Int. J. Environment and Sustainable Development, Vol. 5, No. 3, 2006

Long-term forecasting for Sustainable Development: air travel demand for 2050

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Abstract: Before implementing policy measures that may contribute to a sustainable development, one has to determine in one or other away in advance if these measures will have their intended effects. As sustainable development necessitates long-term perspectives, a robust vision of possible future states of the world is vital. This paper discusses two different approaches to gain insights into possible future states of the system of interest. One is the classical scenario approach, and the other is the empirical modelling approach. This paper considers possible future air travel demand as a case study, as in that system long-term visions of up to 50 years are necessary. This paper discusses a need for more sustainable development in the aviation sector and argues that changes in that system require long horizons for action. It explains the need for developing ideas about the possible future air travel demand for the period up to 2050. This paper presents a brief review of the literature on scenarios and exploratory modelling. It discusses both the scenario and empirical modelling approach to come up with plausible future states of the system and gives a convergent forecast of future growth in the year 2050.

Keywords: forecasting; aviation; air travel demand; sustainable development; networks.

Reference to this paper should be made as follows: Cunningham, S. and de Haan, A.R.C. (2006) 'Long-term forecasting for Sustainable Development: air travel demand for 2050', *Int. J. Environment and Sustainable Development*, Vol. 5, No. 3, pp.297–314.

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1 Introduction: problem statement

Sometime in the past, aviation has been seen as a nation's pride. Governments spent a considerable amount of money to keep the national carriers, the so-called flag carriers, literally in the air. This led to a large overcapacity of the aviation system, as many more seats were available than the size of the actual demand for air travel.

The situation in the aviation industry changed drastically when privatisation was introduced. Since then, carriers need to have a positive net financial result without any additional governmental support. The total available capacity of the aviation system, which was higher than the actual demand, had to be filled with extra demand for air travel as soon as possible. In other words, the overcapacity seats had to be filled. This led to serious reductions in ticket prices, supporting high growth figures in terms of people flying and the number of flight movements per year.

Within less than a decade, many air travellers experienced congestion signs at airports and people living around airports experienced a huge increase in noise levels and a deterioration of the local air quality.

Technological developments had always been there, but were now more seriously boosted, as the industry needed to react on the new situation. New technology became available, capable of transporting comparable number of travellers by producing much less noise and gas emissions. Larger aircraft and faster turn around times decreased the effects of congestion at airports.

Although the improvements due to technological changes have been considerable when measured per traveller (usually measured per aircraft seat travelled over one kilometre: seat × km), the growth in the aviation system has been so large that the overall situation has not improved but actually deteriorated.

Underestimating the improvements achieved by the developing and introducing new technology would be seriously unfair. The emission of hazardous substances has spectacularly decreased since the last 30 years, with figures up to 85%. That is indeed a fantastic achievement. Nevertheless, growth figures of up to 9% per year for years in a row can quickly erase such tremendous improvements and turn the overall effect into negative numbers.

The concept of Sustainable Development is promising in solving the dilemma between the positive effects we all experience from flying and the adverse effects, both directly (like noise) and indirectly (like contributions to climate change). How can we keep the positive effects while at the same time reduce the negative ones? Sustainable Development, as described by Brundtland (1987), requires a fulfilment of the needs of the present generation without compromising the needs of future generations. It thus requires a long-lasting solution for the stated dilemma between positive and negative effects of flying.

Unfortunately, Sustainable Development as such does not give us many practical solutions to actually solve the dilemma. At best, it gives us the criteria to which we can compare our solutions to see if they indeed are contributing to a Sustainable Development.

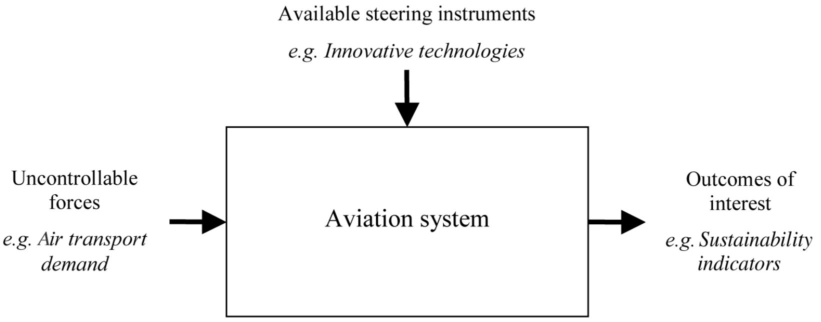
Several areas might be available in which one can start looking for solutions for the stated dilemma that also can score well on the criteria that are of interest from a sustainability point of view. One of these areas is the already mentioned technological area. As technology improved the performance of the aviation so much already in the past, can it help again to overcome currently experienced negative effects of flying?

