Multimodal, efficient transportation in airports and collaborative decision making

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Abstract. Be it snow, volcanic ash or strikes, crisis events impose high costs on the air transport system and society. Airlines have progressively learned to mitigate the irregular operations arising from such events through procedures such as Collaborative Decision Making (CDM) for traffic flow and airport departure management; however the passenger's door-to-door journey during difficult times often remains unpleasant. Meta-CDM (Multimodal, Efficient Transportation in Airports and Collaborative Decision Making), aims at taking a passenger-centric approach when examining how airside and landside CDM can be interlinked with other transport modes to minimize the impact of severe disruptions. In this paper, we provide a preliminary analysis of past successes and failures of passenger-centric operations, by documenting the state of the art in airport CDM, by investigating representative disruptive events and by studying the conditions of development of airport intermodality. In addition, as the success or failure of any new concept depends on which metrics it is being evaluated against, we also discuss the need of relevant KPIs to measure the success of an extended CDM concept.

Keywords. Collaborative Decision Making, Total Airport Management, Disruptive events, Resilience, Multimodality

1. Introduction

Air Transportation is intrinsically tied with other modes of transportation, such as rail, roads and water. The objective of making each passenger or cargo's door-to-door journey seamless cannot be achieved without a better understanding of the multi-modal transportation network. In its vision for Europe in 2050, the

European Commission [1] sets the goal: "90% of travelers within Europe are able to complete their journey, door-to-door within 4 hours. Passengers and freight are able to transfer seamlessly between transport modes to reach the final destination smoothly, predictably and on-time." The regular occurrence of significant perturbations that propagate through the system and sometimes even paralyze it highlights the need for further research on its resilience and agility and for adequate coordination at the network level. At the airport level, this is beginning to be addressed by Collaborative Decision Making (CDM) initiatives, tools and procedures. The objectives of the META-CDM project are to study the conditions under which Collaborative Decision Making can help the transportation system deal with major disruptive events as they affect civil aviation and facilitate the passenger's journey.

Crisis events, whether caused by severe weather perturbations or strikes, impose high costs on the air transport system and society. Airlines have progressively learned to mitigate the irregular operations arising from such events through procedures such as CDM for traffic flow and airport departure management; however the passenger's door-to-door journey during difficult times often remains unpleasant.

Recent events have shown the need for better handling of crisis themselves and also of the recovery process. The objectives of Airport Collaborative Decision Making (A-CDM) are to reduce delays and improve system predictability, while optimizing the utilization of resources and reducing environmental impact. Several European airports have by now completed their conversion to A-CDM. A-CDM is one of the five priority measures in the Flight Efficiency Plan published by IATA, CANSO and Eurocontrol.

The present paper aims at surveying the current state of CDM in Europe through a case study on a major hubs and paving the way towards innovative multimodal passenger-centric transportation through the CDM initiative. The paper is organized as follows. Section 2 describes the research state-of-the-art on the topic. Section 3 presents the case study on Roissy Charles de Gaulle airport. Section 4 focuses on the upcoming projects and discusses the future challenges to be met. Section 5 draws the conclusion and formulates the next research questions.

2. Research overview

2.1. Collaborative Decision Making

A number of European airports have, over the past decade, taken major steps that aim at coordinating surface operations with airborne traffic. The A-CDM programs have resulted from many years of implementation efforts. Munich, Brussels, Paris CDG, Frankfurt and London Heathrow airports are now labeled A-CDM. The objectives of A-CDM are to reduce delays and improve system predictability, while optimizing the utilization of resources and reducing environmental impact. An airport is considered a CDM airport when A-CDM Information Sharing (ACIS), Turn-Around Process (CTRP) and Variable Taxi Time Calcula-

Figure 1. Collaborative Decision Making Process.

tion (VTTC) concept elements are applied at the airport [2]. In Europe, airport CDM has been implemented successfullly at several airports and are expanding. Collaborative Air Traffic Management is now a key component in both SESAR and NextGen.

