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*Full Research Papers* should contain original research not previously published elsewhere. They should normally be between 4,000 and 7,000 words although shorter or lengthier articles could be considered for publication if they are of merit. The first page of the papers should contain the title and the authors' affiliations, contact details and brief vitae (of about 50 words). Regarding the following pages, papers should generally have the following structure: a) title, abstract (of about 150 words) and six keywords, b) introduction, c) literature review, d) theoretical and/or empirical contribution, e) summary and conclusions, f) acknowledgements, g) references and h) appendices. Tables, figures and illustrations should be included within the text (not at the end), bear a title and be numbered consecutively. Regarding the referencing style, standard academic format should be consistently followed. Examples are given below:

- Airbus (2003), *Global Market Forecasts 2003-2022*, Toulouse: Airbus.
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- Forsyth P. (2002a), 'Privatization and Regulation of Australian and New Zealand Airports', *Journal of Air Transport Management*, 8, 19-28.
- Papatheodorou, A. (2008) The Impact of Civil Aviation Regimes on Leisure Market. In Graham, A., Papatheodorou, A. and Forsyth, P. (ed) *Aviation and Tourism: Implications for Leisure Travel*, Aldershot: Ashgate, 49-57.
- Skycontrol (2007) *easyJet welcomes European Commission's decision to limit PSO abuse in Italy*. 23<sup>rd</sup> April. Available from: <http://www.skycontrol.net/airlines/easyjet-welcomes-european-commissions-decision-to-limit-psy-abuse-in-italy/> (accessed on 22/08/2008).

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*Industry Perspectives* should be up to 1,000 words and provide a practitioner's point of view on contemporary developments in the air transport industry. Contributors should explicitly specify whether their views are espoused by their organization or not.

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## Editorial

This issue of the *Journal of Air Transport Studies* includes five papers and an opinion paper.

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The second paper by **Parastoo Dastjerdi, Chris Markou** and **Jacques Roy** uses a survey approach to investigate the application of Radio Frequency Identification (RFID) in Airline Maintenance Operations with a view to assessing the current use of RFID in aviation maintenance and evaluating future opportunities as well as barriers to this technology.

**Andreas Wittmer** and **Nicole Oberlin** set out to investigate challenges of an ancillary revenue pricing approach for full service network carriers, using a qualitative means-end approach to find attributes which are important to air passengers and influence their ticket buying behaviour. In addition, the perception of an ancillary revenue system in the full service network carrier market is explored.

**Dipesh Dhital** and **Yvonne Ziegler** examine application opportunities that Additive Manufacturing, also known as 3D Printing, presents for the aviation / aerospace industry. It is suggested that this technology be fostered as it has the potential to contribute to fuel savings and tackle air and noise pollution.

**Renato Redondi, Paolo Malighetti** and **Stefano Paleari** focus on the accessibility of European municipalities by air transport. The measure of accessibility used is based on the overall travel time required to connect each pair of cities in the network, including ground travel to and from airports and waiting times between connecting flights when a direct flight is not available. The authors propose a general framework to evaluate the best policy options at country level for alleviating travel times from remote territories.

Last, **William B. Rankin** opines that airports and airlines worldwide should review their security plans and consider adoption of a Security Management System for risk mitigation. Moreover, based on the results of a survey of selected US airports which found low

employee preparedness in the event of a terrorist attack, it is recommended that a checklist be developed for employee training to protect employees from terrorist attacks.

We would wish to take this opportunity to thank our authors for their thought-provoking contributions and our referees for their support in publishing the present issue of the Journal. The open access character of the Journal, aiming at the widest possible exposure of its content to the academic and business audience, is facilitated by our continuing partnership with Air Transport News. Enjoy reading!

*Professor Dr Andreas Papatheodorou, Editor-in-Chief*  
*Dr Antigoni Lykotrafiti, Associate Editor*

## **GEOGRAPHIC CORRELATES OF LOWEST AVAILABLE AIRFARES ON AUSTRALIAN AIR ROUTES**

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### **ABSTRACT**

Deregulation of the airline industry in Australia has produced lower airfares. However this perspective rarely incorporates spatial insights and usually utilizes archival data. The purpose of this paper is to conduct a first-stage confirmatory analysis of up-to-date airfares charged on 24 major routes within Australia using Skyscanner, a web-based and consumer-oriented tool to access

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<sup>4</sup> **Weiyang Zhang** is a PhD student at Ghent University's Department of Geography. He holds a Master's degree in Human Geography from the University of the Chinese Academy of Sciences (Nanjing). His PhD research focuses on urban networks and polycentricity in Chinese mega-city regions.

airfares. This tool displays fares during an on-line booking process prior to purchase, just as consumers would experience it. We apply Skyscanner to extract one set of current fares -- lowest fare data -- on the routes and then use linear modelling to establish variables that can be utilized to predict these lowest fare prices. While far from a full accounting of the cost of Australian air services, this test of Skyscanner as a data source, along with the successful confirmatory linear analysis, shows that the underlying configuration of the nation's urban population, distance, direct connections, and characteristics of links and networks of low cost carriers are powerful influences upon prices charged. We suggest that Skyscanner and similar data sources may provide researchers with alternative low cost data that may shed insight into many air transport pricing questions.

Keywords: *Australia, airfares, Skyscanner, confirmatory linear analysis, urban networks*

## 1. INTRODUCTION

The purpose of this paper is to examine the spatial variation in the lowest airfare cost of inter-city travel within Australia using a non-traditional data set. Given the relatively large average distances between Australian cities, air transport is by far the most important, and in some cases even the only viable way for convenient inter-connections between places. As a consequence, air passenger transport is the key to Australia's day-to-day territorial integration, and understanding its configuration is therefore critical to its role in that nation's broader social context. To date, research on the geography of Australia's domestic air services has focused on the supply of connections (Fuellhart and O'Connor, 2012) which reflected the outcomes of corporate restructuring (Weller, 2009) and the impact of new low cost carriers (Forsyth, 2003).

In this research we change the focus of the analysis to the perspective of the consumer and explore the *lowest available fare* for a range inter-city connections using a web-based tool – Skyscanner -- that is also accessible by prospective passengers. We show how location within the country is important to the air fares charged so that the activity of the airline industry is linked in no small way to the geography of social equity with the country. In doing so, we suggest that Skyscanner and similar web sites may have considerable utility to air transport analysts. This extension of the research provides a more nuanced understanding of the relative friction of distance of traveling between city pairs and acknowledges the importance of the mind-set of a consumer looking for a ticket at the lower end of available price options. While the *lowest fare* is not the *only fare* consumers shop for, the analysis of lowest cost tickets across routes provides a starting point for the assessment of Skyscanner as a research tool. In doing so the paper both explores the spatial equity of the airline deregulation while providing a supply-side price analysis of Australian air travel.

It is clear that the fare charged for airline connections is the result of a complex interplay between cities' locations, distance between one another, their size and industrial structure, and the wider market context in which airlines operate. That complex interplay has been explored in analyses of major geographical factors that influence airfare pricing in different domestic markets. The relative importance, and the spatial consequences, of these factors tend to play out differently: pricing in a large and liberalized market such as the United States (Reynolds-Feighan, 2001) obviously differs from that in a geographically smaller and regulated market such as Japan (Yamachuci, 2000, Zhang et al. 2008), while at a continental scale the experience of pricing in Canada (Mentzer, 2000) and the US differs from that in the European Union (Alderighi et al., 2004, Goetz and Graham, 2004). This is partly because of the impact and presence of alternative travel modes and the geographical outline of the respective urban systems.

To take these analyses a stage further requires finer scale city-specific and time-specific data. The lack of data outside the US means much research on pricing has relied upon archival data provided in the Airfare Consumer Report, published quarterly by the U.S. Department of Transportation's (USDOT) Office of Aviation Analysis (Brueckner et al., 2013, Fuellhart et al., 2013, Neal, 2014) as well as other databases. These data typically provide information on average fares actually (and already) paid across fare classes over different periods of time. However, the expansion of online booking systems has opened up new possibilities for research on this aspect as shown in Zhang et al. (2013) and Zook and Brunn (2005, 2006). We test one such possibility to present an analysis of the geographies of lowest-market airfares in the Australian context. Put differently, we explore the air travel price-point opportunities that exist for market-wise airline shoppers by analysing the *lowest fares actually on offer and available at the time of sale* by using a real-time fare quoting system available to all consumers with a web connection. The goal is to conduct a confirmatory examination of the components of Australian airfares using this one specific and constrained group of fares both to comment on the makeup of the fares themselves and the potential use of Skyscanner for more complex analyses.

The remainder of this paper is organized as follows: First we provide a brief literature review on trends in the airline industry in general and in Australia in particular, focusing on the potential drivers of pricing in a liberalized market such as Australia. Second, we describe the empirical framework and methodology. Third, we examine the results of the confirmatory analysis both through descriptive assessment and statistical modelling. Finally, we wrap up the paper with a discussion of the implications of the study and suggest some issues for future research.

## **2. LIBERALIZATION IN THE AIRLINE INDUSTRY AND THE GEOGRAPHY OF AIRFARES**

The airline industry is one of the economic sectors where the effects of a neoliberal praxis have been substantial (Bowen, 2002, Weller, 2009). In general, government regulation and control has increasingly been replaced by an ethos of liberalization, which involves both deregulation (i.e. the relaxation or removal of regulations on passenger fares, air freight rates, market entry and exit, choice of routes and aircraft, level of service, and forms of competition and collaboration) and privatization (i.e. the transfer in whole or in part of airlines from the public sector to the private sector). Although deregulation and privatization in the airline industry are best understood as ongoing bundles of processes that develop unevenly in time, space, and form, it is clear that air transport is now increasingly subject to free-market forces, achieved through the removal of most regulatory controls over pricing, while at the same time – at least theoretically – permitting carriers

to enter and leave certain markets at will. From a supply standpoint, air transport may be among the most footloose industries in the world.

Liberalisation has been expressed geographically in two major dimensions. The first is that the route structures that make up airlines' networks in deregulated markets have come to be a combination of (1) more direct and nonstop services between important cities or wherever the traffic volumes justify and (2) hub-and-spoke structures for interconnecting other city-pairs (O'Kelly, 1998, Derudder and Witlox, 2009). These dimensions intersect when the "important cities" are also the hubs, as services to the hub can provide economies of scale and scope in aircraft operations. The geographic selectivity in favour of large cities, those centrally located, or international gateways has re-shaped the distribution of air services away from the patterns established under regulation. Goetz (2002:7) found significant impacts of this change on airfares, identifying "pockets of (fare) pain" in U.S. locations outside the new focal points. Lee and Luengo-Prado (2005) illustrate that effect by showing that the fare outcomes reflect differences between cities in their mix of passengers (business versus leisure).

The second dimension has been the entry into the market of low-cost carriers. Although specifying carrier typologies is an increasingly difficult task, the air transport literature generally distinguishes between two types of carriers, i.e. full-service carriers (FSCs) and low-cost carriers (LCCs). FSCs run a complex business model bundling a series of services, using sophisticated yield management techniques to utilize their fleet of multiple aircraft types, along with in-flight entertainment, VIP waiting lounges, complex frequent flyer benefits, and other 'frill' services (Hazledine, 2010). The USDOT (2005) definition of LCCs uses a business model approach and focuses upon dimensions such as (i) the presence of a single passenger cabin class, (ii) the 'no frills' service, (iii) standardized aircraft utilization, and other characteristics. LCCs tend to more often deploy point-to-point network structures and offer more direct flights (Gillen and Morrison, 2005). The fundamental impact of the LCC has been upon price, so that the geography of their services is critical to the geography of the airfares at both specific airports and within multi-airport regions.

These two dimensions can intersect. Some LCCs' networks are now so extensive that they too operate hubs. In the US context, for instance, it is estimated that nearly 20% of LCC Southwest Airlines' passengers now arrive at their destination by transferring onto another flight at one of its hubs (Taneja, 2004). In addition, FSCs have launched their own low-cost subsidiaries in response to the low-cost competition (e.g. Jetstar by Qantas) (Graham and Vowles, 2006). In this context the provision of services to cities, and the fares charged to reach them, is shaped not only by the basic network configuration but also by the part that LCC operations play in that network. These two



dimensions provide a framework to analyse geography of the cost of air travel within Australia, utilising a new data source on airfares.

### **3. THE AUSTRALIAN CONTEXT: POLICY, ROUTE STRUCTURE, CARRIERS, AND OTHER FACTORS**

#### *3.1 Deregulation*

Prior to 1990 Australia had a regulated air transport industry, called the “Two Airline Policy”, a heritage discussed in detail by Weller (2007). In 1990, that approach was removed, and a deregulated era began (Forsyth, 1991). Details of the change are summarised in a *National Aviation Policy Paper* of the Australian government (Australian Government, 2009). Looking back to the decisions of 1990, that report observed (p.7):

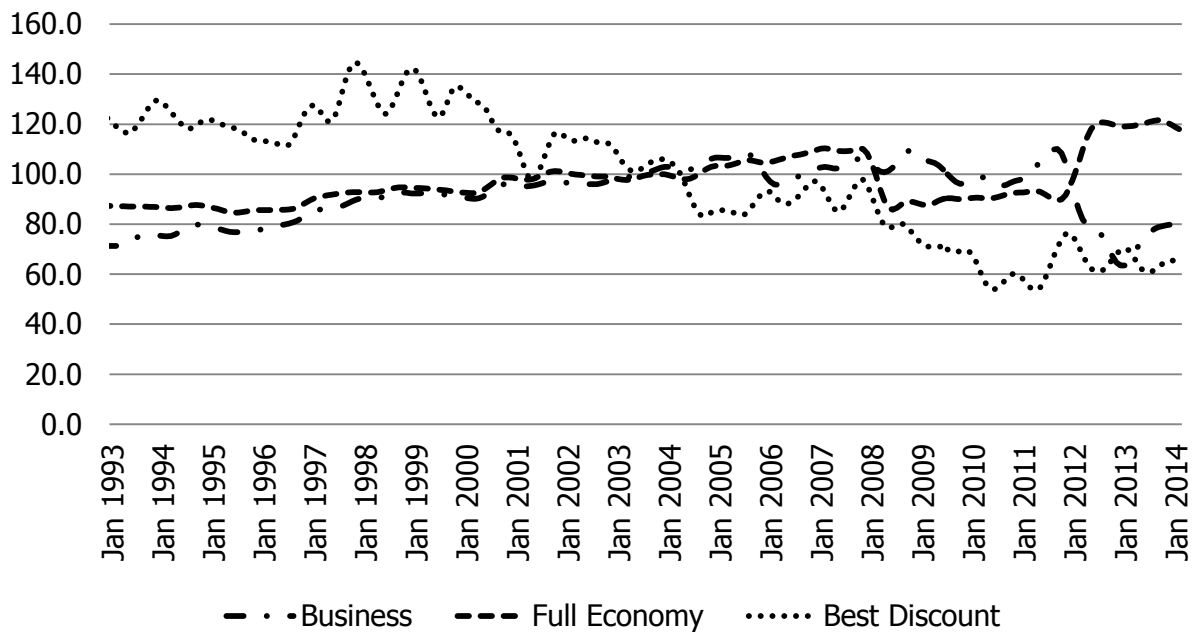
“Australia’s domestic interstate aviation market has been deregulated for nearly twenty years. Competition and the ability of the industry to respond to market demand has seen airlines offer lower prices, more flights and a wider variety of services than was the case before deregulation. The result has been increasing numbers of Australians travelling by air to do business, to educate themselves or simply to enjoy themselves. Domestic air travel has more than trebled over the past twenty years, with over 50 million passenger movements in 2008–09 through more than 180 domestic airports”.

And, more specifically with respect to fares (p 55):

“Within five years of the abolition of the two airlines policy air fares had fallen by 22 per cent. Consumer benefits have continued to flow, with the best discount fares in 2009 a further 40 per cent cheaper, in real terms, than equivalent fares in 1995”.

Though this observation is a commonly expressed one, the data in Figure 1 shows that outcome has been very dependent upon the type of fare. Large falls have been recorded in the “best discount” fare, but less change has been felt elsewhere. De Roos et al. (2010) show that outcome reflects head-to-head competition between Virgin Australia and Qantas, as well as the presence of a LCC. Falls in domestic fares have slowed, and indeed some of the fall has been reversed. For residents in cities that have limited or no service from LCCs, this latter outcome might be particularly relevant.

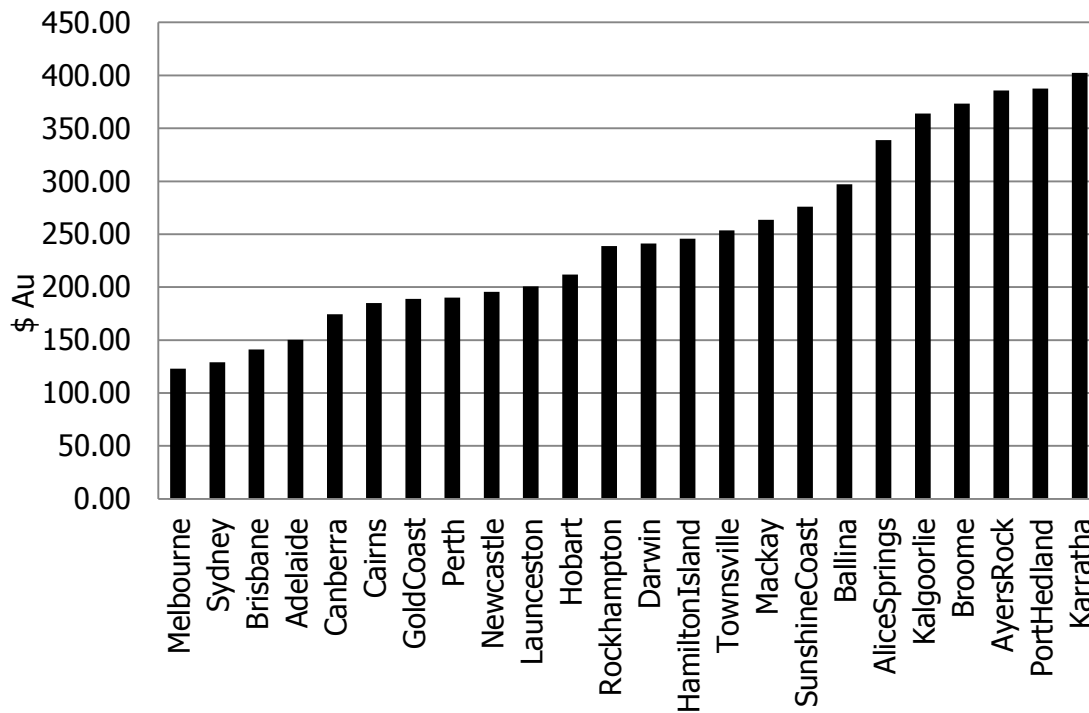
**Figure 1- Index of Airfares, Australia 1992-2014  
(13 month Moving Average Value)**



**Source:** BITRE Australian Domestic Air Fare Indexes

The key issue for the current research is the lowest price charged on actual routes. Insight on that outcome is provided by the data displayed in Figure 2, where we examine 24 of the most important nodes in Australian air transport and display the average of the lowest fare available at each city (details of its precise calculation are provided below, and see Figure 3 for a map of the cities). This data shows there is a 3.5 times difference between the cities with the three lowest fares (Melbourne, Sydney and Brisbane) and the three with the most expensive (Karratha, Port Hedland and Ayers Rock). Just six years after the deregulation of the Australian airline industry, Quiggin (1997:54) observed that “the distributional effects of deregulation are unclear, but are probably favourable on balance”. Some twenty years on, and after the introduction of LCCs, the data in Figure 2 suggests the distributional and geographic effects may be more severe than was apparent in 1997.

**Figure 2- Average Cost Lowest Price Fare Available**



Source: Skycanner 2013

**Figure 3 - 24 Major Air Traffic Nodes in Australia**



### *3.2 Airline Service Networks*

The spatial structure of the Australian airline network reflects the dominance of a few cities in its urban system (O'Connor et al., 2001). As can be seen in Figure 4, there are a small number of large, and a large number of small airports. The three largest cities, Brisbane, Sydney and Melbourne – along the Pacific Seaboard -- are within one or two hours flying time of one another and have many direct services. In contrast the smaller airports to the right in Figure 4 are mostly more distant, or indeed remote. Longer distance flights, on balance, should cost more, simply due to the effect on fuel and labor costs. In addition, the inter-city links from more distant locations can require a connection via a larger hub, usually adding traffic to the main links along the Pacific Seaboard. More traffic between the three major cities in this corridor justifies more daily direct connections which provide greater scope and scale for price competition. These features of the network suggest that the length of flights, and the availability of direct connections, will be influential on the air fares charged.

### *3.3 Carriers and LCCS*

Though there has been considerable turmoil in the Australian aviation industry following de-regulation in 1990, paradoxically growth and change within the de-regulated era has produced a duopoly not dissimilar to that of the regulated era. De Roos et al. (2010) have shown that the carriers on a route can be critical to the airfares charged, with the head-to-head competition between Qantas and Virgin having the greatest effect on price. Those effects are likely to be felt on the main inter-city routes.

It is important to consider is the role played by low cost carriers Jetstar, and originally Virgin, whose low cost role has now been taken by Tigerair. An analysis of the number of inter-city sectors flown in Australia in 2013 shows the two LCCs airlines accounted for 17% of the total (BITRE, 2013). The busiest LCC routes were between Melbourne, Sydney and Brisbane as well as to the Gold Coast, while the other large shares of LCC activity are found on some of the sectors to tourist destinations. Thus, it is clear that any understanding of Australian airfares will require recognition of the LCC presence on a route.

### *3.4 Special Cases of Air Transport Demand*

There are a small number of special cases in the Australian air network. Prominent among them are small mining towns, where air services are essential for the movement of fly in-fly out labour for the management and operation of this critical and large Australian industry (McKenzie, 2010). Good examples of these are Karratha and Port Hedland. In spite of only having 14,000 inhabitants, the latter has on average three daily direct flights from Perth. The fact that fares are often paid as part

of employment contracts removes an incentive for discounting in these markets, and it is not surprising that Karratha and Port Hedland are prominent to the right in figure 2. Though this seems an isolated effect, there is some indication that the work commuting of miners has had some overall impact on the air traffic system (Tourism Research Australia, 2013). Using data on the community profiles of the cities identified in Figure 3 (Australian Bureau of Statistics, 2011), and an analysis of the urban impact of the resources boom (Australian Bureau of Statistics 2013), we determined that a mining centre our analysis would be one where the mining industry employed 20% or more of the local workforce.

In addition, there are a large number of smaller centres with limited services. Some of these are part of Australia's tourism industry (Ayers Rock, Cairns, Hamilton Island) where price levels may be set to reflect the expected purchasing power of (international) tourists. A small number of passengers, and often a single airline, provide little scope for competition on fares, so that these places are likely to experience higher airfares. We did not explicitly account for multiple airport regions in this paper, as there is only one example where a major urban market has more than one airport (Gold Coast on the edge of Brisbane) and we have no evidence on the overlap of the markets of these two airports).

Based on this discussion, it can be expected that in the Australian domestic market, airfares will primarily reflect market forces (albeit that competition will be imperfect given the oligopoly that still exists). Available prices will reflect the overall demand for direct connections between the larger city pairs (creating pressure to lower prices), the distance between cities reflecting access to more remote places (pressure to increase prices), and the presence of LCCs (pressure to lower prices). Then on particular routes such, as those used by mining industry staff and international tourists wanting to access small remote locations, there may be some special pressures on prices. Taken at face value, many of these predictions should not come as surprise. However for a consumer planning a vacation or a travel manager planning a business trip, the key questions are: "Do these relationships hold when shopping for my low-priced domestic trip, and what is their specific effect on the fare I pay", when (for many) the lowest fare is a most important consideration.