Technology plays a special role in the aviation system, much different from the role it plays in for instance the car industry. The world's car fleet replaces itself roughly every 15 years (at which time the far majority of the cars have been replaced by new models). New technologies therefore spread within this period throughout the whole car fleet. Of course, usually new technologies will have to be designed first and will first be introduced in the high-end cars and later in more common models, so this process of technology diffusion might take still a few more years. Still, however, the situation in the aviation industry has a much different time horizon. Designing an aircraft and building a working prototype might take roughly ten years, after which the design stays in service for 30–35 years. Thus, a full replacement of the current fleet with a fleet of new promising sustainable technologies might take almost half a century when starting today.

If technology wants to play a vital role in bringing Sustainable Development closer to its needs, given the high growth figures of air travel demand, to deliver a serious increase in efficiency. It is not unlikely that the more radical kinds of technology can make this a huge increase in efficiency that actually occur. To apply more radical changes in the aviation system, it is likely that new designs are essential. And, as has just been pointed out, a quick application of this radical technology in the form of exchanging a complete fleet is not going to happen in a short amount of time. Thus, technological change in the aircraft industry has tended to be incremental.

If the effect of a new innovative technology in the aviation system is to be measured beforehand, one must know about the possible future states of the aviation system. In Figure 1, the square represents the aviation system. When new technology for the purpose of increasing sustainability levels is introduced, this system will change (arrows going into the square from above) and produce different outcomes (arrows on the right) that represent Sustainable Development. Despite the difficulty of constructing sustainability indicators, such sets of indicators do exist, for instance, INFRAS (2000) or de Haan (to be published).

Figure 1 The problem diagram around the issue of aviation and sustainability



The system will also change due to uncontrollable things as in this case, for instance, the demand for air travel from society. Could a governmental institution stimulate the development of new technologies and maybe also the implementation of them in line with Sustainable Development needs within international agreements, it will be much harder, given ideas of a free liberal market with a competitive economy that is common nowadays, to consciously influence the demand for air travel. If the demand is there, the market will react with a capacity of the aviation system that can fulfil the demand.

As the uncontrollable force of air transport demand is changing the aviation system, it will also change the outcomes of interest. That means if one wants to determine the effects of a new innovative aviation technology with respect to sustainability issues, one has to have some possible, plausible future states of the aviation system in terms of air transport demand. For each of these possible, plausible future states of the aviation system, the impact of the innovative aviation technologies has to be determined. Thus, each technology considered has to be scored on each sustainability indicator for each possible, plausible future state of air travel demand.

Therefore, interesting questions with respect to the effect of a new, innovative aviation technology on the contribution to Sustainable Development of the aviation system include both the total level of world air traffic demand, as well as the way this demand is structured through the airline networks.

This paper presents an integrated approach to forecasting air travel demand. Section 2 looks more closely at the nature of sustainability with respect to air transport. This paper discusses an empirical model of air demand in Section 3. A complementary scenario approach is discussed in Section 4. The resulting possible future states of air travel demand are compared in Section 5. Conclusions to this paper are presented in Section 6.

2 Sustainability issues in aviation

In 1987, the Norwegian Prime Minister Brundtland, published the output of this committee, the report ‘Our common future’ (Brundtland, 1987) in which she introduced the most recited description of Sustainable Development: “Sustainable Development is a development that meets the needs of the present generation, without compromising the ability of future generations to meet their needs”.

Brundtland’s report stressed the limited carrying capacity of the Earth, as well as the importance of social equity in dividing the world’s resources. Equity both within generations, and between generations, is significant. For reasons of justice and fairness ‘overriding priority should be given to the world’s poor’. A world with a few very rich but many poor unable to satisfy basic needs, is socially and sustainably very much out of balance. However, prior centuries have shown that such a state is, if ethically undesirable, still potentially very long lasting. Planned and progressive change is needed.

Since the publication of Brundtland’s report in 1987, a lot of definitions of the concept Sustainable Development have emerged (Upham et al., 2003). The topic of Sustainable Development has proven to be both very interesting for the people (as it receives so much attention), and to be a very confusing concept as well (as there are so many definitions).

Recently, the Organization for Economic Cooperation and Development (OECD) presented four principles that, together, should cover the essence of the concept of Sustainable Development. These principles are (OECD, 2001):

- *Regeneration*: use of renewables within their rates of natural regeneration.
- *Substitutability*: use of non-renewables is limited to possibilities of substitution by renewables.

- *Assimilation*: no release of hazardous substances exceeding assimilative capacity of the environment.
- *Avoiding irreversibility*: maintaining or restoring the integrity of the ecosystem should be safeguarded.

This presentation of the concept of Sustainable Development is slightly more specific than Brundtland's definition of it, as it points to specific topics and shows in what direction specific developments and progress should be made. The OECD focuses very strongly on environmental issues as waste, emissions and the use of resources. Though some issues of social justice are indirectly covered by critically looking at emissions and resource usage, the OECD description of Sustainable Development, other than Brundtland's definition of the concept, does not particularly pinpoint at social issues of justice, equity and equality, both within and between generations.

