 6 million metric tonnes of CO_2 that are released into the atmosphere. The study focuses on a pushback rate control strategy that helps regulate pushback rates when the surface is in a congested state. This method relies strongly on a threshold limit denoted as N which limits the number of aircraft to be permitted for departure in order to allow a much more efficient throughput. The value given to this variable is indeed crucial and is dependent upon the airport, arrival demand, runway configuration and meteorological conditions.

There were a total of 16 demo periods; during some of these periods it was possible to apply the pushback rate control system due to congestion conditions on some runway configurations.

Taxi time until take-off, are reduced when the aircrafts are ordered to remain at their corresponding gates.

The graph above represents a set of the results obtained from the study in which it is possible to notice the red bars that represent the holding time at the gate. Clearly green bars, representing the taxi time until take-off, are reduced when the aircrafts are ordered to remain at their corresponding gates.

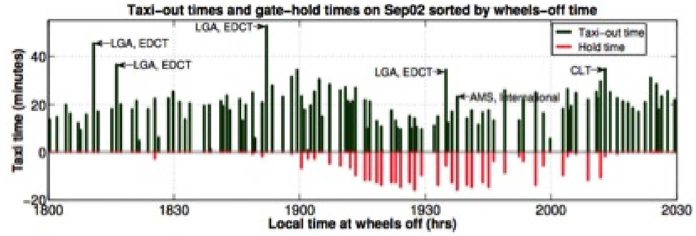

Figure 6: Taxi-out and gate-hold times from the field test

The contrast between the application of the pushback rate control and a normal situation is that the average taxi times are reduced considerably. The system seems to be at its maximum efficiency when the peak demand is reached, during late afternoon periods (1800-2000).

A total of 247 flights were held at their corresponding gates experiencing an average hold of 4.3 minutes. At highly congested period up to 44% of the flights were ordered to remain at the gate therefore reducing runway utilization and increasing engine off time. During the field test a total of 1077 minutes elapsed in gate holds, or 18 hours.

Translating this data to fuel burn savings, it can be said that from the saved 17.9 hours of taxi time a range of 12,000-15,000kg of fuel were avoided. This represents 50-60kg of fuel saved per flight. The presented method requires much more basic procedures allowing for an easy implementation.

Regarding Airport surface management and Runway scheduling, a paper developed within the framework of the eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM2009), grants **Airport surface management and runways scheduling** [4] analysis and its further optimization. Performed by Raphael Deau, Jean-Baptiste Gotteland and Nicolas Durand.

The paper deals with the interactions that have to be developed between the runways scheduling (AMAN-DMAN) systems and the surface management (SMAN) system, in order to reduce the ground delay. It studies the way to integrate Advanced Surface Movement Guidance and Control Systems together in order to optimize the runways sequences in busy airports. The research is carried out in Roissy Charles de Gaulle airport. Firstly, a runway sequence analysis is performed where the ground delay that would result from the only runways capacities limits is evaluated. This delay appears to be half less important than the delay measured by a complete ground simulation of the same traffic sample, in which the whole taxiing constraints of aircraft are considered.

Subsequently the integration of these runway sequences into surface management where the ground conflicts resolution algorithms are refined so to be integrated in the SMAN system of the airport, in order to minimize the impact of the taxi delay and to fit to an evolutive runways scheduling. The resulting ground delay should be reduced and the traffic predictions of the DMAN system should become more relevant.

The last step of the funnel leads to the conception of a new **Taxi System**, in this case attached to NextGen (United States National Airspace System). **ANTS** (Automated NextGen Taxi System) [1] aim a towing system that suggests the unique use of an electric pushback during the gate-to-runway taxi delaying the engine start up. The preliminary cost estimated for ANTS implementation amounts to about $25 million in Phoenix Sky Harbor International Airport (PHX). However, in a very short period of time, the return on investment proves its merit by repaying initial costs after only a couple of months, taking into account fuel expenses during taxi and assuming every aircraft uses the system. After the first two months, fuel savings were calculated to an average of $18 million a month on more than 38,000 flights (ACI, 2010). Therefore, implementing ANTS to PHX gives the airport a great cost advantage, saving nearly $200 million for its air operators in the first year of operation.