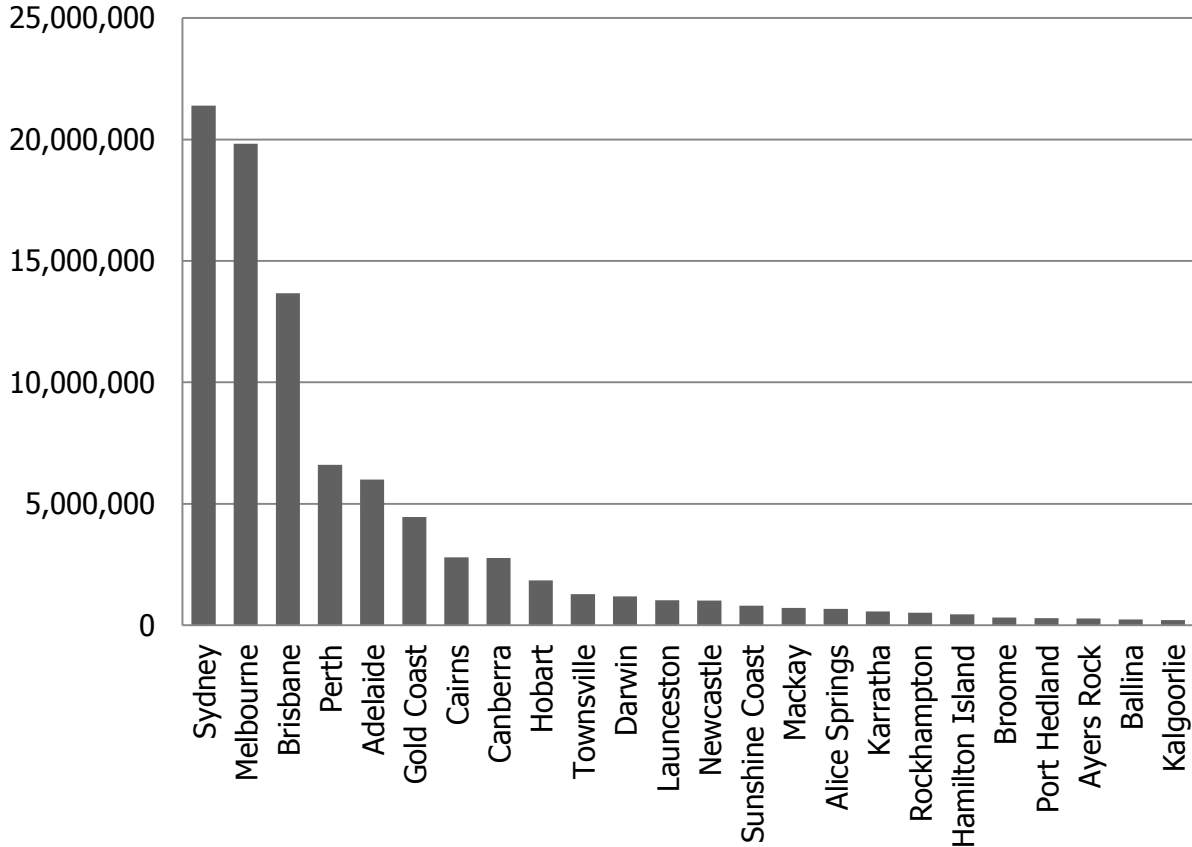
The paper now turns to a regression analysis to confirm the effect of these several factors, indicated by the literature and Australia's particular geography.

**4. A STATISTICAL ANALYSIS OF THE GEOGRAPHY OF AUSTRALIAN AIRFARES**

*4.1 The Data*

As noted earlier the focus of attention was a set of 24 cities (Figure 3) with airports that handled at least 1% of Sydney's total number of *domestic* passengers in 2009-10 (Bureau of Infrastructure, Transport and Regional Economics, 2010). This set ranged from Sydney, with more than 21 million domestic passengers to Kalgoorlie with about 215,000 passengers (see Figure 4).

**Figure 4- Passengers at 24 Australian Airports 2013**



**Source:** BITRE Aviation Statistics.

After eliminating 10 connections where it was unlikely that air transport was the major mode of transportation (e.g. Newcastle-Sydney, Launceston-Hobart and Brisbane-Gold Coast), for the remaining connections we gathered information on the cheapest available airfare. This was obtained from *Skyscanner*, a passenger flight, hotel and car hire search engine that ‘crawls’ offers from all major carriers and can be used to find if there is a direct connection and also the cheapest deal for a desired route. We recognize that the lowest available fare may apply only to very few seats on all of the flights, and that not all consumers are searching for the lowest fare. However to accomplish

our goal of an initial testing of the use of Skyscanner through modelling fares, we chose lowest fare as the price of interest. The airlines' willingness to advertise the availability of these low fares (even if only for a few seats) is an important expression of market competition that justifies this.

To iron out the possible effects of seasonal fluctuations, booking time, and the presence of non-daily direct connections (key influences on price as shown by De Roos et al., 2013), data were averaged for 15 December 2013, 15 March, 15 June and 15 September 2014. So for instance, the price for the Brisbane-Melbourne link is the average of the cheapest available cost on those four dates, assuming a consumer may explore different times of the year in which to take a trip. In calculating the average low fare across time it is important to note that the "typical" consumer books their ticket at a wide range of times prior to the flight. Our calculation of average lowest fares reflects the fact that such tickets are at least available more than 300 days in advance. Thus, while many flyers may not purchase their ticket nearly a year in advance, it is possible to do so.

The number of direct connections was arrived at in the same way. Given that in the Australian domestic market the cost of a one-way ticket tends to be roughly half of a two-way ticket (with the exception of booking fees etc.), we assumed A-B and B-A to be equal. This data source also enabled us to identify the number of flights available, whether direct connections were available (we found 72 city pairs) as well as whether a LCC (Jetstar or Tigerair) operated on the route. The LCC dummy variable refers to the presence of LCCs rather than competition per se. While it is possible for LCCs to have a monopoly on a route, it turned out that only Gold Coast-Cairns and Melbourne-Mackay are LCC monopolies (or were monopolies during the data gathering).

The distances of the inter-city links were based on great circle calculations of actual direct inter-city distances. The discussion earlier suggested that special attention needed to be paid to mining centres and small towns. Using the approach outlined above, we have identified Karratha, Kalgoorlie, and Port Hedland as mining centres, while 'small towns' are those with city populations less than 50,000 (Karratha, Hamilton Island, Broome, Port Hedland, Ayers Rock, Alice Springs, Kalgoorlie) Specifying the 'small city' dummy is of course contentious. We applied three thresholds (20k, 50k, 80k), and there is a significant effect in all three instances. Residuals or  $R^2$  do not shift dramatically.

It is worth noting that our method of averaging ticket prices over several time periods only indirectly accounted for possible differences in service or "quality" based on the specific items included in each ticket. The "connections" parameter and more importantly the LCC parameter (see below) were proxies, since service differences in Australia (e.g., baggage allowances, etc.) are largely based upon the differences between LCCs (Tigerair, Jetstar) and full(er) service airlines (Qantas,

Virgin Australia). However in other situations, where more complex regional, temporal, and competitive environments are found, the adjustment of fares to account for service levels via hedonic price regression may prove useful for future research (for a discussion see Papatheodorou et al., 2012). In addition, future researchers utilizing a “connections” variable may find it useful to calculate a link quality measure, as can be found in Wittman and Swelbar (2013).

#### *4.2 The Approach*

Based on this data, and a final sample size of 266, we devised a simple regression model of the form:

$$Y = a + b_1(X_1) + b_2(X_2) + b_3(X_3) + b_4(X_4) + b_5(X_5) + \text{Error}$$

Where:

- Y is the average of the lowest cost fares quoted for a city to 23 others
- X1=distance between each city pair
- X2= the number of direct connections between each city pair (as a measure of market size)
- X3= the importance of mining (a dummy variable)
- X4= the existence of a small town in any city pair, measuring the effect of low demand
- X5=competition in air transport system, a dummy variable registering the presence of LCCs.

We bring the different variables together in a weighted least squares regression model to examine the relative impact of each of the variables, their overall explanatory power, and then study the exceptions through an analysis of the regression residuals. The weighed least squares approach (Ruppert and Wand, 1994) is used to maximize the efficiency of our parameter estimation given the presence of heteroskedasticity - the fact that the standard deviations of some of our variables in model estimations are not constant. In addition, we tested for the presence of multicollinearity, a statistical phenomenon in which two or more predictor variables in a multiple regression model are highly correlated (e.g. we can assume mining, small towns, and the lack of LCC presence to be correlated). In this situation the coefficient estimates of the multiple regression may be hard to interpret, and we therefore use a formal detection method – the variance inflation factor (VIF) – to comment on the credibility of the regression parameters.



### 4.3 The Results

Our statistical results, in the form of a WLS regression equation are:

$$Y = 84.985 + 0.029X_1 - 9.578X_2 + 59.844X_3 + 104.53X_4 - 25.667X_5$$

The R<sup>2</sup> is 87.7%, with parameter estimates shown in table 1.

The overall statistical explanation is strong, with all indicators having the expected signs and all being statistically significant. There are no problems in terms of multicollinearity or heteroskedasticity, the former of which was confirmed by VIFs and the latter tackled by using natural log of connections and applying WLS instead of OLS. It is also critical to reiterate that these findings model the cheapest fares currently available in the future – as many passengers would actually purchase if given the opportunity – rather than reverting to mean fares already paid.

**Table 1 - Results of the Statistical Analysis**

Model Variables	Unstandardized Coefficients		Standardized Coefficients	Significance		Collinearity Statistics
	B	SE	Beta	t	p	VIF
(Constant)	84.985	7.277		11.678	.000	
Distance	.029	.003	.335	10.229	.000	1.206
# connections	-9.578	1.611	-.315	-5.945	.000	3.151
Mining city	59.844	17.019	.137	3.516	.001	1.700
Small city	104.530	11.741	.354	8.903	.000	1.773
Low-cost airlines	-25.667	9.112	-.142	-2.817	.005	2.836

These results confirm that the prices charged for airfares at Australian cities reflect the interactions between the spatial distribution of the market and the operational response of the airlines. The distribution of the market is captured by three measures. The first, distance between cities, is the statistically strongest effect (see Table 1) and shorter flights are cheaper, which is expected. In Australia however most short distance flights are along a corridor that includes the three largest cities, the nation's largest tourist destination and the nation's capital. Hence the benefits of low fares seem to be greater in just a small part of the country. That observation is reinforced by the small city variable, the second market measure in our analysis. Several different size measures were used for this variable, but the overall results were the same, confirming its consequence. The results show the smaller the city the higher the airfare. Smaller cities usually have fewer flights – so

the competitive market pressures are lower. The simple measure for the mining industry was also statistically significant, showing that its unusual large and regular business passenger demand in remote locations flows over into the prices charged.

The effect of the airline industry's operations were measured statistically in the model by the number of direct flights and presence or absence of a LCC. In this analysis the number of direct flights is the second strongest influence on fares. The more direct flights available, the lower are the fares between cities. Large, closely spaced markets are more likely to be served by direct flights. On these routes Qantas and Virgin can use yield management strategies to offer discounts at certain times of the day, or on some days of the week. That influence on fares is strengthened by the presence of Jetstar and Tigerair for whom direct flights (with quick turnarounds) are a key part of their business strategy. These two broad effects are obviously interdependent as closely spaced large markets are more likely to have direct connections by both full service and LCC airlines and as a result maintain strong downward pressure on fares. Hence the geography of Australia's urban settlement itself is a key influence on the geography of its airfares.

Our modelling approach produced accurate estimates of the actual value of fares for the larger city pairs. However, it was less accurate for some other city pairs. The ten largest residuals (or error terms), both for under-predictions and over-predictions, are shown in Table 2 and close study of them provides some more research insight. The ten city pairs in the top half of the table are routes where the statistical model underestimated the actual fares charged on the route. It is apparent that there are special additional factors at work in remote places with special tourist attractions. Ayers Rock, Alice Springs and Broome figure in nine of the city pairs in the top half of the table. The special factors that shape the fares charged to these locations are probably associated with remoteness and the sheer difficulty of access, especially for tourists with limited flexibility in their travel arrangements (e.g., fixed trip times). In addition, on some of these routes, on some days, one airline can have a monopoly position.

On the routes listed in the bottom half of the Table, airfares are lower than the statistical approach would suggest, although the size of the errors are much less than those recorded at the cities at the top of the table. Routes from a few places (mainly from smaller and distant ties) to Hamilton Island are the main example here, which may be because special promotional fares are used to attract consumer attention on these routes.

**Table 2 – Residual Values from Regression Analysis**

<b>Airfares Under-Estimated</b>		
<b>City Pairs</b>		<b>Standardized Residual</b>
Karratha	Ayers Rock	4.61
Ayers Rock	Kalgoorlie	3.83
Sunshine Coast	Rockhampton	3.55
Broome	Ayers Rock	3.54
Port Hedland	Ayers Rock	3.25
Alice Springs	Broome	2.67
Sunshine Coast	Broome	2.29
Broome	Port Hedland	2.26
Mackay	Ayers Rock	2.19
Mackay	Broome	2.15

<b>Airfares Over-Estimated</b>		
<b>City Pairs</b>		<b>Standardized Residual</b>
Adelaide	Ballina	-1.70
Newcastle	Hamilton Island	-1.68
Canberra	Ballina	-1.59
Launceston	Hamilton Island	-1.57
Perth	Kalgoorlie	-1.55
Adelaide	Hamilton Island	-1.50
Sydney	Kalgoorlie	-1.47
Canberra	Hamilton Island	-1.46
Brisbane	Hamilton Island	-1.44
Brisbane	Karratha	-1.37

The fact that the major positive and negative error terms relate to just two broad classes of locations underscores the overall effectiveness of the modelling approach across the majority of cities and especially in the major eastern seaboard corridor. It should be particularly noted that the standardized residuals of the over-estimated airfares are all really quite small. Further calibration of some variables may prove valuable in future applications of the method, particularly where the model underestimated airfares.

## 5. DISCUSSION AND CONCLUSION

As both leisure and business consumers sit in front of their keyboard shopping for flights, the pricing of air transportation may seem to be a "black box." A substantial contribution of the paper was to use a new database which searches for low fares and mimics the process of consumer shopping before purchase. In Australia, perhaps because the route system is rather simple (say in comparison to China, The United States, or the EU) we found that this insight on pricing system was somewhat transparent and easy to relate to the pattern of cities and air services.

In this paper we have collected and analysed low fare data available to all consumers through Skyscanner. Although lowest offered fare is but one slice of ticket sales, it is an important one both for savvy consumers and for airlines promoting services. The confirmatory statistical analysis presented here was successful in modelling these fares in the Australian contest, demonstrating that both the analytical technique and data source have merit. We showed that almost 90% of the variance in lowest available airfares across the busiest 24 airports in cities in Australia is associated with just five variables, which is perhaps all the more impressive given that some of our measures in this initial trial with the data set are rather coarse. Nevertheless, these variables measure the patterns of settlement and the operations of the airlines. In essence the geography of airfares reflects Australia's urban geography with lowest fares in a narrow coastal corridor, medium fares in smaller centres across the rest of the nation and very high fares in remote tourist locations. Data shows that the difference from the cheapest to the most expensive routes is a multiple of 3.5 times.

This outcome is a major contrast to the controlled fares of the regulated duopoly where cross-subsidies from busy routes kept fares lower on less-busy routes, as outlined by Weller (2007). Deregulation has meant a steady shift away from that circumstance. As Goetz and Vowles (2009) observed, the outcomes of deregulation can be "good, bad or ugly". In Australia, it seems the "good" is found on flights between Melbourne and Sydney, while the "ugly" is seen in the isolated inland. In effect, the market- focussed deregulation of the airline industry, which underscores the economies of airline operation in densely-settled short corridors, favours the big and the clustered against the small and the dispersed. That such a result has been achieved in a simple urban system may provide a timely warning for policy makers in other nations. Our results show falls in average airfares can be a misleading view of the outcomes of deregulation. The long term management of a deregulated market requires not only monitoring of average fares but also requires careful and regular monitoring of air fares on a sample of routes, which should be linked to a capacity for action where actual air fares can be shown to be are well above estimated operating costs.

An extension of that thinking will require two areas for further research on the impact of deregulation. One involves closer attention to the circumstances surrounding air services to small towns and remote locations where above average fares are likely. Although airline operations to these places are fundamental to the accessibility of resident communities, there seems to be limited research attention paid to the type, frequency and competitive arrangements of services on these routes. At the very small and isolated end of the scale some of the services will be subject to subsidy; this applies in the U.S. (Grubestic and Matisziw (2011) and Australia (Australian Government, 2013). Can a fare analysis like that carried out here identify routes that call for further action?

The second area deserving closer attention is the operation of low cost carriers, again dealt with in simple terms here. The aggregate data assembly undertaken here suggests that LCCs are moving beyond the busy inter-city and major tourist markets to serve a wider array of destinations. To what extent is this shift by full service carriers to gain cost advantages and move into different union labour arrangements? What has been the change over time in the routes served by LCCs? If that shows a shift into the smaller city end of the market what has been the effect on fares? These two broad set of questions will require additional data for which Skyscanner may be useful.

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## RFID Applications in Airline Maintenance Operations

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### ABSTRACT

Radio Frequency Identification (RFID) has been widely used in different industries in recent years but its use in the aviation industry has been very limited. In this article, the use of RFID technology is explored in relationship to airlines' maintenance operations. The main objectives of this article are to assess the current use of RFID in aviation maintenance and to evaluate future opportunities as well as the barriers to this technology in regards to airline maintenance operations. To this end, a survey of airlines was conducted in 2013. The results show that the airline industry has recently taken notice of RFID and that its use is growing. The results also show that airlines are facing several barriers for RFID implementations. They are: lack of knowledge, cost of Enterprise Resource Planning (ERP) integration, cost of tags, lack of support from managers, and immaturity of technology. This research has also identified the categories of parts that can benefit the most from RFID.

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Keywords: *Radio Frequency Identification (RFID), Supply Chain Management, Air Transportation Industry, Airline Maintenance, Aviation*

## **1. INTRODUCTION**

Aviation is an essential part of the global economy. Its worldwide transportation system is the number one enabler of globalization. A recent study of the Air Transport Action Group (ATAG) and Oxford Economics has confirmed that around 56.6 million jobs are supported by aviation globally. In addition, aviation generates about \$2.2 trillion in global economic activities (ATAG, 2012).

Regardless of all the economic advantages that can be derived from aviation, the average industry profits are not significant and airlines are struggling a great deal in order to recover their cost of capital. Between 1970 and 2010, the average annual post-tax profit for the airline industry has been estimated at about 0.1% of the annual revenue (IATA, 2013). Moreover, the structure of the airline industry is extremely complex. High value, long-service life and complex configurations are characteristics of capital equipment in the aviation industry, which make managing assets a challenge. Maintaining the aircraft in service for a timeline of thirty plus years is what drives profits (Amann, 2002).

All of these pressures result in constant demand in the market for innovative ideas that provide a competitive advantage. In recent years, airlines have been looking for new innovative ideas that can improve the efficiency of their supply chain management as it is the key to keeping their planes in the air, generating income, and enjoying high customer satisfaction ratings. Radio Frequency Identification (RFID) is an automatic wireless system that has the ability to identify, capture and communicate real-time information in order to facilitate data visibility and product traceability throughout the supply chain. RFID can create improvements in operational activities and result in cost reduction and therefore create a more efficient value chain (Sarac, Absi, & Dauzère-Pérès, 2010).

The serviceability and maintenance of aircraft is very important for airlines as their operations can shut down without the proper performance of such systems. In addition, the logistics activities of an airline are directly related to the maintenance operations and strongly associated with the competitive advantages of the airline. Considering the challenges in asset and inventory management and the need for innovation to create competitive advantage in airlines, maintenance operations represent a suitable case for assessing the application of RFID.

This research was conducted in collaboration with the International Air Transport Association (IATA). It uses a survey approach to investigate the application of RFID in Airline Maintenance Operations. The main objectives are to assess the current use of RFID in aviation maintenance and evaluate the future opportunities as well as the barriers to this technology in regards to airline maintenance operations. More specifically, the objectives are 1) to explore the status of the industry regarding the use of RFID in maintenance operations, 2) to identify the categories of aircraft parts that can benefit the most from RFID tagging, 3) to provide an example demonstrating the return on investment in maintenance operations, and 4) to discuss the barriers to RFID implementations in maintenance operations and future opportunities.

### *1.1 Literature Review*

RFID systems are made of three main components: the RFID tag, the reader and the communication infrastructure that is called middleware. Middleware acts as a bridge between the RFID and the network database (Ngai, Moon, Riggins, & Yi, 2008). The idea behind RFID is marking the object with a tag that acts as an identifier and usually has some writable memory to store data. The tag acts on one side as an identifier to locate the object and on the other side to make relevant information about the object available.

In recent years, RFID has been widely used in several industries such as healthcare, fabric and clothing, food, library services, mining and retailing (Ngai et al., 2008). The total market worth of RFID in 2013 was estimated \$7.88 billion, up from \$6.98 billion in 2012. This number is forecasted to increase to \$9.2 billion in 2014 and \$30.24 billion in 2024 (Das & Harrop, 2013). Radio frequency identification (RFID) is believed to be the fastest growing smart label market with an annual estimated growth of 180% (Ngai et al., 2008).

RFID technology has high potential in the area of aircraft maintenance operations. According to Poirier & McCollum (2006), the aerospace and defense sectors present the highest possible return for RFID and therefore are the most likely to find acceptance within their industry. US Department of Defense already uses RFID for many parts of its operations. One of which is tracking parts of an airplane. RFID can help facilitate and accelerate parts tracking with the help of real-time information sharing (Poirier & McCollum, 2006). In 2005, as an initiative to enable airlines to benefit from RFID advantages, the US Federal Aviation Administration (FAA) published a statement that allowed the use of passive RFID on commercial aircrafts. The statement mentioned that passive RFIDs do not cause any harm and safety issues to the aircraft (Chang et al., 2006).

The aircraft manufacturers, Boeing and Airbus, had started using RFID for asset and tool management in the late 1990s. However, in 2006, shortly after the FAA approval of passive RFID, they started planning for RFID solutions and product developments for airline use (Harbison, 2013; O'Connor, 2005). In 2007 Boeing teamed up with Japan Airlines to demonstrate that RFID can speed the inspection process of oxygen generators on board of a Boeing 777 commercial airline (Zaino, 2013). In the same year, a TAP and Airbus team also studied and deployed RFID solution for tracking parts in an engine repair shop (Edwards, 2012). In 2011, Boeing worked with Alaska Airlines on a pilot study to validate the significance of RFID use for labor intensive maintenance (Boeing, 2011).

Airbus has started tagging life vests and passenger seats across A350 XWB and A320 family, A330, and A380 production lines. In 2009, Airbus took the opportunity to include permanent tags in the aircraft's specifications, covering replaceable parts, Life Limited Parts (LLPs), repairable parts and parts with a Mean Time Between Unscheduled Removals (MTBUR) of less than 60000 hours. Low MTBUR parts are parts that tend to fail more often. Some 2200 components were included for tagging (Harbison, 2013).

Following OEM initiatives, some airlines also started implementing RFID technology for parts management. Delta Air Lines, for example, has been taking advantage of RFID in their maintenance operations. Delta has reported significant time and cost reduction as well as improvements in data accuracy and inventory management because of RFID implementations (Lewis, 2013).

Lufthansa Technik AG (LHT), a leading MRO service provider, has also started using RFID for logistics purposes in order to track the components and parts of the aircraft (Canaday, 2011). In addition, they have started using RFID as an attachment to the documents that travels around with the parts. This allows them to track the movement of the part and the document along the supply chain. The company has reduced manual data entries and the associated errors, and therefore, has improved data accuracy and the speed of the process (Zhang, 2012).

From our literature review, it appears that there are only a few studies on the application of RFID in airline maintenance operations. Despite the recognized advantages that RFID can bring to areas such as inventory management and logistics in airlines, there are very few studies that can be used as a foundation to enquire about the use of RFID in the airline maintenance operations for the purpose of parts management.

### *1.2 Methodology*

Following several IATA RFID meetings with a number of airlines and manufacturers, the major airframe OEMs and many airlines suggested having an industry survey conducted to understand the status, perception and needs of the airline industry regarding RFID technology and also to determine what significant aircraft parts could benefit from RFID. A self-administered survey was designed by IATA with the input of two major airframe OEM companies, regulatory authorities and IATA staff. The IATA RFID Survey can be viewed in Appendix 1.

The selected contacts were restricted to airline professionals who were expected to be involved with decisions on using RFID in aircraft maintenance operations. The survey was available to airlines' personnel without discriminating whether the airlines were IATA members or not. This includes engineers, technical and IT professionals, supply chain, and senior management experts closely

associated with an airline's technical operations (engineering and maintenance) division. In order to capture the individual opinion of experts, it was mentioned that several responses from the same airline would be considered.

The survey was conducted from July 29, 2013 to September 27, 2013. The questionnaire was sent to over 538 individuals at 240 airlines. The airframe OEMs helped disseminating the survey through their customer service departments. At the end of the survey time period, 93 replies were received from 67 airlines. This gave a response rate of 17.3 percent on an individual level and of 28.3 percent on an airline level. For clarification purposes, the Survey was also sent to Approved Maintenance Organizations (AMOs also known as MROs) that are wholly owned or closely affiliated with an airline.

In addition to the RFID survey, interviews, archival data and observations were used. A series of semi-structured interviews were conducted with airline managers who are involved in RFID implementations or have a proven knowledge about the matter. Informal interviews were also conducted when clarifications were needed on certain aspects or answers to the RFID survey.

### *1.3 Respondents' Profile*

The highest percentage of respondents belonged to the airlines' engineering department subgroup (40%). The second subgroup of participants was senior management (27%) and the third one was maintenance professionals (19%). Supply chain/logistics (11%) and other technical professionals (3%) were the remaining functions represented on the respondents list. Most of responding airlines were from Europe (42%), including Russia and the Commonwealth of Independent States (CIS) followed by Asia, Pacific and Oceania (25%), North America (9%), Middle East (9%), Africa (8%) and South America (7%). The geographic distribution of our sample reflects the distribution of airlines. More airlines are based in Europe; a highly fragmented market followed by Asia Pacific and Oceania. In terms of size, 31% of responding airlines have a large fleet of aircraft (greater than or equal to 100), 40% have between 30 and 100 planes and 29% have 30 or less.