Even more specific than the OECD approach is the approach of the Air Transport Action Group (ATAG). Hired by ATAG, the Swiss INFRAS Consulting group published a study called Sustainable Aviation. INFRAS describes Sustainable Development in terms of social, environmental and economic terms, a well-known distinction that is also used by for instance Shell (2001). INFRAS uses indicators for each of the three elements social (people), environmental (planet) and economy (profit). This indicator approach has also been performed by the European Environmental Agency's (EEA) TERM project (EEA, 2001).

The European Union has taken the definition still further, by considering sustainable transport (EU, 2001), as depicted in Figure 2.

Figure 2 The EU adopted definition of sustainable transport

Sustainable Transport (EU, 2001):

- *Allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promises equity within and between successive generations;*
- *Is affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy, as well as balanced regional development;*
- *Limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and, uses non-renewable resources at or below the rates of development of renewable substitutes while minimizing the impact on land and the generation of noise.*

Taken from the definition as given in Figure 2, the factors that are of importance when it comes to Sustainable Development, and this sustainability issues are (categorised under the three axis of social (people), environmental (planet) and economic (profit)).

From Figure 3 with sustainability factors, the above-mentioned dilemma between keeping the positive effects while reducing the negative ones can clearly be recognised.

Figure 3 Operationalising the social, environmental and economic characteristics of the concept Sustainable Development

Social	Environmental	Economic
PE1 Basic access and development needs of individuals and societies being met	**PL1** Consistent with ecosystem health Limits emissions and waste within the planet's ability to absorb them	**PR1** Basic access and development needs of companies being met Supports a competitive economy
PE2 Safe		**PR2** Affordable operation
PE3 Consistent with human health	**PL2** Uses renewable resources at or below their rates of generation Uses non-renewable resources at or below the rate of development of renewable substitutes	**PR3** Efficient operation
PE4 Promises equity within and between generations		**PR5** Supports balanced regional developments
PE5 Fair operation Offers choice	**PL3** Low impact on land	
	PL4 Low noise generation	

Factors such as access and development needs, affordability, choice and competitive economy seem to go hand-in-hand and represent the effects of aviation that are desired. The rest of the cells represent the effects that are or can be undesirable. These include safety, health, environment, resource usage, land use, equity and regional balanced development. Some of these factors for the particular case of aviation are highlighted as follows.

Safety: air travel has always been one of the safest ways to travel, when looked at the number of fatalities per flown kilometre (Anderson, 1989). The general public has expectations based on that history of safety (KLM, 2003). Safety in terms of absence of danger leading to a low number of fatalities and injuries is an objective on its own. ICAO measures accident rates in the number of fatalities (deaths among passengers and crew during flight operations) per 100 million passenger kilometres (ICAO, 2004). Incidents, violations of safety standards that do not cause any deaths, are also measured by ICAO (2004). They also are good indicators for safety as they measure the occurrence of potentially very dangerous situations.

According to the EU transport White Paper (EC, 2001, p.40), an issue that is closely related to safety is the growth figures for the demand of air transport. Curbing the growth figures could be caused by the media coverage of large crashes in aviation. Although statistically aviation may stay equally safe (as the number of fatalities per travelled kilometre does not increase), the absolute number of crash occurrences might affect the growth figures. If the growth figures of the last decades continue in the next few decades, statistically several Boeing 747 crashes per year, involving over 400 people, can be expected. Statistical safety might be something else than public's perceived safety.

Emission/climate change: currently, aircraft are emitting roughly 2–3% of all man-emitted carbon dioxide (CO_2) (EC, 2005; Intergovernmental Panel on Climate Change (IPCC), 1999). When looked at individual seat × km figures, aircraft have been increasingly good at reducing the amount of hazardous substances. For instance, the amount of fuel needed to transport the same number of people and goods has decreased in the last 40 years by 70% (EC, 2005). Every newly introduced type of aircraft lays the boundary a bit further. Like the new A380 who is, per seat kilometre flown, emitting less CO_2 than any other type of aircraft.

An important issue is of course the possible growth of the sector. Becoming more and more efficient per individually travelled kilometre, there is an economic incentive to make more use of air transport, which might results in a negative net effect in total. IPCC (1999) uses several scenarios of air travel growth, ranging from 6.4 to 15.5 increase in 2100 compared to the year 1990. That traffic will then use between 2.7 and 9.4 times the fuel needed for aviation in 1990. A comparable effect can be seen with the introduction of the low-cost carriers. They only took over part of the existing market and filled the rest of their seats up with travellers who would not have made the trip without the existence of the low-cost carrier. This clearly positively contributes to a Sustainable Development, as more access and developments needs are fulfilled and probably also "the less wealthy people can afford to fly (which gives more equity within the society), but the downside is, for instance, more emission of undesired substances in the atmosphere.

A related issue is that of transport to and from the airport. The more the aviation sector grows, the more people need to find their way to and from the airport, resulting in extra roads to be constructed, locally undesirable more traffic jams and emissions from cars. This environmental burden is a substantial and serious local problem; the global effects of it are very small.