In [3], the authors develop and analyze two approaches to incorporate stochastic optimization models in a CDM-like setting. These models are able to create a traffic flow management plan for a set of flights whose flight plan intersect a volume of airspace undergoing a severe capacity reduction. In their scenarios, the ANSP allocates certain resources to the flight operators and the flight operators then optimize the use of resources they are given.

One of the first efforts to evaluate the potential of CDM at the network level is undertaken by Bertsimas and Gupta [4]. They propose an Air Traffic Flow Management model with a CDM framework from an airport setting to an airspace context incorporating fairness and airline collaboration. Their empirical results of the proposed model on national-scale, real world datasets, show promising computational times and a proof of the strength of the formulation.

2.2. Delay propagation and operations under degraded conditions in the Air Transportation Network

The world transportation industry is a critical infrastructure with a significant impact on local, national and international economies. Most cities are peripheral nodes, i.e. the majority of their connections are within their own community. The nodes that connect different communities are usually hubs. Between China, Europe and the US, the European network has the highest percentage of destinations, the highest number of direct flights per airport, but connections requiring intermediate airports require larger waiting times than in the American and Chinese networks. In Europe, there is a high percentage of airports accessible within a single day, probably because each country favors connectivity towards its own local airports. Such policies reduce the efficiency of coordination between countries, resulting in higher waiting times.

Significant effort has gone into trying to better understand delay propagation in the air transportation network over the past few years. Pyrgiotis et al. design an analytical queuing and network decomposition model that computes the delays due to local congestion at individual airports and captures the "ripple effect" causing the propagation of such delays [5], both in Europe and in the US. AhmadBeygi et al. study the relationship between the scheduling of aircraft and crew members, and the operational performance of such schedules [6], in order to develop more robust airline planning tools. They observed the following:

- Propagated delays create significantly more impact than the original root delays themselves,
- A single delay can "snowball" through the entire network,
- Keeping aircraft and crews together can help to mitigate the impact of disruptions,
- Delays that occur early in the day can cause greater propagation than delays later in the day,
- It is most important to prevent delay propagation early in the day.

Because flight cancellations are rare (less than 3% of domestic flights), they are difficult to predict. Flight cancellations are less likely on more competitive routes, flights into and out of hubs, and infrequently served routes. Full flights are inversely proportional to the likelihood of being canceled. Seelhorst et al. [7] identify the factors inducing flight cancellations, using the characteristics of the routes, airports, aircrafts, passenger traffic and delay for domestic US flights. The cancellation prediction is used to estimate the reduction in flight delays caused by canceling some flights. In [8] are presented network rewiring schemes that increase resilience to different level of perturbations while maintaining the total number of flight and gate requirements. Hubs located in the core of the network increase efficient connectivity but are critical targets. Hubs in the periphery offer smaller benefits with respect to efficiency but their failures do not destroy the connectivity of the rest of the network. In Europe, reactionary delays, or "knock-on" effects, add up to nearly half of the delay minutes. Cook and al. [9] evaluate the costs of reactionary delays as a non-linear function of primary delay duration. They highlight the need for tactical delay models, taking into account marginal costs, reactionary costs and non-linearities.

When a disruption occurs, airline schedule recovery tries to maintain operations and get back to schedule as quickly as possible while minimizing additional costs. The different mechanisms they rely on are aircraft swaps, flight cancellations, crew swaps, reserve crews and passenger rebooking. Usually airlines react by solving the problem in a sequential manner. First, infeasibility of the aircraft schedule is examined, then crewing problems, ground problems and finally the impact on passengers. In this process, the passengers' issues are the last accommodated.

Over the past few years, severe weather perturbations have paralyzed the air transportation system. In Europe, the eruption of the islandic volcano in 2010 had the longest and biggest economic impact on aviation [10], with more than 100,000 flights canceled. Bolic et al. offer recommendations to better address such large disruptions, stressing the need for better information exchanges between all the stakeholders.

2.3. Multimodal Transportation

The Eyjafjallajokull volcanic eruption in 2010 had such an impact on aviation that it also had a series of knock-on effects on other modes of transportation. These can be explained by the rigidity and complex nature of transport networks, as well as by the lack of appropriate preparation. There are two types of multimodality to be distinguished. The first is related to the airport access, usually a short commute. The second is the inclusion of the airport in a multimodal network linking it to other centers.