Another step in the automation of taxi systems is considering the crew capable of managing the taxiing procedure without the help of the ATC. The level of autonomy within low visibility conditions is deepened along the subsequent paper **Evaluation of an Autonomous Taxi Solution for Airport Operations during Low Visibility Conditions** [2]. The study took place in Netherlands and a simulator was used to recreate a situation of Low Visibility Conditions. The purpose of the study was to evaluate the capability of the flight crew to carry out the tasks of the Air Traffic Controller (ATC). The experiment was repeated several times changing some variables such as the visibility conditions and the level of autonomy. The results showed that the flight crew does not have problems of safety doing the taxi by itself, but when talking about efficiency during Low Visibility Conditions the help of the ATC is needed because the flight crew does not have enough information about other aircrafts in the airport.

Concept Idea

The previous analysis stage is indeed a fundamental phase in order to fully comprehend the state of the corresponding fields dealt within this investigation. Both the scientific and industrial projects are useful in defining and setting clear objectives to the outlook of the current status of the art. Along the following section all conclusions extracted from the gathered ventures will be summed up and filtered to subsequently form what can be considered as the final idea to be obtained from this study.

Referring to the studied papers it is noticeable that a clear distinction can be brought up from the aircraft surface movement field. In the current era projects within this area tend to follow one out of two directions to reduce delay, improve efficiency, and reduce emissions at the airfields.

Firstly dealing with what can be defined as surface management. This region of research deals with the coordination of aircraft movement along an airport, their pushback and taxiing operations. These can be efficiently ordered through the use of complex mathematical algorithms as we have seen throughout a variety of scientific papers. These methods tend to vary, and as seen can be focused on different variables such as

- Holding times at gates or other areas in order to reduce waiting times at taxi ways,
- Scheduling of runways depending on flight times,
- Assignation of slot times,
- Increase efficiency of taxi routes while avoiding stops and congestion at taxiways,
- Redesign taxiways to represent shorter paths in terms of distance and time.

All of these methods have been thoroughly tested during field trials, some at important international airports and produces positive feedback, which represents clearly how it may be only a matter of time until some of these projects are certified and implemented for use on a constant basis.

Conclusions drawn from these projects presented a noticeable decrease in fuel consumption while on ground when compared to generic surface operations. This benefit stands out with extreme importance since the bargaining power of the aviation industry is at most times held by airlines, which at times of economic recession are focused on the reduction of costs, one of them being fuel consumption. With extravagant figures for savings projects such as these, shows ideas such as these would probably be funded by airlines from all around the globe. Other factors such as the objectives published by agencies such as **CleanSky** push airports to fund these projects and implement as soon as possible.

However in a society where the use of aircraft has been projected to threefold in the coming 30 years the reduction of congestion is an extreme risk. This meaning that coordination of flights and efficient taxi operations are required to reduce delay times if not make them disappear.

Secondly, there is an alternative direction which industries can be aimed towards, that is complete redesign the taxi and pushback approach. Nowadays pushback operations are carried out through the use of the well-known tow tractors, which attached to the nose gear guide the aircraft during short distances. While on taxiways aircraft are generally propelled with the use of its own engines, an inefficient attitude with exceeding fuel consumption and emission releases.

A number of projects have been ideated in the past years in order to tackle this issue. Scientific projects such as the **Autonomous NextGen Taxi System** otherwise known as **ANTS**, centered on the idea of automatic lightweight vehicles capable of powering the aircraft throughout its taxiing and delivering it to its assigned runway, is a reasonable solution. Other approaches involve one engine off taxing operations that are already being implemented in many circumstances. Projects with high prospects include the **TaxiBot** system which using available airport vehicles that must be lightly adapted are able to cut off completely aircraft engine fuel consumption by allowing the pilot to control the plane with the help of an attached tow tractor and by this mean reach the runway.

Future projects on such fields should be extensively based upon both of these approaches in order to fulfil the aims presented at the beginning of this investigation.

Automation of the airport

A fully integrated automation will guarantee maximum transparency within all levels. It could be performed from check-in to reclaim, and from baggage handling to airport administration. The automation proposed along this research benefits throughout the airport growth, from the initial planning stage, through operation, leading towards modernization. The scope of this paper is to uncover a path to unite operations together in one central framework. Just requiring the input of data in a single location. This central management provides the consistency of the data and the automatic debugging of errors. This will be accompanied by the simplification of the procedures trying to limit the operational cost.