Noise: aircraft produces noise that is seriously deteriorating quality of life near airports. Aircraft does not only produces noise when flying, but also when taxing or standing at the gate and using their auxiliary power unit to run different aircraft systems. This last part is called apron noise. When flying, aircraft noise originates from the airframe itself and the engines.

Noise, also aircraft noise, has negative effects on human beings. Sleep is disturbed. The human body is generally more aroused when exposed to periodic noise resulting in higher heart rates and higher blood pressure wit long-term health consequences. Also negative effects on the body's ability to defend itself against intruders such as bacteria or viruses are found.

The hindrance people perceive from being exposed to noise is not the same for everybody and is influenced by several factors, such as culture and lifestyle. The European citizens are among the most sensitive to aircraft noise. Partly because of their relative high standards of living and their demand of a nice and comfortable living space, because Europe is among the most densely populated areas with a lot of air traffic that disturbs a lot of individuals.

Noise hindrance is an important reason for a lot of airports why they cannot grow in terms of aircraft movements while their physical capacity of runways and terminals could easily handle many more passengers. Airports around the world have noise contours determining exactly how many aircraft movements can be made per year at what time during the day. Sometimes this has been a reason to rebuild the airport at a place further away from densely populated areas, like it happened in Oslo, Norway or in

Munich, Germany. Also in the Netherlands there have been plans to close down Amsterdam Airport Schiphol and build a completely new airport some kilometres out of the coast in the North Sea.

Technology has brought a considerable improvement in the noise performance of aircraft. Changing from new designs for airframe and engines, to, so-called, *hush kits* that could be applied to existing aircraft and thereby improving their noise performance. While the noise performance of individual aircraft has drastically improved, the total amount of flight movements has also grown largely. Therefore, nowadays, noise hindrance is also seen as how often a person is disturbed instead of how much noise each disturbance actually exposed to that person.

The human ear responses differently to different frequencies. Noise measures are, therefore, often expressed in so-called A weighted decibels. The weight factors stress those parts of the spectrum that the human ear is sensitive for and deemphasise the rest. The decibel scale is a logarithmic scale; a rise of 10 dB(A) is actually a twice of the noise level.

The experience of noise is determined by several factors; two important factors are the maximum sound level and its duration. For aviation purposes, a sound exposure level method is introduced that measures all the sound energy of an event that someone is exposed to. The European standard methodology for measuring aircraft noise, L_{DEN}, is based on a sound exposure level method. L_{DEN} measures the average noise level over a specified time (in dB(A)) with an extra 5 dB(A) for evening noise (19:00–23:00 hr) and an extra 10 dB(A) for night noise (23:00–6:00 hr).

Geographical area around an airport that exceeds a certain chosen level of L_{DEN} dB(A) can be drawn on a map to give a so-called noise contour. All places outside the contour are exposed to less noise. The contour is often fixed in size by governmental regulation. Back calculation then gives the opportunities for the airport to operate. Several combinations of number of flights, noisiness of aircraft and timing of flight movements give a specific noise contour.

Technology that can reduce noise from aircraft operations can, therefore, be used to reduce the noise contour, increasing the number of flights or a combination of both.

3 Forecasting: data, model and issues

Recognition of the time-scales of social and technological change entails adopting a long-term view of flight demand. Yet, forecasting flights for over half a century gives some serious problems. The two main civil aircraft manufacturers publish yearly a market forecast for their aircraft that goes 20 years into the future – not even half of the time span we would like to address here.

Several approaches are possible. One is identifying the most important factors that influence the system to analyse and that are not under control of the one who would like to make changes in that system. Of these factors especially the ones that are highly uncertain and have high impact on the outcomes of the system are of serious importance. Selecting these factors and quantifying their possible values for the target year 2050 forms the scenario, both in text and number. A second approach is using the data of the last several years about those parts of the system that are of interest. By making regression models, factors can be identified that summarise the data from previous years. An adequate description of past system behaviour, coupled with an adequate understanding of causal mechanisms, allows planners to cautiously project future trends. This paper uses a combined approach of both empirical (econometric modelling) as well as causal analysis (scenario approach). We favour the combination of both these techniques over using each separately in presenting a robust forecast.

The data are taken from world development databases, and from the yearly reports of aircraft manufacturers (Airbus, 2004; Boeing, 2003, 2005; World Bank Development Indicators, 2004). There are five dimensions of the data: *air travel, distance, gross national income, population, region* and *year.* Air travel is a measured in 'revenue passenger kilometres', a measure of air travel volume. Distance is the approximate great circle distance in kilometres between regional centres. Gross National Income is from the World Bank Development Indicators. Population is aggregate regional population levels. Regions are classified somewhat differently by all three sources: the World Bank uses nation-states; Airbus aggregates into regions and Boeing uses 12 'super regions'. We aggregate regional data using the most aggregate classification – that of Boeing. Ten years of data are reported in common between Boeing and the World Bank, and are used for analysis purposes. The Airbus data reports 2004 and a 20-year growth forecast; this information is used for calibration purposes (Table 1).