## 2. DISCUSSION OF RESULTS

Not all of the questions were answered by all respondents. Some questions presented a low rate of response because they were not applicable to some respondents. Therefore the sample size for each question is different based on the number of responses received. As applicable, some questions were analyzed at the airline level while others were presented at the individual level since in some cases more than one survey response was received from the same airline.

### 2.1 Current Use of RFID in Maintenance Operations

Out of the 93 individuals who responded to the survey, 19 replied that their airline was implementing RFID at time. These 19 individuals belonged to 12 airlines (18 percent). The remaining 74 individuals from 55 airlines (82 percent) stated that their airline had not implemented any RFID projects yet. A limited number of airlines had embarked in RFID pilot studies a few years ago (2005 – 2008); however these studies were discontinued and were not included as current RFID projects. Table 1 displays the list of region and fleet size of the 12 airlines that are implementing RFID at the moment. As observed in survey results in Table 1, large airlines are predominately exploring the use of RFID along with some medium size airlines. No small airline is working with the technology as of the time the survey was conducted. This is not a surprising result as larger airlines can spread investments over a larger fleet. The benefits from efficiencies in larger fleets are significantly higher. As shown in the cost benefits analysis that was conducted of the use of RFID tags on Oxygen generators (Dastjerdi, 2014), the initial investment increases only slightly with the fleet size. Therefore, airlines with larger fleet size enjoy economies of scale.

**Table 1. Airlines with current RFID projects distributed per region and fleet size**

	Fleet ≤ 30	30 < Fleet < 100	Fleet ≥ 100	Total
Europe	0	3	4	7
North America	0	0	2	2
Asia Pacific & Oceania	0	1	2	3
Total	0	4	8	12

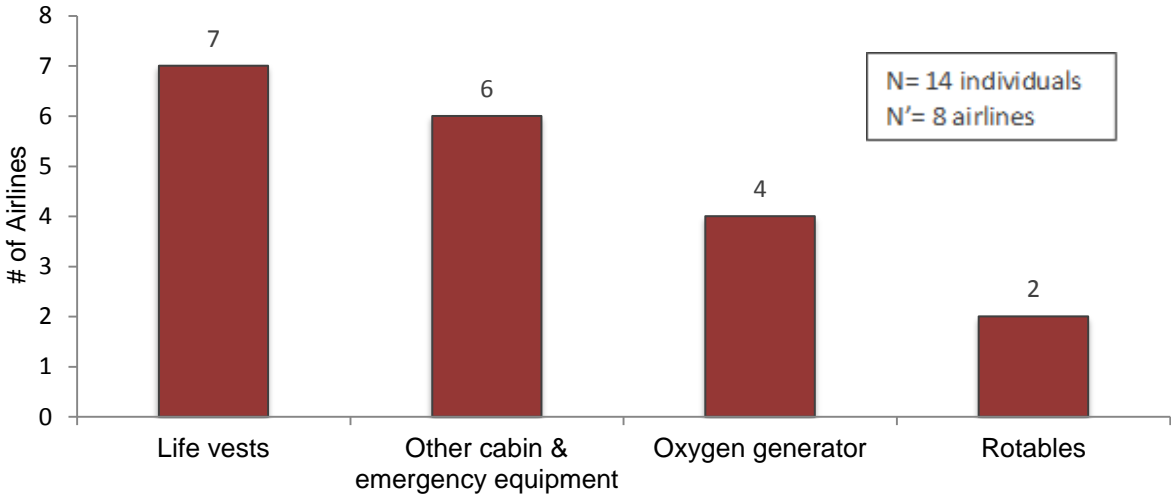
Out of the 12 airlines which have current RFID projects, 4 said they implemented RFID on Aircraft (Flyable) parts only, 4 on both aircraft and Non-Aircraft (Non-Flyable), and 4 implemented it on Non-Aircraft parts only. Respondents were also asked to provide the specific parts or group of parts that they were tagging. As shown in Figure 1 of survey results, life vests are the most popular application of RFID in flyable parts with 7 out of the 8 airlines mentioned using RFID for life vests.

RFID tags are placed on life vests to facilitate and speed up the maintenance checks. While the technician walks through the aisle with a hand-held reader, the status of each vest can automatically be determined by looking at the reader screen. The RFID tag reflects signals to the transmitting reader and would mark any damaged or missing life vests with a red light on the screen indicating absence (loss of signal from the specific life vest). The rest of life vests are given a green light. Therefore, the technician will only check those life vests with a red light, instead of having to manually inspect each and every life vest. Due to pre-synchronization between the life vest and the RFID tag, the technician knows which life vest has the problem (Lewis, 2013).

In addition, RFID is used increasingly for other cabin items. The Industrial Development Director for maintenance components at a major European Airline mentioned using RFID on seat covers and textile at his airline. This allows the airline to track the number of washes for each cover. He explains that some airlines are allowed to perform only a limited number of cleaning per item therefore RFID would be a very useful solution to track the number of washes. He continues: "You have to be able to identify your Part Number (PN) with the textile tag attached to it. If the textile tag (not RFID) is not readable you have to throw away your part, even if some potential cleaning remains and the item is still usable. With the RFID tag, you should be able to identify the good PN and re-issue a proper textile tag to have your item serviceable. In addition, in a warehouse where you have textile it is very tough to do inventory; RFID can provide an easy solution for this problem."

In addition, two major European airlines mentioned using RFID to tag rotables such as engine components. The tags used are low memory and only serve as identification devices for warehouse purposes for now. High memory RFID tags that allow storage of the main history of maintenance of a part are not used for this purpose yet.

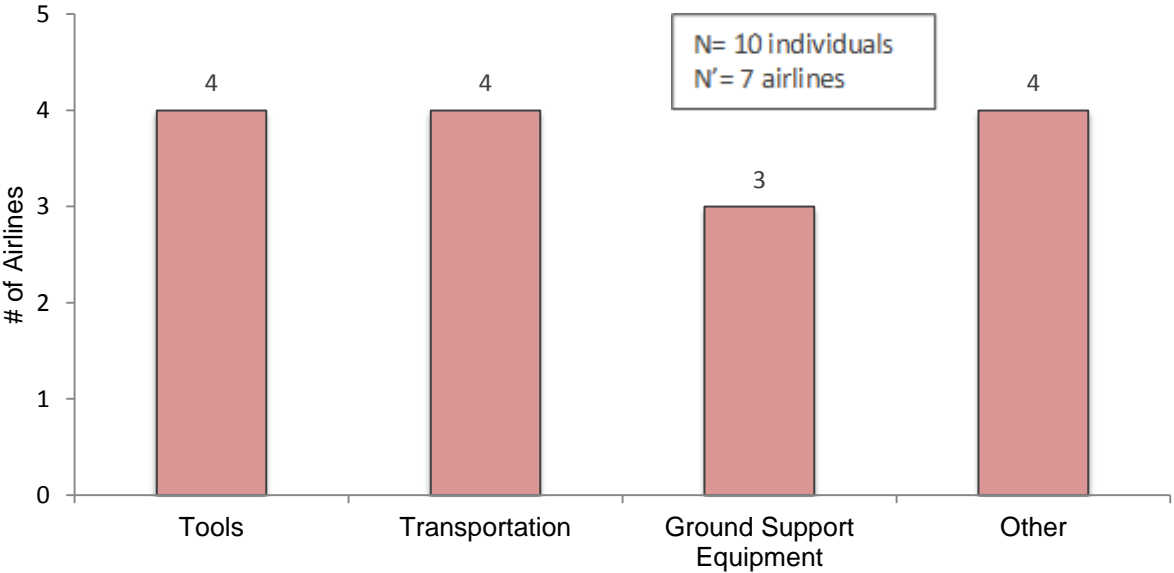
**Figure 1. RFID activities on aircraft parts**





Respondents also provided the specific cases for application of RFID on Non-Aircraft parts. As shown in figure 2, the use of RFID to track tools is a popular application which affects maintenance operations directly. Such uses relate to tool check in/check out by a technician/mechanic, tool location by use of active tags, tools calibration and etcetera. Tools for aviation applications are very specialized and have specific designs that require regular calibration at certain time intervals. In addition, the highly trained aircraft engineers are costly to employ. RFID can minimize the time to look for and to locate tools and allows delegating tasks such as tool calibration to less trained staff (Price, 2007). The "Transportation" category refers to transportation equipment and fleet. In the category "other", shop towels, Employee IDs and Unit Load Devices (ULD) were mentioned.

**Figure 2. RFID activities on non-aircraft parts**



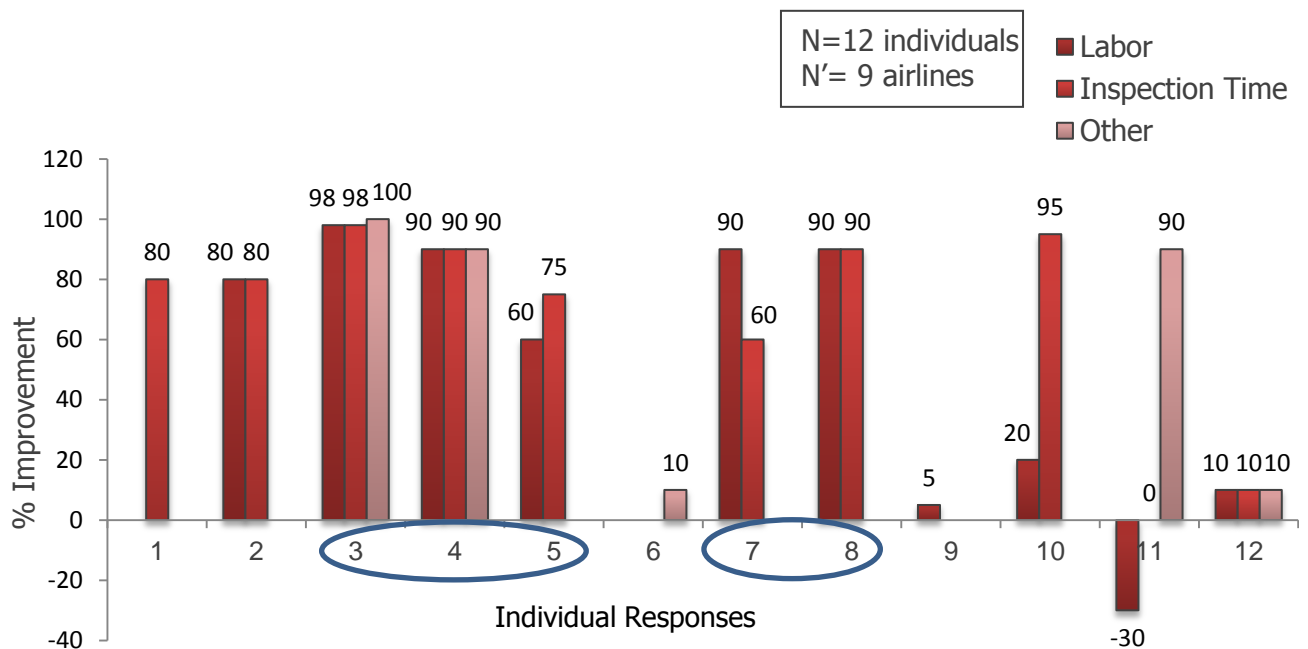
*2.2 Potential Benefits of RFID in Airline Maintenance Operations*

RFID may be an excellent technology but if it doesn't provide a Return on Investment (ROI), its application will be questioned. Airbus has been using RFID for logistics and parts/tools tracking purposes since 2005 and has achieved clear ROI in their RFID applications (Harbison, 2013). Looking at airlines, Lufthansa Technik provides one example of successful RFID implementation to identify and track LLPs in chemical cabinets. Lufthansa has reported "97 percent accuracy and 80 percent time reduction and significant cost savings" (Greengard, 2013). Delta has also seen significant inventory and labor reductions by using RFID (Lewis, 2013). Delta has seen 98 percent time reduction in labor by using RFID to check Oxygen generators (Swedberg, 2013).

Respondents to our survey were asked to estimate the percentage of improvement they believed RFID brought to their tasks. Although this question is subjective, it shows what each individual perceives regarding the benefits of RFID.

Figure 3 displays the results based on 12 responses from 9 airlines. The missing 3 airlines did not provide an answer because their RFID project has not been fully incorporated yet and therefore this question was not applicable to their situation. The responses circled together come from different individuals within the same airline. Differences between these individuals' perceptions can be explained from the fact that 1) the individuals worked on different projects and 2) the perception was slightly different although showing very close trend.

**Figure 3. Improvements upon RFID use<sup>8</sup>**



Respondent #11 reported the implementation of RFID to track shop towels in their engine shop. This was done primarily to improve safety and compliance (i.e. ensuring towels are removed from a component prior to release to service). Although, it has negatively impacted labor productivity by 30 percent, the safety benefits and 100 percent compliance far outweighed the more cumbersome process. Previously, the technicians were free to just grab towels from a bin whenever they needed one. But, after implementing RFID, the technicians had to go through a check-in/check-out process for every shop towel they used. Overall, it was a positive trade-off.

<sup>8</sup> The responses circled together come from different individuals within the same airline.

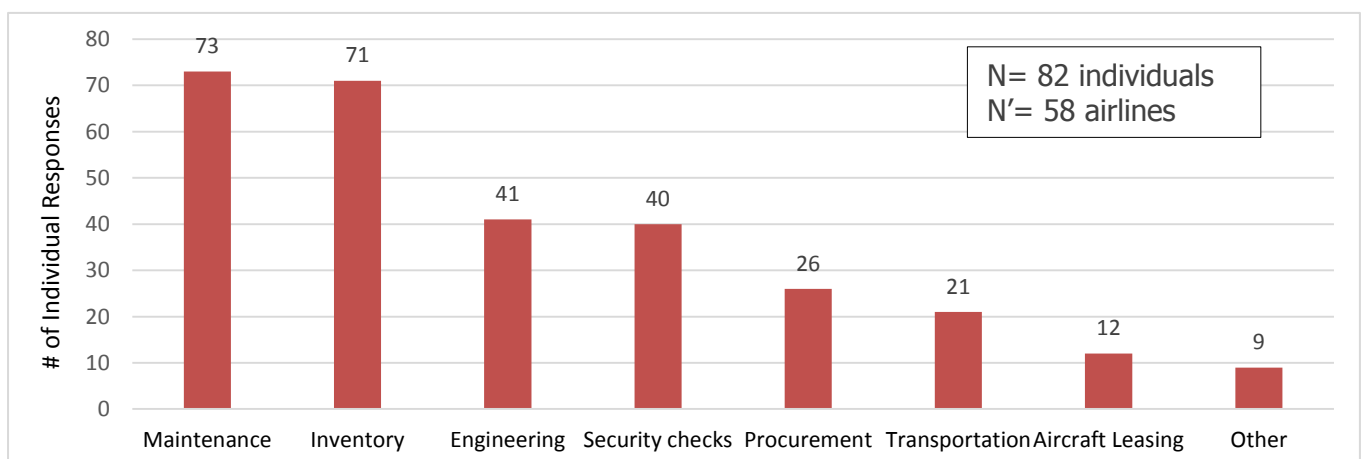
### 2.3 Future Use of RFID

Based on the survey results, current use of RFID application is limited to 18 percent of the industry but this number should be growing as 76 percent responded they are going to have RFID projects in the near future. Out of the 21 respondents from 21 airlines who replied that they were not planning any future RFID projects at the moment, 11 were from small airlines, 4 from medium size airlines and 6 from larger airlines. In order to shed some light on this result, some smaller airlines were interviewed to better understand their perception. The result of the interviews suggested that smaller size airlines normally have a component spare agreement and do not own their own parts; therefore they do not see a reason to use this system. In addition, some mentioned that in smaller airlines it is easier to manage parts manually and there is less need for RFID.

However, being a small airline can be an advantage for RFID adaptation. Literature review confirms that the smaller organization size can make the adaptation of RFID and utilization of the productivity potential easier (Strüker & Gille, 2010). In addition, occasionally, a carrier may still own or track their assets even if their maintenance is done by a third party on a time and material basis, but per contract, the carrier provides the inventory to the vendor for installation during the repair process (IATA, 2009). In such cases and also for the labor intensive inspections such as checking life vests and oxygen generators, RFID can bring advantage regardless of the size of an airline.

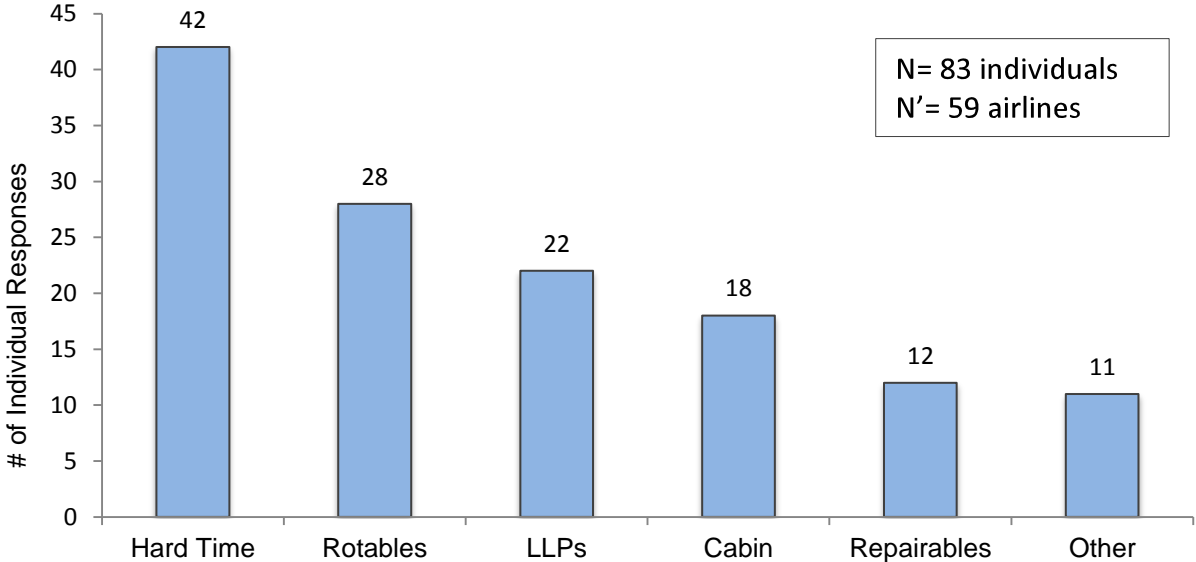
Respondents to our survey also reported on the functions or departments that would gain the most in efficiency improvements through the use of RFID. Results are reported in Figure 4. In the category "other", the following were mentioned: Part pooling, asset tracking and operational health and safety.

**Figure 4. Departmental improvements upon RFID deployment**



Similarly, survey participants were asked what group of parts were to be given priority for RFID tagging in the future. In other words, which parts could potentially benefit the most from RFID tagging? Results are shown in Figure 5. In the category "other", some respondents mentioned: Tools & calibrated equipment, Ground Support Equipment (GSE), In Flight Entertainment (IFE) systems, consumables, chemicals and expendables.

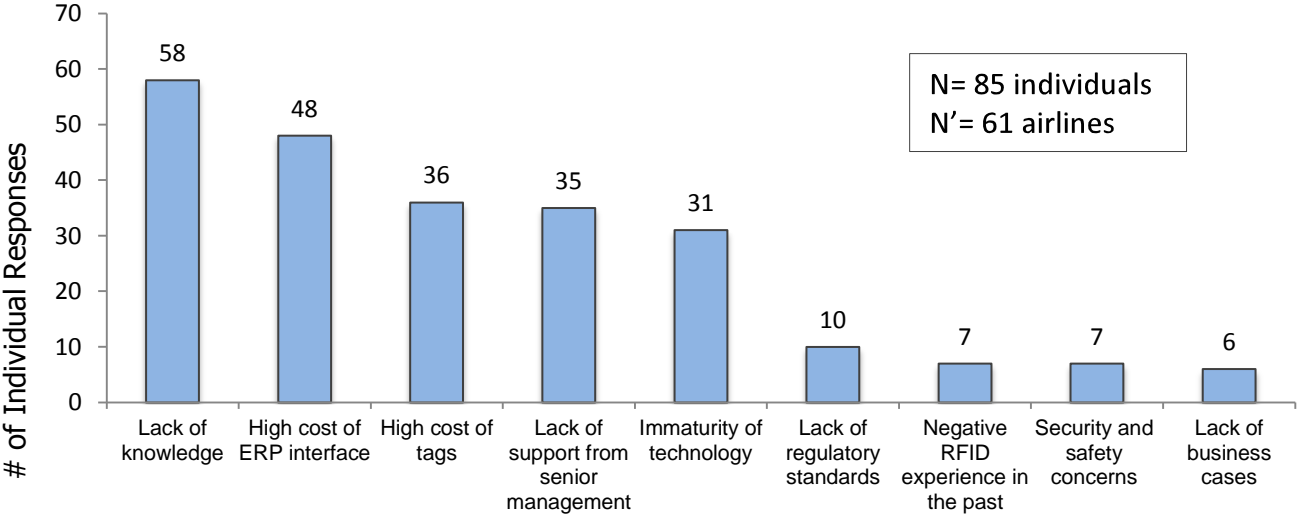
**Figure 5. Tagging priority**



*2.4 Barriers to RFID Implementation*

Respondents were asked to mention the limitations and barriers towards RFID implementation. Lack of knowledge, high cost of ERP interface, high cost of tags, lack of support from senior management, and immaturity of technology were the main barriers according to the respondents as shown in Figure 6.

**Figure 6. Barriers to RFID implementation**



#### *2.4.1 Lack of Knowledge*

"Lack of knowledge" was identified as the number one barrier. This is visible in the responses that were provided by some respondents as there seems to be a lack of knowledge with respect to some fundamental aspects of RFID. Many respondents replied that it was too difficult to obtain the skills and knowledge necessary to successfully implement a complete system, due to the complexity of configuring and operating numerous hardware and software components. Literature review confirms that potential adopters find it challenging to gain the necessary knowledge and skill for implementation of RFID systems. The configuration and system characteristics are complex and require extensive knowledge (Huang, Qu, Zhang, & Yang, 2012).

#### *2.4.2 Cost of ERP Integration*

Respondents also showed significant concerns about the costs of reengineering their processes to support RFID and to integrate the RFID system with their existing information systems. As seen in the literature, the high cost of initial investments in RFID infrastructure may lead to a "wait and see" approach which is the case for many Walmart suppliers. The "wait and see" or "slap-and-ship" approach means tagging the parts right before they leave the supplier site and shipping to the customer. This kind of approach is desirable by some companies as it postpones the need for further investments until the cost of technology decreases (Poirier & McCollum, 2006).

The application for cabin items such as life vests and oxygen generators does not necessarily need integration with the ERP system. As a major American airline explains, for oxygen generators and life vests, the airline has acquired specific software that connects to the tags and readers and can validate the expiry date and the availability of the vests and generators on the plane. The use of RFID without the full ERP integration would allow airlines to take advantage of the value RFID can offer to some extent without worrying about the investment required in ERP integration.

#### *2.4.3 Cost of Tags*

Some respondents showed some concern about the high cost of tags. However this concern is mostly attributed to their "lack of knowledge". Today, a tag can cost less than \$1 US if ordered in quantities. High memory tags can cost more depending on memory size and volume. However, prices are dropping fast and will drop substantially, once the industry firmly commits to the technology.

#### *2.4.4 Lack of Support & Regulatory Standards*

Next on the list, many respondents mentioned a lack of support from senior management. There is also the lack of regulatory standards and limited support from authorities. Some airlines mentioned that there is lack of a real initiative by the type certificate holders and equipment OEMs to create the approvals for items; e.g. where and how the tags should be installed on each part so that it does not interfere in installation or create other system problems. Lack of standards, interfaces with suppliers and MRO ERP systems are also perceived as barriers.

Acceptance of uniform industry standards is required to eliminate complexities and achieve interoperability and higher data security. This is extremely important especially for pool parts; all the operators should be able to read the RFID information. Not many MRO systems vendors have provided RFID interfaces yet. Therefore, one of the main focuses should be on harmonization and standards through the industry in order to facilitate the adaptation of RFID technology. The OEMs should do more than just informing airlines and providing vision and goals. They should also communicate with airlines a detailed implementation timeline that allows airlines to understand the operating factors of RFID as well as the resources required.

#### *2.4.5 Immaturity of Technology*

Immaturity of technology is another main barrier. Research shows that passive tags do not work well against conductive surfaces. Also hand and arm position affects the read capability (Davis et al., 2010; Griffin et al., 2006; Sydänheimo et al., 2006). In aircraft maintenance, the consequences of tag failure in aircraft maintenance are more severe than it would be in other industries and therefore, this incapability can act as a real burden (Davis et al., 2010).

Some carriers that had or witnessed negative RFID experience were interviewed to gain more insights. As an example, a major Asian airline mentioned that they implemented a pilot RFID project for their oxygen generators in the past but they decided to discontinue. As the airline explained, the main reason for discontinuing at the time was the immaturity of the technology. When a technician was walking through the aisle to scan the generators, if more than one tag was in the neighborhood, the hand terminal reader read the incorrect data.