Parallel to the conception of an automated system it is important to envision the human role within the system, maximizing to the furthest the interaction between human and machine. This variable strictly relies on unrelenting technology development in areas such as decision support tools and visualization technologies. Straightforward, this should be accompanied by an ease of the use of complex systems. The optimal synthesis of our scenario, depicted subsequently, will determine the degree of modern automation systems and the necessity of humans in the loop.

The whole process of computerization conceives the automatic assignation of runways, which directly copes to sort out the problem of pre-departure sequencing. A mechanism throughout which aircrafts are computationally communicated to exit the slot they are in. This is due to the fact that, as seen in prior researches, holding pushback for a couple of minutes saves tons of fuel.

The combination of the above implementations joint to the revolution of take-off and landing throughout the complete computerization of non-piloted tows, as it will be shown, will lead to fulfill the economic pursuits of airlines. Besides, this proposal tackles delays issue, as it would allow a perfect harmony between the taxiing of every aircraft, proportionating the required space and speed so as to deal every situation.

Surface Management

As observed through the various papers studied and previously stated, it is vital for future concepts to involve surface management systems. Many of them encompass the use of mathematical algorithms to sequence planes at various states.

The most efficient method published implicates the elongation of holding time of aircraft that in time avoids congestion at taxiways. These stops carried out at taxiways represent an extremely high consumption; the avoidance of these actions is of tremendous importance to reduce the overall fuel use and emissions. Other methods such as the Collaborative Departure Queue Management systems are able to greatly reduce volumes of fuel use.

Aircraft sequencing also plays a big role since many issues can arise if this performance is avoided. Different classes of aircraft tend to leave turbulent streamlines at runway take off areas and therefore require a waiting time to be established. The correct ordering of these aircraft classes will allow a much more efficient departure sequence reducing delays and surface congestion.

In order to build these algorithms a highly efficient surveillance system must be set up along the entirety of the airfield. Such systems have been implemented at projects from companies as **ATRiCS** with their **Follow the Greens Initiative**. These are based upon high performance surveillance systems that are extensively linked to the lighting system on ground and through their use guide the aircraft along the surface.

All in all, the main objective in future airport operations should aim to reduce taxi time since all other consequences tend to be connected to the latter.

Autonomous taxing

In the attempt of furthering within autonomous taxiing and the methods of movement, the idea of electric taxi robots, automated tow trucks that perform all operations independently. These robots will run on battery-powered with electric motors. The employment of lightweight material is a key feature so to upgrade the efficiency of the tow. Speed will be limited up to 40 kilometers per hour with the possibility of enabling extra power in case it is required.

Pilot is connected with the bot through a touch screen inside the cockpit. This taxiing system contemplates sensors hidden in the airport surface permitting the taxi robot be directed towards the destination selected. The navigation system of these vehicles will be integrated into S-MAN system in order to achieve a perfect harmony between the taxiing of every aircraft. Besides the incorporation of a new accident-free navigation performance will grant the pilot the freedom of no worrying about the driving and navigating tasks.

A novelty presented will be the integration of a lithium-ion battery able to be recharged wirelessly. This battery can also allow the tow to acquire more power in order to proportionate space, speed in case they are required and grant more independency to the tow.

Benefits presented by these Electric taxi robots are:

- Fuel consumption drop.
- Better management of traffic flow within the surface of the airport.
- Increase in capacity.
- Reduce of controller and pilot workload.
- Decrease in emissions, turning to be an environmentally friendly system.

Method for movement

The objective is to optimize the taxi time and reduce as much fuel as possible by riding off the aircraft thrust during the taxi time. In order to achieve this objective the aircraft during the taxi time needs to be propelled by other means instead of its engines.

The idea is to introduce rails in the airport from the apron to the runway. Those rails will propel the aircraft, depending on the inbound or the outbound at the taxi; the aircraft will be connected to the rails in the apron or in the rails and will be disconnected at the end node (in the apron or in the runway).

The advantages of this idea are:

- Lack off the auto propel of the aircraft so it will reduce the fuel.
- A more precisely control of the aircraft so it will allow increasing the search velocity at the taxi ways and reducing taxi time.
- A higher automation of the process which will reduce voice time between the pilot and the controller that reduce the work of the controllers and also reduce the taxi time.