Table 1 Key dimensions of flight demand

Dimension	*Operationalisation*
Air travel	Measured in revenue passenger kilometres
Distance	Great circle distance between regional centres
Gross National Income	World Bank
Population	World Bank
Region	Boeing regional classification: North America, South America, Central America, CIS region, China, North East Asia, South East Asia, South West Asia, Middle East, Europe and Oceania.
Year	1985, 1990, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002

We are looking for robust, parsimonious models for describing previous historical growth patterns in the air travel network. This simple causal model can be used to create a common causal framework for comparing forecasts, and for evaluating parametric uncertainty among the forecasts. Finally, armed with suitable future growth scenarios, the model may be used to make projections of network growth and morphology.

Gravity models have been previously and successfully used in modelling international trade patterns. These models postulate that trade volumes between nations are proportional to national economic activity, and inversely proportional to distance. (Thus, for instance trade between proximal, wealthy nations is liable to be very intensive.) A variety of additional explanatory variables have been used including: population levels; geophysical factors and shared languages, trade agreements or history.

Gravity models have been critiqued for their exclusively empirical approach. Efforts have been made however to integrate gravity models of trade with formal, theoretical accounts of international transport flows. One source, for instance, unifies a gravity model formulation with general equilibrium modelling, a leading neoclassical economic approach for the analysis of international trade.

The gravity model approach is imminently suitable for modelling world air traffic flows. This approach offers a causal basis for describing historical patterns of air traffic flows. This causal formulation allows for nuanced discussions of future flight travel scenarios. Trend analytic approaches may neglect the underlying causes of air travel, and may therefore be less suitable for robust and long-term analysis of air travel patterns. There are deep correspondences between travel and trade: indeed a substantial portion of the world's air fleet is devoted to air cargo transport. An interdisciplinary approach that extends methods of trade analysis to transport should therefore be received. Finally, a gravity model is especially useful for understanding the topology of future air travel networks. Thus, the topology as well as volume of future air networks has a significant impact on the sustainability of future air travel. Deep uncertainty underlies forecasts of air travel – scenarios of future network morphology remain unclear.

A set of models is presented in this section each with a common set of performance indicators. The significance of variables is presented, using *t*-test. The accuracy of the model is reported in both R^2 (a measure of variance explained) and log-likelihood (a measure of unexplained patterns in the data). The robustness of the model is given using Akaike's Information Criteria (AIC). This measure rewards accurate models while penalising those with many parameters. A lower value of AIC indicates a more robust model under uncertainty.

The basic model indicates that the air travel between regions is proportional to the gross national income and inversely proportional to distance. A correction factor is applied to intraregional travel: this acknowledges competition between alternative modes of travel and the often significant distances involved with intraregional travel. This model makes it clear that there are significant structural differences between regions in terms of growth and base capacity.

Table 2 presents the result of a linear regression with regional 'dummy' parameters. This allows for the fitting of regional specific intercepts and regional specific growth rates. Although a linear regression, the functional form is trans-log. This allows for more accurate modelling of the marginal effects of distance and economics on flight travel.

Table 2 Basic regression model

Type	*Variable*	*Description*	*Model 1*
Dependent	Y	Natural log of the revenue passenger kilometres	
Independent	B	Intraregional traffic	−13.717*
	C	Region-specific intercepts	–
	X	Region-specific growth rates, GNI	–
	P	Natural log of the product of populations	−1.062*
	D	Natural log of the distance between regions	−2.993*
		Log-likelihood	−351
		AIC	759
		Multiple R^2	88.4%

*Significant at $p < 0.05$, see the following table for region-specific detail.

Table 3 gives the regional specific growth and intercept variables withheld from Table 2. We hypothesise that intercept variables represent fixed regional assets in the form of infrastructure. The growth parameter may represent regional capability to translate economic growth into a fixed infrastructure. Institutional and governance relationships may play a key role here (cf. Henisz, 2002). These assets and institutional arrangements, combined with economic growth variables, set the level of flight demand between regional pairs. The model suggests relatively high regional assets for regions such as North America, Europe and Oceania. Comparatively poor assets are found for Africa and South America. Thus, long-term and sustained growth and investment will be needed for these areas to reach parity with the other regions of the world.

Table 3 Regional specific assets and intercepts

Boeing region	*Region-specific intercept*	*Region-specific growth*
Africa	−6.07	−0.49
Central America	−4.15*	0.43*
China	−7.37*	0.53*
CIS region	19.86*	−0.46
Europe	−10.55	0.67*
Middle East	1.18	0.24*
North America	−6.29*	0.52*
Northeast Asia	−8.14	0.57*
Oceania	−14.14*	0.82*
South America	−16.08*	0.84*
South East Asia	−4.83	0.47*
South West Asia	1.09	0.23

*Significant at $p < 0.05$.