Steele et al. pose the problem of predicting the changes in passenger demand between different modes of transports during a disturbance of one or more of its systems [11]. Their research develops a simplified dual-mode UK transport model using system dynamics and recent data, to test responses to disturbances. The partial substitution of some short-haul flights with High Speed Rail transport, either through modal competition or complementarity, is already in place in four European hubs (Frankfurt Main, Paris CDG, Madrid Barajas, Amsterdam Schipol). Janic [12] shows that the High Speed Rail substitutive capacity does not act as a barrier to developing air/rail substitutions at the airport. Even a a modest substitution may produce substantial savings in airline costs and passenger delays.

For the passengers, traveling across several modes of transportation to complete their journey can be difficult, especially when it comes to planning travel times. To improve the passenger's experience, more and more advanced transport information systems (ATIS) provide services such as route planning, navigation, updates on disruptions, real time information alerts and replanning tools. Zhang et al. [13] build a supernetwork, where the networks for different modalities are integrated. They distinguish road, rail, air, water transportation as well as private (e.g. foot, bike, car) or public modes (e.g. bus, train, tram, metro). Some links are time independent, others time dependent or stochastic time dependent. The travel time and monetary cost may also be computed. The authors tested their tool for the Eindhoven region with success and are working on improving the computation time of their model.

Reliability of the schedule in a multi-modal trip is essential. The traveling time in each mode and the waiting times in between should be balanced to improve passengers' experience. Hsu [14] develops a simple model to represent the transfer waiting time for a connecting service at multi-modal stations, where waiting time takes into account the characteristics of both the connecting service and its feeder service. The results show that transfer waiting times is mostly affected by the capacities and headways of the connecting and feeder services. They suggest that transfer waiting time cannot be improved without operational coordination with the feeder service.

The linkage between airside and landside which appears essential to deal with disruptive events, can be called Airport intermodality. Intermodality is the use of several transport modes in one trip when the transport modes are coordinated thanks adequate intermodal infrastructure, and intermodal agreements concluded by transport operators. At an airport level, we can distinguish two different types of intermodality:

- Airport access intermodality, when the use of the land transport (bus, tramway, train, etc.) aims at linking the airport to the city center.
- Network integration intermodality, when the use of the land transport is in the scope of the airport integration in the regional or national network of the landside transport modes (High-Speed train, etc.).

Laplace and al. [15] considered both intermodality definitions to study the conditions of development of the airport intermodality in Europe, in the MODAIR study funded by EUROCONTROL between 2004 and 2006. The aim of the study was to determine the conditions of development of the airport intermodality:

- At intermodal actors levels, by analyzing their expectations and incentives to develop intermodal agreements,
- At nations and Europe levels, by identifying the main modifications of the transport environment that may ultimately result in modifications in the level of intermodality.

The analysis on both levels was supported by the use of indicators of airport intermodality.

The Strategic Research and Innovation Agenda (SRIA) is the new strategic roadmap for aviation research, development and innovation developed by ACARE. In the customer-centric mobility topic, "planning, payment and single ticketing support for intermodal journey selection" is expected to have started by 2020. By 2050, "door-to-door integrated journey planning, payment and single ticketing & accountability, and automatic journey monitoring and disruption management for over 90% of journeys" are to be in place.

3. Case study: Roissy-Charles de Gaulle, a major Hub Airport in Europe

This section covers information obtained from various sources, through interviews with some of the main stakeholders and the thorough examination of available documentation regarding this particular airport.