In addition, sometimes the reader was not able to read the tag. In such cases, the technician had to open the Passenger Service Unit (PSU) in order to access the tag. This resulted in worsening the situation and decreasing work efficiency. It was also mentioned that the reader weighted about 1.4 kilograms and it was heavy for a mechanic to carry. Therefore the airline decided that the maturity of technology was not sufficient, and hence they stopped the implementation. However, it should

be mentioned that many of the results observed at the time have been already addressed and reversed using current technology.

#### *5.6.6. Lack of Business Cases & Other Concerns*

There is significant skepticism around RFID's ability to live up to the performance and capability claims being made by solution providers. Even though solution providers promise great read distances and trouble free implementations, some airlines tend to be quite reserved.

Business cases and industry examples will have to pave the way. One airline mentioned that "it would vastly improve acceptance of the technology if an airline could visit a peer with a working solution and see first-hand that RFID actually works and delivers a quantifiably significant benefit." There are few cases where an airline is acknowledging a vendor's solution. In these cases, some kind of co-marketing agreement could be setup where an airline would be agreeable to help sell an RFID solution in exchange for a share in the profits generated and/or massive discounts. Such arrangements are common for MRO/M&E software solutions and it does greatly influence a purchase decision to know if a competitor who is using a product is happy with it and is willing to let others see in person why they are so happy with it.

### **3. CONCLUSIONS**

The landscape of the aircraft maintenance industry is evolving rapidly. If carriers want to become more competitive or maintain an existing comparative advantage in terms of overall operating costs, they need to be more conscious than ever about maintenance dynamics. RFID can help improve visibility, inventory management, safety and compliance, and speed up processes. These advantages make RFID applications extremely useful and promising for airlines.

Certainly the airline industry has taken notice of RFID, as evidenced by our survey results which showed that 76 percent of the airlines surveyed are planning RFID projects for the future. Comparing this to the 18 percent of airlines surveyed which currently have a RFID project in place, one can see how RFID usage is poised to grow in this industry. All of this indicates that future study and improvements in this area would not only be warranted but welcomed by any organization which is searching for better and quicker ways to do their business.

This work has also identified the category of parts that can benefit the most from RFID. The use of RFID for labor intensive parts such as life vests and oxygen generators is recommended. RFID for tools, ULDs, GSEs and fleet management are other useful applications. This can bring benefits to the maintenance program and facilitate logistics. Depending on the inventory management strategy,

an airline may also consider application of RFID for other categories such as expendables, parts with low MTBUR, pool components, corrosion monitoring, etc.

Due to some technology barriers, when it comes to conductive surfaces and also due to harsh operating conditions of aircraft, RFID may not be as efficient for tagging engine parts or parts that are in obscure locations or operating under extreme conditions and temperature.

In addition, the barriers to RFID implementations in airlines were identified. Some barriers mentioned are: lack of knowledge, cost of ERP integration, cost of tags, lack of support and regulatory standards, the immaturity of technology, lack of business cases and etc. The number one barrier was identified as the lack of knowledge. Organizations like IATA, have a key role in enhancing the knowledge in the industry. IATA regularly hosts RFID events that encourage experience and knowledge sharing. These events and workshops will have a positive impact on the overall industry knowledge and should be endorsed by airlines' higher management.

Other barriers such as cost of tags and support from authorities and regulatory standards would improve as the technology use becomes more widespread. The growth of RFID use in aviation in the future will contribute to its acceptance and harmonization throughout the airline industry. The immaturity of the technology is another barrier that will be overcome as suppliers will design more sophisticated RFID systems over time. As mentioned previously, there are airlines which have chosen not to use RFID after bad experiences. Improvement in the specificity of the RFID system that eliminates the extra hassles they encountered would be the key to having them adapt to this technology.

Further, as literature review confirms, one of the greatest challenges in RFID research is to bridge the gap between practitioners and researchers (Ngai et al., 2008). This article aimed to give managers and practitioners the type of data and the information that can help them in decision making. Practitioners can take advantage of the results of this article to understand the status and perception of their peer airlines regarding RFID use. The challenges and the benefits associated with RFID implementations identified in this research can also be used as a theoretical model for future implementation projects in the airlines.

### *3.1 Study Limitation*

The size of our sample may limit our ability to generalize the results to the whole airline industry. Also, some questions in the questionnaire may not have been clear enough even though the questionnaire was pretested with a few airlines and experts. Therefore, this may have caused confusion for some of the respondents and affected the responses provided. However, in questions



where possible confusion was suspected, the respondents were individually contacted for clarifications.

### *3.2 Future Research*

A literature survey of RFID shows that about a third of all RFID research concentrates on RFID technology and in particular its components (i.e., tags, readers, and antennae). As the technology matures, there should be more attention being paid to less developed research areas, such as business and organizational applications. (Ngai et al., 2008).

That being said and considering the potential of RFID use in the airline industry, more research should be done regarding how best to make use of this technology. Specifically, how can RFID be improved upon to address the current concerns over its applicability. Future studies should also aim at studying the impact of RFID and advantages on the entire aviation supply chain from suppliers to OEMs to MROs to airlines which are the end users.

Further case studies should also be conducted on-site the airlines that are implementing RFID or have previously done so. Such research would focus on the costs and benefits of RFID and determine the areas of improvements needed in order to make the technology use more widespread.

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## APPENDIX 1: RFID SURVEY



ENGINEERING & MAINTENANCE  
PAPERLESS AIRCRAFT OPERATIONS  
RFID SURVEY 2013

Airline Name: <input type="text"/>		Airline IATA Code: <input type="text"/>	
1	DOES YOUR AIRLINE CURRENTLY EMPLOY ANY RFID APPLICATIONS?	<input type="radio"/> YES <input type="radio"/> NO	
IF YOUR ANSWER TO THE ABOVE QUESTION IS YES, PLEASE ANSWER QUESTIONS 2,3 AND 4. IF NOT, PLEASE MOVE TO QUESTION 5.			
2	DO YOUR CURRENT RFID ACTIVITIES INVOLVE RFID TAGS ON AIRCRAFT PARTS OR NON AIRCRAFT PARTS?	<input type="checkbox"/> FLYABLE (AIRCRAFT PARTS) <input type="checkbox"/> LIFE VESTS <input type="checkbox"/> OXYGEN MASKS <input type="checkbox"/> OXYGEN GENERATORS <input type="checkbox"/> SEAT COVERS <input type="checkbox"/> OTHER <input type="text"/> <input type="checkbox"/> NON-FLYABLE (NON AIRCRAFT PARTS) <input type="checkbox"/> TOOLS <input type="checkbox"/> DOCUMENTS <input type="checkbox"/> TRANSPORTATION <input type="checkbox"/> GROUND SUPPORT EQUIPMENT <input type="checkbox"/> CHEMICALS <input type="checkbox"/> OTHER <input type="text"/>	
3	WHAT IS THE APPROXIMATE % OF IMPROVEMENT IN TERMS OF PROCESS EFFICIENCY BEFORE AND AFTER RFID IMPLEMENTATION?	LABOR <input type="text"/> %    INSPECTION TIME <input type="text"/> % TURN AROUND TIME <input type="text"/> %    SAVINGS <input type="text"/> % OTHER <input type="text"/> <input type="text"/> %	
4	WHAT IS THE APPROXIMATE SPLIT OF YOUR RFID ACTIVITIES BETWEEN AIRCRAFT PARTS AND NON AIRCRAFT PARTS? (THE SUM SHOULD BE 100%)	FLYABLE (AIRCRAFT PARTS)                      NON FLYABLE (NON AIRCRAFT) <input type="text"/> % <input type="text"/> %	
5	IS YOUR AIRLINE GOING TO EMPLOY ANY RFID APPLICATIONS IN THE FUTURE?	<input type="radio"/> YES <input type="radio"/> NO IF YES, PLEASE SPECIFY THE TIMELINE: <input type="text"/>	
6	UPON RFID DEPLOYMENT, IN WHAT FUNCTIONS OF YOUR ORGANISATION, DO YOU EXPECT TO SEE EFFICIENCY IMPROVEMENTS?	<input type="checkbox"/> MAINTENANCE <input type="checkbox"/> ENGINEERING <input type="checkbox"/> SECURITY CHECKS <input type="checkbox"/> PROCUREMENT <input type="checkbox"/> INVENTORY <input type="checkbox"/> TRANSPORTATION <input type="checkbox"/> AIRCRAFT LEASING <input type="checkbox"/> OTHER <input type="text"/>	

7	<p><b>WHAT IS THE PRIORITY FOR THE NEXT GROUP OF PARTS THAT COULD POTENTIALLY BENEFIT FROM RFID TAGGING? PLEASE ALLOCATE NUMBERS TO YOUR PRIORITY SELECTION WITH 1 BEING THE HIGHEST PRIORITY.</b></p>	<p>EXPENDABLES <input type="text"/> CONSUMABLES <input type="text"/> ROTABLES <input type="text"/>  REPAIRABLES <input type="text"/> LLPs <input type="text"/> IFE SYSTEM <input type="text"/>  CHEMICALS <input type="text"/> CABIN <input type="text"/> HARD TIME* <input type="text"/>  OTHER <input type="text"/> PLEASE SPECIFY <input type="text"/></p> <p>* HARD TIME: ITEMS WITH EXPIRY DATES</p>
8	<p><b>REGARDING THE MAINTENANCE HISTORY OF THE RFID TAGGED PARTS, WHAT IS YOUR PREFERENCE?</b></p>	<p><input type="radio"/> MAINTENANCE RECORDS TO BE STORED ON THE RFID TAG (HIGH MEMORY)  <input type="radio"/> RFID TAG (LOW MEMORY) TO BE SERVED AS AN IDENTIFICATION TO LINK AND OBTAIN THE MAINTENANCE RECORDS FROM IT SYSTEM  <input type="radio"/> OTHER <input type="text"/></p>
9	<p><b>WHAT WOULD BE THE CRITERIA FOR POTENTIAL PARTS MARKING? PLEASE SELECT ALL THAT APPLY.</b></p>	<p><input type="checkbox"/> HIGH VALUE PARTS    <input type="checkbox"/> PARTS RELATED TO AIRCRAFT LEASE  <input type="checkbox"/> PARTS WITH LOW MTBUR*    <input type="checkbox"/> LIFE LIMITED PARTS  <input type="checkbox"/> NON SERIALIZED PARTS    <input type="checkbox"/> SERIALIZED PARTS  <input type="checkbox"/> CONFIGURATION DATA CAPTURE    <input type="checkbox"/> POOL COMPONENTS  <input type="checkbox"/> PARTS WITH REPEATING MAINTENANCE TASKS  <input type="checkbox"/> OTHER <input type="text"/></p> <p>* MTBUR - MEAN TIME BETWEEN UNSCHEDULED REMOVALS</p>
10	<p><b>DO YOU PREFER RFID TAGS TO BE INSTALLED AT DELIVERY OR BY THE AFTER MARKET?</b></p>	<p><input type="checkbox"/> INSTALLED AT DELIVERY  <input type="checkbox"/> BY AFTER MARKET, FOR SELECTED EXISTING AIRCRAFT PARTS:  <input type="text"/></p>
11	<p><b>PLEASE LIST ANY DATA ELEMENTS THAT YOU WOULD LIKE TO SEE ON AN RFID TAG? PLEASE SELECT ALL THAT APPLY.</b></p>	<p><input type="checkbox"/> AT BIRTH RECORD (SERIAL NUMBER, PART NUMBER, ETC.)  <input type="checkbox"/> CURRENT OWNER / OPERATOR OF THE COMPONENT  <input type="checkbox"/> MOST RECENT AUTHORIZED RELEASE CERTIFICATE (FAA FORM 8130-3 / EASA FORM 1, OTHER)  <input type="checkbox"/> LATEST STATUS (MODIFICATION, SB STATUS)  <input type="checkbox"/> ALL MAINTENANCE RECORDS OF THE PART  <input type="checkbox"/> OTHER <input type="text"/></p>
12	<p><b>WHY DO YOU THINK RFID TAGS HAVE NOT BEEN USED SO FAR IN COMMERCIAL AVIATION?</b></p>	<p><input type="checkbox"/> HIGH COST OF TAGS  <input type="checkbox"/> HIGH COST OF IT TO INTERFACE WITH AIRLINE ERP / MS / IT SYSTEM  <input type="checkbox"/> LACK OF KNOWLEDGE OF RFID AND ITS POTENTIAL  <input type="checkbox"/> RFID TECHNOLOGY IS NOT MATURE  <input type="checkbox"/> NOT A PRIORITY FOR SENIOR MANAGEMENT  <input type="checkbox"/> TRIED RFID IN THE PAST AND HAD NEGATIVE EXPERIENCE  <input type="checkbox"/> AFRAID THAT DATA CAPTURED CAN BE USED AGAINST AIRLINES INTERESTS  <input type="checkbox"/> OTHER <input type="text"/></p>
13	<p><b>WHAT WOULD BE YOUR APPROXIMATE EXPECTED RETURN?</b></p>	<p>RETURN ON INVESTMENT <input type="text"/> %    PAYBACK PERIOD <input type="text"/></p>

## ANCILLARY REVENUE PRICING

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### ABSTRACT

The airline industry has evolved from a system of long-established state owned carriers operating in a regular market to a dynamic, deregulated industry. This development – especially the emerging competition of low-cost carriers – has had a major influence on the price setting behaviour of airlines. Profitability of airlines is limited and pricing systems are reconsidered.

To stay competitive, traditional full service carriers consider the implementation of ancillary revenue systems, which are similar to low-cost carriers. This paper investigates challenges of an ancillary revenue pricing approach for full service network carriers.

A qualitative means-end approach is used to find attributes, which are important for air passengers, and influence their ticket buying behaviour. In addition, the study provides insight into the perception of an ancillary revenue system in the full service network carrier market.

The findings present 18 ticket purchase attributes and 15 behavioural terminal values in hierarchical value maps. Based on these values, it is evident that most passengers appreciate if some services are included in the price and not offered as ancillaries. Benefits of ancillary revenue systems include the individual ticket creation, customisation, improved price-performance ratio, flexibility gains and progressive ideas. The main drawbacks of the system include a complicated and complex booking process, feelings of uncertainty, branding problems, a distortion of competitive behaviours, a system similar to that of low-cost carriers, feelings of paying extra for every service and a perceived decline in service and quality.

*Keywords: Airlines, ancillary revenues, full service network carriers, pricing strategies*

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## **1 INTRODUCTION**

The airline industry has evolved from a system of long-established state owned carriers operating in a regular market to a dynamic, deregulated industry. This development – especially the emerging competition of low-cost carriers (LCCs) – has had a major influence on the price setting behaviour of airlines. Profitability of airlines is limited and pricing systems are reconsidered.

One newly emerged strategy, which finds its origins in lowcost carrier business models, is the ancillary revenue system. This system began with the increase in oil prices in 2002 when airlines imposed additional fees for upgrades to the ticket fare. Soon thereafter, this change extended into fees for other services such as meals, baggage and seating assignments, thereby considerably increasing the expected revenues.

However, there are certain risks connected to this pricing strategy as it is a typical characteristic of LLC's. Hence, the implementation of such a system might damage the image of full service carriers representing traditional values, high quality product and quality services as well as customer orientation by offering individual support. Therefore, it must be proven whether such a pricing approach fits within the overall marketing strategy and within the holistic corporate image.

The goal of this study is to determine and answer the following research questions:

- Could an ancillary revenue pricing approach be a suitable and successful pricing strategy for full service carriers?
- Is there a willingness and acceptance to pay for auxiliary services?
- Which attributes and attribute levels have a major influence on the ticket purchase-decision process both during the flight experience as well as on post-purchase behaviour?
- How can ancillary revenue components be bundled to maximise customer utility?
- What impact might an ancillary revenue approach have on the image of a full service network carrier?

## **2 THEORETICAL FRAMEWORK**

### *2.1 Pricing Strategies in the Airline Industry*

In today's world, air transportation services are affordable to the majority of society. However, upon closer examination of the development of the airline industry, it is evident that this has not always been the case. One major factor that has contributed to the current situation is the airline deregulation phase of 1978 (Peoples, 2012).

The emergence of low-cost carrier business models combined with the development of the Internet as a major marketing tool are especially challenging for full service network carriers. To cover high fixed costs full service airlines must reconsider and rebuild their pricing strategies. It is often impossible to establish reasonable airfares that cover all costs. To address the high fixed costs, some full service network carriers either adopt the LCC business models or establish low-cost carrier subsidiaries that are inserted into distinct low-cost carrier routes or markets (Basso et al., 2008).

Carrier pricing strategies are often complicated and incomprehensible because a variety of internal and external factors influence the cost structure. Nevertheless, the numerous strategies can be categorised into overall strategies, which is essential for understanding pricing behaviour (Chi et al., 2009). Overall, the pricing strategies can be classified as linear or nonlinear. In the airline industry, linear pricing is used in connection with the concept of flat rates whereas nonlinear pricing reflects other strategies. These nonlinear strategies are commonly used in highly competitive, incomplete market environments with imperfect information. In contrast to linear pricing, nonlinear strategies reflect the concept that customers pay different ticket fares without justification for identical or similar flights (Hernandez et al., 2012).

Airline pricing strategies can be broadly classified as traditional pricing, LCC pricing, dynamic pricing and newly emerged pricing strategies.

#### **TRADITIONAL AIRLINE PRICING**

In traditional airline pricing, the revenue management uses several price levels and inventory systems. Air fares are established and adapted based on capacity, market conditions and demand forecasts. In contrast to other strategies, competitive prices are not explicitly examined as it is assumed that they already influence general market conditions.

Because price transparency has increased in importance during the last 20 years, customers now compare airfares from different providers. Accordingly, it has become imperative that airlines constantly predict and assess current as well as future market conditions. Moreover, they must adapt their prices immediately. Global distribution systems and travel agents enable airlines to



obtain information about specific needs of consumers, such as ideal departure times and preferred airlines. Additionally, these global systems allow for the modification of prices based on general business policies (Gunther et al., 2012).

## DYNAMIC PRICING

Although, dynamic pricing was originally perceived as a low-cost carrier pricing strategy, today it is often adapted by legacy carriers and appears in various forms. Yield management can be understood as dynamic pricing as both terms represent a method of maximizing returns by defining dynamic prices that differ according to seat load factors and booking or consumption times. Moreover, differentiations can occur due to specific market segments.

Ancillary revenues play an important role in dynamic pricing and can be subdivided into three main strategies, namely, unbundling, traditional fares with add-ons and bundling (Wittmer et al. 2012, Wittmer, Rowley, 2014).

Unbundling is also referred to as the offering of à la carte services. A la carte simply means that customers can choose services from the menu. It is a pricing mechanism that displays the description and prices of individual product and service attributes offered with a flight ticket (Granados et al., 2012). A pure a la carte pricing approach is primarily provided by low-cost carriers. In addition to the basic flight, customers pay separately for almost every additional service such as checked bag, reserved seating, etc. (Tuttle, 2012).

The objective of unbundled pricing is to fight back against commoditisation and sustain the position of direct distribution channels. Furthermore, customers prefer flexibility in choosing services that maximise utility based on their requirements. Because GDS and online travel agencies enabled consumers to easily compare air fares, airline revenues continuously decreased, and as a result, many airlines started the à la carte pricing in their direct distribution system to inform customers about the various product bundles and (Luo et al., 2007; Granados et al., 2012).

Another type of dynamic pricing are fare options, which enable travellers to choose between different service packages according to their requirements (Tuttle, 2012).

Air Canada and Air New Zealand were among the first airlines to introduce a strategy with fare options. On the one hand, they maintained the traditional product, which includes the flight, hand luggage as well as on-board catering, while on the other hand, they began providing a defined set of add-on services (Air Canada, 2013).

The third ancillary revenue strategy is called bundling and refers to the situation where an airline provides several predefined packages for different customer groups with the option of adding specific services. This strategy, which is quite new, is essentially a further extension of fare options.

#### NEWLY EMERGED PRICING APPROACHES

In more recent times, some airlines have attempted to adapt their pricing strategies by implementing new forms. One such approach is the pay-by-weight pricing system, also known as pay-by-the-pound, a rather simple approach first introduced by Samoa Air. While booking a flight ticket, passengers are requested to indicate their approximate body weight as well as the expected weight of their luggage in kilograms. Based on that data, the system then calculates the overall airfare for the passenger (Samoa Air, 2013).

Another approach is the variable pricing system, which was introduced by Allegiant Air in 2011. This pricing system is based on the agreement that customers pay a final ticket price depending on the cost of fuel cost at the time of take-off. Thus, travellers pay a certain ticket price at the time of the reservation but may be assessed an additional fee if fuel prices have increased by the time of departure (Tuttle, 2013a).

There is also the personalised or customised pricing system model. To date, however, this model has only been discussed at the theoretical level; it has not been implemented. According to this approach, passengers pay a flight price based on their individual travel and purpose history. Furthermore, other aspects, such as nationality or marital status of the passenger, would influence the airfare composition. Accordingly, the airfare is not influenced by time of purchase or choice of seat class but rather by personal factors (Tuttle, 2013b).

#### *2.2 Consumer Decision Making*

How people behave when facing the challenge of making decisions is a widely discussed subject in common literature. The theory of judgment and decision making can be found in the disciplines psychology, sociology, business management, economics, political sciences, medical sciences, engineering and other fields (Arkes & Hammond, 1988). In the current study, the theory of judgment is used in the field of business management to explain the behaviour of consumers. More specifically, how consumers evaluate offerings and make buying decisions.

Judgment is "the mental or intellectual process of forming an opinion or evaluation by discerning and comparing" (Merriam-Webster, 2014). In other words, it is the power or ability to make a decision based on the evidence (Arkes & Hammond, 1988).

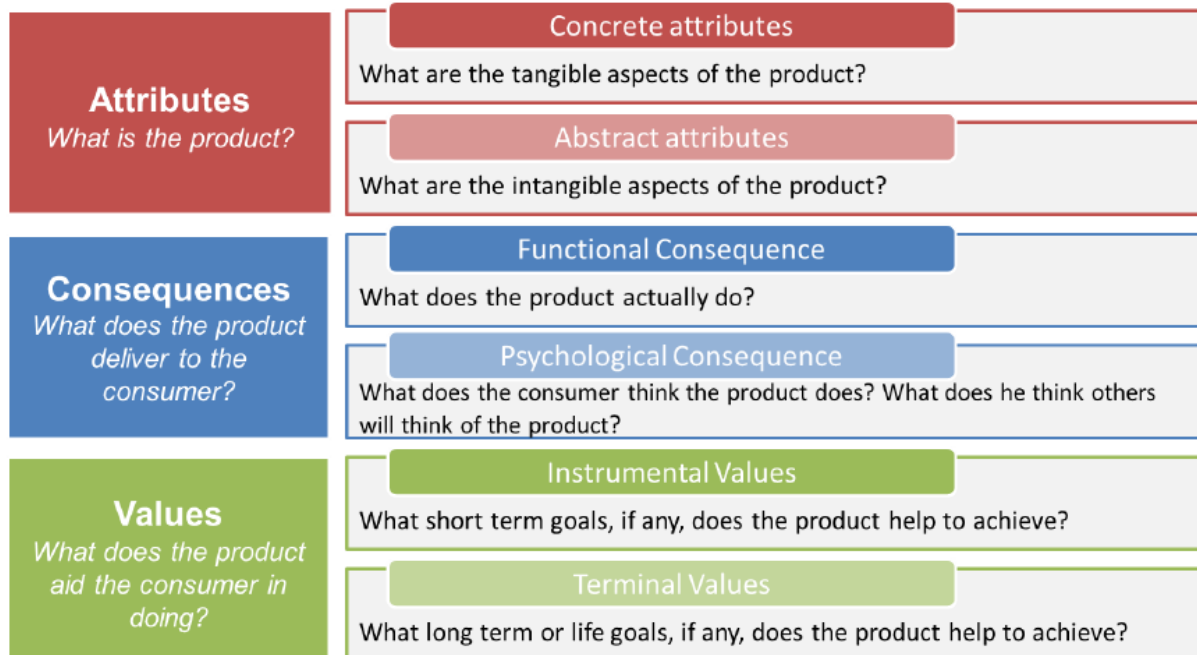
Although there are studies about judgment and decision making that date back to 1918 (Thorndike, 1918; Edwards, 1954; Hammond, 1955), the systematic empirical study of judgment and decision making began in the 1960s. This was especially the case in the field of cognitive psychology, which focused on motivational research. Decision analysis focuses on a priori decomposition, which is the separating of the decision process into several components before making the decision (Arkes & Hammond, 1988). According to this theory, consumers must fulfil a multifaceted task when making buying decisions as they are often faced with several alternatives and a large number of product attributes that must first be evaluated (Solomon, 2013, Wittmer, Riegler, 2013). Consumer decision-making models explain the problem solving process, a process that begins with the recognition of a need. Consequently, to solve the problem, the customer must pass through several steps including a search for information search, the evaluation of alternatives and the process of purchase and post-purchase evaluations (Howard & Sheth, 1969; Engel et al., 1973). Because the consumer has well-defined preferences and aims to maximise utility, the he or she chooses the option that maximises his or her received value (Bettman et al., 1998). Consumers, when confronted with difficult value trade-offs, such as price versus convenience (Bettman et al., 1991), apply either a heuristic or a systematic decision process (Gigerenzer & Gaissmaier, 2011; Doyle, 1998).