The model shows fundamental uncertainty regarding infrastructure investment and growth in the CIS region. (Standard errors about the parameter are twice larger than that of any other region.) The model suggests that the CIS region is actually *loosing* the infrastructural development capacity. Clearly, the region is in a unique situation within the time periods studied with the downfall of the Soviet Union. A long-term governance structure for the region remains a source of uncertainty.

A number of other parameters are below levels of significance. Although the parameters are indistinguishable from zero, they do not constitute a source of parametric uncertainty in the model. A number of other models are tested, but discarded for the lack of fit. These models include non-stationarity, market saturation and structural inequality. Non-stationarity is the hypothesis that the network changing over time in ways not captured by the causal parameters of the model. Market saturation considers the hypothesis that wealthier regions should expect lower marginal gains in traffic than poorer regions. Structural inequality hypotheses suggest that traffic may be disproportionately led by the wealthier regions. Distinct treatment of GNI (by whether it is a leading or lagging in the regional pair) is needed.

4 Scenario approaches

This model similar to previous efforts (de Haan, 2005) emphasises several key demand-side uncertainties about the future growth. Air travel demand and economic growth are intimately linked. The magnitude of future economic growth remains unclear. This paper presents a simple, trend extrapolation of world proportions of GNI by region. These forecasts represent a basis for 'what if' calculation about the future (Porter et al., 1991). We couple this naïve forecast with a more nuanced discussion of the nature of technological competitiveness and evidence for and against world 'economic convergence'.

Other uncertainties include the distribution of future world population. The United Nations, US Census Bureau as well as the Population Research Bureau have presented a number of long-term scenarios for the world population growth. We adopt a base-line scenario and examine the impact of these levels on the future traffic. Other factors include the rate of maturity for the North American, European and Asian markets respectively. These are estimated, based on previous trends, using the econometric model of the previous section. As will be seen stagnant US air travel, slow but robust European growth, and long-term and sustained Asian growth is forecasted.

The future of flight is sensitively dependent on scenarios of the world economic growth and demographic transition. The strength of these links is made clear with the gravity model. Other significant factors not considered include the availability of oil, and the nature of technological change. Table 4 gives our forecasts of future world economic growth by region-wise. The forecast is based on an exponential growth model. Exponential growth arises whenever constant percentage growth rates are attained.

Table 4 Regional gross national income (trillions of US$) and future prospects

Boeing region	*2000*	*2025*	*2050*
Africa	1.4	4.6	15.0
Central America	1.0	3.6	12.8
China	5.0	66.0	565.4
CIS region	1.2	11.6	110.4
Europe	11.1	36.4	116.8
Middle East	1.2	6.8	37.4
North America	10.3	37.8	137.4
Northeast Asia	4.0	14.0	48.5
Oceania	0.6	2.3	9.2
South America	2.4	8.3	28.9
South East Asia	1.8	11.3	70.6
South West Asia	2.9	19.0	122.8

The history of the past 15 years has shown a pattern of overall growth. The highest levels of growth have been in Asia – and most especially China. Growth within Asia has proven rapid, if fitful. The Southwestern Asian growth however has been rather more sustained.

Future prospects suggest extraordinary levels of wealth in the future Asia. Given this model China will bypass North America and Europe in wealth before 2020. South East Asia will bypass both North East Asia and Europe by 2050. This is based on a naïve trend extrapolation model: it is intended to provide a baseline, descriptive case for planning. More elaborate causal economic models have and should be built. As noted earlier what is of particular interest to this paper is the interaction between specific economic and population growth scenarios, and structural econometric models. In Section 3, we outline an explicit structural model of growth; in the section to follow we discuss the implicit and qualitative models of network growth presented in trade materials by Boeing and Airbus.

Fagerberg (1994) examined evidence that the lower developed nations tend to grow more rapidly. Returns to capital, both human and monetary, are central to this argument. Wealthier nations also tend to invest more in infrastructure (including the flight infrastructure). This approach considers the role of innovation and strategic mechanisms leading to national economic growth. This approach is appropriately sceptical of simple naïve forecasts of growth based on prior history.

Thus, any forecast of future flight networks is highly dependent on these underlying assumptions of economic growth. This paper does not aim to forecast future economic growth, but rather to more fully explore the relationship between economic growth and flight levels. Table 5 gives forecasted levels of future population (Population Reference Bureau, 2005; US Census Bureau, 2004). Like the previous model, these figures are the result of an exponential trend extrapolation. More elaborate population models can and should be introduced.

Table 5 Regional population levels, current and forecasted (millions)

Region	*2000*	*2025*	*2050*
Africa	722	1230	1821
Central America	159	216	250
China	1270	1485	1447
CIS region	281	284	275
Europe	746	619	600
Middle East	241	388	507
North America	313	386	457
Northeast Asia	196	221	192
Oceania	26	41	47
South America	177	470	529
South East Asia	520	646	746
South West Asia	1355	1949	2406

High levels of population help to dampen flight demand, as wealth is then spread among a larger population. The scenario presented in Table 5 has South West Asia (and India in particular) leading in regional population; Africa is somewhat farther behind. China has moderated its population growth. In contrast, Europe has declined in absolute population numbers.