3.1. Airport characteristics

Roissy Charles de Gaulle (CDG) is one of the major airports in Europe. It is the 1st cargo airport in Europe, offering more than a 1000 flights per week to the United States, the Middle East and Asia, and the 2nd largest passenger airport in Europe. CDG is the only European airport that can simultaneously use 4 runways. Its Air Traffic Control capacities reach a maximum of 72 arrivals per hour and 76 departures per hour (not simultaneously). A capacity record was achieved in 2008 with 127 movements per hour. The two longest runways are used for heavy aircraft, with extended length to meet environmental and noise constraints. The two shorter runways are used for lighter aircraft because the neighboring communities imposed a two runways limit for heavy aircraft. This large airport is covered by 80 km of taxiways, making it difficult to ensure appropriate deicing and desnowing in the winter. CDG is a multimodal center. It is located at the heart of a high-speed rail network. With high speed trains, Brussels, London, Marseille, Amsterdam can be reached in less than 3 hours. Through the express motorways, without congestion, it is 20 minutes far from Paris, less than 3 hours from Brussels and Frankfurt.

3.2. Airport Collaborative Decision Making

Since the end of the 1980's the bottlenecks of the air transportation system are no longer the en-route airspaces but the airports themselves. The CDM project started in 2003 at CDG and its foundation relies on the following items:

- Collaborative departure sequence,
- Strengthened information sharing,
- Adverse and unusual conditions,
- Performance management,
- Fine tune Air Traffic Flow Management (ATFM).

The CDM stakeholders are composed of the DSNA (Direction des Services de la Navigation Aerienne), SNA (Services de la Navigation Aerienne) of CDG, Air France, Easy Jet, Fedex, airlines associations, Meteo France (weather forecast provider). Some of the most relevant flight parameters to CDM processes are the Target Off-Block Time (TOBT) and Target Start Up Approval Time (TSAT). The TOBT,issued by the Handling Agent or Aircraft Operator, is the estimated time when the aircraft is expected to be fully ready for push-back and/or start-up upon reception of the according clearance. The TSAT is a calculated time considered by ATC planning systems, at which a flight might expect push-back and/or start-up clearance, in order to achieve an optimized over all departure sequence. It considers all contributing factors from the airport (OPS concept, demand, deicing, Variable Taxi Time, etc.) and restrictions from ATC.

The CDM@CDG website makes it possible for all actors and stakeholders to have access to the same information and improves situational awareness. A "plateau CDM", i.e. a dedicated fully equipped room, with 16 specific posts, is used in case of degraded conditions. It ensures than the main actors can communicate and make decisions in the presence of others. It is most often opened during degraded conditions in the winter season. For instance, during the week of January 7th 2013, it was in use during four days. On a given day, the CDM actors have visio-meeting at least once a day, usually to discuss the next day forecast, until adjustements are made then. The collaboration between actors encompasses a posteriori meetings, and scheduled monthly meetings for debriefing and continuous improvement purposes.

3.3. Key Performance Indicators (KPIs)

Several performance evaluation levels exist for CDM@CDG:

- at the airport level to be compared with competing airports,
- internally to test the CDM tools efficiency,
- within each major actor.

The KPIs used internally are usually specific to the airport in question. At CDG, ADP looks mainly into the taxi time and off-block delay. Delays are accounted for using month-to-month and year-to-year comparisons. It was considered that CDM and GLD (Local Departure Management) allowed aircraft to save 1 minute of taxi time per flight, over all flights, including those which did not incur any delays. There is a specific accounting for departures at CDG, due to the fact it operates literally as two decoupled airports. Some discussion is still ongoing about the sensitivity of delay accounting to delay definition changes.

When it comes to each actor, not all of them are keen on sharing the nature of their internal KPIs. However, one airline explained they rely on KPIs on punctuality, flight connections, luggage access for instance. Other KPIs are specifically used for CDM purposes: some are real time indicators, others monthly, others are oriented by the scope of the European Performance Scheme. One of the main european freight operator explained that most of the current performance evaluation is done by human operators. They often rely on experience, habits, to trigger contigency plans. They highlight the problem of simply defining appropriate KPIs for each system, whether package sorting, routine maintenance or flight operations. Relying on several sub-contractors makes it even harder to monitor the overall performance. It was noted that, so far, the performance of CDM@CDG disclosed to all actors was only the measure of tons of fuel saved. A baggage handler we interviewed said they had no KPIs measures, but that they noted an increase in operations efficiency with CDM. This was through offering the possibility to change the estimated departures slots.