The only disadvantage in this project is the building cost and the remodeling of the airport infrastructure. The project will only be feasible in the case that the fuel saving is higher than the building cost. We must also take into account the cost of the energy consumed by the engine that pulls the plane along the rails. The consumption as a function of time for this device is going to be much less than that consumed by the aircraft if propelled.

$$\Sigma_{i=0}^{n} \int_{t0}^{tf} f_{\text{engines}}(t, k_i) > \Sigma_{i=0}^{n} \int_{t0}^{tf} f_{\text{rails}}(t, k_i) \qquad (1)$$

- n: Number of aircrafts
- t: Taxi time
- k:Wasting fuel coefficient

So that the saved costs related to a time t, would lead to the following equation:

$$\Sigma_{i=0}^{n} \int_{t0}^{tf} f_{\text{engines}}(t, k_i) - \left(\text{Cost infrastructure} + \Sigma_{i=0}^{n} \int_{t0}^{tf} f_{\text{rails}}(t, k_i) \right) = \text{Saved cost}$$

To reduce $f_{railes}(t, k_i)$ there are two ways or create a device that propels the aircraft using low energy or as in our case create surfaces in which the aircraft can be moved easily and thus reduce the force required to push the plane.

Our design is based on the use of rail-based quantum levitation theory that minimizes the friction that makes the weight of the surface plane. This theory is a drawback because of the need for a high degree of magnetism, which requires a very low temperature that currently can only be achieved with expensive materials like liquid nitrogen. That with todays technology is not feasible. The idea of quantum levitation is very recent and is expected to be developed in the near future.

Sources of energy

In order to power all of these systems an efficient source of energy is required. Many choices arise regarding its location but without doubt the clearest one remains ins situating the power source at the airport site in order to avoid transportation issues and losses that may appear over long distance energy transfers. To comply with the stated aims it is necessary for this source to provide renewable energy, and therefore result in zero emissions being released into the atmosphere. Modernized airports aim to obtain large percentages of its energy from non-polluting methods. Ideas considered include solar panels across large open surfaces, rooftops or fields, most of the times very common at airfield sites. Wind farms would offer difficulties to low altitude flight and should therefore not be considered. Energy from close locations is also an option; this idea would contemplate other sources such as nuclear power.

Other options include approaches in which the transmission of this commodity may be avoided; this can be achieved through the use of fuel cells. These can be mounted directly on to the required vehicles and can be powered by different elements. The most widely known type includes the hydrogen fuel cell, although storage sites at the airport would be required.

Terminal Redesign

[3] The airport is an intermodal infrastructure that allows passengers and cargo to change from ground transportation to air transportation, this idea intends to change the concept of airport as it is known nowadays basing on the metro model. Since the objective is to find a way to reduce fuel burn and emissions by reducing taxi time this revolutionary idea accomplishes all our objectives and more.

The proposal is to have an underground airport (where we could realize all the management, checking and security steps) that connects directly the passenger from underground to the aircraft located on its runway and ready for departure [5]. This idea seems very futuristic but if we think about it we have done it already, we have created huge stations below ground and by developing the airborne metro we could have a lot of benefits some of them stated below:

- No taxi time.
- More surface area which would allow a substantial increase in the number of runways.
- Less congestion at the airports.
- More accommodation for the passengers since the number of delays would be reduced as well as the holding time.
- Less complicated surface management procedures.

These direct consequences lead to other advantages such as the reduction of fuel burn and emissions, the increment of efficiency and capacity, reduction of costs In conclusion the airborne metro seems to be the solution to many of the problems of nowadays aviation in terms of airport management but we have to recognize that the cost will be excessive. For this reason and because the idea imply the design of new technologies and the re-estructuration of the airports we have to discharge it but we aim its further development because it may be very interesting to construct one and see it‘s performance.

Conclusion

Along the research the conception of ideas and their subsequent maturity have always been under the considerations for granting expansion of airspace capacity, intensification of safety, cost reduction and the diminishing of the environmental impact. The implementation of the former mind-sets has allowed the system to be upgraded to a level of automation where the role of humans within the loop is almost negligible.

The optimization of the surface dealt within the former exposures prerequisites a complete revolution of the airport, encompassing the infrastructure and surface management therefore leading to the unification of all stakeholders empowering as priory mentioned: coordination and management so as to achieve safety, efficiency and security.

Within the approach to a new airport concept it is important to underline the necessity of resorting to multidisciplinary releases such as material science so as to enable the elite innovations of each knowledge field uniting towards a new airport model that will sort out the difficulties presented in the system, and reaching business conditions that nowadays remain utopic.

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