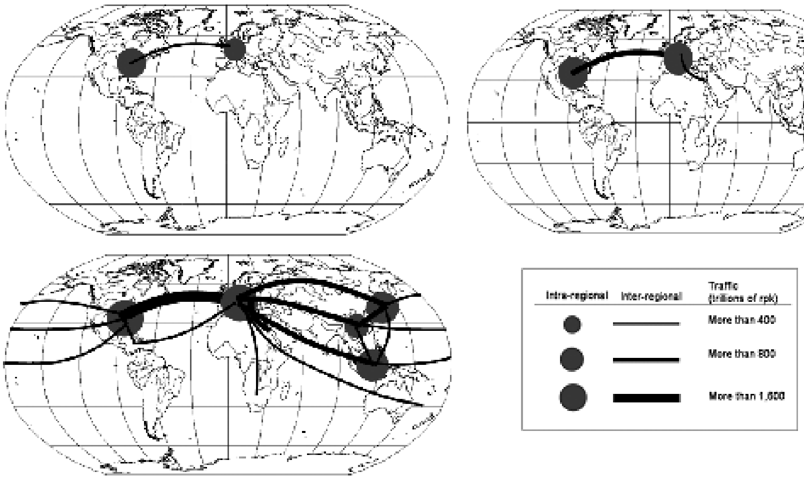
The primary sources of uncertainty are twofold. The first source is uncertainty regarding regional capability of translating economic growth into air travel infrastructure. A causal model of air travel growth is presented below. The model attempts to quantify hypotheses concerning the growth and morphology of the future flight network. The second source is uncertainty regarding regional determination translate economic growth into the flight infrastructure. As will be discussed below, the CIS region appears to be regions of deep uncertainty regarding the future infrastructural investment.

A scenario approach also suggests that we examine both the high impact as well as the high uncertainty factors leading to the forecast. The future economic growth of China and South East Asia are highly uncertain – but they are bound to have a profound impact on the future morphology of the flight network. This, then, should be the basis for alternative scenarios of future flight. Although the future of the CIS region remains highly uncertain, growth in the flight demand to the region appears to be externally driven. CIS regional growth remains, therefore, a low impact factor in future planning.

5 Forecasts and comparisons

We begin with the baseline scenarios, as given in Table 5. Figure 4 shows the world air travel network for three different periods: 2000, 2025 and 2050. This figure is a visualisation of the travel flows predicted by the gravity model and our scenarios of economic and demographic growth. We find that the morphology of the network is remarkably stable across a range of plausible scenario parameters and alternative formulations of the econometric model. More sensitive to assumptions are the magnitudes of flows between specific regions.

Figure 4 World travel network: 2000, 2025 and 2050



As noted earlier, the model is aggregated by region. As a result, the figures show intraregional 'hubs' and interregional 'spokes'. In Section 6, we outline the results of the model, and compare and contrast these results with facts and forecasts from other air travel forecasts (Airbus, 2003; Boeing, 2005; IPCC, 1999).

At the coarsest approximation, world air travel in the year 2000 consists of two hubs, and the traffic between these hubs. North America and Europe are the preimminent air destinations of the modern era. The intensity of pan-European travel is roughly 400 trillion revenue passenger kilometres; trans-Atlantic travel is roughly of equal scale. North American traffic is as great as European and trans-Atlantic travel combined. All other destinations combined do not equal the traffic in and between these two major hubs.

The next 25 years is notable for the expansion of pan-European flight traffic. In addition, Europeans will also begin travelling in large numbers to regions just outside the core member states. Slow growth is expected from the matured North American market, although Central European and European destinations will continue to be growth leaders.

The gravity model, and the Boeing and Airbus forecasts, are in moderate agreement. All the three anticipate good prospects for growth as travellers expand from regional hubs – from North America to Central America and Europe to the Mediterranean basin. All three expect strong growth in pan-European flight travel. All three anticipate slower than usual growth in the trans-Atlantic routes. And finally all anticipate subdued growth in a matured North American market. The expansion of Mediterranean travel is somewhat under debate, as is the severity of the decline in North American hub growth.

Also under contention is the level of world growth expected in this period. High world growth in travel is expected in the gravity model, resulting from strong Asian-centred growth (7.3%). In contrast, the Airbus and Boeing forecasts anticipate more moderate growth (5.0% and 4.7%, respectively) stemming from travel out of the 'traditional' hubs of Europe and North America.

By the year 2050, regional hubs in Asia will come into play. World growth has significantly subsided. Overall growth rates are half that of the previous 25 years. The 50-year growth rate is 5.4%, in substantial agreement with forecasts of the IPC. Mature and expansive hubs in China, Northeast and Southeast Asia are all expected. These hubs will draw trans-Pacific traffic from North America. Expansive trans-continental routes from Europe to Asia are anticipated as well. Despite a network of flight links encircling the globe, significant portions of the world remain comparatively untouched.