The main achievements of CDM, some of them quantifiable, are listed below:

- Safety, capacity, punctuality, equity and environmental benefits,
- less ground traffic,
- better load balancing,
- more precise en-route information,
- an aircraft that pushes back is ensured to be able to take off,
- one of the main airlines has gained in breaking and engines maintenance, while for another the Low Visibility Procedure brought a gain of 4 minutes per flight and 6 tons of fuel saved per day.

3.4. Crisis Management

The main expected benefit of CDM processes is the increased situational awareness and communication between actors in case of severely degraded conditions. In case of an abnormal situation, the SNA, airlines, ADP, AOs, Handlers, ACC cmove to the plateau CDM. A crisis situation is when a problem becomes political or the medias are involved. Then the operational managers of the airlines, ADP, DSNA/DO are included. If the crisis is such that the planned schedule for a day has to be cut down, the decision moves to the DGAC. The CDM@CDG website proves very useful in case of degradation, with up to 200 operators logged in, even stakeholders across the world.

The freight operator interviewed described this particular type of pre-defined crisis situation. Service recovery covers severe weather disruptions (snow, volcanic ash ...). There is a pre-established plan regarding flights and routes, where the potential impact is evaluated, based on statistics and load ratio. Its impact is re-evaluated upon the set up of the contingency plan. After the crisis, feedback is collected. The operator at CDG deals with day-to-day analysis while its headquarters in another city deals with the tactical and strategic debriefing. If necessary, most of the operations can be delocalized in Koln (packages and options, whether the whole or part of operations). When flights are cancelled, trucks (i.e. road mode switch) can help cope and transport some of the goods across Europe.

One of the airlines interviewed has the following importance scheme: Safety first, then on-time performance, then the customer satisfaction. They have tools to evaluate knock-on effects displayed on their screen. Each contingency plan relies on all stakeholders coming together (flight operations, ground operations, press service ...) and emails sent to passengers (smartphone application available). This airline team at CDG only has access to information at CDG, but its headquarters can get wider information from their other locations.

Another airline has a crisis cell with representatives of human resources, law experts, communication service, etc. at their Operation Control Center, as well as an integrated plan to handle passengers stranded at CDG. In parallel a crisis cell is also organized at the airport in connection with the airline crisis cell. The crisis cell is isolated on the airport so as to not disturb operations services, and in close cooperation with ADP. If necessary, the airline has foldable beds and designated areas to organize overnight stays. It also has contracts with bus companies in case there are so many stranded passengers that part of them may have to be sent to various hotels in the paris and suburbs area.

On the interviewed ground handler's side, in case of bad weather conditions, the alert is given by ADP. Such information transfer takes in general around 15 minutes. An alert can also be derived from the CDM tool when observing a lot of delayed flights with the regulation code corresponding to bad weather conditions. If the problem comes from another airport than CDG, the ground handler is directly informed by people in place at this airport. More generally, additional information is collected from direct phone calls to the different stakeholders. During the crisis situation generated by the islandic volcano eruption in 2010 a map on the cloud evolution in the European airspace was provided by their Office in England.

3.5. Examples of past crisis situations and stakeholders' points of view

In december 2010, heavy snowfalls led to the complete closure of CDG airport. CDM@CDG explained that a chain of events occured. First, the airport was functioning close to capacity, there were considerable amount of passengers in the terminals, they were close to parking saturation but the situation was still under control. The problem was at the network level, because London, Frankfurt and Moscow were also experiencing heavy snowfalls. When Heathrow closed, CDG had not been aware of it long before, and had to accomodate several of Heathrow-bound long haul flights. This stresses the need for better communication between the main airports in Europe. The cargo company interviewed explained that, from their point of view, there should be a distinction between closing passenger operations and cargo operations. Some communication issues were noted, because this company attributed the CDG closure to the lack of deicing fluid left at CDG. However, they have, for cargo, their own deicing bases and still had enough deicing fluid to keep running most of their operations. At the time, they were not consulted about the issue. It highlights the fact that, when multimodal hubs close for crowd management reasons, cargo operations might be able to accomodate part of their operations. During the volcano eruption in 2010, an example of collaboration between stakeholders was observed: Fedex helped companies transport via the road network passenger luggages stuck in CDG airport when the passengers were stuck in other hubs, thanks to their multimodal capabilities.