As the individual's brain is not able to process all of the available information, it applies specific decision rules to evaluate product alternatives. Reisen et al. (2008) found that in the early stages of the decision-making process, individuals tend to use heuristic decision-making strategies. In later stages and until the end of the process, the individual evaluates the alternatives more carefully. During this phase, consumers trade off price against other factors and then make their purchase decision. Hence, it could be assumed that price is the instrumental factor that dominates systematic decisions, whereas other product attributes are prevailing factors when making heuristic choices.

During this decision-making process, consumers are influenced by a variety of factors, including those of a situational, sociocultural or psychological nature, as well as by the marketing mix of the different suppliers. While developing the marketing strategy and mix, companies should be aware of this process and its influencing factors to take advantage of them (Solomon, 2011).

The means-end theory, developed by Gutman in the early 1990s, is a concept based on customer behaviour knowledge. The model makes it possible to connect peoples' behaviours with consumer values in what are known as means-end chains. Means are understood as products, objects or activities whereas ends reflect desired states of being (Gutman, 1981). The goal of this theory is not only to identify explicit consumer relations and build attitudes towards products but also to discover and analyse the implicit nature of this correlations between product attributes and personally developed values. Figure 12 illustrates this process in a simplified way (Kuss et al., 2007a).

**Figure 1: Means-end process**



**Source:** Kuss et al., 2007a

Figure 1 illustrates the holistic means-end process in greater detail. The product attributes such as the price or the quality are identified first. The attribute level is then subdivided into tangible attributes and intangible attributes. Attributes are linked with consequences, which are divided into functional and psychological (UXmatters, 2013). Functional consequences reflect the tangible or physical-tangible outcomes of using a certain product, such as eating a meal that satisfies hunger or using a car to travel from one location to another. Psychological consequences represent the psychological as well as the social outcomes of product usage. Usually, these consequences are internally or personally perceived, reflecting how the consumption of a product affects one's emotional state. For instance, the use of a certain shampoo might cause the consumer to feel more attractive or the wearing of a certain brand may cause one to feel more stylish. These affective qualities are often linked with expected social consequences, for example, how your friends perceive you. Consumers might experience both positive and negative consequences. Given that customers usually focus on the accumulated benefits they receive by consuming a product than about product attributes in general, the segmentation of consumer groups should rely heavily on this knowledge.

However, consumers also consider the undesirable consequences of using a product. These consequences are the perceived risks associated with the purchase of a product and can be divided into physical, financial, functional and psychosocial risks. During the purchase decision process, consumers are constantly weighing the perceived benefits and risks of a product or service with the

intent to make the best possible decision. As such, core values are at the bottom of the hierarchy and are split into instrumental and terminal values. In general, because these values are derived from people's life goals, they incorporate certain emotional associations with those goals. Instrumental values, for example, reflect preferred modes of behaviour such as acting as an independent person, demonstrating responsibility and thinking logically. Terminal values, on the other hand, are favourable states of being or broad psychological states such as being happy, feeling attractive, being considerate or receiving social recognition (Wittmer, Riegler, 2013, McGraw-Hill, 2013).

### **3 RESEARCH PROCEDURE AND DATA**

As the aim of this paper is to investigate and analyse whether an ancillary revenue pricing system can be a successful strategy for full service network carriers, theoretical and empirical research was conducted. The theoretical portion of the study focused on the various pricing strategies and consumer behaviour whereas the empirical data were obtained from qualitative interviews. The interviews focused on five ancillary revenue options, namely, the basic flight, seat reservations, free checked bags, rebooking/cancellation options and business class upgrades. The goal of the qualitative interviews was to investigate four different areas, all of which influence or are linked with the implementation of an ancillary revenue system.

First, the results of the interviews provided valuable clues regarding attributes and attribute levels that influence customer purchase behaviour, customer experience and customer post-evaluation of a flight offer. These attributes have been used to identify the underlying consumer preferences, and as such, they serve as simulators of purchase behaviour.

Second, this study investigated what passengers expect from the various airline categories, such as low-cost carriers, major network airlines that include carriers such as Lufthansa and British Airways and premium airlines such as Singapore Airlines and Emirates. The objective was to gain insight about the general perception of different airline categories and to gain an understanding of the main distinctive attributes. Furthermore, the possible impact of an ancillary revenue pricing system on the future image perception of full service network carriers was explored.

The survey was highly linked to consumer behaviour. The means-end theory of Gutman (1981) provides an approach to measure behaviour based on final values. The laddering method, which is derived from the means-end theory, was specifically used while developing the interview guide and during the final analysis. Laddering provides insight into the demand side, thus enabling marketers to explain the meaning of product attributes to consumers and to present their underlying consequences and values. Accordingly, these insights into consumer behaviour can be effectively

used in future marketing activities.

The data for the analysis were collected through semi-structured, one-to-one, in-depth interviews that were administered to a sample of 18 persons. On average, an interview with the selected persons, according to the quota sampling plan, ranged from 30 to 45 minutes.

## **4 ANALYSIS AND RESULTS**

### *4.1 Ticket Purchase Decision Attributes*

During the interview, the participants were asked during the flight experience and after the purchase to identify the attributes they considered important when purchasing their tickets. Moreover, additional attributes were also investigated during the survey. The aim of this approach was to identify different attributes and their levels of importance and to analyse the underlying associated instrumental and terminal values using hierarchical value maps.

#### ATTRIBUTES & ATTRIBUTE LEVELS

A comparison of the responses of the 18 interviewees indicated that while the majority value similar attributes, there are some discrepancies with respect to attribute levels. Table 1 presents the attributes and the attribute levels most frequently mentioned by the participants.

**Table 1: Attribute levels and explanations**

<b>Attribute</b>	<b>Attribute level</b>	<b>Description</b>
<b>Service Quality</b>	Quality of service friendly staff cooperative, helpful staff professional staff customer care customer support	Service quality was mentioned with respect to the general degree of good or bad service on the plane; the friendliness, cooperativeness and professionalism of the staff; the customer support at the airport or via hotlines; and the perceived individual customer care.
<b>Cost Element</b>	Ticket price cost-performance ratio additional/hidden costs	The cost attribute of a flight ticket was mentioned in connection with overpriced or cheap tickets, bargain offers, additional and hidden costs, cost-performance relationship and general cost savings.
<b>Food &amp; Beverage</b>	On-board catering quality of food/ beverages variety of choice	This attribute was addressed in connection with on-board catering, either free or at a cost and referenced. the quality of the food & beverage and the variety of options.
<b>Time Element</b>	Direct flight flight schedule transfers/stopovers punctuality handling/transaction time delays strikes	This element was mentioned in connection with time savings, which occur at the attribute levels; flight schedules (time of departure & arrival); direct flights; transfers/stopovers; efficient handling or transaction times; punctuality; delays and strikes
<b>Holistic Quality On All Levels</b>	Plane condition staff education/service food & beverage quality comfort level of equipment	This element reflects the perceived quality on all levels on-board and on the ground. It was referenced with respect to the maintenance and the overall condition of the plane and maintenance, the level of education of the staff, the quality of the food and beverage and the comfort level of the equipment.

<b>Flight Comfort</b>	Comfortable flight comfortable seats legroom/space convenience products air quality climate cleanliness	This attribute addresses comfort level with respect to the seats, the general space between seats and other equipment and legroom. Also mentioned was air quality, general climate plane the plane, cleanliness and convenience products such as headphones, blankets, pillows, magazines, etc.
<b>Condition Of Fleet/ Planes</b>	Age of plane equipment maintenance design technology	The condition of the plane was mentioned in connection with the age of the fleet (modern or outdated and the general impression of the equipment and maintenance of the plane, the overall exterior and interior design of the plane and the relevant technology of the plane.
<b>Security &amp; Safety Standards</b>	Airline brand familiarity with processes condition of plane staff training safety instructions	The security and safety attribute was mentioned in connection with the condition of the planes, the brand of an airline, the professionalism of the staff, the familiarity with the processes and the communicated safety instructions.
<b>Airline Choice</b>	Brand image reliability confidence familiarity past experiences	With respect to the airline they fly, most interviewees emphasised the importance of brand image and the degree of confidence they have in the brand, the reliability of the brand and their familiarity with the processes according to past experiences.
<b>Choice Of Offers</b>	Additional services class (economy, business, first) destination choice	This attribute reflects the perceived choice of offers such as additional services, flight class and the variety of offered destinations.
<b>Entertainment System</b>	Technology/state-of-the art contemporary choice of films/games, etc. multilingual options	The entertainment system was mentioned with respect to the quality of the technology, the contemporariness of the technology, movies, etc. the choices offered with respect to movies, games, etc. and the multilingual options offered



<b>Flexibility</b>	Individual ticket choice choice of flights rebooking option cancellation option upgrade option	The element flexibility was mentioned in the context of individual ticket choice, the choice of flights, the rebooking or cancellation option and the upgrade option.
<b>Feel Of "Flying"</b>	Flight as an experience design of servicescape	Participants stated that using a plane should transmit a special feeling of flying and therefore the servicescape, such as interior design, clothing of the staff, the processes and the overall contact should be designed in a unique way to evoke that special experience.
<b>Stress-Free Travel</b>	Well-organised (package) reliability, punctuality confidence, familiarity	The flight and the processes associated with the flying experience should be as organised and as stress-free as possible.
<b>Customer Involvement</b>	Purchasing of ticket e-ticket self-check-in	Some customers stated the customer involvement during the ticketing process as well as during e-ticketing and the self-check-in as an important attribute.
<b>Simple Handling</b>	Booking processes instructions/ information	Customers want the booking processes and all associated handling process including instructions and information given at the airport to be clear and succinct.
<b>Costs For Getting At Airport</b>	Time costs financial costs	Costs associated with getting to and from the airport were mentioned with respect to both time and money, factors that are dependent on the location and accessibility of the airport.
<b>Business Offers</b>	Lounge access priority check-in priority luggage	This attribute was mentioned in relation with the lounge access, priority check-in and priority luggage.

## HIERARCHICAL VALUE MAPS

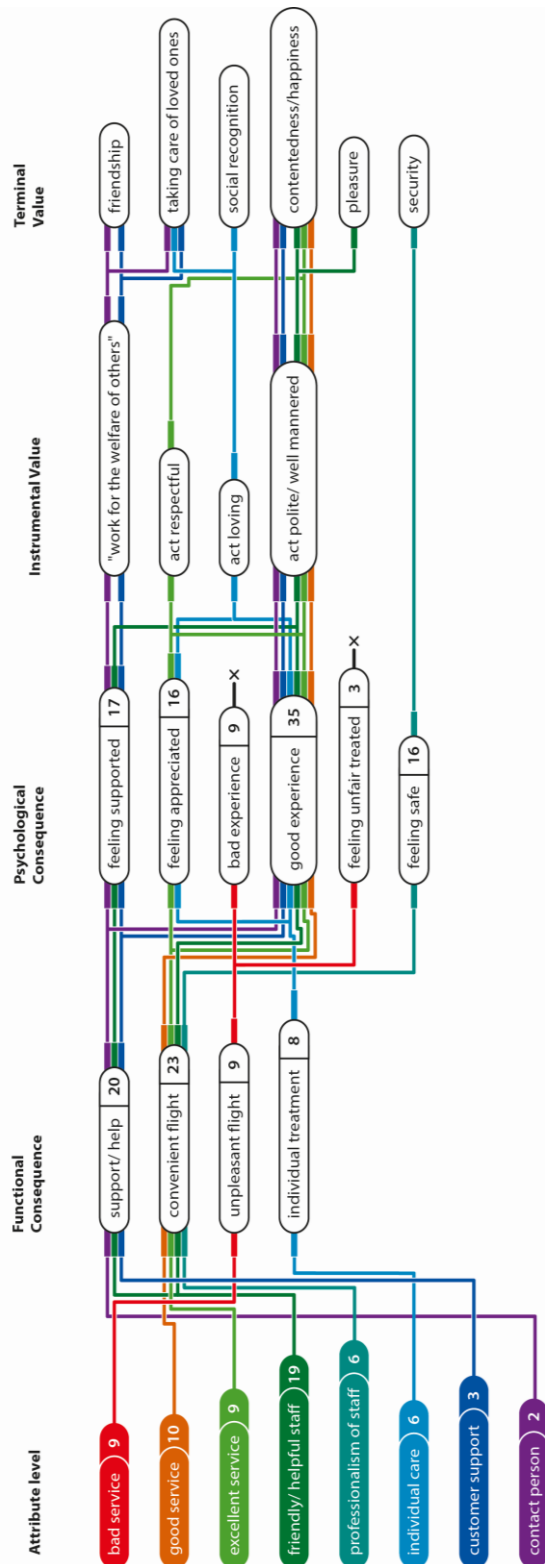
The possible value associations between the investigated attribute and attribute levels are identified by creating hierarchical value maps. In a first step, functional and psychological consequences were detected based on the explicit answers given during the laddering interviews. Potential implicit instrumental and terminal values were then derived from the identified consequences.

Each individual has underlying values with respect to preferred modes of behaviour (instrumental values) and preferred modes of being (terminal values). Usually, customers associate consequences, which may be either benefits or risks, with the consumption of certain products or services, which may then lead to personal values. As a result, individuals prefer to consume products that embody their personal values and might serve as instruments to achieve their final preferred modes of being.

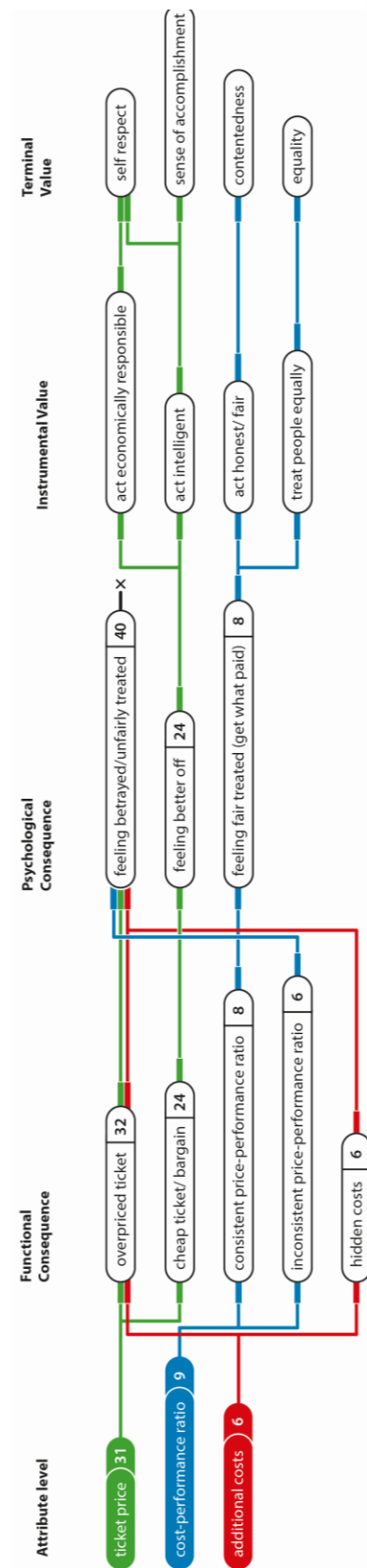
Figures 2 and 3 show instrumental value maps for service quality and cost element. Service quality is the attribute most frequently stated by the respondents, though it was in context with various attribute levels and various consequences. For example, excellent service leads to the functional consequence of a convenient flight and the psychological consequence of feeling appreciated and having a positive flight experience. From this, it was concluded that these consequences are linked to the instrumental values of act respectfully, politely and, mannerly, which in turn leads to the terminal values of contentment and happiness. By referring to the professionalism of the staff, it is concluded that the interviewees link this with a convenient, comfortable flight and a feeling of safety, which in turn leads to the terminal value of having a secure and safe life.

Overall, service quality is highly valued by passengers as it leads to various pursued values such as friendship, caring for loved ones, social recognition, contentment, pleasure and security.

**Figure 2: Service Quality Map**



**Figure 3: Cost Element Map**



The cost element, which is illustrated below, involves three attribute levels that lead to different functional consequences, such as an overpriced or cheap ticket, a consistent or inconsistent cost-performance ratio and hidden costs. Such functional consequences, in turn, result in psychological consequences such as feeling betrayed or victimised or feeling well compensated. Finally, it is probable that consumers want to attain the terminal values of self-respect, a sense of accomplishment, contentment and equality.

#### *4.2 Expectations of Airline Categories*

One part of the interview was designed to identify customer expectations and perceptions of different airline categories. The categories were divided into low-cost carriers, major airlines and premium airlines. LCC's include airlines such as easyJet, Ryanair and Southwest Airlines. Major airlines include normal size carriers such as Swiss, Lufthansa, Air France and British Airways whereas premium airlines are represented by carriers such as Singapore Airlines and Emirates.

Frequently mentioned attributes relating to expectations of low-cost carriers are cheap tickets, easy and accessible transportation from one place to another, additional and hidden costs, less or no free on-board catering, fewer included services (reduced to the minimum) and reduced or even poor service quality. There are also some repeatedly mentioned characteristics, some positive and some negative. These include, on the positive side, sufficient safety and security standards, friendly and helpful staff, fast booking process, efficient general handling processes, a high degree of capacity utilisation, individual package creation and different marketing activities in comparison to other airlines. Negative characteristics associated with LCCs are low level of comfort, poor customer support, use of old aircraft and outdated equipment, less professional staff, unexpected flight cancellations, delays and poorly located airports.

In connection with major airlines, interviewees consistently mentioned the high service quality. They also frequently mentioned the free on-board catering and the complementary services. Repeatedly mentioned attributes included high level of comfort, friendly and helpful staff, good safety and security standards, quality at all levels, good customer support, interesting entertainment programs, modern fleet and contemporary interior equipment, reasonable price-performance ratios, punctuality, efficient processes, professional staff, greater number of destinations, no luggage problems, good communication with consumers and lounge access. The only negative concern was related to high costs for tickets.

Finally, in a third step, the interviewees were asked to identify further expectations based on a comparison between major airlines and premium airlines. The majority of the respondents cited the exclusive, high level service performance offered by premium airlines. They also repeatedly

mentioned attributes such as high-tech entertainment programs, modern equipment and design, superior quality at all levels, friendly and attentive staff, professional and multilingual staff, individual customer care, exceptional comfort level, excellent on-board catering, state-of-the-art technology, highly positive flight experience, modern fleet, nice lounges, punctuality, reliability and new and innovative service offerings.

#### *4.3 Possible Impacts on Future Image Perception*

There are possible impacts of introducing an ancillary revenue pricing system on the future image perception of full service carriers. In a first step, respondents were asked what personal advantages and disadvantages they would expect from such a system. They were asked to consider the potential impacts and changes on the overall image perception of airlines.

Results from the interviews indicate that most respondents have mixed feelings regarding an ancillary pricing system. On the one hand, many emphasised the advantage of customisation and individual ticket creation, which is perceived as an extended benefit that further strengthens the loyalty towards the Swiss brand. They appreciate the opportunity to be involved in the ticket creation process and to have a flight that meets their specific requirements. In the opinion of these respondents, such a customisation option would further improve the price performance relationship and would accordingly result in flexibility gains as it allows for the airline to offer more precise service options.

In general, there was no apparent tendency with respect to changes in image perceptions among the different age groups. Surprisingly, many participants in the age groups 30 to 50 and 51 or above demonstrated positive, or at least uncertain, attitudes towards such a pricing approach. Many of these participants believe that this system reflects a progressive idea that may be quite conceivable in the future as it is a customer-oriented approach.

On the other hand, several interviewees raised concerns about implementing this system. Most notably, people who did not travel regularly or who only infrequently booked their tickets online were concerned that the booking process might become too complex and too time-intensive with this approach. Furthermore, inexperienced users felt uncertain or overwhelmed as they were worried about forgetting certain add-ons or neglecting other important issues. Thus, these participants indicated that they prefer the status quo.

Another major issue, which is perceived as critical by the interviewees, is the deformation or distortion of the competitive behaviour. Because ancillary revenues were originally perceived as an LCC pricing strategy, this approach bears the risk of altering the image of the airline. Several respondents stated that the airline might undergo a shift in the low-cost airline category and be in

direct price wars with them. Although the implied consequences are not evident, passengers are confident that the current quality and service standards of the airlines will be maintained. The consequence might be that Swiss customers act on this assumption and thus perceive a decline in quality and service when, in fact, there has been the standards have remained intact.

However, this topic is highly controversial and the majority of passengers advanced the opinion that the image highly depends on the way the change is communicated. When customers believe that they are paying additional fees for services that had typically been included in their package, they experience a negative psychological consequence as they believe they are being prevented from satisfying their personal values.

## **5 SUMMARY AND CONCLUSIONS**

The knowledge about crucial attributes that are influencing consumers while booking, experiencing and post-evaluating the purchase of a flight ticket, provide a useful background to better understand customer behaviour in the flight ticket purchase process. By interpreting underlying preferred modes of behaviour (instrumental values) as well as end states of being (terminal values), it was found that values such as living a secure and safe life and caring for others are the values most pursued by passengers. By understanding which attributes are of high customer value and by identifying their possible sources, airlines can actively improve their service with respect to these specific attributes.

Further, the analysis of expectations and perceptions of different airline categories can be effectively used for airline positioning. When implementing a new pricing strategy, such as the ancillary revenue approach, airlines should consciously avoid shifting towards the expectations of low-cost airlines.

Based on the literature and on empirical findings, the suitable response would be that the success of this pricing system is dependent on its implementation and on the means of communicating information about the system.

A possible option would allow passengers to choose a flight package that involves different services and allows the passenger to deselect ancillary services that they do not need. By providing such an offer, passengers who prefer to purchase a complete package because they do not want to spend time on or are overextended by the booking process can buy their flight ticket according to the traditional method. In contrast, passengers who want to customise their packages can select flight attributes that allow them to access underlying values. A further positive consequence of this system is that at the beginning of the booking process an overall airfare is indicated to the

customers and they can then take advantage of price discounts by deselecting services. Thus, they do not feel as if they are paying extra for every service, but rather, they are able to find a better price if they take their time and adapt the ticket to their individual needs.

It is concluded that an ancillary revenue system bears risks as well as opportunities. The importance lies in the fact that full service airlines understand how they want to differentiate themselves from low-cost carriers and that they clearly distinguish themselves by establishing a unique selling proposition that does not only focus on the financial aspects but also emphasises additional benefits. There are limitations to this study that lead to further research in the field of ancillary revenue pricing. First, the learning of passengers (learning curve) could be taken into account especially when evaluating the buying behaviour during the buying process. Passengers learn and are assumed to adjust to new forms of booking or selection services. Second, information technology could have an impact on pricing. It could be assumed that personalised pricing is fact, which would then have an impact on the perception of prices and on subsequent behaviour.

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# **ADDITIVE MANUFACTURING - APPLICATION OPPORTUNITIES FOR THE AVIATION INDUSTRY**

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## **ABSTRACT**

Additive Manufacturing also known as 3D Printing is a process whereby a real object of virtually any shape can be created layer by layer from a Computer Aided Design (CAD) model. As opposed to the conventional Subtractive Manufacturing that uses cutting, drilling, milling, welding etc., 3D printing is a free-form fabrication process and does not require any of these processes. The 3D printed parts are lighter, require short lead times, less material and reduce environmental footprint of the manufacturing process; and is thus beneficial to the aerospace industry that pursues improvement in aircraft efficiency, fuel saving and reduction in air pollution. Additionally, 3D printing technology allows for creating geometries that would be impossible to make using moulds and the Subtractive Manufacturing of drilling/milling. 3D printing technology also has the potential to re-localize manufacturing as it allows for the production of products at the particular location, as and when required; and eliminates the need for shipping and warehousing of final products.