Earlier we noted two distinct visions of the future of world travel. Boeing (2005) presents a vision of point-to-point travel. Passengers fly from one place to anywhere; a full spectrum of flight lengths are expected. Airbus (2003) presents a 'hub-and-spoke' vision where both short hops to regional centres, and then long-hops to international destinations are necessary. Which of these visions best matches the gravity model forecast?

In principle both visions of travel are true. Expansions of hubs are forecast, with unprecedented levels of intra-Asian traffic. Expansions of links are forecast with vastly expanded trans-Pacific and trans-Asian flight destinations. The model presented here anticipates an intensification of air travel all across the board.

All flight links, both long- and short-haul, will expand dramatically. The morphology of the network, however, will not change. The gravity model demonstrates the significant spatial component of flight economics. Longer trips are more fuel intensive, and correspondingly more expensive. Intraregional flights dominate most travel plans; interregional flights will remain proportionally half that of all travel.

This forecast is undoubtedly demand-led. It is equally important and valid to consider supply-side characteristics. Consider, for instance, the implications for European flight travel. A 50-year gravity model forecast anticipates *12-fold* increases in travel throughout the Mediterranean basin, *11-fold* increases in trans-Asian flight, *6-fold* increases in pan-European flight and *3-fold* increases in trans-Atlantic flight.

Even despite these remarkable multipliers, we foresee comparatively subdued growth in air travel comparison with the rest of the world. Can European airports, challenged by physical infrastructure as well as environmental regulation, possibly support such a huge rise in traffic? How many new airports and expansions are needed to keep up with the demand? How many existing berths and runways be allocated or specialised to meet this expected demand? One implication of the forecast may be the development of a set of new airports in Eastern Europe, specialising in Asian flight traffic. Rimward airports specialise in intraregional travel. A hub in Central Europe may handle the shorter intraregional flight legs.

The US hubs have kept up with growth across the entire lifecycle of flight from early to mature markets. European markets have also maintained growth. Whether European (and Asian) flight hubs keep up with future demand will be a matter of foresight, careful demand planning and a recognition of the environmental and economic costs and benefits of air travel.

6 Conclusions

In this paper, we examined both the overall levels of air flight for the next 50 years, as well as considered the distribution of flight travel across the world regions. On the demand-side of the forecast, a very brisk rate of air travel demand is expected (5.4% yearly). The Asian market is expected to be the major recipient of regional growth. We argue that strong increases in demand based simply on flight length are unlikely – all flight legs both long- and short-haul are expected to grow dramatically. Despite forecasts anticipating a fundamental change in the distributional characteristics of the network, we argue that all segments and flight lengths will grow proportionately. (Contrast for instance forecasts by Boeing (2001, 2005); Airbus (2000, 2003) and Hensgens (2003) which present differential forecasts of network change.)

As suggested in Section 1 of this paper, around the problem diagram, uncontrollable external forces seriously affect the outcomes of interest of the aviation system. This paper suggests a substantial growth of all segments of air travel within the next 50 years. Without any other changes, this would seriously increase the sustainability aspects of access and development needs and choice, as well as it would seriously decrease the sustainability aspects such as health and environmental burden.

Technology might be one of the measures to solve this dilemma. However, the growth figures found suggest efficiency increase needed of a factor three and more. While in the past, these kinds of efficiency gains have been achieved in fuel use (70% less fuel for the same number of people transported), it is not likely that this can happen again without seriously changing the aircraft paradigm.

As changing a aircraft paradigm in highly resistant to change system, similar to the aviation system, will be very hard and at the same time the economic incentives are not so strong to adapt the aircraft design into a new paradigm. Therefore, it is likely to say that technology will surely play a role in the solution to the stated dilemma, but that technological changes alone are not enough and additional measure of a non-technological kind are also necessary.

Suggestions for further research and improvement: the analysis model should be further expanded by region. The Boeing 'Africa' region is not fully adequate for modelling. North Africa flight has high prospects for growth, whereas sub-Saharan traffic is expected to remain stagnant. The econometric model should examine the evidence for morphological change more thoroughly. We examined alternative models that suggested the marginal demand for travel over distance was changing over time. These models were rejected for a simpler, and we argue, more robust formulation: travel demand on all scales is increasing. However, a more detailed pursuit of the matter would be worthwhile, given the impact that this parameter has on future aircraft design and facilities management.

Further investigation into the social and economic causation of flight demand is also warranted. A simulation approach might help clarify the growth and composition of flights at expected levels. A model that examined the top 100 airports of 2050 might add needed detail and clarity to these aggregate predictions. A model of industrial organisation could consider the future prospects of carriers, and explore the consequences of strategic partnership. Fleet composition and new technology choices may strongly impact the nature of future greenhouse gas emissions. Scenarios might be used to examine supply-side limitations – in oil as well as infrastructure. Macroeconomic models may help clarify the impacts on flight of fuel shortages and high fuel prices.

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