3.6. Insight on the passenger aspects for different stakeholders

One airline's policy in case of crisis situation is to protect the 1st wave of departure/arrivals and rely on preemptive cancelling the day before (24h notice to passengers). They have levels of alert for passengers: green passengers, amber passengers (checked-in but not onboard), red passengers (onboard). Another airline mentioned they lead passengers survey to get information on the whole travel of the passenger. However, this survey does not consider a priori the ground access to and from the aiport. The ground handler is informed of passengers complaints via the airlines. Complaints focus more on the fact that flights are delayed than on the lack of information on these delays. However, in case of crisis situation, airlines can have difficulty to evaluate the delay. Some information are provided by ADP to passengers but these information can be irrelevant if they do not provide directly from airlines.

4. The future of Collaborative Decision Making

This section first addresses the short-term evolution of CDM as forecasted by its main actors. It then tackles the topic of developing CDM at different levels and with various perspectives, in view of improving the Air Transportation System as we know it.

4.1. Improvements and evolution demanded by the different stakeholders

Overall, when asked what they would like CDM processes to be improved on, the interviewed actors insisted on the following aspects:

- Better information sharing, operational collaboration, for instance with smartphone enabled CDM, and push notifications when relevant information is updated on the website. Better communication on each actor's constraints.

- Pre-departure sequence: de-icing operations taken into account in the pre-departure sequencer, stage 3 of the development with UDPP (User-Driven-Prioritisation Process), STAM management (already planned by CDM@CDG).
- Linked A-MAN, D-MAN, optimal turn around process, anticipated departure sequence.
- Harmonization of websites across airports and creation of a single website for all informations relevant to the actors.
- Better available measures when it comes to the recovery process, such as gate availability, taxiway closures, crew availability, expected rolling times, or number of available pushback trucks.
- Clear identification of the system bottlenecks, in crisis situations.
- Public, transparent CDM performance indicators, available to all stakeholders. This would enable both the identification of benefits and of bottlenecks. It would also help returns on experience processes, debriefings, to create a circle of excellence.
- Putting the pilots in the loop, with docking guidance systems that show the TOBT/TSAT. This is currently in place in some German airports. At CDG, the pilot currently only receives the first TSAT via datalink and the updates are through the radio, which generates misunderstandings. The main drawback of data link is the cost.

With a longer term perspective, several actors mentioned the importance of the following items:

- Development of B2B messaging, acommon message format for all portals.
- En-route data-sharing, or onboard communications enabled.
- Point to point trajectories, and GPS RNAV approaches, no need for ILS. Same minimas as for ILS. No need for vectoring.
- Increased levels of automation, particularly the ability for tools across different airports and platform to "communicate" by themselves.
- Some sort of CDM processed at the network level.
- Better tools to reaccommodate passengers when a flight has been cancelled or is sufficiently delayed that they will miss their connections. This should also alleviate the recovery process and the needs for human resources readily available to handle stranded passengers.

Overall, most of the actors believe there are no current technical limits to possible improvement, and that the only constraints are political and financial.

4.2. New projects of interest

4.2.1. DFlex

One very interesting aspect of the monthly CDM@CDG meeting our team attended in May was a report on an experiment named DFlex [16]. The experiment consists of allowing partnering companies to shuffle aircraft within their own departure slots list with the virtual queue while awaiting push-back clearance. The concept was published by Burgain, Clarke and Feron in 2009. The experimental phase of the project started in September 2012 and will last until August 2014. The partners are composed of Air France, FedEx, ADP and Metron.

There are several functions under study. The first consists of swapping two flights only. The swaps are currently constrained neither by the equipment type, nor by the take-off runways, nor by the type of flight short/long haul). The second is activated when a flight is ready to push back but it is late on the TSAT list. It is then moved up in the TSAT list, and all the other airline flights within the list are delayed accordingly. The third is activated when a flight is cancelled; all the flights within the company then gain one slot in the queue.