*Keywords: 3D Printing Technology, Additive Manufacturing, Application in Aviation Industry, Aerospace Applications, Unmanned Aerial Vehicles (UAV), Defense Applications*

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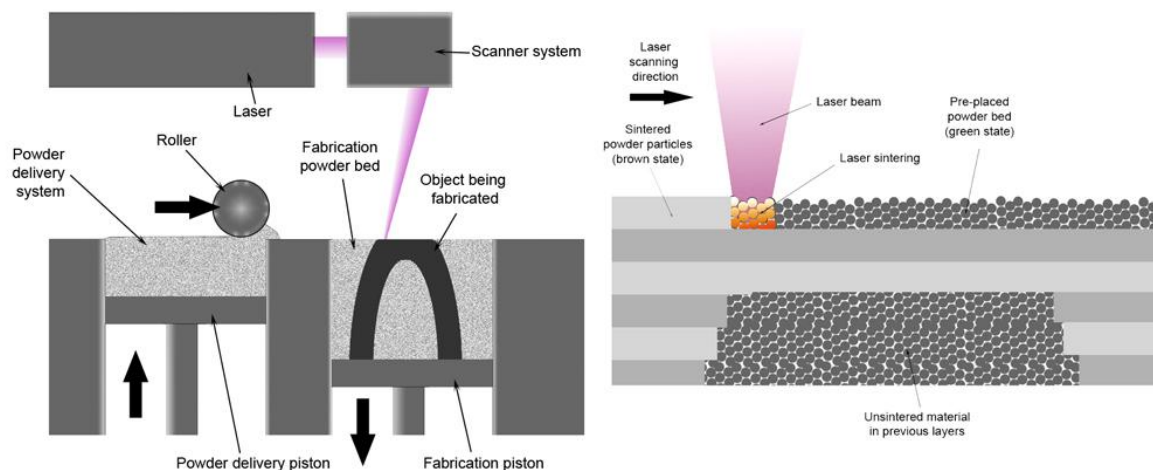
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## 1. ADDITIVE MANUFACTURING

### 1.1 Definition

Additive Manufacturing (AM) also referred as “3D printing” is a process by which digital 3D design data is used to build up a component in layers by depositing material and fused together to create a single object as opposed to ‘subtractive manufacturing technologies’ (i.e., milling, cutting a work piece from solid block) (Anderson, 2013a). AM is opposite to the conventional manufacturing methods (e.g., extrusion and injection molding) in which the parts are molded into specific forms, or cut and formed from a block of material. AM is thus an alternative to these conventional manufacturing methods, while also providing cost efficiency and flexibility in production. With AM techniques such as laser sintering, it is possible to produce high quality industrial grade complex products (AT Kearney, 2015).

**Fig.1 Selective laser melting system schematic**



**Source:** Materialgeeza, 2008

### 1.2 Advantages

Karunakaran stated in Ipmd (2013) some of the advantages of additive manufacturing:

- “Assemblies without joints (elimination of welded joints),
- Produce complex shapes which are difficult/impossible by other means,
- Objects with gradient materials,
- Components of non-equilibrium materials (D’Aveni, 2015).

There are many other advantages of AM technology in comparison to the conventional 'subtractive' manufacturing techniques, which are described as follows:

### *1.2.1 Accelerated Time to Market*

Along with the rise in competition in the market, the companies have to conceptualize and market their products quickly, which needs faster and accurate decisions during the conceptual phase. AM enables to produce prototypes easily and also materialize the concepts with necessary iterations as required. This enables faster and better decision making at early stages of product development and also helps to optimize profit (Huang et al., 2012). With AM, parts could be made directly from the CAD design. Some of the parts, considered impossible from conventional methods, could also be created easily using fewer machines (AT Kearney, 2015). Also, AM could be used in many industries for wide applications, and allows flexibility in design and customization. It also results in less scrap parts and has shorter production cycles (Anderson, 2013a). AM could be utilized along with Rapid Prototyping (RP) – which is the construction of functional prototypes.

### *1.2.2 Fewer Manufacturing Errors*

3D printers create a fully functional prototype, it enables designers to make inexpensive multiple iterations on the design. Possibility for such design optimization at the early stages reduces the chances of error in the final product output, and also minimizes the need for multiple product iteration at later stages which might be expensive and also lead to project delays (Huang et al., 2012).

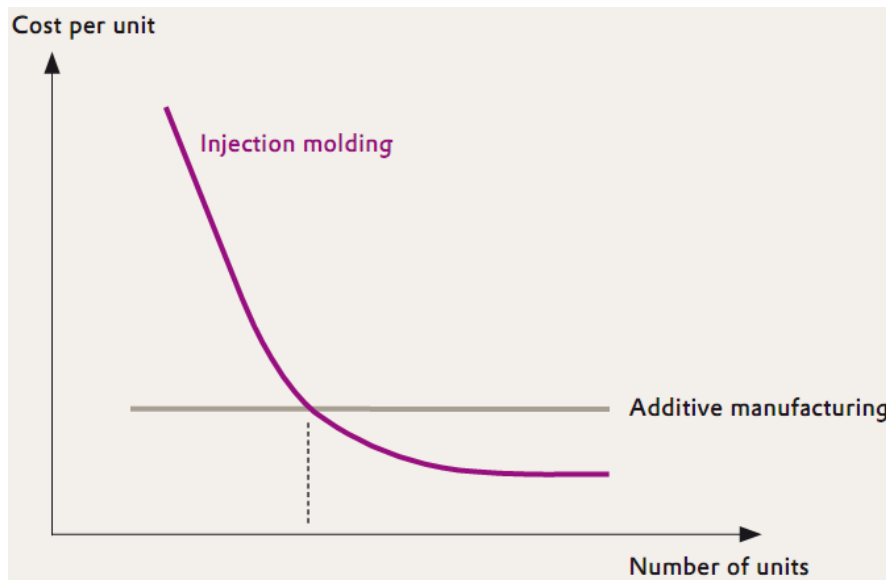
### *1.2.3 Cost Savings*

AM techniques over the traditional outsourced prototyping had helped businesses secure significant cost savings during the economic recession (Atzeni / Salmi, 2012). Now, AM is also used for series production. This provides Original Equipment Manufacturers (OEM) the opportunity to create a distinctive profile for themselves, provide flexible products and services to their customers, all supported within the cost saving benefits of AM techniques. AM also enables to manufacture small batches of products at low unit costs in comparison to the conventional method, as it does not need expensive mold creation or different machinery setup. In several cases AM would reduce a part's cost, compared to traditional manufacturing techniques by 90% (Bonezone, 2013).

AM also allows not only rapid cost-effective prototyping but also cost-effective batch production. Many product requests are for relatively high but limited piece counts. For these products, the conventional mass production technique is too expensive, as it needs costly molds and large plants. Thus, AM is furthermore beneficial for smaller batch productions. It has been found that AM

technologies are significantly more economical for low-volume production than injection molding, as shown in Fig. 2. Injection molding is cost-effective only for mass production, because of the high cost of the mold required for this process (Monsheimer, 2010).

**Fig. 1 Comparison of cost-effectiveness of additive manufacturing in comparison to the injection molding based on production volume**



**Source:** Monsheimer, 2010

#### *1.2.4 Greater Confidentiality*

Using AM, a company can produce the product prototype in-house and prevent the leakage of designs and concepts. In today's competitive market, it is very important to maintain and protect the product development information and designs, as leakage might lead to lost opportunity (Huang et al., 2012).

#### *1.2.5 New Functionalities Through Custom Tailored Materials*

Thermoplastics are one of the materials that are ideal for AM. Thermoplastics are easy to pulverize, and can be selectively melted. Their chemical and physical properties can also be customized, which makes it suitable for AM uses. Also, custom tailored materials are being introduced for AM uses which enable new functionalities. For example, the German company Evonik developed an ultra-flexible polyamide (PA) that has 8 times the flexibility and 5 times the tensile strength of the standard material as shown in Fig. 3. Different industries have different requirements for materials. For example, the aircraft construction requires polymers that can withstand extremely high temperatures, and are flame resistant. Such optimized polymers enable new functionalities as per

the need and demand, and could also clear ways to replace other conventional manufacturing materials, such as metals, with plastics (Monsheimer, 2010).

**Fig. 3 Comparison of the material properties of a standard polyamide and an ultra-flexible polyamide specially developed for additive manufacturing**

	Standard grade	New flexible material
E modulus	1,700 MPa (246,500 psi)	100–250 MPa (14,500–36,200 psi)
Elongation at break	15 %	>100 %
Tensile strength	45 MPa (6,250 psi)	8 MPa (1,160 psi)
Notched impact strength	3.5 KJ/m <sup>2</sup>	No break
Melting point	186 °C (366 °F)	150 °C (302 °F)
Common refreshing rate	50 %	Not necessary

**Source:** Monsheimer, 2010

Similarly, AM techniques such as Electron Beam Melting (EBM), have high quality output such that it has been able to certify titanium alloys to the same ASTM and ISO standards as are in current use, which is a major plus point (Bonezone, 2013). But AM's true value proposition lies in the fact that it can produce parts that no other manufacturing technique can produce. These include novel porous structures and constructs that open up new markets and new opportunities for the products/components that truly did not exist before AM (Conner, B. et al., 2014).

#### *1.2.6 Laser Sintering Enables Layers Only Millimeters Thick*

In parts production using polymers, AM already competes with conventional extrusion and injection molding techniques, in terms of quality. Selective Laser Sintering (SLS), one of the AM techniques, is very well suited to plastics and can produce layers as thin as 0.15 mm. Much thinner layers (up to 0.08 mm) are also possible, although at this level of thickness the powder polymers used as raw material become very difficult to handle, because internal forces of attraction prevent the tiny particles from trickling (Frazier, 2014). Comparative measurements as shown in Fig. 4 indicate the performance of laser sintered AM technique in comparison to the injection-molded process.

**Fig. 4 Comparison of the technical properties of a part produced by laser sintering and one produced by injection molding**

		Test method	Laser sintered test bar	Injection molded test bar
Density	g/cm <sup>3</sup>	DIN 53479	0.95	1.04
E modulus	MPa	DIN 53457	1,700	1,400
Tensile strength	MPa	DIN 53455	48	46
Elongation	%	DIN 53455	18	>50

**Source:** Monsheimer, 2010

### *1.2.7 Economies of Scale*

AM with its capability to produce even low number of products at a very low cost margin could create an environment free of economies of scale. Additive manufacturing should be considered as a compliment to the manufacturing process, which provides cost savings and margin that could help job creation and growth. AM technology provides a competitive advantage in both time to market the product and return on investment. It thus, provides manufacturing capability to even the smaller manufacturing facilities serving the smaller markets. It thus gives manufacturing power back to the individual or small production levels (Conner et al., 2014).

### *1.2.8 Design And Redesign*

Design and redesign is one of the important advantages of AM. With AM it is possible to produce a complex product through a simple design. AM enables to consolidate several individual parts of an assembly into a single, complex product output. This eliminates part numbers for assembly at later stages, inventory of separate parts, labor and inspection. It is also possible to redesign the parts relatively easily without the need for changing the mold or manufacturing machine. A redesign could be made in the parts to consist of thin skins and mesh structures, instead of solid material. This would save in manufacturing material, time and cost and result in a lightweight product. All this could be done easily with the redesign in the CAD design and get the final product 3D printed without the need for any other hassle or processes.

Also, parts could be redesigned using topology optimization, which is a method whereby the process decides mathematically to put materials in the parts to optimize the strength to weight ratio. The material used and the product weight have been found to be reduced by more than 50 percent in some cases, using these techniques (Anderson, 2013).



Also, a completely different product in comparison to the current product, or the stronger and lightweight product could be easily produced using the AM technique, by simply redesigning the part as desired (Anderson, 2013). It enables a design-driven manufacturing process - where design plays an important role and determines the production and not the other way around as it happens in conventional manufacturing method, where due to the product facility and availability of molds for product designs, determine the production.

### *1.2.9 Elimination of Logistics Costs*

Manufacturing will see a re-localization. Through affordable printers the production of certain products can take place anywhere and anytime and drastically reduce the costs of shipping and warehousing (Hagerty and Linebaugh, 2012).

*"The technology opens up new design possibilities. Traditional manufacturing typically involves taking a big chunk of metal and cutting and shaping it into a useful object. The design is often kept simple to reduce the number and difficulty of steps and hold down production costs. With 3-D printing, everything is controlled by a computer code; an intricate design is no harder for the printer to spit out than a simple one."* - David Burns (President of ExOne) (Hagerty and Linebaugh, 2012).

Instead of ending the traditional manufacturing facilities, AM is being adopted by them, and utilized in the existing process to facilitate its advantages. 3D-printed tools, jigs, moulds etc allow set up of production lines more quickly. For example, in the field of aviation, cockpit and cooling-duct parts for aircraft are 3D-printed and then combined with other parts. 3D printing is as much a complement as a competitor to mass production (The Economist, 2013a).

Also, lightweight construction for airplanes is a key sector for additive manufacturing. Lightweight construction is an undisputed construction principle in the transportation industry, for example, where it is used to reduce fuel consumption and emissions (Liu et al., 2014).

### *1.3 Limitations*

There could be certain limitations that OEMs might face regarding the AM technology in the beginning. The lack of an experienced AM partner might make it difficult for an OEM in the beginning, as it requires a bit of time and help. Also, the lack of budget and vision could be the obstacle to the wide scale adoption of AM techniques at this point, as it requires some capital costs at the beginning for the systems, while considering for a manufacturing facility.

Also, the lack of standard industry recognized standards for the materials, processes and testing methods could be another obstacle for the wide-scale implementation of AM techniques at present. For now, 3-D printing best suits products that are highly complex and need customization, for



manufacturing in small volumes. The current limitation in build speed and maximum part size are also the challenges (Anderson, 2013). However, the process will get cheaper and faster along with the improvement in technology and wide-scale adoption (Hagerty and Linebaugh, 2012).

*"You need an economic and technical justification to manufacture a part in a certain way,"* Processes in certain industries, such as the aerospace industry, lend themselves better to 3D printing. For other industries, that follow different processes, the uptake is slow. *"It's a learning obstacle and it will take time for companies to change this (their processes for manufacturing)."* – Wohlers(Sharma,2013)

## 2. ADDITIVE MANUFACTURING PROCESSES

A number of additive processes are now available. Various classifications are found in different researches. Classifications based on 'layer deposition method' and 'state of materials' are presented in this report as follows:

### 2.1 Classification Based On Layer Deposition Method

They differ in the way layers are deposited to create parts and in the materials that can be used (Wong and Hernandez, 2012).

**Table 1: Classification of based on layer deposition method**

Type	Technologies	Materials
<b>Extrusion</b>	Fused Deposition Modeling (FDM)	Thermoplastics, eutectic metals, edible mate
	Fused Filament Fabrication (FFF)	PLA and ABS plastics
	Melted Extrusion Modeling (MEM)	Metal wire or plastic filament
<b>Granular</b>	DirectMetal Laser Sintering (DMLS)	Almostany metal alloy
	Electron Beam Melting (EBM)	Titanium alloys
	Selective Heat Sintering (SHS)	Thermoplastic powders
	Selective Laser Sintering (SLS) or Melting (SLM)	Thermoplastics, metal powders, ceramic powders
	Powder bed and inkjet head 3D Printing (PP)	Plaster
<b>Laminated</b>	Laminated Object Manufacturing (LOM)	Paper, metal foil, plastic film
<b>Light Polymerised</b>	Stereolithography (SLA) or SL	Photopolymer
	Digital Light Processing (DLP)	Liquid resins

## 2.2 Classification Based On State Of Material

Classification based on the criteria of material's state: liquid based, solid based, and powder based, are as follows: (Wong and Hernandez, 2012).

**Table 2: Classification of Additive manufacturing technologies based on state of material.**

Type	Process	Technologies
<b>Liquid Based</b>	Melting	Fused Deposition Modeling (FDM)
	Polymerization	Stereolithography (SLA) or SL
		Polyjet
<b>Solid Based</b>	LaminatedObject Manufacturing (LOM)	LaminatedObject Manufacturing (LOM)
<b>PowderBased</b>	Melting	Selective Laser Sintering (SLS) or Melting
		Electron Beam Melting (EBM)
		Laser Engineered Net Shaping (LENS)
	Binding	3D printing (3DP)
		Prometal

## 3. ADDICTIVE MANUFACTURING MARKET ANALYSIS

### 3.1 Global

According to the research from *'Markets and Markets'*, AM is growing in almost every manufacturing sector with a global additive manufacturing market of \$1,843.2 million in 2012 and expected to grow at a CAGR of 13.5% to reach \$3,471.9 million by 2017 (MarketsandMarkets, 2013). Another forecast from *'Forbes'* estimated the size of the emerging 3D printing industry to be \$3.1 billion by 2016 and \$5.2 billion by 2020 (Forbes, 2012). Additive manufacturing so far has tapped just 8% of its global market potential, according to industry experts surveyed by Wohlers. By that measure, the market opportunity could be \$21.4 billion (DiChristopher, 2013). *'McKinsey Global Initiative'* expects the yearly economic impact of 3D printing technology to reach at least \$550 billion by 2025 (Hasse, 2013).

The Wohlers Report, 2011, showed a 37.4% increase in AM industrial system shipments, the highest growth in over 6 years. For the same year, the annual industry revenue for products and services was US\$1.325 billion, a 24.1% increase over 2009. In the AM industry's 23-year history, its CAGR has been 26.2%. The report predicted the industry will ship 15,000 industrial systems per

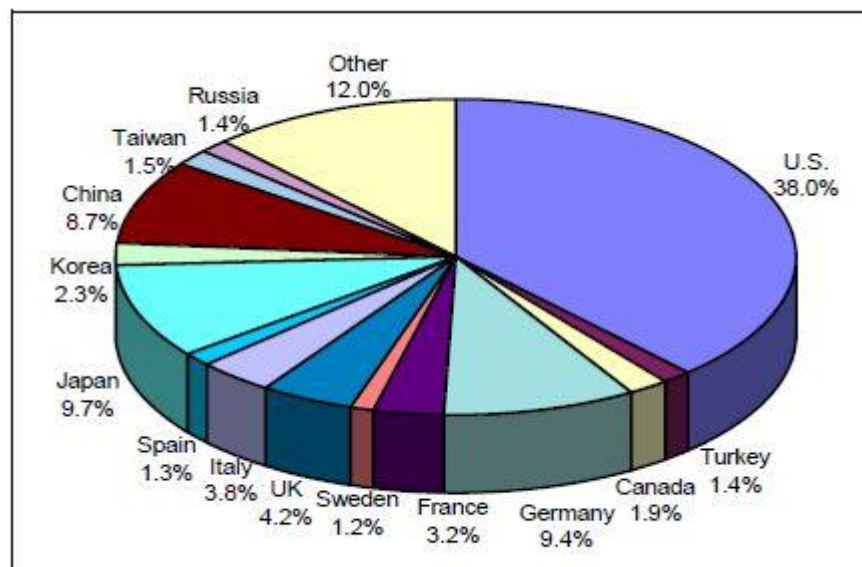
year by 2015, driven in large part by systems selling between US\$5,000 and US\$25,000, with annual revenues of US\$5.2 billion by 2020 (Wohlers, 2012).

*Market share by Country (Industrial AM Systems)*

“Manufacturers from the United States, Europe and Australia are already investing heavily in AM as they sincerely believe that it will bring manufacturing advantage back to developed countries” – Guruprasad K.Rao (CEO, Imaginarium India Pvt. Ltd.)

Fig. 6. shows the percentage of cumulative industrial additive manufacturing systems installed by country from 1988 through the end of 2012. The U.S. continues to lead by a large margin. Japan, Germany, and China have the second, third, and fourth largest installed bases, respectively. The “Other” segment includes countries into which a relatively small number of AM systems have been sold. As of May 2013, 16 companies in Europe, 7 in China, 5 in the U.S., and 2 in Japan were manufacturing and selling AM systems. It has dramatically changed from a decade ago when it was 10 in the U.S., 7 in Europe, 7 in Japan, and 3 in China. Also, all of the metal powder bed fusion systems are manufactured outside the U.S. 7 manufacturers of these systems are in Europe and 2 are in China (Tctmagazine, 2013).

**Fig.2 Percentage of cumulative industrial additive manufacturing systems installed by country from 1988 through the end of 2012**



Source: Wohlers Associates, Inc.

**Source:** Tctmagazine, 2013

“China will ultimately become one of the largest and possibly the strongest [country] in applying and developing AM technologies” –Graham Tromans (Additive Manufacturing Consultant)

China currently lags behind US and few other countries. However, it is estimated to provide one of the biggest AM market growths in coming years. China has some of the world's largest 3D printers, including a 12-meter long machine that is used to print titanium wing and fuselage parts for short-haul aircrafts. China has also found a way to 3D print moulds in foundry sand, which could be a faster and more accurate way to cast metal. China has also utilized AM for its space program to make the seats for the astronauts. China eyes to upgrade its manufacturing potential into the future by the use of AM techniques; as the rising labor costs already takes away some of its advantages from the current manufacturing potential (The Economist, 2013a). Considering both the AM market and installed AM systems, China had only about 3.6% of the 3D printing market, compared to the nearly two-thirds of the market held by the US, and Europe. However, the AM market in China has been growing rapidly. In 2008, China's installed systems grew 39.7 percent, from 1,986 to 2,472 (Anderson, 2013a).

### *3.2 Aviation / Aerospace Market Segment for 3D Printing*

Aerospace industry continuously pursues the improvement in efficiency of aircraft and reduction of air pollution. For these objectives to be met, the aircrafts should achieve weight reduction, and have lightweight parts. Also, the aerospace industry is highly characterized by the use of highly complex parts that are manufactured in small quantities and have high unit costs. Thus, this makes aerospace industry very suitable for the utilization of AM techniques.

Aerospace industry is already one of the three largest market segment for the AM technologies. Since, the manufacturing of complex parts in series production are very expensive, also due to the small lot sizes, aerospace industry has highly utilized AM techniques for various purposes. In 2011, 9.6% (US\$115 million) out of the total US\$1.2 billion AM market was accounted for the aerospace market segment. (Gausemeier et al., 2011). AM is already being used for a various applications within the aerospace industry as mentioned below:

- Customized interior of business jets and helicopters,
- Structural parts of unmanned aerial vehicle (UAV),
- Turbine blades,
- Windshield defrosters,
- Swirler - fuel injection nozzle for gas turbine applications,
- Engine components by GE,
- Nozzles for rocket engines by NASA.

#### **4. ADDITIVE MANUFACTURING (3D PRINTING) IN AVIATION/AEROSPACE**

The involvement of military and defense sector has also played a huge role in the development and implementation of AM to the aviation/aerospace sector. For example, in China the AM-created parts are being used in the J-15, J-16, J-20, and J-31 jet fighters, the Y-20 transport aircraft, and the C919 commercial airliner (Anderson, 2013b).

##### *4.1 Advantages for Aviation Sector*

According to Airbus, an aircraft produced entirely through additive manufacturing would be 30% lighter and 60% more cost-effective than current machines. The Boeing 787 aircraft has more than 30 SLS-sintered components installed (Lyons, 2012). It is expected that such applications would further increase in the future. High cost of manufacturing aerospace parts has remained a challenge across the supply chain. However, AM techniques allow the use of different materials, optimized design, flexibility in design and manufacturing, and more energy efficient processes, which are highly beneficial to the aerospace industry. Use of AM has resulted in part optimization (improved part design requiring less raw material). It is more sustainable (lower energy consumption over the product lifecycle, resulting in a reduced CO2 site footprint).

A joint study by EADS and EOS, on the DMLS technology (one of the AM techniques), utilized for the re-design and production of the Airbus A320 nacelle hinge brackets, highlighted the potential cost and sustainability benefits of the DMLS technique during the process. By using the optimized design, energy consumption over the whole lifecycle (including manufacturing and operational phase) of the brackets was lowered by almost 40%. One of the advantages of such AM techniques is that the process itself uses only the material that is really needed to build the application. Thus the consumption of raw material can be reduced by up to 75%. The optimized design for the engine cowling hinge itself could reduce the weight of the aircraft by 10 Kg. Weight reduction is a very important factor in aviation and this could result in benefits regarding the savings in fuel consumption. For the door hinge parts, it was found that the CO2 emissions over the whole lifecycle could be reduced by almost 40% over by optimizing the design. The consumption of raw materials was reduced by 25% compared to the conventional rapid investment casting.

Laser additive manufacturing (LAM), has two main benefits in aircraft production, cost and efficiency. In January 2013, China produced the world's largest 3D printed titanium component - a 4 meter long primary load-bearing structure that is supposed to be used in China's C919 commercial airliner, using laser metal deposition. LAM was also used to produce a three-meter long central wing spar that will be used in COMAC's C919 passenger jet. The technology was also used to manufacture C919's front windshield frame in 2009 and a central wing rib in 2010. The

windshield frames were to be purchased from a European company at a price of USD 500,000 per frame, with a two-year manufacturing cycle. In 2009, however, the frame was produced in China in only fifty days at one-tenth the cost as estimated for the conventional manufacturing technique. Similarly, the roughcast weight of the 3D-printed aircraft wing-rib was only 136 Kg, which is 91.5% less than the expected 1,607 Kg weight as obtained from the traditional forging method (Anderson, 2013b).

Also, compared to traditional methods of subtractive manufacturing, little scrap or waste is produced by additive manufacturing. LAM has been identified to save almost 90% of the raw material at 5% of the cost of the same part produced through subtractive manufacturing in some cases. LAM can also be used to repair damaged parts. Instead of scrapping and replacing damaged components, metal powder can be fused directly onto damaged areas, restoring the original strength of the component. Moreover, LAM could produce complex structural parts that would be extremely high-cost or even impossible to create using traditional manufacturing processes. In aircraft design, such benefits as provided by the AM techniques allow engineers to optimize the weight of the aircraft (Anderson, 2013b). The final output in terms of production could also be improved if small but multiple parts are made in the same production run (Conner et al., 2014).

#### *4.2 Present Utilization In Aviation/Aerospace*

In the US, LAM has been used in the production of nonstructural flight hardware components for Air Force fighter jets (F-35). It is also used in the Honeywell's T-Hawk Micro Air Vehicle, where the used polymer parts are created using laser sintering. Boeing has also sought the supply of titanium alloy parts for structural components on its commercial aircraft. These parts would be used as the substitutes for the currently used standard machine grades of alloy. Boeing has also made more than 20,000 parts using 3D printers that have been used in military aircraft, and there have been no incidents of a single part failure until now (Lyons, 2012).

NASA has also been utilizing the AM technology for various applications. A Mars rover being designed for future missions is supposed to use about 70 AM (using FDM technique) created parts including the pod doors, camera mounts and housings (Anderson, 2013b). NASA is also committed to send a 3D printer onto the space station by 2014, and aims to gradually increase the self-sustaining ability of such missions, and reducing their dependency for resupply of parts and components from earth. AM could be the solution, as it could produce the parts, tools and components in the space from only the raw material already available, for the replacement and maintenance purposes. Also, as per the use of the AM technique, the parts could be recycled and

used to make new parts. This reduces the cost and time needed to manufacture and transport the space parts (Lyons, 2012).

An AM start-up company in the US has already tested the use of 3D-printing (in zero gravity) for outer space use. It has been demonstrated that the process would work successfully while also providing the advantages of 3D reduced material wastage, and reduced need for human involvement. AM is being seriously considered as an ideal manufacturing technology for outer space applications (Lyons, 2012). In smaller components, the European Aeronautic Defense and Space Company (EADS) Innovation Works printed metal hinges for engine covers that met performance requirements in tests for conventional parts in 2011. More recently, EADS used LAM to print an Airbus A380 wing bracket with a more complex shape than the original bracket design (Anderson, 2013b). In China, the J-15 variant fighter uses many titanium main bearing components printed using additive manufacturing, including the complete nose landing gear. Also, China's Y-20 transport aircraft, the J-16, J-20, and J-31 aircrafts, are also being designed to use 3D printed titanium and M100 steel (Anderson, 2013b). GE Aviation is also utilizing the AM technology for creation of parts for the hot side of turbine engines. Aerospace industry has highly utilized the metals-based additive manufacturing, in addition to the other polymer based AM techniques such as the FDM (Frazier, 2014)

#### *4.2.1 Unmanned Aerial Vehicle (UAV)*

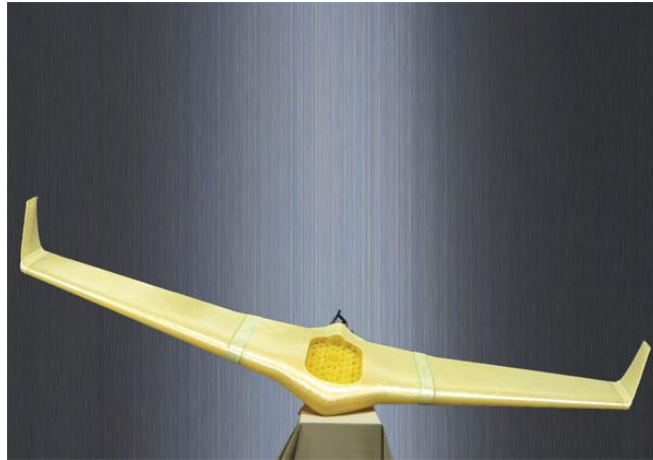
The flexibility of AM technology for design and redesign has allowed for the use of trial-and-error approach for the design and construction of an Unmanned Aerial System (UAS). The first UAS made using the AM technology highly utilized the benefits of AM technique for trial-and-error approach. The builders of this UAV opted for design, print, test and repeat process, which was only possible because of the benefits as possible from AM technology. It also saved a lot of time and money. This UAV project was backed by the company 'SelectTech Geospatial' and only had two person team, with a shoestring budget (Grimm, 2012b). FDM based 3D printer was used for the construction of UAS parts (all parts excluding only the engine and landing gear) (Grimm, 2012a). With an airframe made entirely of FDM's ABS, it became the first 3D-printed UAS to do so (Stratasys, N.A.).

Complete designs and production of UAV parts and components using the AM technology is already on the verge of becoming a viable industry. 3D-printing can construct an UAV functional prototype ready to be used. The parts built with the SLS technology and Windform materials are light-weight, durable and performing. Another company, Aurora Flight Sciences Corp. in Cambridge, also uses FDM to manufacture UAVs as shown in Fig. 7. The UAV was 3D printed using a commercial, off-the-



shelf material called Ultem 9085. The UAV which weighs only 3.3 lb, and was constructed in 58 hours, and cost less than US\$1,750 to build (Eitel, 2013).

**Fig.3 Aurora's entire structure printed using FDM technology**



**Source:** Eitel, 2013

"Printing the UAV helps minimize logistics because it reduces the number of parts going into the plane and slashes material usage. The technique also helps keep inventories low because it is location agnostic."

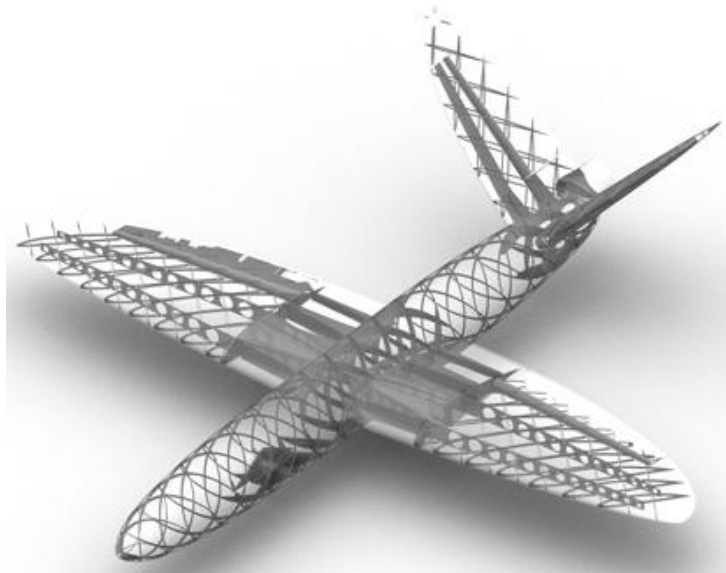
FDM isn't as strong as composite and lags a bit on the modulus-to-weight ratio. However, for small UAVs, it provides an immense benefit of design freedom, low cost and less build time. From various such small 3D printed UAV projects, it has been determined that the performance of such small UAV are almost close to that of the conventional composite UAVs (Coykendall, 2014).

Advanced AM technologies such as SLS, FDM and Composite Lay-up allow for the creation of rigid and lightweight UAV parts and structures not otherwise achievable with conventional manufacturing methods. Due to such advancements of technologies, UAVs are experiencing performance improvements as well as endurance enhancements due to the lightweight structure.

Another additive manufactured UAV, the SULSA (Southampton University Laser Sintered Aircraft) flew in 2011. The UAV was built in only four structural parts using the nylon based SLS technology. The four components consisted of the fuselage and rudder fins, the nose cone and two outer wings – which all simply clipped together to form an UAV with a 2m wingspan (Richardson, 2011). AM allows for the construction of a highly-tailored UAV to be developed from concept to first flight in days. Construction of a similar UAV using conventional method and materials, such as composites would normally take months, before the first flight. Also, since no tooling is required during the manufacturing process, complete changes to the shape and scale of the UAV can be made during the design stages at no extra cost. (Green Car Congress, 2012).

Even the complex aerodynamic structures can be manufactured cost-effectively and quickly from CAD design data using AM technology. Movable parts like flaps or hinges for example can easily be integrated into the wings or body within a single manufacturing operation (EOS, N.A.).

**Fig.4 *SULSA structural design.***



**Source:** EOS, N.A.

#### *4.2.2 Aerospace*

Aerospace designs are often made of titanium and are complex structures. AM technology in this segment is mainly used for preproduction and R&D, and not volume production yet. The 3D-printed parts include brackets and components for the fuselage and engine. The components are generally made in moderate volumes of thousands. However, low batch volumes, special materials and complex designs make it suitable for AM technology to be involved in the aerospace market segment.

Nine of the NASA centers use AM technology based manufacturing (Eitel, 2013). NASA also recently used AM technology (SLS based technique) to make the 3D-printed rocket injector, which is the largest 3D-printed rocket engine component NASA ever has tested, and generates 20,000 lb of thrust. The 3D-printed rocket injector was successfully tested, and further brings AM based technology to much wide-scale adoption and acceptance, in the field of aerospace. The injector part was made using the nickel-chromium alloy powder for SLS based process. One of the key elements to reduce the cost of the rocket engine parts is to minimize the number of components. By using the AM method, the rocket injector could be built in only two parts. However, a similar rocket injector manufactured from a conventional manufacturing method consists of 115 or more parts

assembled. Fewer parts need fewer assembly. This along with the reduction in material usage highly accounts for huge cost savings.

Also, the rocket injectors manufactured traditionally using conventional methods take months to make because a lot of measuring has to be done and it has to be exact. AM allowed design and redesign in the CAD design data which was then 3D-printed into only two separate builds, attached together into a full-scale rocket injector (Eitel, 2013). A US based company, 'Made in Space', is also working with NASA to soon send a 3D printer that would be used in space to print tools for the crew of the International Space Station. Innovations like additive manufacturing, or 3D printing, foster new and more cost-effective capabilities in the U.S. space industry - NASA

#### *4.2.3 Aircrafts*

Boeing already makes about 300 different smaller aircraft parts using 3-D printing, including ducts that carry cool air to electronic equipment. Some of these ducts have complicated shapes and had to be assembled from several different pieces while using the conventional manufacturing method, resulting in high labor costs (Hagerty and Linebaugh, 2012). However, the same parts are reported to be successfully made using AM method at a cost savings of 25% to 50% per part (Wee, 2013).

Honeywell also utilizes AM method to build heat exchangers and metal brackets (Hagerty and Linebaugh, 2012). Also, it is very difficult to find spare parts and components for the old aircraft models during the MRO or repair requirements. Such rare spare parts are also being 3D-printed, and is one of the potential markets for the AM industry. For example, 3D-printing was used to build spare parts for leaking toilets on the ageing McDonnell Douglas MD-80 jets. The production of these aircrafts had ceased long ago and it is very difficult to find the specific spare parts. The spare part for MD-80 jet was 3D-printed using the aerospace-grade plastic (which does not ignite or produce toxic fumes if burned) (The Economist, 2013b).

A typical F-18 fighter jet also uses several of the 3D-printed components. A typical F-18 fighter jet contains some 90 3D-printed parts (for example, parts of the cockpit and cooling ducts) (The Economist, 2013b).

#### *4.2.4 Engines*

GE Aviation is one of the companies that is actively engaged in the field of AM technology for applications in aircrafts and engines. In 2012 it acquired '*Morris Technologies*' and '*Rapid Quality Manufacturing (RQM)*'. GE Aviation has used additive metals in the production of its next generation jet engine, the 'LEAP 56'. The AM technology has been currently used for the production of parts such as the fuel nozzles, which has a very demanding application in a harsh environment. This

needs for the special material to sustain such working conditions, and AM built additive metals have been found very suitable for such purposes (Huang et al., 2015).

GE Aviation aims to produce more than 32,000 complex metal parts annually using the AM methods (19 nozzles per engine and 1,700 engines per year) (Anderson, 2013). By 2020, GE expects to 3D-print tens of thousands of such parts for its jet engines alone (The Economist, 2013b). *Pratt & Whitney*, another aircraft engine manufacturer, is also using the process to make blades and vanes in compressors inside jet engines (Hagerty and Linebaugh, 2012). Many other companies are also expected to introduce additive metal parts into the future aircraft engines, airframes and other aerospace applications.

"We're saving probably on the order of 50 to 75% in total cost," "That can be total material cost. It can be labor. It can be the design time," –Gareth Richards, (LEAP program manager at GE Aviation)

#### *4.3 Future Potential for Aerospace/Aviation*

According to one of the research reports (Gausemeier et al., 2011), the aerospace industry was identified to be one of the most promising business opportunities for the application of AM in the future as well.

Many manufacturers jumped on board and have been increasing their investments into AM-technologies. Thereby, they succeeded to improve the ratio of functionality and costs of AM technologies. Functional-driven design is the key to success, and AM is mainly used for manufacturing critical parts or for low scale production.

"Someday, Boeing should be able to make an airplane wing without cutting or bending any metal" – Michael Hayes (Design engineer, Boeing) (Hagerty and Linebaugh, 2012)

Production of aircraft wings using AM method could be one of the potential applications in the future. The wings could be made, layer by layer by fusing powdered metal or other materials using AM machines. Although AM technology has been around for 25 years, it had been mainly used for making models, prototypes and smaller items. Now big manufacturers including Boeing, GE and Honeywell are exploring ways to use it to make large scale parts pieces in much higher volumes.

The application of AM in the defense industry is also expected to grow as new techniques are developed and as additional materials are introduced. Military and aviation fields are especially suitable for the adoption of AM technology. AM is still expensive and not much suitable for mass manufacturing, but parts component manufacturing in the defense industry that require fewer part orders can already benefit from the technology.

Currently, there are few options for AM using carbon fiber parts. One of the challenges is the cost of material and the scale of production required to make it competitive. However, there are some technologies that produce nanofiber-impregnated materials. Such materials boost mechanical rigidity and resistance to chemicals and vibration. This could soon find its way into the aviation/aerospace application. For example, wing deflection in UAV's additive design could soon be addressed with carbon fiber to allow wider wingspans (Eitel, 2013). According to one of the research reports, within the aerospace industry, the production of aircraft has been selected as the most promising field for AM technologies in the future. The scenario for customized parts requirement in the aircraft production could highly fosters the application of AM technologies (Gausemeier et al., 2011)

## **5. CONCLUSION**

3D printing 'Additive Manufacturing' has received a lot of attention and buzz in the industry these days because of the economic and technological advantages it provides. It's mainly relevant to aviation industry in terms of advantages like weight reduction, reduction in use of material, reduction in manufacturing cycle, ease in manufacture of complex components etc. Such technology should be further encouraged and implemented readily and widely as it has the potential to solve various issues ranging from fuel cost saving (weight reduction) to air and noise pollution reduction, and also provide an economic boost to the aviation / aerospace industry as a whole.

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## THE ACCESSIBILITY OF EUROPEAN REGIONS AND AIRPORT NETWORK

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### ABSTRACT

The objective of this work is to evaluate the accessibility of European municipalities by air transport. We focus on travels that typically require the use of air transport by computing the quickest paths between any pair of municipalities separated by more than 500 km. The total travel time includes three components: i) travel by car or High Speed Train to reach the origin airport, ii) travel by air from the origin airport to the destination airport, including waiting times when no direct flight is available and iii) travel by car or High Speed Train from the destination airport to the municipality of destination. For each territorial unit, we calculate the population-weighted average travel time to reach any other municipality in Europe.

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This statistic identifies which European regions are “remote” due to difficulties accessing the nearest airport or a limited offer of flights. Finally, we propose a general framework to evaluate policy options for improving the accessibility of remote regions.

Keywords: *Airport Network, Accessibility, Remote regions, Policy options, Shortest Path, European market .*

## 1. INTRODUCTION

Wegener et al. (2001) defined accessibility in terms of indicators that “describe the location of an area with respect to opportunities, activities or assets existing in other areas and in the area itself, where ‘area’ may be a region, a city or a corridor”. Evaluating the accessibility offered to citizens has always been an important issue for policy makers and regional governments, so a large body of literature has studied the relationship between accessibility and regional development (for example, Spiekermann and Wegener, 2006, Vickerman, 1999).

The objective of this work is to study accessibility in Western Europe, taking into account both air and ground transportation. We focus on travels that typically require the use of air transport by computing the quickest paths between any pair of municipalities separated by more than 500 km.

Air transportation accounts for a significant portion of travel times between most pairs of municipalities. Burghouwt and Veldhuis (2006) employed air-side accessibility measures to evaluate the connectivity of European airports involved in the transatlantic market. Paleari et al. (2010) compared air-side accessibilities for Europe, US and China. Shaw (1993) and Shaw and Ivy (1994) studied the accessibility of the hub-and-spoke structure to US airline passengers. When computing travel times by air, this work employs a definition similar to that of Paleari et al. (2010): the total air travel time includes both flight times and waiting times spent in intermediate airports when no direct flight is available.

The contributions of this paper with respect to previous studies are related to three aspects. Firstly, when computing the accessibility index the paper employs an origin-destination approach, jointly considering the effects land-side accessibility to airports and air-side accessibility offered by airports. The latter also considers waiting times in intermediate airports when direct flights are not available, calculated on published flight scheduling.

Secondly, while previous studies on European intermodal accessibility have considered only NUTS2-3 regions (Lutter et al., 1992; Chatelus and Ulled, 1995; Wegener et al., 2001; Copus et al., 2002), this paper computes travel times in a much more detailed network with 76,498 distinct municipalities. It allows considering for each municipality in Europe, the effective infrastructures employed, including the choice of the most convenient airports, depending on the specific municipalities of origin and destination, and the ground access to those airports.

Thirdly, from a policymaker perspective this paper proposes an innovative framework for evaluating the priority to improve accessibility of remote regions. That could be obtained, for example, by increasing air services offered by airports serving remote regions, that is the standard approach

adopted by policymakers when setting Public Service Obligations – PSO. However, the paper also identifies the cases in which a more effective approach would be to invest in land-side infrastructures to allow travelers to quickly reach major airports that are farther away from remote regions but with better developed air networks.

The paper is organized as follows. The next section describes the methodology and dataset employed. Section 3 describes our empirical results on the overall accessibility of cities. Section 4 focuses on remote territories and proposes a general framework for improving accessibility. Section 5 concludes.

## 2. METHODOLOGY AND DATA

Table 1 shows the twenty Western European countries and territories covered by our analysis. Our dataset includes 76,498 different municipalities, with a total population of more than 378 million and an average population per municipality of about 5,000.

This paper computes travel times for journeys between each pair of municipalities in the sample, including ground and air travel. The overall travel time to connect municipalities  $i$  and  $j$ , denoted  $t_{i,j}$ , is separated into three components:

- 1)  $t_{i,o}$ : travel time by car or High Speed Train (HST) from the origin municipality ( $M_i$ ) to the origin airport ( $A_o$ ). This is a much more precise approach than those employed by previous studies since it allows considering the specific infrastructures necessary to access the airports, including the presence of freeways, speed limits and HST services. The latter includes all HST services coordinated between the train operators and the airlines.
- 2)  $t_{o,d}$ : travel time by air from the origin airport ( $A_o$ ) to the destination airport ( $A_d$ ). If a direct flight exists  $t_{o,d}$  only includes the flight time. If no direct flight is available between the origin and the destination airports, this component includes both flying times and waiting times in intermediate airports<sup>16</sup>. For indirect connections, we assume a minimum interconnecting period of 45 min for all intermediate airports. To guarantee the feasibility of connections we consider scheduled flights operating on a specific and typical day in autumn: Wednesday, 12 October 2011. Information on scheduled flights is collected from the OAG (Official Airline Guide) dataset. To compute the minimum travel time  $t_{o,d}$  by air, we apply the methodology introduced by Malighetti et al. (2008).

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<sup>16</sup> Some passengers may prefer to make one-stop trips even if direct flights are available, when lower fares compensate the costs of the extra time. However, since we aim to evaluate remoteness, we build a time-based index. For this reason, information on offered fares is not considered in this analysis.

3)  $t_{d,j}$ : travel time by car or HST from the destination airport ( $A_d$ ) to the destination municipality ( $M_j$ ).

**Table 1. Countries, municipalities and populations covered by the analysis. Year 2011.**

Country	No. of airports considered	No. of municipalities	Population	Population municipality
Austria	6	2,259	8,208,012	3,633
Belgium	5	580	10,801,107	18,623
Denmark	6	96	5,399,255	56,242
England	47	2,109	44,021,561	20,873
Finland	12	414	5,295,918	12,792
France	45	36,040	60,884,686	1,689
Germany	39	12,187	81,551,275	6,692
Ireland	3	78	2,327,507	29,840
Italy	38	8,101	60,045,068	7,412
Luxemburg	1	36	314,046	8,724
Netherlands	5	491	15,761,607	32,101
Northern Ireland	2	16	840,290	52,518
Norway	30	423	4,440,441	10,497
Portugal	3	283	9,934,918	35,106
Scotland	8	583	4,590,490	7,874
Slovenia	1	200	1,935,248	9,676
Spain	39	7,983	45,076,146	5,647
Sweden	36	1,886	7,520,741	3,988
Switzerland	5	2,524	7,494,142	2,969
Wales	1	209	2,320,880	11,105
All territories		76,498	378,763,338	4,951

Before this analysis can begin, we need to link each municipality with the airports most likely to be employed by its population. We consider the two nearest airports for each municipality, in terms of travel times in 2011. We also include any other airports offering more than 50 routes (again, in 2011) within 200 km of the municipality.

We do not consider travel times between pairs of municipalities whose distance is less than 500 km, since air travel is probably not necessary to complete the journey.

Among all possible combinations of origin airport and destination airport for a given pair (i,j), we find those which give the minimum travel time  $t_{i,j} = t_{i,o} + t_{o,d} + t_{d,j}$ .

In general, there could be different airport pairs to allow travelling from municipality i to j. That is the case of municipalities located in the catchment areas of different airports. An innovative feature of this approach is that it selects the alternative path with the lowest travel time  $t_{i,j}$ . For example, if a passenger located in the London area wants to reach a destination in the Milan area, the algorithm selects the best departure and arrival airport in order to reduce overall travel time  $t_{i,j}$ . The optimal solution depends on the specific municipalities of origin and destination.

In general, the most well-connected municipalities are close to airports linked by a direct flight. In contrast, remote municipalities often involve long travel times by car to reach the origin airport and/or an indirect flight to the destination airport.

The accessibility index for a municipality, denoted  $t_i$ , is defined as the population-weighted average travel time to all other municipalities:

$$t_i = \frac{\sum_{j=1}^{n_i} p_j \cdot t_{ij}}{\sum_{j=1}^{n_i} p_j}$$

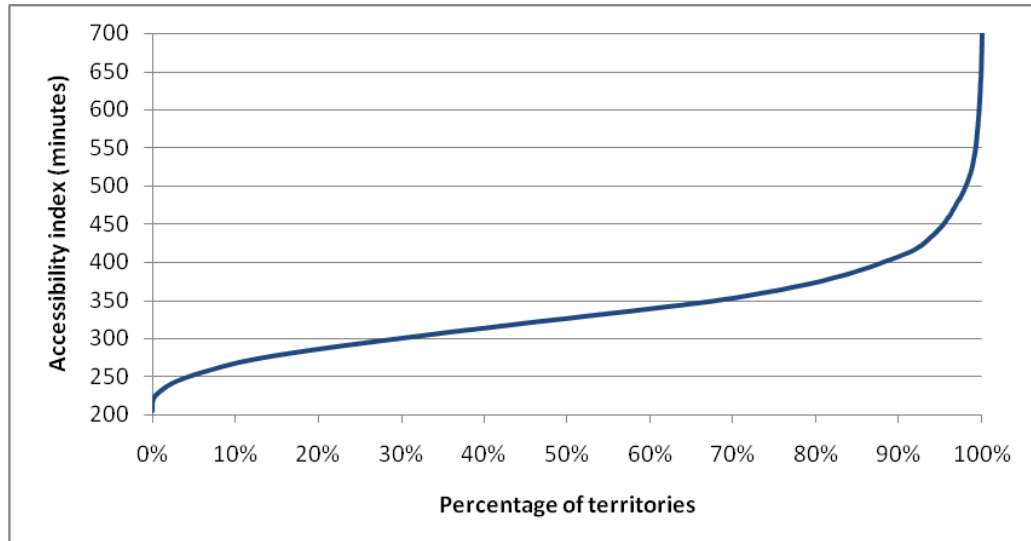
Here  $n_i$  is the number of municipalities farther than 500 km from municipality i and  $p_j$  is the population of municipality j. By weighting for the population of municipalities we consider the different attractiveness of the connections. Since on average remote municipalities are less populated, travel times to reach them are also underweighted. The difference between our approach and the gravity approach is that we do not consider in the weighting system the "as the crow flies" distance between origin and destination municipalities. Our analysis is restricted to Europe and only when distances between origin and destination are higher than 500 km. Paleari et al. (2010) show that 80% of direct flights in Europe have a distance between 1.000 and 2.500 km. So, for European connections the population-weighted index is not significantly different from the gravity approach.

### 3. EMPIRICAL RESULTS

Table 2 reports our statistics on accessibility, grouping the municipalities by country or territory. The average accessibility index of a country depends on its geographical position with respect to the other countries. England is the most well-connected country in Western Europe, with the smallest weighted average travel time  $t$ . It is noteworthy that in terms of travel times, England is more accessible than countries that are geographically central such as Austria, Germany and Switzerland. As expected, the least connected countries are Finland, Norway and Sweden. Norway has the greatest variation in the weighted average travel times of individual municipalities, with a standard deviation of 74.8 minutes.

Figure 1 shows the distribution of municipalities by accessibility index  $t$ . Almost 90% have a weighted average travel time less than 400 minutes. Given that the overall average is about 300 minutes (Table 2), the vast majority of municipalities have accessibility indexes not exceeding the average by more than 30-35%. However, the least connected municipalities have accessibility indexes exceeding 600 minutes, almost twice the average.