With DFlex, swapping flight priorities does not necessarily change in TSAT, because the TSAT includes many other factors. It was found that DFlex was very useful during periods of maximum airport stress. Although the initial period of evaluation of DFlex is now finished, DFlex as remained in operation following the request of Air France and FedEx, based on positive initial results. DFlex has been implemented while not accounting for possible runway load imbalancesor other possible drawbacks. During the first evaluation period (03/26 to 04/19), there were 40 swap demands over 9 days, and all were accepted. The second evaluation period will be during the winter 2013-2014. FedEx reported positive outcomes for DFlex: 33 reordering requests were sent to CDG Prior-Departure Sequencer, resulting in a net gain of 123 minutes of delay. There were no cost-benefit analyses done for CDG prior to the implementation of DFlex. In the future, companies such as Britair and Airlinair will also be included in DFlex.

4.2.2. CAREX and multimodal european freight

The future European high speed rail freight service will by 2013 place Roissy-CDG. Carex [17] already gathers the major transport players (including Air France, FedEx and La Poste, french postal service), adding considerable economic weight to the Aerotropolis Europe, Paris association. The Carex multimodal concept relies on using the European high-speed rail network to carry almost 900 airfreight pallets and containers per day over distances of between 300 and 800 kilometers, involving:

- A shift from trucks and short- and mid-range aircraft to high-speed trains if the appropriate airport-based air and rail terminals are connected to high-speed rail links.
- A service tailored to suit the logistics chains and transport plans of integrators, with priority given to Express freight in order to guarantee next-day delivery, followed by less urgent air cargo freight.
- To secure an appropriate network for its services, the Roissy Carex partners forged links with other organisations at local level throughout France and Europe. The Lyon Carex, Liege Carex, London Carex and HST Cargo Schiphol Carex organisations were created, now all under the Euro Carex banner.

4.3. Further research paths to be explored to expand the CDM concept and its benefits

4.3.1. CDM 'light'

A CDM 'light' could be a good solution for several middle sized airports. It could be done by offering a more simple sequencing tool. The Thales groups collaborates with Meteo France, linked to the DGAC by contracts, to provide new weather forecast displays for airports. In Corsica for instance, there are dense nominal situations. The keys items to be improved are more coordination, a tool to share information, with maybe some forecasts up to 3 hours ahead. It would only require a small web portal and pre-established, validated procedures, a lighter version of CDM@CDG with less costs associated to the humans. This can also be introduced through new equipments, such as datalink air/ground. The main reason to support CDM light is as follows. The performance of the network does not only depend on the main airports, but also on the smaller ones. They are the feeders to the hub airports. Even if uncertainties are reduced at the hubs, the uncertainties at the spokes remain the limit to seamless door-to-door itineraries for passengers travelling throughout Europe.

4.3.2. Multimodality

Multimodality is slowly becoming a reality, at least within the European transportation system. The principal difficulty is not whether it should be done or not - it is widely admitted that flights lasting less than one hour could be advantageously replaced by ground transportation, such as rail, but how. Indeed, finding an economically viable path towards fully integrated multimodal transportation will require leveraging today's resources and investing the profits in system improvement until satisfaction is reached. Such a plan may last several years or decades to be executed and would be highly sensitive to political noise. However, industry today offers interesting leads towards an acceptable implementation plan. For example, some European airlines already emit origin-destination fares that are using rail transportation for some or all of the passenger journey. To achieve this, the airlines have developed a capability to optimize individual passenger routes through heterogeneous air and rail traffic schedules. Such modest, initial steps, are not to be neglected as they represent economically viable initial steps towards the transformation of the system. Follow up steps could include the decentralized, but possibly coordinated optimization of schedules between rail and air operators. One of the key difficulties is the extent to which such activities run against free market laws. One of the airlines interviewed sells TGV tickets to its passengers. Even though the databases and schedules are shared, there is no common optimization between the rail and the airside. Even if there is a TGV station at CDG, the passenger has to find its luggage and take it to the train, and its train may not be departing from the train station inside CDG. The cargo company interviwed, though well-versed in multimodal transport, still encounters different difficulties depending on the modes. For instance, they cannot track their trucks in Europe, because they belong to sub-contractors, the only information they have are the departure and arrival time.