**Figure 1. Distribution of territories by accessibility index.**





**Table 2. Accessibility statistics by country (in minutes).**

Country	Weighted average	Median	Minimum	Maximum	Std. Dev
Austria	287.5	307.8	227.6	406.7	27.0
Belgium	309.0	296.5	279.5	384.0	20.2
Denmark	286.1	290.9	221.9	456.6	46.4
England	266.1	260.6	216.3	595.3	35.7
Finland	402.0	453.4	297.4	634.7	69.2
France	310.5	334.8	220.7	706.5	60.7
Germany	306.0	298.9	217.7	548.2	35.8
Ireland	293.1	309.3	231.8	461.8	67.8
Italy	303.8	309.1	210.4	681.0	55.4
Luxemburg	369.2	297.8	322.3	394.5	14.4
Netherlands	312.1	309.7	276.1	416.1	19.2
North. Ireland	297.9	295.5	276.7	341.9	17.6
Norway	377.9	417.7	271.9	691.2	74.8
Portugal	322.2	342.0	267.1	564.0	41.9
Scotland	293.4	293.0	229.9	634.4	54.1
Slovenia	337.2	348.3	295.9	459.4	25.9
Spain	305.2	339.3	204.7	674.0	60.2
Sweden	370.7	409.7	274.7	640.3	71.4
Switzerland	271.8	282.5	231.7	387.0	23.4
Wales	313.9	311.3	243.7	504.8	42.3
All territories	305.4	324.5	204.7	706.5	60.8

**Figure 2. Accessibility index by municipality.**

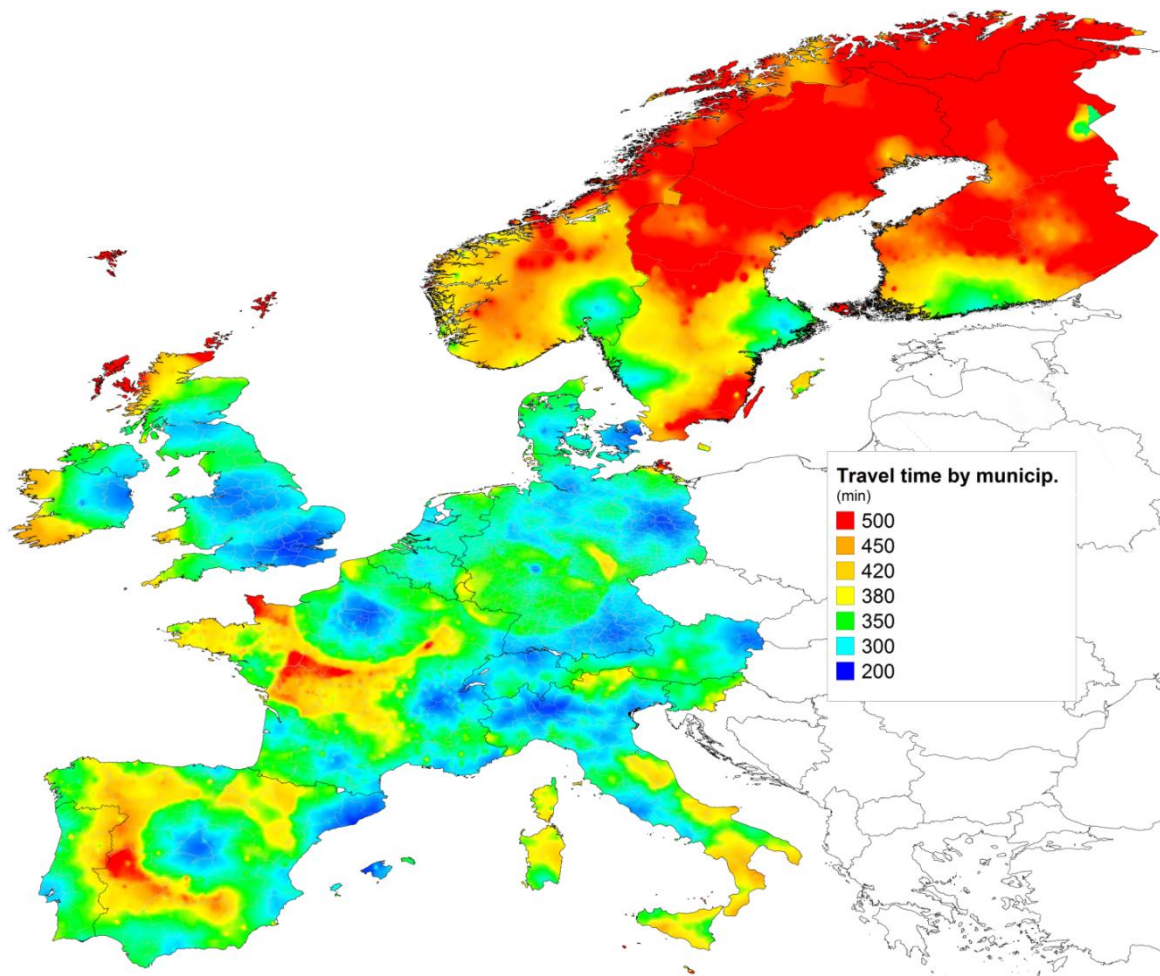


Figure 2 shows the geographic distribution of the accessibility index. It shows that even municipalities located near the geographic center of Europe may have low accessibility. This phenomenon is more accentuated in France, where small airports tend to have just a few European connections. In Spain, low accessibility affects cities close to Portugal and those located midway between the seaside and Madrid.

**Table 3. Identification of remote territories.**

Percentile	Population in Remote municipality				
	90.0%	92.5%	95.0%	97.5%	99.0%
Travel time limit	408.0	421.1	445.9	487.9	536.5
Denmark	2,089	1,993	1,993	-	-
England	40,022	5,999	2,275	2,275	2,275
Finland	2,386,398	2,218,248	1,602,466	876,529	178,535
France	3,908,435	3,132,755	1,857,975	992,279	320,457
Germany	211,778	82,304	60,890	55,650	8,903
Ireland	316,869	290,308	82,558	-	-
Italy	2,290,288	1,323,297	122,309	15,498	6,170
Norway	1,046,552	853,572	584,225	239,851	125,144
Portugal	471,728	291,870	66,058	29,721	29,721
Scotland	56,600	49,630	44,300	42,420	41,800
Slovenia	16,883	16,883	9,334	-	-
Spain	2,422,075	1,616,118	781,126	378,091	91,381
Sweden	2,396,662	2,028,237	1,133,261	575,144	77,271
Wales	64,831	49,737	4,515	4,515	-
Number of territories	7,634	5,725	3,817	1,909	764
Population	15,631,210	11,960,951	6,353,285	3,211,973	881,657

Table 3 aims to identify the remote territories. In particular, it shows the total populations of the least connected areas in each country, counting all municipalities with travel times above the 90%, 92.5%, 95%, 97.5% and 99% percentiles computed for the entire sample.

Interestingly, Austria, Belgium, Luxemburg, Northern Ireland, Netherland and Switzerland do not have any municipality with an accessibility index above the 90% percentile. The countries with the largest populations in remote municipalities are the three Scandinavian countries (Sweden, Norway, and Finland) together with France, Spain, and Italy.

The remainder of our analysis deals with those municipalities whose accessibility indexes are above the 95th percentile, meaning that their travel times are greater than 445.9 minutes. Henceforth, the term "remote territory" refers to one of these cities. The number of remote territories is 3,817, and their total population is more than 6 million. Following this definition, Austria, Belgium, Luxemburg, Netherland, Northern Ireland and Switzerland do not have any remote territories. In fact, from table 2 one would observe that their maximum accessibility indexes are lower than the limit of 445.9 minutes.

#### 4. REMOTE TERRITORIES AND POLICY IMPLICATIONS

Table 4 shows statistics on travel times for remote territories. Interestingly, France comes first in terms of the total population in remote territories, followed by Finland and Sweden. All three countries have more than one million people living in their remote territories.

Spain has about 780,000 people living in remote territories, and Norway has about 580,000. Table 4 also decomposes the travel times from remote territories into three components: i) travel to the origin airport, ii) travel by air, and iii) travel from the destination airport to the destination territory. (These components were defined in Section 2.)

**Table 4. Statistics on travel times for remote territories (travel times in minutes).**

	No. of remote territories	Population	Average Access. Index	Travel to origin airport	Travel by air	Travel from dest. airport	Std Dev.
Denmark	1	1,993	456.6	28.9%	56.7%	14.4%	-
England	1	2,275	595.3	39.5%	49.2%	11.4%	-
Finland	222	1,602,466	495.2	16.0%	70.8%	13.2%	37.5
France	2,145	1,857,975	503.2	25.9%	60.5%	13.6%	52.4
Germany	41	60,890	519.5	54.6%	33.6%	11.8%	27.9
Ireland	7	82,558	449.4	27.8%	58.0%	14.2%	5.1
Italy	49	122,309	470.4	33.9%	52.0%	14.1%	34.9
Norway	288	584,225	497.6	21.0%	67.4%	11.6%	70.8
Portugal	6	66,058	504.1	41.7%	45.4%	12.9%	41.9
Scotland	13	44,300	588.8	11.2%	78.4%	10.4%	63.2
Slovenia	1	9,334	459.4	35.4%	50.4%	14.2%	-
Spain	414	781,126	493.4	23.9%	62.9%	13.2%	36.5
Sweden	628	1,133,261	490.5	11.1%	75.3%	13.6%	34.7
Wales	1	4,515	504.8	41.1%	44.7%	14.2%	-
All territories	3817	6,353,285	517.3	22.6%	64.5%	12.9%	49.4

Long air travel times imply that the origin airports do not have direct flights to many destination airports, so travelers accumulate waiting time in intermediate airports. Long travel times to or from an airport indicate problems of geographical accessibility.

The case of France is of particular interest. In this country, there are two areas with municipalities classified as remote (see figure 2). The first includes territories in the lower Normandy region,

closer to the English Channel. That does not come as a surprise since that area is relatively isolated and not served by high speed train - HST.

The second includes more central municipalities located in the Centre and Pays de la Loire regions, despite being served by HST. Our approach already considered all scheduled HST offered in coordination with Air France flights. However, even if travel time by HST to Paris Charles de Gaulle is relatively short, on average travelers have to wait here more than 110 minutes before taking a flight to the European destination considered, employing a minimum connection time of 45 minutes.

Furthermore, the French remote municipalities identified in this study are distant from the nearest HST stations by more than 90 minutes by road. So, after considering all those components, average time to take a European flight from Paris Charles de Gaulle can easily be higher than 250-300 minutes, against an average of 117 minutes of land-side accessibility for remote regions (see table 4). So, HST in France does not improve the overall accessibility index of these municipalities.

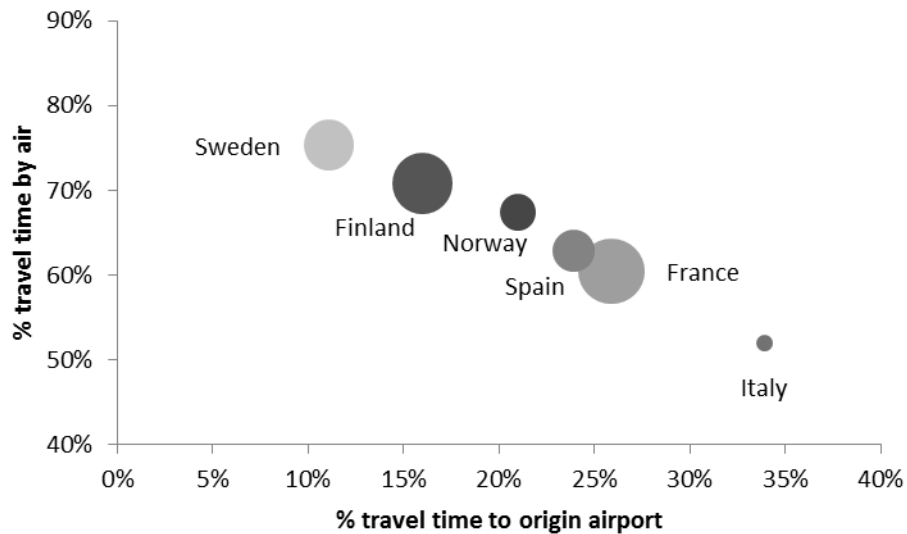
#### *4.1. Statistical Properties Of Remote Regions*

For the six countries with the largest populations in remote territories, Figure 3 plots the percentage of travel time to the origin airport against the percentage of air travel time.

For Sweden and Finland, the main factor contributing to long travel times is the quality of connections offered from origin airports. In Spain and France, on the other hand, the main problem is the excessive distance between remote territories and the most suitable origin airports.

The division into ground and air travel offers insight into the types of policy remedies that would be effective. When a country's remote territories require long air travel times, their accessibility could be improved by increasing the origin airports' offer of direct flights, especially to the major European airports (Redondi et al., 2010). However, this is not always the most effective policy. For example, it could be that an airport serving several remote territories is very small, with a very limited capacity. In this case, the bottleneck could be overcome by improving land-side accessibility to larger airports.

**Figure 3. Proportions of travel times in remote regions due to ground travel and air travel .**



When the main problem faced by remote territories is high travel times to reach origin airports, the most evident solution would be improving land-side infrastructure. For example, a government could improve existing roads or build new highways from remote regions to serve major airports. Another solution would be to create new airports to serve the remote regions. However, it could also be that the airports closest to remote territories are not often employed by the population, due to a low number of offered flights and destinations. If this is the case, travelers would often drive to a farther airport with better connectivity. Thus, land travel times could also be reduced by increasing the connectivity of nearby airports.

In order to better differentiate the policies required to improve the accessibility of remote regions, Table 5 provides detailed information regarding the land-side accessibility of origin airports in each country. The first column is the total population of remote territories in that country, and the second column is the average number of origin airports linked to each remote territory (see Section 2). From the methodology section, the minimum number of airports linked to each territory is two. The second and third columns describe the propensity of the population to use just one of the linked airports. The concentration is the value of the Herfindahl-Hirschman Index - HHI. When this index equals 10,000, it means that passengers from remote municipalities have no choice but to employ only one origin airport to reach their destinations.

The lower the index, the higher the number of alternative departure airports that are employed to reach destinations in quickest paths.

The fourth column reports the percentage of the population that finds it quicker to travel to the closest airport, regardless of destination. Table 5 also reports the average travel time to reach the closest airport, and the average travel time to reach the linked airport or airports that are located farther away.

In order to compare the connectivity of the closest airport with the connectivity of other potential origin airports, we define the following index:

$$C_d = (1 - \%Pop) \times \Delta TT$$

Here %Pop is the percentage of the population that finds it quicker to employ the closest airport, reported in the 4<sup>th</sup> column of Table 5.  $\Delta TT$  is the difference between the average travel time required to reach the closest airport and the average travel time to other airports, reported in the 5<sup>th</sup> and 6<sup>th</sup> columns of Table 5 respectively.

We name  $C_d$  the "connectivity deficit" of the closest airport with respect to the other airports that serve the area. The rationale of  $C_d$  is to measure the potential advantage of policies to improve the network quality of the closest alternative. It measures the average time lost by a person living in one of the remote territories who has to use an airport with better connections farther away than the closest alternative. So, if network quality of the closest airport improved, travelers would save  $C_d$  in terms of access time.

Among countries with a large population in remote territories, the connectivity deficit is highest for Italy, at 23.7 minutes. The value of this index is 20.4 minutes for Norway, and 14.4 minutes for Spain. The closest airports in these countries are not always employed as origin airports; on average, people living in these countries who require better connectivity will spend this much extra time travelling to reach farther airports. On the other hand, Finland has an index of 5.6 minutes while France has an index of merely 0.4 minutes. In these countries, the airports closest to remote regions are better equipped to serve their population.

**Table 5. Statistics on land-side accessibility for remote territories (travel times in minutes).**

	Population	No. of Territ.	No. of origin airports	Concentr. by origin airports - HHI	% pop. to closest airport	Travel time to the closest airport	Travel time to other airports	Connectivity deficit of the closest airport (C <sub>d</sub> )
Denmark	1,993	1	2.0	8,080	89.2%	124	201	8.3
England	2,275	1	3.0	8,824	0.0%	193	237	43.5
Finland	1,602,466	222	2.7	7,992	78.0%	74	99	5.6
France	1,857,975	2,145	1.9	8,217	84.8%	133	136	0.4
Germany	60,890	41	4.0	7,497	16.9%	119	319	166.2
Ireland	82,558	7	3.0	6,675	79.6%	109	191	16.8
Italy	122,309	49	3.9	4,667	40.6%	138	178	23.7
Norway	584,225	288	2.0	8,104	75.0%	63	145	20.4
Portugal	66,058	6	2.6	7,713	52.3%	201	227	12.7
Scotland	44,300	13	2.8	9,905	76.7%	77	85	1.9
Slovenia	9,334	1	1.0	10,000	100.0%	163	-	-
Spain	781,126	414	2.6	7,208	62.8%	105	144	14.4
Sweden	1,133,261	628	2.1	8,563	81.0%	44	101	10.9
Wales	4,515	1	2.0	5,790	30.1%	196	213	11.9
All territories	6,353,285	3,817	2.2	8,021	79.6%	114	141	6.9

#### *4.2. Policy Implications*

The connectivity deficit index allows us to distinguish between the possible causes of remoteness. Based on this index and the percentage of total travel time spent reaching the origin airport, the following framework can point to the appropriate policy remedy.

- If the percentage of travel time to reach the origin airport is above average (see Table 4), the priority is to reduce land-side travel time.
- If the connectivity deficit in the remote territories is below average (see Table 5), it means that the airports are already well suited to serve the remote territories. To improve accessibility, the best policy is to improve roads and create new highways serving the airports. This is the case of France.



- If the connectivity deficit in the remote territories is above average (see Table 5), the remote population is spending time traveling to airports that are farther away but have better connectivity. The priority of policy-makers should be to improve the closest airports' network quality. That could be obtained either by increasing the number of destinations or by increasing frequencies to major airports, when already connected. The population will then choose the closest airport more often, and spend less time traveling by ground. If the air service of the closest airports cannot be improved, the best policy is to improve land-side accessibility to larger but more distant airports. This is the case of Italy, Spain, and Portugal. It also applies to Germany, even though this country has a much lower population in remote territories.
- If the percentage of travel time by air is above average for remote territories (see Table 4), the priority is to reduce air-side travel time.
- If the airports closest to remote territories have a below-average connectivity deficit (see Table 5), it means they are already well placed to serve the remote population. The optimal policy is to increase the number of flights and destinations offered by the closest airports. If that is not possible, the government should improve both land- and air-side connectivity to larger airports farther away. This is the case of Finland.
- If the airports closest to remote territories have an above-average connectivity deficit (see Table 5), it means that some of the population employ more distant airports. The priority should be to increase the number of flights and destinations from those airports. An alternative policy is to improve the land-side accessibility to larger airports, with a more extensive network of destinations, further away from remote regions. The risk of this policy is to excessively increase access time by ground. This is the case of Sweden.

## **5. CONCLUSION**

To the best of our knowledge, this work is the first to address the issue of accessibility in Western Europe at the municipality level. Our measure of accessibility is based all the overall travel times required to connect each pair of cities in the network, including ground travel to and from airports and waiting times between connecting flights when a direct flight is not available.

The paper defines remote territories as municipalities whose average travel time to other cities is above the 95th percentile. Norway, France, Finland and Sweden suffer most from remoteness.

We also propose a general framework to evaluate the best policy options at a Country level for alleviating travel times from remote territories. We determine whether improving land-side infrastructure or increasing the number of routes offered by airports will have the greater impact on accessibility.

Specific analyses are still required to better identify the practical policies for particular territories. Another future development could be to carry out cost-benefit analyses of the different options identified to improve accessibility of remote regions.

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## **INDUSTRY PERSPECTIVE: PREPARING AIRPORTS AND AIRLINES FOR TERRORIST ATTACKS**

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**Note:** These views are not espoused by Florida Institute of Technology, but solely that of the author.

### **1. INTRODUCTION**

With terrorist threats in the news, now may be the time for airports and airlines worldwide to review their security plans, and consider adoption a Security Management System (SeMS) for risk mitigation. Additionally, developing a checklist for employee training to protect employees from terrorist attacks should be encouraged. Many terrorist incidents may include, but not be limited to chemical, biological, cyber, radiation, nuclear blast, and explosives, that are likely threats to airports and airlines. For this very reason, every airport and airline should have already developed a security program that addresses terrorist threats. If your airport or airline does not have such a plan, volunteer you should develop one (Melton, 2003).

Evidence of terrorist threats is highlighted by three recent articles. An article published by the National Terror Alert Center of Homeland Security states that in the Middle East, "Terrorist groups have seized control of nuclear material at the sites that came out of the control of the state," and that such materials "can be used in manufacturing weapons of mass destruction" (The National Terror Alert Response System , 2014a). Another article published by Press TV states that the Khorasan Group has been, "carrying out research and experiments on improvised explosive devices created to undercut security at airports" (Press TV, 4014). Finally, an recent article on imminent

attacks on the United States (U.S) claims that “agents across a number of Homeland Security, Justice and Defense agencies have all been placed on alert and instructed to aggressively work all possible leads and sources concerning this imminent terrorist threat” (The National Terror Alert Response System , 2014b).

## **2. THE GOAL OF TERRORIST CELLS**

The goal of terrorist cells is to effect large-scale political or ideological change; however, their immediate goals are designed to achieve short-term goals attached to their actions. For this reason, the aviation security programs should ensure that employees know the various types of terrorist intentions and characteristics they might include (Melton, 2003). Popular literature on this subject suggests that terrorist intentions aim to:

1. To produce widespread fear.
2. To obtain worldwide, national, or local recognition for their cause by attracting the attention of the media.
3. To harness, weaken, or embarrass government security forces so that the government overreacts or appears repressive.
4. To steal or extort money and equipment, especially weapons and ammunition.
5. To destroy facilities or disrupt lines of communication in order to create doubt that the government can provide for and protect its citizens.
6. To discourage foreign investments, tourism, or assistance programs that can affect the target country’s economy and support of the government in power.
7. To influence government decisions, legislation, or other critical decisions.
8. To free prisoners, and to
9. To satisfy vengeance. (Melton, 2003)

### **3. THE SECURITY MANAGEMENT SYSTEM**

To prepare for terrorist incidents, airports and airlines of all sizes need to consider the availability and response of local authorities in the event of a terrorist incident. Terrorist incidents may include large numbers of people, thereby making response by local authorities low or nonexistent. One problem with security programs, however, is that information in these programs may be highly restricted and not available to local security agencies and individual employees.

The answer to these questions may lie in the adoption of a Security Management System (SeMS). Just like Safety Management Systems (SMS), SeSM has four primary components: (a) policy, (b) risk management, (c), assurance, and (d) compliance. SeMS can be used to seek out and discover aviation security problems, such as non-compliant Security Identification Display Area (SIDA) challenge issues, or a construction employee's lack security compliance on the job site. In fact, a healthy SeMS can assist in the reduction of letters of investigation, and more importantly, security threats to passengers, airlines, and airport operations. A key component to the success of the SeMS relies on the concept of the *accountable executive*. This is the local official who is ultimately held responsible for meeting security compliance. At many airports or airlines this may be the local Security Coordinator, the Airport Director, or in the case of an airline, the Station Manager (Forrest and Price2013).

### **4. SURVEY OF SELECTED U.S. AIRPORTS**

In a recent survey U.S. airports were surveyed. One hundred percent (100%) of the respondents surveyed indicated that their security plans addressed the availability and response from local authorities, and 69.5% of the respondents indicated that their security plans addressed security incidents in all the categories of possible security threats. However, all other responses averaged less than 50% preparedness's in each case, with only 4.4% of the respondents indicating that they had a Security Management System (SeSM). Only 30.4% of the respondents surveyed indicated that they provided employee training to *all* employees to prepare for terrorist threats/attacks/incidents. The sum of all the responses averaged only 38.15% preparedness overall.

Nine of the respondents to the survey answered a limited qualitative question on security preparedness's. These limited qualitative responses indicated that 6 respondents had employee training for chemical incidents; 5 for biological incidents; 1 for cyber incidents; 1 for radiological incidents; 3 for nuclear blast incidents; and 9 for explosive incidents; an average employee training preparedness of 18.2% for the responding airports.

## **5. CONCLUDING REMARKS**

In the wake of recent terrorist events, airports and airlines must prepare for terrorist attacks or incidents, and a recent survey of U.S. airports found a low level of security preparedness in the event of an actual attack. To correct these issues, now is the time for airports and airlines to review their security programs and prepare in the event of an actual terrorist attack or incident. This preparation should include the recognition of terrorist intentions and characteristics in today's world, types of potential attacks or incidents, recognizing terrorist activity, and incorporating heightened anti-terrorism awareness measures into security planning efforts. While the ideas set forth in this opinion may only be applicable in a small number of potential cases, the now is the time for airports and airlines to adopt a SeMS for security threat, or risk assessment. This would require that airports and airlines review their security programs, and consider the incorporation of a SeMS, which may be used for a number of emergency preparedness purposes, not just terrorist attacks or incidents.

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