4.3.3. Improvement of the Decision Making Process

The authors believe that much benefit could be obtained by studying the best decision making process in case of crisis situations. Furthermore, the first research initiatives, such as by Grabbe et al. [18], are being pursued place to understand how to integrate the decision making process into Traffic Flow Management. Because equity and fairness ensure adherence of all stakeholders to the CDM procedures, it is necessary to identify which strategies lead to the best decisions and how to incentivize them. Hunter et al. [19] started tackling the issue with simulations regarding the impact of user gaming in the Next Generation Airspace System in the US. They show how performance can be altered by the user strategies and the planning horizons. Some even lead to a "race-to-the-bottom" scenario, which is detrimental to all actors.

4.3.4. Shifting the focus towards the passenger

Flight delays do not accurately reflect the delays imposed upon passengers' full multi-modal itinerary. The growing interest to measure ATM performance calls for metrics, that reflect the passenger's experience. Cook and al. [20] design propagation-centric and passenger-centric performance metrics, and compare them with existing classical metrics, with regard to intelligibility, sensitivity and consistency. The passenger oriented metrics cover: departure and arrival delays, the ratio of scheduled trip time to final arrival delay, canceled flights, missed connections, re-routes, extra flights, extra flight time, weighted load factor, aborted trips and extra wait time. The authors also identify the top ten critical airports in Europe according to three different network classifications. In [21], Bratu et al. calculate passenger delay using monthly data from a major airline operating a hub-and-spoke network. They show that disrupted passengers, whose journey was interrupted by a capacity reduction, are only 3% of the total passengers, but suffer 39% of the total passenger delay.

Given the limited system capacity, it is key to understand how to transform "unwelcome delay", e.g. waiting in line, into a "productive delays", either sitting down or shopping, for instance. There are several interesting and original aspects to the problem that make it very different from the airside. First, there is the considerable freedom of movement that passengers enjoy, which allow almost arbitrary queue re-ordering, especially if long passenger queues do not end up occupying huge space in a terminal (eg Atlanta Hartsfield). This allows many "virtual queue" management policies to be issued, allowing passengers running out of time to be directed faster through security in a way which is not easy to detect (and react against) by other passengers. One of the challenges of such procedures is that passengers are much more unstructured than aircraft: Many passengers may display off-nominal behaviors. In addition, it is difficult to make changes to a system whose very function is to ensure the security of the entire air transportation infrastructure. It becomes very important to understand, for example, whether long waiting lines during congested times also play a role in ensuring system security.

5. Conclusion

Collaborative Decision Making at congested airports has demonstrated that considerable improvements could be achieved at airports by air transportation agents, without sacrificing internal objectives and the means for different operators to achieve them. This paper presented the results of a first case study of the Meta-CDM project on Collaborative Decision Making at Roissy Charles de Gaulle airport. Through prior work and data analysis, interviews, and engineering design, the benefits of extending Airport CDM to include the landside, including ground transportation, can be shown to be real and significant for the passenger. The many options available to enable a true Multimodal, Efficient Transportation in Airports for the passenger's benefit in the spirit of CDM will require careful quantitative future analyses. Their practical implementation will benefit from the patient efforts and experience accumulated so far with Airport-CDM. From multimodality to "CDM light" while trying to account for the passenger, several paths will be explored during the reminder of this project. The overall goal always being to pave the way for a more efficient, more resilient, and more passenger-friendly Air Transportation System.

6. Acknowledgments

The authors would like to thank the different stakeholders who were so eager to share their insight regarding CDG airport. The authors would also like to thank Remy Denos, from the European Commission, for his guidance on the Meta-CDM FP7 project. The Systems Modeling and Optimization Branch at NASA Ames was kind enough to provide the authors with feedback.

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